

Final MBR-Network Workshop

“Salient outcomes of the European R&D
projects on MBR technology”

BOOK OF PROCEEDINGS

31 March – 1 April, Berlin (Germany)

Berlin 2009

Organised by:

Supported by:

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KOMPETENZZENTRUM
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Book of proceedings

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TorOve Leiknes, Norwegian University of Science and Technology
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**Introduction to the final MBR-Network workshop
“Salient outcomes of the European R&D projects on MBR technology”**

Dear workshop participants,

On behalf of MBR-Network, we are pleased to welcome you in this workshop kindly endorsed by the International Water Associations, sponsored by Veolia Water and supported by the European Membrane Society, the European Membrane House and the European Desalination Society.

MBR-Network is a coalition of four major research projects financed by the European Commission, all entirely dedicated to further development of the MBR technology, the membrane based process for advanced wastewater treatment. These projects engage about 50 European and international companies and institutions and will be completed by the end of the year 2009 after more than 3 years of intensive activity. They have generated significant technological breakthroughs, and key know-how which further improved the competitiveness and acceptance of this innovative wastewater treatment process.

Together with the partners of the MBR-Network projects, we are delighted to have the opportunity to present the salient outcomes of the European projects to the international MBR community and water professionals.

We trust that this event will be not only very informative but that it will as well provide many contacts and exchange opportunities in a friendly atmosphere. We also hope all participants will find their attendance to this workshop truly rewarding, inspiring and enriching.

Boris Lesjean
Berlin Centre of Competence for Water
Project Coordination AMEDEUS

TorOve Leiknes
Norw. Uni. of Science and Technology
Project Coordination EUROMBRA

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Heleen De Wever (VITO, Belgium).
Wouter De Wilde (Aquafin, Belgium)

Conference Program

TUESDAY 31 MARCH 2009 – MBR-NETWORK FINAL WORKSHOP CONFERENCE DAY 1

Session I – Opening and Key Notes

Chairman: B. Lesjean

(Berlin Center of Competence for Water, Germany)

Opening addresses

Prof. R. Ben-Aim

(Chairman of IWA Specialist Group "Membrane Technologies")

EC activities and strategy on membrane R&D

A. Tilche, M. Schouppe

(European Commission, Research Directorate)

Page 1

Trends in world-wide membrane bioreactor research

N. Cicek, W. Yang

(University of Manitoba, Canada)

Page 3

MBRs and the TMP jump – self accelerating fouling phenomena

T. Fane

(Singapore Membrane Technology Centre, NTU)

Page 5

Quorum quenching: a new biofouling control paradigm in MBRs

C.-H. Lee, Kyung-Min Yeon, Jae-Hyuk Kim

(Seoul National University, South Korea)

Page 7

Session II - Membrane fouling characterisation and monitoring

Chairman: J. Crespo

(IBET Institut experimental and technological of biology, Portugal)

Development and application of a proteins and polysaccharides sensor for on-line fouling control in membrane bioreactors

R. Mehrez, M. Ernst, V. Iversen, A. Drews, M. Kraume, M. Jekel

(TU Berlin, Germany)

Page 9

The European MBR tour of the Delft filtration characterisation method

J. H.J.M. van der Graaf, A. F. van Nieuwenhuijzen, S. Geilvoet, A. A. Moreau, M. Lousada

Ferreira, P. Krzeminski

(Delft University of Technology, The Netherlands)

Page 11

The quest for indicators of membrane fouling in membrane bioreactor systems

T. de la Torre, J. Stueber, V. Iversen, A. Drews, B. Lesjean

(Berlin, Center of Competence for Water, Germany)

Page 15

New developments in membrane bioreactors characterisation and monitoring

C. F. Galinha, G. Carvalho, C. Portugal, R. Oliveira, M. T. B. Crespo, M. A. M. Reis, J. G.

Crespo

(REQUIMTE/CQFB, Chemistry Dept, Portugal)

Page 17

Foulant dynamics on supported media membrane bioreactor

R. Aryal, S. Vigneswaran, J. Kandasamy, A. Grasmick

(University of technology, Sydney, Australia)

Page 19

Organic matter in MBR sludge waters: Foulant identification and cleaning considerations

A. Fenu, O. Braimah, J.W. Mulder, M. Kennedy, G. Amy

(UNESCO-IHE Institute for Water Education, Delft, The Netherlands)

Page 21

Session III - Membrane fouling control and cleaning

Chairman: C. Cabassud
(INSA Toulouse, France)

- Aeration and fouling dynamics in HF SMBR: determining criteria and phenomena Page 23
J. Lebègue, M. Héran, A. Grasmick
 (GPEB, University of Montpellier, France)
- New advances in MBR aeration and fouling control Page 25
S. Pollet, B. Teychene, S. Khirani, M. Sperandio, C. Cabassud, C. Guigui
 (INSA Toulouse, France)
- Sludge filterability and dewaterability in municipal MBR Page 27
G. Guglielmi, D. Chiarani, G. Andreottola
 (University of Trento, Italy)
- Effects of various flux enhancers in MBR: lab tests vs. pilot scale operation Page 29
V. Iversen, S. Hermann, A. Drews, R. Mehrez, M. Ernst, M. Jekel, B. Lesjean, M. Kraume
 (TU Berlin, Germany)
- Fouling origin and cleaning strategies in MBR Page 31
A. Grelot, C. Machinal, A. Tazi-Pain, A. Grasmick.
 (Anjou Recherche, Water Research Centre of Veolia, France)
- Optimised electrospun nanofibers for municipal wastewater treatment by Textile Bioreactors (TBR) Page 33
E. Fatarella, L. Lombardi, V. Iversen, S. Paulussen, U. Brüss, B. Lesjean, M. Kraume
 (Next Technology Tecnotessile, Italy)

Session IV – Process modelling and control

Chairman: J. Van der Graaf
(TUD Delft University of Technology, The Netherlands)

- Specificities of ASM-based biological modelling of MBR processes Page 35
A. Fenu, G. Guglielmi, J. Jimenez, B. Lesjean, I. Nopens, J. Roels, D. Saroj, M. Sperandio
 (UNESCO-IHE Institute for Water Education, Delft, The Netherlands)
- Biological modelling of membrane bioreactors and impact of primary sedimentation Page 37
J. Jimenez, P. Grelot, A. Tazi-Pain
 (Anjou Recherche, Water Research Centre of Veolia, France)
- Technical feasibility and optimal control strategy of dual (hybrid) MBR-CAS concepts for plant refurbishment Page 41
W. De Wilde, K. Moons, D. Bixio, C. Thoeye, G. De Guedre
 (Aquafin, Belgium)
- Advanced control of MBR systems using on-line fouling sensor measurements Page 43
E. Brauns, E. Van Hoof, C. Huyskens, H. Elslander, F. Vanhoof, P. Lens, H. De Wever
 (VITO, Unit Separation and Conversion Technology, Belgium)
- CFD analysis of MBR-units, Recommendations for system design and operation Page 45
J. Saalbach, M. Hunze
 (FlowConcept GmbH, Hannover, Germany)
- Evaluation of mixing efficiency & nutrient removal in membrane bioreactors via CFD modelling with experimental validation Page 47
Y. Wang, M. Brannock, G. Leslie
 (University of New South Wales, Sydney, Australia)

Session V – Novel European MBR technologies

Chairman: A. Joss
(EAWAG, Switzerland)

- Assessment principles for membrane and membrane module development: a case study
S. Buetehorn, J. Kochan, C.N. Koh, T. Wintgens, D. Volmering, K. Vossenkaul, T. Melin
(RWTH Aachen University, Germany) Page 49
- Developpement of new hollow fiber modules for MBR application
W. Bosq, F. Saux, J. M. Espenan, O. Lorain
(Polymem, France) Page 51
- Development of a novel Fibre Sheet membrane for MBR's: the FiSh
M. Heijnen, R. Winkler, M. Vogg, G. Roeder, P. Berg
(Inge AG, Germany) Page 53
- Innovative European made flat-sheet module systems for MBR application
B.Kreckel, U.Brüss, A. Grélot, A. Tazi-Pain
(Director of A3 Water Solutions, Germany) Page 55
- From concept to international export of European MBR filtration system
D. Volmering, K. Vossenkaul
(KMS Puron) n. a.
- Development of containerised turn-key MBR plants
D. Vilim, P. Hlavinek, J. Kubik, P. Hlustik
(Envi-pur ltd, Czech Reppublic) Page 57

Session VI – Process integration and new processes

Chairman: P. Hlavinek
(BUT Brno University of Technology, Czech Republic)

- The effect of organic peak loads on membrane biofouling in a pilot scale MBR treating municipal wastewater
Ben Zwicklenpflug, Marc Boehler, Adriano Joss, Hansruedi Siegrist
(Eawag, Swiss Federal Institute of Aquatic Science and Technology, Switzerland) Page 59
- Decision tree for full-scale submerged MBR configurations
H. De Wever, C. Brepols, B. Lesjean
(VITO, Unit Separation and Conversion Technology, Belgium) Page 61
- Operational experience of MBR demonstration plant with post denitrification in Berlin-Margaretenhöhe (ENREM-Project)
C. Lüdicke, J. Stüber, R. Gnirss, B. Lesjean, M. Kraume
(Berliner Wasserbetriebe, Germany) Page 63
- Operational experiences with the hybrid MBR Heenvliet, a smart way of retrofitting
J.W. Mulder
(Water Authority of Hollandse Delt) Page 65
- Challenges and potentials of biofilm-MBR for municipal wastewater treatment
T.O. Leiknes, J. Phattaranawik, I. Ivanovic
(NTNU- Norwegian University of Science and Technology, Norway) Page 67
- Anaerobic membrane bioreactor for domestic wastewater treatment
G. Gugliemi, D. Avesani, C. Cabassud, V. Yvenat, S. Pollet, O. Lorain, A. Schmidt, B. Pfaff, S. Pillay, K. Foxon, J. K. Bwapwa, C. Buckley
(University of Trento, Italy) n. a.

Session VII – Full-scale implementations, economics and market

Chairman: T.O. Leiknes

(NTNU Norwegian University of Science and Technology, Norway)

- MBR standardisation in Europe: market interest, technical potential and initiation of formal actions Page 69
W. De Wilde, A. Tazi-Pain, M. Richard, B. Lesjean, G. de Gueldre
(AquaFin, Belgium)
- Major items and outcomes of the CEN Workshop Agreement N° 34 on Submerged Membrane Bioreactor (MBR) Technology Page 71
F.-B. Frechen
(University of Kassel, Germany)
- An aeration energy model for an immersed membrane bioreactor Page 73
B. Verrecht, G. Gugliemi, J.W. Mulder, C. Brepols, S. Judd
(Cranfield University, UK)
- Potential for MBR applications for wastewater treatment in the Middle East and North African region Page 75
M. J. Bino, S. N. Al-Beirut, M. Wade
(The Inter-Islamic Network on Water Resources Development and Management (INW), Jordan)
- Potential and implementation of full-scale dual (hybrid) MBR-CAS concepts in newly accessed countries Page 77
D. Bixio, L. Maes, W. De Wilde, J. Deurinck, C. Thoeye, G. De Gueldre
(AquaFin, Belgium)
- Economic aspects of large scale membrane bioreactors Page 79
C. Brepols, H. Schäfer, N. Engelhardt
(Erftverband)
- The European MBR market: specificities and future trends Page 81
E. Huisjes, K. Colombel, B. Lesjean
(Berlin, Center of Competence for Water, Germany)

Final key-note, award and closure session

Chairman: R. Ben aim

(Chairman of IWA Specialist Group "Membrane Technologies")

- Submerged MBR technology: an unfinished international adventure of 20 years Page 83
K. Yamamoto
(The University of Tokyo, Japan)

Poster Session

<p>Performance Assessment of MBR Applications for Metropolitan Wastewater Treatment in the United Arab Emirates <i>Alnaizy, R., Sarin, V.</i></p>	<p><i>Page 85</i></p>
<p>Effect of aeration and viscosity in submerged membrane reactor <i>Aryal, R.K., Vigneswaran, S., Kandasamy, J.</i> <i>University of Technology, Sydney, Australia</i></p>	<p><i>Page 87</i></p>
<p>Development and evaluation of a Discontinuous reactor of moving bed and submerged membranes for the waste water treatment <i>Ávila-Arias, J.A., Delgado-Luna, I.P., Bernal-Martínez, A., Cuevas-Rodríguez, G</i> <i>University of Guanajuato, Mexico</i></p>	<p><i>Page 89</i></p>
<p>Development Perspectives of on-site MBR Treatment plants in the municipal wastewater sector of China <i>Binz, C.</i> <i>Eawag, Institute of Aquatic Science and Technology, Swiss Federal</i></p>	<p><i>Page 91</i></p>
<p>Cleveland Bay Wastewater Treatment Facility - Retrofitting Membranes within Existing Structures <i>Boland, T., Hartley, K.</i> <i>Townsville, Australia</i></p>	<p><i>Page 93</i></p>
<p>Comparison of Pharmaceutical Substances Removal between a Full Scale Conventional Activated Sludge Process and a MBR Pilot Plant <i>Bouju, H., Buttiglieri, G., Malpei, F.</i> <i>Polytechnico, Milano, Italy</i></p>	<p><i>Page 95</i></p>
<p>The Fate of ¹⁴C-Radiolabelled Diclofenac and 4'-Hydroxydiclofenac in a Laboratory Scale MBR <i>Bouju, H., Hommes, G., Wintgens, T., Corvini, P.</i> <i>Polytechnico, Milano, Italy</i></p>	<p><i>Page 97</i></p>
<p>Integration of photocatalysis and biological oxidation in MBR for pesticides degradation <i>Casas López, J.L., Sánchez Pérez, J.A., Ballesteros Martín, M.M., García Sánchez, J.L., Malato Rodríguez, S.</i> <i>University of Almería, Spain</i></p>	<p><i>Page 99</i></p>
<p>Techno-Economic Study of a Pilot-Scale MBR Plant for Pharmaceutical Wastewater Treatment <i>Chang, C.Y., Chang, C.J., Chang, J.S., Vigneswaran, S. Ben Aim, R.</i> <i>Chia Nan University, Taiwan</i></p>	<p><i>Page 101</i></p>
<p>Advanced analysis of polysaccharides in MBR fouling by chromatography <i>Charlery, C., Drews, A., Kraume, M., Kroh, L.</i> <i>TU Berlin, Germany</i></p>	<p><i>Page 103</i></p>
<p>Long Term Operating Experience with Pilot plant MBR using Submerged Hollow Fiber Membrane <i>Chung, J.H., Heo, Y.R., Lee, J.H., Lee, E.S.</i> <i>Daewoo Institute of Construction Technology, Korea</i></p>	<p><i>Page 105</i></p>
<p>Industrial Xenobiotics Removal from Urban Wastewater in Membrane Bioreactors: Pilot and full Scale Experiences in Italy <i>Di Fabio, S., Fatone F., Bolzonella D., Cecchi F.</i> <i>University of Verona, Italy</i></p>	<p><i>Page 107</i></p>
<p>Influence of nitrifiers on SMP concentration, rejection and fouling in MBR <i>Drews, A., Charlery, C., Kroh, L., Kraume, M.</i> <i>TU Berlin, Germany</i></p>	<p><i>Page 109</i></p>
<p>Optimization of Submerged Membrane Bioreactor Process for Wastewater Treatment by Minimizing the Fouling Phenomenon <i>Etxebarria, J., Iturbe, D., Urkiaga, A.</i> <i>GAIKER Technological Centre</i></p>	<p><i>Page 111</i></p>

Advanced Purification Of Industrial And Mixed Wastewater By Combined Membrane Filtration And Sonochemical Technologies <i>Fatarella, E., Cioni, I., Ciabatti, I., Venturini degli Esposti, E.</i> <i>Tecnotessile, Italy</i>	Page 113
Use of MBR for Treatment of Effluent from Liquefied Natural Gas Industry <i>Fauveau, C.</i> <i>Veolia Water, Antony, France</i>	Page 115
2D-Fluorescence spectroscopy as a novel monitoring tool in MBR modelling for wastewater treatment systems <i>Galinha, C.F., Portugal, C., Carvalho, G., Guglielmi, G., Chiarani, D., Andreottola, G., Oliveira, R., Reis, M.A.M., Crespo, J.G.</i> <i>University of Trento, Italy</i>	Page 117
Challenge Testing Membrane Microfilters at a Wastewater Facility in the New York City Watershed <i>Habib, J.A., Vial, D.</i> <i>Pall Water Processing, Washington, USA</i>	Page 119
Oxygen transfer in membrane bioreactors operating at high sludge retention times <i>Henkel, J., Wagner, M., Cornel, P.</i> <i>Technische Universität Darmstadt, Germany</i>	Page 123
Membrane Bioreactors - Influence of dynamic operation <i>Hermann, S., Röttgers, N., Iversen, V., Drews, A., Lesjean, B., Kraume, M.</i> <i>TU Berlin, Germany</i>	Page 125
Impact of operation conditions on the removal of bulk organics and bisphenol a in a pilot MBR <i>Herr, J., Kazner, C., Wintgens, T., Melin, T.</i> <i>RWTH Aachen University, Germany</i>	Page 127
Toward biofouling description in sidestream An-MBR treating municipal wastewater: advanced autopsies on uf modules <i>Herrera-Robledo M., Calderon K., Morgan JM, Noyola A.</i> <i>TU Berlin, Germany</i>	Page 129
Influence of selected operational parameters on (ir)reversible fouling in MBR's <i>Huyskens, C., Brauns, E., Van Hoof, E., De Wever, H.</i> <i>University of Antwerp, Belgium</i>	Page 131
Pilot-scale demonstration and optimization of side-stream MBR using ceramic membrane <i>Kando, K., Suzuki, S., Itokawa, H., Inoki, H., Nakazawa, H.</i> <i>Metawater Co., Ltd, Japan</i>	Page 133
Rheological properties of membrane bioreactor sludge: Influence of total suspended solids and soluble organic matter <i>Khongnakorn, W., Vachoud, L., De la Londe, M., Wisniewski, C.</i> <i>University de Montpellier, France</i>	Page 135
Separation Performance of Polyelocetrolyte-Modified Ultrafiltration Membranes <i>Kochan, J., Wintgens, T., Wong, J.E., Melin, T.</i> <i>RWTH Aachen University, Germany</i>	Page 137
Comparison of the operational processes of three different full-scale membrane bioreactors <i>Krzeminski, P., Atasoy, E., Van Nieuwenhuijzen, A., Van der Graaf, J.</i> <i>Delft University of Technology, Netherland</i>	Page 139
Optimisation of MBR Operation and Reliability Using Failure Mode Analysis <i>Lazarova, V.</i> <i>Suez environment, France</i>	Page 141
MBR aeration and fouling, different levels of observation <i>Lebegue, J., Heran, M., Grasmick, A.</i> <i>Université de Montpellier, France</i>	Page 143
Detailed monitoring of household MBR plant	Page 145

<i>Matulová, Z., Pikorová, T., Hlavínek, P., Drtil, M.</i> <i>University of Technology, Czech Republic</i>	
Searching for optimum fouling control strategies <i>Meabe, E., Sancho, L.</i> <i>CEIT Section of Environmental Engineering, San Sebastián, Spain</i>	Page 147
Decision Support System for mbr fouling control <i>Monclus, H., Ferrero, G., Sipma, J., Comas, J. Rodriguez-Roda, I.</i> <i>University of Girona, Catalonia, Spain</i>	Page 149
Seasonal effect: impact on MBR sludge filterability depending on membrane configurations <i>Moreau, A., Ferreira, M.L., Van Nieuwenhuijzen, A., Van der Graaf, J.</i> <i>TUD, Faculty of Civil Engineering and Geosciences, Delft, The Netherlands</i>	Page 151
Reversible fouling quantifications: any links with full-scale plant permeability? <i>Moreau, A., Krzeminski, P., Van Nieuwenhuijzen, A., Van der Graaf, J.</i> <i>TUD, Faculty of Civil Engineering and Geosciences, Delft, The Netherlands</i>	Page 153
Airlift MBR at municipal WWTP Terneuzen - Pilot research supports full scale implementation <i>Pot, M.A., Van Agtmaal, J., De Boks, P.A., Veraart, A.M.J., Schonewille, H.</i> <i>Evides Industriewater, Rotterdam, The Netherlands</i>	Page 155
Effects of Biofilm Formation on Oxygen Transfer Membranes in Membrane Micro-Aerated Anaerobis Digesters <i>Rathnasiri, P.G., Botheju, D., Bakke, R.</i> <i>University of Moratuwa, Sri Lanka</i>	Page 157
Hydrodynamic CFD simulation of a two-phase flow in an ultrafiltration membrane tube for a side-stream membrane bioreactor <i>Rios N., Nopens I., Vanrolleghem P.A.</i> <i>Department of Applied Mathematics, Ghent, Belgium</i>	Page 159
Mass transfer coefficient determination of a two-phase flow for an UF membrane in a side-stream MBR <i>Rios N., Nopens I., Vanrolleghem P.A.</i> <i>Department of Applied Mathematics, Ghent, Belgium</i>	Page 161
Effect of High Sludge Ages on the Sludge Characteristics in Membrane Bioreactors <i>Schaller, J., Drews, A., Kraume, M.</i> <i>TU Berlin, Germany</i>	Page 163
Microbial population structure of pilot- and full-scale membrane bioreactors <i>Silva, A.F., Carvalho, G., Lousada-Ferreira, M., Van Nieuwenhuijzen, A., Guglielmi, G., Crespo, J.G., Reis, M.A.M., Crespo, M.T.B.</i> <i>IBET/ITQB, UNL, Oeiras, Portugal</i>	Page 165
Performance Evaluation of Submerged Membrane Bioreactor Pilot Units for Refinery Wastewater Treatment <i>Tôrres, A.P.R., Santiago, V.M.J., Piacsek, C.B.</i> <i>PETROBRAS / CENPES, Brazil</i>	Page 167
Asahi Kasei MBR pilot research at the Utrecht WWTP <i>Van Bentem, A.G.N., Kubota, A.C., Nijman, N., Hashimoto, T.B.</i> <i>DHV, The Netherlands</i>	Page 169
Fouling behaviour of model solutions and sludge fractions in membrane bioreactors <i>Van den Brink, P.F.H., Smith, G.O.J., Zwijnenburg, A., Van Loosdrecht, M.C.M.</i> <i>Wetsus, Centre for Sustainable Water, The Netherlands</i>	Page 171
Membrane properties influencing fouling in MBR <i>Van der Marel, P., Zwijnenburg, A., Kemperman, A., Wessling, M., Temmink, H., Van der Meera, W.</i> <i>University of Twente, The Netherlands</i>	Page 173
Combination of flux enhancers for MBR	Page 175

Villwock, J., Iversen, V., Drews, A., Lesjean, B., Kraume, M.
TU Berlin, Germany

Evaluation of Mixing efficiency & Nutrient removal in membrane bioreactors via cfd modelling with experimental validation *Page 177*

Wang, Y., Brannock, M., Leslie, G.
University of New South Wales, Sydney, Australia

Wastewater Upgrading Technologies: A Preliminary Comparison Using Analytical Hierarchical Process (AHP) Analysis *Page 179*

Yang, F., Bick, A., Oron, G.
University of the Negev, Israël

Standarization of Membrane Bio-Reactor Working Groups Using Partial Order Scalogram Analysis (POSA) *Page 181*

Yang, F., Bick, A., Oron, G.
University of the Negev, Israël

The Effect of Biofilm Carriers Filling Ratio and Mixing Regime on Biomass Distribution, Fouling Rate, and Process Efficiency in a Hybrid Growth Membrane Bioreactor (HG-MBR) *Page 183*

Yang, F., Wang, Y., Gilron, J., Brenner, A., Oron, G., Bick, A.
University of the Negev, Israël

Enhanced cleaning process for MBR *Page 185*

Zimmermann, B., Krause, S., Siembida, B., Cornel, P.
Microdyn-Nadir GmbH, Wiesbaden, Germany

Development of a method for on-line measurement of carbohydrates in membrane bioreactor system

Sebastian Aust, Renata Mehrez, Mathias Ernst, Martin Jekel
TU University of Berlin

Development of a sample pre-treatment device for on-line analysis of proteins and carbohydrates in membrane bioreactor systems

Renata Mehrez, Mathias Ernst, and Martin Jekel
TU University of Berlin

EUROPEAN ACTIVITIES AND STRATEGY OF MEMBRANE R&D

Andrea Tilche* and Michel Schouppe*

*European Commission, DG Research, Unit Environmental technologies and pollution prevention
B-1049 Brussels, Belgium
andrea.tilche@ec.europa.eu
michel.schouppe@ec.europa.eu

Keywords: Community research, membrane technologies, wastewater treatment, European Research Area

Abstract

Since a decade (including through the 6th and 7th Framework Programmes covering the periods 2002-2006 and 2007-2013), Community research in water membrane has placed emphasis on developing, integrating and validating technological solutions taking a particular attention to up-scaling issues (from micro to macro scale). The ultimate objective was, and remains today, to mature technology, make it cost-effective in various operational water treatment contexts, as well as attractive to public and private customers. A series of projects will soon deliver final outcomes; others will soon be launched for new investigations of aspects of membrane technology for water treatment. There respective foci range from reverse osmosis for pre/post wastewater treatments, including notably micro-, ultra- and nanofiltration, or membrane fouling aspects, to management practices and advanced wastewater treatment strategies. These projects contribute to creating a strong European Research Area in the field of membrane technologies, including Membrane BioReactor (MBR). Thanks to several research efforts, notably at Community level, the technology of aerobic submerged membrane bioreactors has now evolved from the status of a promising technology to the status of state-of-the-art technology. The European MBR market was initiated in the late 90ies, and in only about 10 years grew to a 2009 forecast of about 700 installations in Europe, 1/3 of which for municipal wastewater treatment.

Membrane technology represents a strategic sector in which Europe is well positioned in terms of S&T excellence. Even though weak on the side of membrane manufacturing, the strengths of Europe lie mainly in the competitiveness of its membrane engineering industry, especially with regards to system integration for municipal or industrial wastewater treatment and for desalination of brackish or sea waters. In particular, Europe benefits from a good network of SMEs active in this field that often are well connected to experienced academic centres.

This research community is wide and of world class. Discussions are now being undertaken between the European water research and membrane communities in order to reinforce synergies and possibly create a “membrane water cluster” under the European Membrane House (MBH) created recently as a spin-off of the FP6 NanoMempro Network of Excellence. These and other networking activities, such as the successful MBR network cluster, demonstrate the dynamism of several European actors to leverage and diffuse Community research outcomes.

Speaking about future research, it is necessary to keep considering the ‘pros’ and ‘cons’ related to the use of current MBR technology. Issues like wastewater characterisation, membrane fouling, hybrid membranes, sludge age, sludge disposal, effluent re-use, energy consumption, costs of purchase and maintenance, training of operators still hamper occasionally the proposed solutions and slow down market penetration. There is a high need for highly controllable and modular wastewater treatment plants that can be optimised according to needs, customers and wastewater contexts. A more system approach is required to designing new plants and upgrading existing ones, so as to reduce their ecological footprint locally, while allowing easy customisation of their performance over time. Due attention shall also be given to holistic approaches and life cycle assessments considering amongst other things greenhouse gases emissions (such as NO, NO₂, CH₄ and CO₂), energy consumption and the routes of involved toxicants in water and sludge.

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- 2) FP6: <http://cordis.europa.eu/fp6/dc/fp6/home.cfm>, FP7 : <http://cordis.europa.eu/fp7/>
- 3) Including the following FP6 projects:
AMEDEUS: <http://www.mbr-network.eu/mbr-projects/proj-desc-amedeus.php>,
EUROMBRA: <http://www.mbr-network.eu/mbr-projects/proj-desc-euombra.php>,
INNOWATECH: <http://www.innowatech.org/plugins/content/content.php?content.20>,
MEDESOL: <http://www.psa.es/webeng/projects/medesol/index.html>,
MEDINA: <http://medina.unical.it/>,
NANOMEMPRO: <http://www.nanomempro.com/>,
NEPTUNE : http://www.eu-neptune.org/index_EN,
RECLAIM WATER: (<http://www.reclaim-water.org/>),
REMOVALS: <http://www.etseq.urv.es/removals/>,
TECHNEAU : <http://www.techneau.org/>
- 4) WsstP : <http://www.wsstp.eu/site/online/home>

TRENDS IN WORLDWIDE MEMBRANE BIOREACTOR RESEARCH

Nazim Cicek* and Wenbo Yang**

*Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba, R3T 5V6, Canada, e-mail: Nazim_Cicek @umanitoba.ca

**Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba, R3T 5V6, Canada, e-mail: umyangw@cc.umanitoba.ca

Keywords: Membrane bioreactor; Wastewater treatment; Commercial application; Critical review

Abstract

Membrane Bioreactor (MBR) technology is advancing rapidly around the world both in research and commercial applications. This presentation aims to characterize and review worldwide academic research efforts in the area of MBRs as well as focus attention to commercial MBR applications in North America. This presentation is essentially an update of a critical review that was conducted by the authors in 2005. A total of 1027 research papers published in peer-reviewed international journals from 1991 to 2008 were used as the database for the analysis provided in this presentation. A significant surge of MBR publications was seen in both 2000 and again in 2005, reaching over 180 papers published per year in 2008. Research on external MBR units appears to have peaked in 1998 and declined since. Although much of the early pioneering research occurred in Japan, France and the UK, countries such as China, South Korea, USA, and Germany, have significantly contributed to the research pool in the last 5 years. Researchers in Singapore, Australia and Italy have added over 30 research articles to the field with most of them in the last three years. The primary research focus has been on water filtration MBRs with some growth in membrane biofilm reactors MBfRs. Fundamental aspects studied in academic research predominantly involve issues related to fouling (more 80%), as well as microbial characterization, performance optimization and modeling. Since 2005, the research focus appears to have switched from feasibility studies of utilizing MBRs for wastewater treatment to evaluating fundamental aspects. Research in North America presents a unique picture as a higher ratio of industrial wastewater treatment and side-stream MBR applications have been studied compared to other parts of the world. For full-scale MBR application in North America GE- Zenon continues to occupy the majority of the MBR market (over 65% overall, and 100% of plants larger than 10MGD). The number of GE-Zenon municipal MBR plants with capacities larger than 1MGD has doubled since 2006 and is expected to double once more by 2012. The overall treatment capacity of MBR plants has also doubled since 2006 and is expected to quadruple by 2012. The largest MBR in operation in North America has a maximum design flow of 20MGD, with the largest MBR awarded for 2012 at 50MGD. Industrial wastewater applications in North America are primarily in the food and beverage industry, chemical plants, manufacturing, and pharmaceutical industries. Number of industrial wastewater treatment plants using MBRs has tripled since 2004, with treatment capacity increasing by 5-fold. Despite the early slow growth of MBR applications in North America (1990s and early 2000s), the last 4 years has seen exponential growth with significant expansion being projected for the near future.

MBRS AND THE TMP JUMP – SELF ACCELERATING FOULING PHENOMENA

A.G.Fane

Singapore Membrane Technology Centre, NTU
UNESCO Centre for Membrane Science & Technology, UNSW

Abstract

Fouling in MBRs is a complex function of mixed liquor properties, membrane selection and hydrodynamic conditions, including fluid cross flow and imposed flux. At constant flux the development of fouling can be seen as a rise in transmembrane pressure (TMP), or suction pressure, over time. The TMP profile tends to have 3 stages that may signify different types of fouling. The first stage is relatively fast and occurs when a new or well-cleaned membrane experiences pore closure and pore blockage due to adsorption and initial convection of foulants. The effect would be exacerbated by high flux, the presence of large pores and membrane hydrophobicity. The second stage is typically extended over 100s of hours and can be attributed to gradual fouling by various components in the mixed liquor, with candidate foulants including fine colloids, polysaccharides, proteins and lipids derived from EPS, SMP and reactor feed components. In addition planktonic bacteria, and small bacterial floc will be convected to the membrane; larger floc (10s of microns) are unlikely to deposit under normal conditions due to their higher critical fluxes unless there are regions of inadequate crossflow. The bacteria that adhere to the membrane will colonize and gradually form biofilms. Thus stage 2 fouling could comprise fouling due to filtration of a complex mixture as well as a developing biofilm. The challenge for MBR operation is to minimize the rate of TMP rise during stage 2. We know that this can be achieved by reducing flux, increasing crossflow, reducing the organic loading rate, by longer SRTs (up to a point) and various additives (coagulants, PAC etc). These actions can be assumed to reduce the rate of foulant delivery and foulant concentrations and this implies a reduction in 'fouling by filtration'. The effect on biofouling is less clear cut. The 3rd stage in the TMP profile is a distinct and rapid increase in the rate of rise (dTMP/dt), the TMP 'jump', necessitating membrane shut down and cleaning. The operating time to reach the TMP jump is influenced by the same parameters that reduce dTMP/dt in stage 2, as well as intermittent relaxation of the membrane and minicleans (back wash with and without chemicals). In this presentation we review phenomena that could (alone or simultaneously) account for the TMP jump.

1. *Inhomogeneous fouling (area loss model)* [1]. This model is based on the observation that fouling is not necessarily homogeneously distributed, and can lead to local area flux distribution. In order to satisfy a constant permeate flow (constant average flux) the local flux must adjust to compensate for non-productive areas. If this dynamic adjustment leads to local fluxes above the critical flux of a dominant foulant (colloids, biofloc etc) the TMP will begin to rise more steeply. This model explained observations for the cross flow membrane filtration of an anaerobic liquor which produced uneven fouling by EPS.
2. *Inhomogeneous fouling (pore narrowing model)* [2]. If the above argument is applied at the level of individual pores then as pores narrow due to slow fouling there comes a point when the local pore flux exceeds critical flux and fouling increases dramatically. This model was used to explain crossflow MF of alginate (a surrogate for EPS) at constant fluxes. A rapid increase in retention of low MWt components of the alginate accompanied the TMP jump, supporting the view that the available pores were adjusting due to fouling. The fact that the TMP jump was observed in a 'non-biological' system shows that changes in biofilms are not a necessary condition for the TMP jump.
3. *Inhomogeneous fouling (pore loss model)*[3]. This model is similar in concept to model 2 and assumes pore closure leads to pore loss with a subsequent increase in local fluxes reaching the critical flux value provoking a rapid change in TMP. The model was used to explain data obtained on a side stream MBR with a multi-channel membrane.
4. *Critical suction pressure model* [4]. Although this model and experimental study applied to deadend filtration it could be relevant to gradual constant flux fouling in an MBR. The study, using a polystyrene latex and a hollow fibre MF membrane, observed a gradual TMP rise followed by a rapid increase in TMP. Both autopsy and modeling suggested a critical suction pressure at which coagulation occurred at the base of the cake.
5. *Percolation theory* [5]. This model was applied to membrane filtration of biological suspensions. The theory is based on the gradual loss of 'cake porosity' due to fouling and infiltration into an existing cake. The permeability of this cake layer is very sensitive to porosity and connectivity. Percolation theory predicts a dramatic drop in permeability at a critical degree of interconnectivity. Cake change phenomena are plausible during the filtration of mixed liquor with its complex particle size distribution.
6. *Inhomogeneous fibre bundle* [6]. Although the TMP jump is not restricted to hollow fibres there are 'self accelerating' phenomena that can lead to rapid TMP rise in this geometry. The effect has been observed in a 'model' bundle where individual fibre fluxes have been measured under conditions leading to slow fouling and bundle blockage. After a steady rise in TMP, a rapid increase was observed due to blockage. Interestingly the

distribution of individual fluxes (as a standard deviation) predicted the blockage event. This has led to the development of a detection method for incipient bundle blockage.

7. *Osmotic phenomena*. Whilst osmotic pressure is not usually considered for MF or UF of mixed liquors it could play a role. The facts pointing to this include, (i) the TMP 'jump' only requires an osmotic pressure of a few 10s of kPa to be significant; (ii) macrosolutes (polysaccharides and proteins) exert modest osmotic pressures; (iii) membrane pore sizes decrease due to stage 2 fouling, leading to an increase in retention of low MWt components (as observed with alginate feed – see model 2). Concentration polarization (CP) of retained species will be significant due to low mass transfer coefficients (low diffusivities and modest shear) and this can be enhanced by cake enhanced concentration polarization (CECP) effects. It is plausible that in an MBR the solute CP values could be from 5 to 50, depending on the influence of CECP. Thus stage 2 fouling and rapidly increasing retention combined with solute osmotic pressure could cause significant TMP rise to maintain the driving force.

It is postulated that several of the above phenomena could act, either in sequence or simultaneously to produce the stage 3 TMP jump observable in MBRs at constant flux.

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QUORUM QUENCHING: A NEW BIOFOULING CONTROL PARADIGM IN MBRS

Chung-Hak Lee*, Kyung-Min Yeon, Jae-Hyuk Kim

School of Chemical and Biological Engineering, Seoul National University, Seoul, 151-744, Republic of Korea
 *e-mail: leech@snu.ac.kr, tel: +82-2-8807075, fax: +82-2-8740896

Keywords: Membrane bioreactor, biofouling, quorum quenching

Quorum quenching, interference of microbial intercellular communication by enzymatic degradation of signal molecules, has proved its potential as a new biofouling control technique in a membrane bioreactor (MBR) for advanced wastewater treatment (1). However, for the successful application of the quorum quenching to MBR under a long-term continuous operation, problems of free enzyme loss should be solved through i) membrane permeate, ii) sludge withdrawal, and iii) enzyme lysis and denaturation in the bioreactor.

One of the solutions was to prepare a magnetic enzyme carrier (MEC) in which quorum quenching acylase is immobilized on magnetic particles. The enzyme immobilization layer was formed on a magnetic ion exchange resin by layer-by-layer (LBL) deposition of an anionic polyelectrolyte followed by a cationic polyelectrolyte. When MEC was applied to MBR in a continuous operation, MEC successfully reduced membrane biofouling compared to the control MBR (Figure 1).

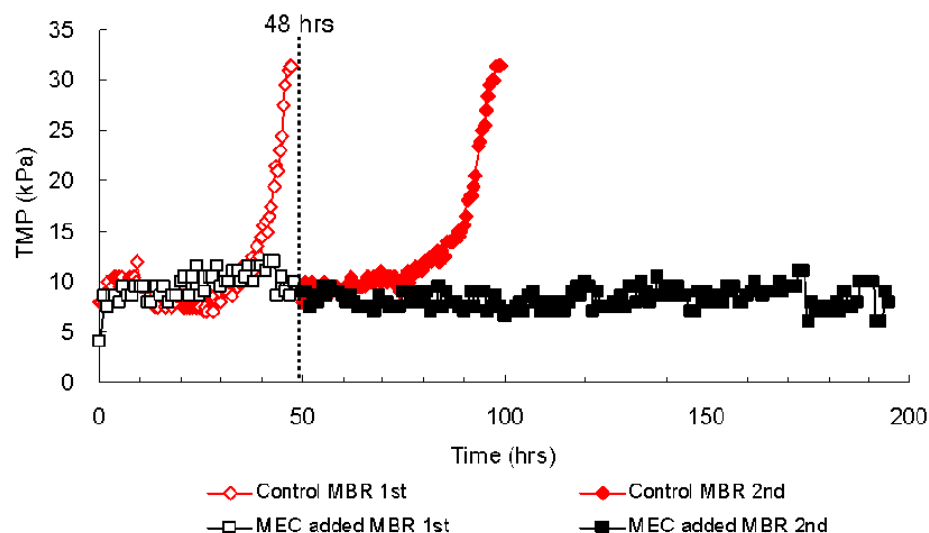
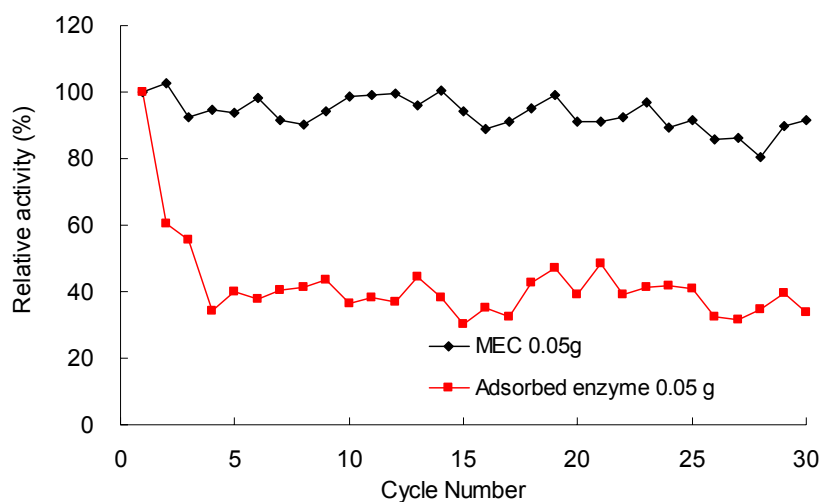
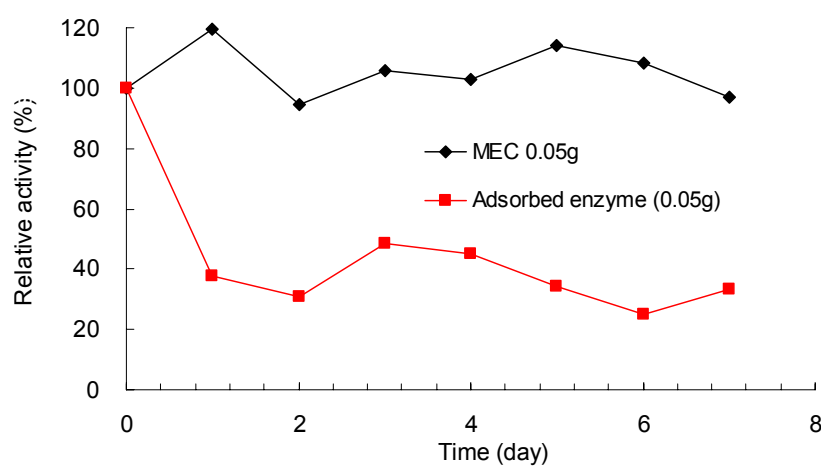


Figure 1. Comparison of TMP build-up between control and MEC added MBR.

Enzyme stability of MEC was determined by both iterative cycle and continuous shaking methods described by Kim (2). As shown in Figure 2, the MEC prepared in this study was highly stable at the shaking condition of 150 rpm under many recycled uses (iterative 30 cycles) for 7 days. In the iterative batch reactor experiment, MEC also showed greatly improved operation stability compared to the free enzyme because it can be easily recovered through a magnetic field.



(a)



(b)

FIGURE 2. Enzyme stability of MEC under (a) iterative cycles of enzyme reaction and magnetic separation using magnet and (b) continuous shaking for 7 days.

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DEVELOPMENT AND APPLICATION OF A PROTEINS AND POLYSACCHARIDES SENSOR FOR ON-LINE FOULING CONTROL IN MEMBRANE BIOREACTORS

Renata Mehrez *, Mathias Ernst **, Vera Iversen***, Anja Drews***, Matthias Kraume*** and Martin Jekel *

* Chair of Water Quality Control, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: renata.mehrez@tu-berlin.de; martin.jekel@tu-berlin.de)

** Centre for Water in Urban Areas, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: mathias.ernst@tu-berlin.de)

*** Chair of Chemical Engineering, Technische Universität Berlin, Straße des 17. Juni 136, MA 5-7, 10623 Berlin, Germany
(E-mail: vera.e.iversen@tu-berlin.de; matthias.kraume@tu-berlin.de)

Keywords: EPS, MBR, proteins, polysaccharides, sequential injection analysis

Introduction

Soluble and colloidal substances like soluble microbial products (SMP) or extra cellular polymeric substances (EPS) are considered to be the major foulants in MBRs (Rosenberger et al 2006). The concentration of SMP (or EPS) present in the supernatant of activated sludge is usually determined by measuring its most important constituents: polysaccharides and proteins. The existing literature data are not consistent with respect to the variation of polysaccharides and proteins concentration during a longer period of operation of MBR systems.

Objectives

The objective of the present work was to develop an on-line sensor which detects polysaccharides and proteins concentration continuously in the supernatant of activated sludge for monitoring of the variation of these substances and for a better understanding of fouling phenomena (Mehrez et al. 2008, Mehrez et al. 2007a).

The paper focuses on the development and automation of analytical methods for continuous analysis of polysaccharides and proteins as well as on the development of an appropriate on-line sample preparation device. Moreover results and the application of the new sensor in a MBR pilot plant is presented.

Materials & Methods

The scheme of the sensor is presented in the figure 1.

Sample pre-treatment. The developed sample pre-treatment device consists of a cylindrical stainless steel filter (surface $\sim 50 \text{ cm}^2$, pore diameter $1 \mu\text{m}$). The filter is submerged in the activated sludge; the sludge is filtrated continuously with a flux between 10 and $17 \text{ Lm}^{-2}\text{h}^{-1}$. The filtration (10 min) is intermitted by the relaxation interval (2 min). All components (pump, valve) are controlled by a clock-pulse generator. The filter is cleaned with 1 % sodium hypochlorite followed by the treatment with 10 % concentrated sulphuric acid.

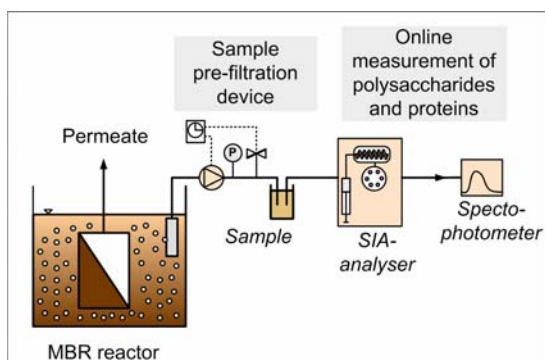


Figure 1: Scheme of the sensor for on-line measurement of SMP components.

Continuous analysis of polysaccharides and proteins The filtrated supernatant is pumped into a small sample vessel equipped with an spill, which discharge the surplus filtrate. Subsequently the SIA analyser aspirates the necessary sample volume from the sample vessel and measures the concentration of polysaccharides or proteins in the supernatant.

Sequential injection analysis (SIA) technique was used to develop and to perform the analysis of polysaccharides and proteins in continuous on-line mode. The apparatus was purchased from FIALab Instruments, USA (MicroSIA). The

methods were developed according to Dubois et al (1956) for carbohydrates and Lowry et al (1951) for proteins. Reaction between the sample and reagents occurred in a newly developed reaction chamber made from analytical glass. The conic form enables the complete removal of fluids from the chamber. The chamber is covered by a PVDF cover fixing the inlet tubes.

The polysaccharides and proteins are measured subsequently, because the phenol reagent used for the determination of carbohydrates interfere with the analysis of proteins.

Results and discussion

Sample pre-treatment. The stainless steel filter let pass carbohydrates and proteins present in the supernatant and retains suspended solids and bacterial flocs in very effective way. Separation characteristics of stainless steel filter with regard to the concentration of polysaccharides and proteins (as well to the turbidity) and DOC are comparable to that of the paper filter (Whatmann, 589/1 black ribbon, 125mm) used for the manual sample preparation. Separation properties remain the same over the time; this guarantee representative sample pre-treatment during the whole filter run-time for subsequent measurement of proteins and polysaccharides. (Mehrez et al. 2007b)

Continuous analysis of polysaccharides and proteins The analytical methods have been developed successfully for on-line mode. The detection of polysaccharides could be realized by using a newly developed reaction chamber. A rapid addition of H₂SO₄ (second reagent) and an appropriate selection of the carrier solution were necessary for proper measurements with SIA. The automated polysaccharides method shows slightly lower limit of detection and quantification (DL: 1.0 mg/L, QL: 3.3 mg/L) as well as method errors (mean SD: 0.5) compared to the standard manual method. Moreover the method shows very good robustness and sensitivity during continuous measurement with standard solution and sludge filtrate. (Mehrez et al. 2008)

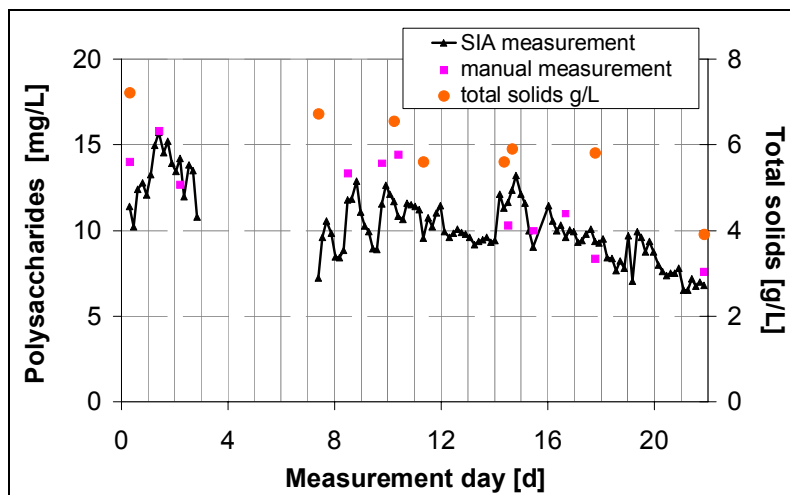


Figure 2: Concentration of polysaccharides measured on-line from 20.10-10.11.08 in MBR pilot plant, Berlin.

The use of the reaction chamber has improved also the sensitivity of the automated protein method in comparison to Mehrez et al. (2007a). Furthermore the method was modified: through the addition of the chelating agent (nitrilotriacetate) precipitates formed during the measurement of sludge samples, containing high salt concentration, have been prevented. Nevertheless the sensitivity of the automated protein method is lower than of standard manual method, resulting in higher limit of detection and measurement error (DL: 3.9, QL: 13.5 mg/L, mean SD: 2.2 mg/L). The method shows acceptable robustness in continuous measurement with standard solution. A small concentration variation of proteins in the sludge filtrate can be reliably analyzed when the calculated values are averaged for longer time period (e.g. 8 hours). By measuring of sludge supernatant and raw wastewater samples good agreement was found between the standard manual method and developed automated SIA method.

The whole sensor system is currently tested in a MBR pilot plant in Berlin, Germany. An example of continuous measurement of polysaccharides in the sludge supernatant from 20th October to 10th November 2008 is displayed in the figure 2. The variation of polysaccharides is moderate during the day; however during 3 weeks of measurement a decrease in the concentration from 15.7 mg/L to 6.8 mg/L have been observed. This decrease correlates very well with the concentration of suspended solids in the reactor, what shows that it is very important parameter which influences the content of polysaccharides in the sludge and probably the fouling propensity of the sludge. The protein concentration measured from 13th Nov. to 02th Dec 2008 shows small decreases from 25.1 mg/L to 18.6 mg/L that had no correlation with the concentration of suspended solids.

Conclusions

An on-line sensor for continuous photometric measurement of polysaccharides and proteins in MBR sludge is available now. The sensor is currently installed at a MBR pilot plant (Berlin Mitte) and the variation of the carbohydrates and proteins concentration in the supernatant of activated sludge is monitored and their impact on fouling in the MBR system is examined.

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THE EUROPEAN MBR TOUR OF THE DELFT FILTRATION CHARACTERISATION METHOD

Jaap H.J.M. van der Graaf, Arjen F. van Nieuwenhijzen, Stefan Geilvoet, Adrien A. Moreau, Maria Lousada Ferreira, Pawel Krzeminski

Delft University of Technology, Faculty of Civil Engineering and Geosciences, Stevinweg 1, 2628 CN Delft, the Netherlands; j.vdgraaf@witteveenbos.nl or a.a.moreau@tudelft.nl

Keywords: MBR, filterability, sludge characteristics, operation

Introduction

In full-scale MBRs enormous differences in membrane filtration performances are found during operation. Parts of the differences are caused by differences in the filterability of the MBR sludge. With the Delft Filtration Characterisation method (DFCm) the filterability of the MBR sludge can be expressed by a normalized parameter. So differences in filterability can be defined and evaluated.

Objectives



In the framework of the MBR-TRAIN and EUROMBRA projects, it was decided to perform filtration tests on various MBR-locations in order to find interesting relations and differences. The tests were done at 10 MBR-sites (see Figure 1).

Fig 1: MBR test sites, where DFCm-filterability tests were performed

Materials and methods

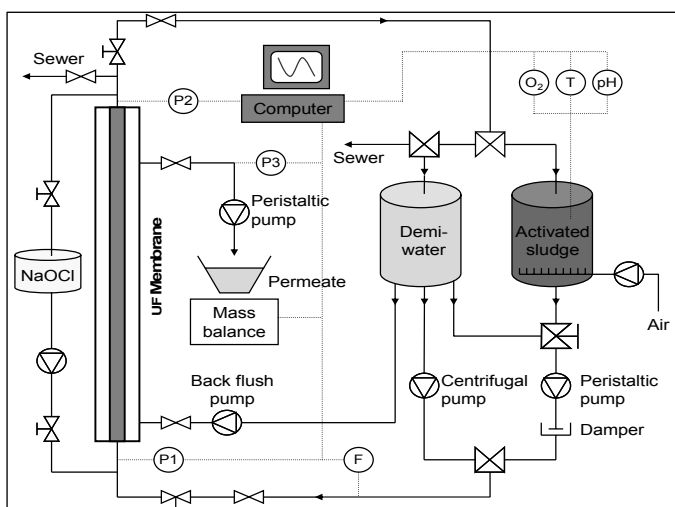


Fig 2: Set-up of the Delft Filtration Characterization installation

The DFCm consists of a filtration unit and a standardised measuring protocol for the determination of the filtration characteristics of MBR-sludge. In Figure 2 the equipment is described. The protocol is described in detail by Evenblij [1]. For each test approximately 30 L of MBR-sludge is needed. The protocol produces a value ΔR_{20} , which is the extra resistance when filtrating 20 L/m^2 . This parameter has to be as low as possible in order to create good filtration conditions. Furthermore many physical and chemical parameters were measured.

Results and discussion

Comparison between MBRs

In Figure 3 the results of the ΔR_{20} measurements are presented. From earlier experiments the filtration can be estimated as good when ΔR_{20} is less than $0.1 (*10^{12} m^{-1})$, moderate for values between 0.1 and 1.0 and poor for values higher than 1.0 [2]. So from Figure 3 differences in filterability can be shown between all installations. It also can be illustrated that the filterability in summer usually is better than in winter, which also is supported by the operational experience with the MBR installations

In general the installations with high ΔR_{20} values also show a poor performance in practice.

This is illustrated by the Schilde-case [3] where due to the bad filterability of the sludge the installation had to be taken out of operation and started-up after some modifications with new sludge; then the filterability became better and also the performance of the full scale-unit.

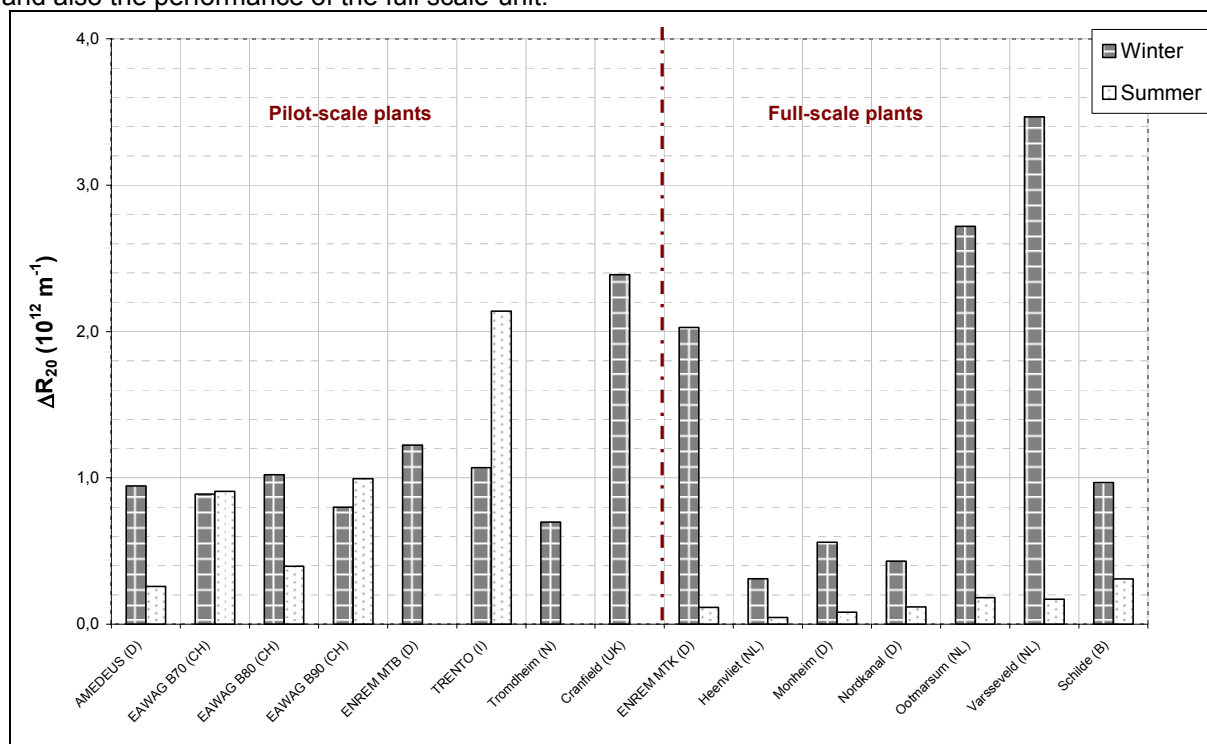


Fig 3: ΔR_{20} values for all of the MBR-sites

Sludge instability

In the EAWAG experiments the MBR sludge was investigated during different phases of the process (rather highly loaded) [4] In Figure 4 the various filterability values are shown. It can be seen that in the beginning of the treatment process the sludge is very unstable with respect to filterability but further on in the process the filterability improves; after division into different membrane tanks the sludge further improves in filtration quality; the differences between the various filtration units must be explained by differences in hydraulic detention time and sludge concentration (see following item).

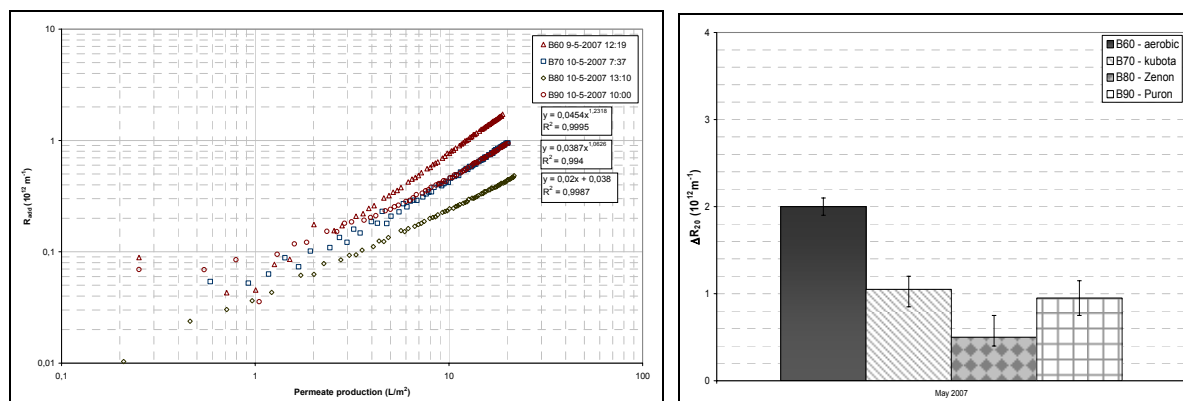


Fig 4: results for the EAWAG test-site (B60 –aerobic tank; B70, B80, B90- different membrane tanks)

Sludge concentration

In the Cranfield experiments the mixed sludge is fed to different MBR tanks at different hydraulic regimes finally leading to different sludge concentrations. In Figure 5 the ΔR_{20} is shown as a function of the sludge concentration. It is clear that high sludge concentrations lead to an improvement of the filterability.

This is also found in the Trondheim experiments where supernatant from a Kaldness process is tested under normal and flocculating conditions (with higher sludge concentration).



Fig 5: influence of the sludge concentration [5]

Influence of temperature

The influence of temperature is clear; in Monheim the filterability is in winter however still rather moderate but not as good as in summer; because this installation is dimensioned with not many extra capacity, in practice in winter serious hydraulic capacity problems occur which can partly be explained by the decrease in filterability. The influence of the temperature is further illustrated by Figure 6 showing the filterability after changing the temperature of the sludge; in many situations the filterability is less when changing the temperature to 10°C or lower.

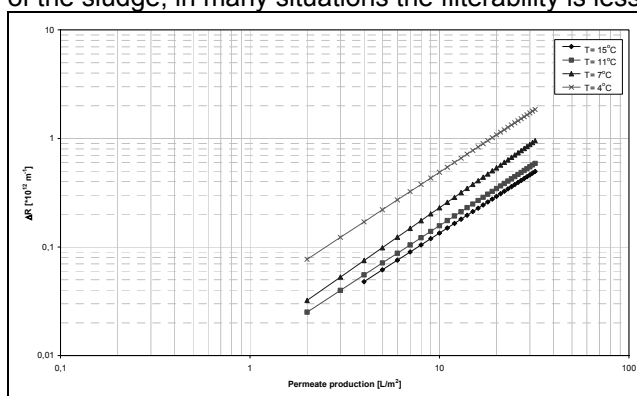


Fig 6- Filtration curves from membrane bioreactor sludge at different temperatures.

Filterability model

In order to explain the various differences many attempts have been tried to correlate good or bad filtration properties with specific substances like EPS and SMP; until now with poor results. In our research the conclusion can be drawn that a relation does exist between the filterability and the concentration of submicron particles, colloids with a size of 0.1-1.0 μm , in the free-water phase. Furthermore it is possible to influence the amount of these submicron particles: they increase in numbers at a negative temperature shock, the numbers are generally higher at lower temperatures, the numbers do relate with the sludge concentration (at high concentrations > 10 g/L the numbers decrease and the filterability improves), the numbers increase when putting the MBR sludge into stress (for instance substrate additions). This all leads to the conclusion that flocculation and deflocculation plays a determining role in the creation of a good filterability.

Conclusions

In order to establish a good filterability the DFCm is a very effective tool for practical and scientific purposes. Very interesting relations and differences were measured, which were supported by operational experience, leading to the main finding that flocculation and deflocculation is a very important process in order to create a good filterable MBR sludge.

Acknowledgements

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THE QUEST FOR INDICATORS OF MEMBRANE FOULING IN MEMBRANE BIOREACTOR SYSTEMS

T. de la Torre^{*}, V. Iversen^{**}, J. Stüber^{*}, R. Mehrez^{***}, A. Drews^{****},
B. Lesjean^{*}, M. Kraume^{**}, M. Ernst^{***}, M. Jekel^{***}, F. Meng^{**}

^{*}Berlin Centre of Competence for Water, Cicerost. 24, 10709 Berlin, Germany (teresa.delatorre@kompetenz-wasser.de)

^{**}Chair of Chem. Engineering, TU Berlin, Straße des 17. Juni 136, 10623 Berlin, Germany

^{***}Chair of Water Quality Control, TU Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

^{****} Now working with: University of Oxford, Dept. of Eng. Sci., Parks Rd, Oxford OX1 3PJ, UK

Keywords: fouling; extracellular polymeric substances (EPS); membrane bioreactors (MBR)

Introduction

After the work of Rosenberger *et al.* (2006), numerous posterior studies have tried to replicate the relationship found at that time between polysaccharide (PS) concentration in activated sludge supernatant and long term fouling rates in membrane bioreactors (MBR). In some cases, this linear relationship could be confirmed, whereas no relationship could be found in other studies (Drews *et al.*, 2008). Unfortunately, as the studies are performed in different conditions (different membrane, SRT, hydraulic conditions and different incoming wastewater), the resulting fouling rates are rarely comparable. In order to obtain a significant database of comparable results from different plants, a monitoring campaign started in 2007 in Berlin with four MBR systems. In these units, fifteen parameters have been monitored on a weekly basis over ten months to characterise the mixed liquor. To the knowledge of the author such a comprehensive monitoring campaign was never performed before on so many MBR systems and will provide information about the contribution of the different parameters to the fouling propensity of activated sludge in MBR.

Objectives

The objective was to evaluate the possibility of obtaining a universal parameter which could be used as a quick, easy indicator for short and long term fouling in MBR. The final objective would be the automatic adaptation of the filtration conditions in the plant based on the on-line measurement of this parameter.

Materials & Methods

Fouling propensity of the different MBR mixed liquors from these units was evaluated using the *in situ* Berlin Filtration Method (BFM), which measures the critical flux (J_c) of the activated sludge directly in the plant so that there is no alteration of the sludge sample. Geometry and aeration are set to mimic hydrodynamic conditions in a full scale technical module. The conditions of the assay are fixed, meaning that the results from the different plants are comparable. The BFM, represented in Fig. 1, uses a filtration test cell with a UF flat-sheet of PES with a filtration surface of 0.025 m². Further characteristics are described in de la Torre *et al.*, 2008a. The protocol for the measurement of the J_c is a flux-stepping method based on Le-Clech *et al.* (2003) which includes relaxation between

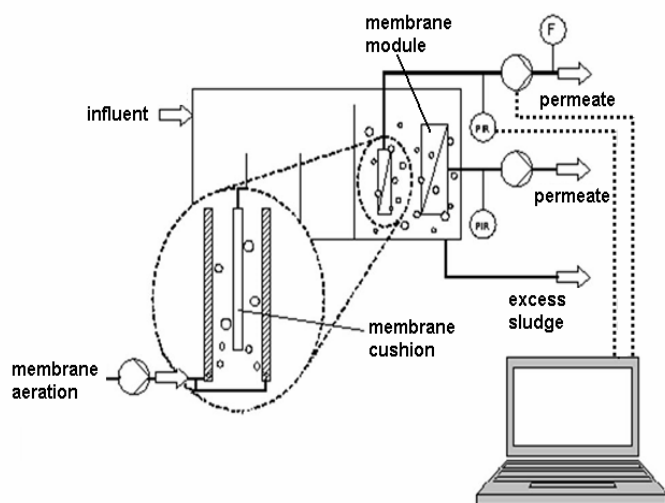


Figure 1: Scheme of the *in situ* BFM test cell

steps and a modification consisting in a small step at constant flux equals to 10 L/(m²*h) before every filtration step which enables the possible detection of irreversible fouling. The J_c data obtained were evaluated against the parameters measured during the monitoring campaign. These parameters were time to filter (TTF), capillary suction time (CST), bound and soluble extracellular polymeric substances (EPS), sludge volume index (SVI), total solids (TS), organic total solids (oTS), biopolymers (measured with size exclusion chromatography), total organic carbon (TOC), nitrate, nitrite and transparent exopolymer particles (TEP). TEP represents a novel parameter which has been recently introduced in the investigation of fouling in membrane processes (de la Torre *et al.*, 2008b). They are mainly acid mucopolysaccharides and represent a sticky fraction of the EPS. Additionally, the sludge from each plant was fractionated with filters of pore size 50 μ m, 10

μm , 2 μm and 0,2 μm subsequently. In every fraction, PS, proteins, TEP and COD were analysed in order to identify the most significant fraction for fouling and obtain information about the size of the main foulants.

Results and discussion

From the data analysis performed to date, only the polysaccharide and TEP concentrations in the sludge filtrate seemed to influence significantly the J_c data. The bound parameters (bound proteins, bound polysaccharides and bound TEP) did not show any correlation with J_c . Neither did the soluble proteins, TTF, CST and SVI. Hence, these parameters cannot be considered as a universal indicator of the fouling propensity of MBR sludge samples, as often assumed. The fractionation study did not reveal any activated sludge fraction as the most important one for short term fouling. A multivariable analysis will be performed with the whole database, and possible non-linear relationships between parameters will be studied. The J_c results obtained with the BFM seemed to agree with the performance of the units and this measurement technique was able to detect irreversible fouling in the plants when severe fouling events appeared.

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NEW DEVELOPMENTS IN MEMBRANE BIOREACTORS CHARACTERISATION AND MONITORING

Claudia F. Galinha¹, Gilda Carvalho^{1,2}, Ana F. Silva^{1,2}, Carla Portugal^{1,3}, Rui Oliveira¹, Maria T. B. Crespo², Maria A. M. Reis¹, João G. Crespo¹

¹REQUIMTE/CQFB, Chemistry Dept., FCT-Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

²IBET/ITQB, Apt. 12, 2781-901 Oeiras, Portugal

³CEBAL, R. Pedro Soares, Apt. 6158, 7801-908 Beja, Portugal

E-mail: jgc@dq.fct.unl.pt

Keywords: MBR, 2D-Fluorescence Spectroscopy, FISH, DGGE, Monitoring

Introduction

Membrane bioreactors (MBR) are widely applied for wastewater treatment. However, the progressive membrane fouling due to deposition of cells and cell products on the membranes reduces the permeability of the system, resulting in substantial maintenance costs and shortening membrane life span. Extracellular polymeric substances (EPS) are the major fouling agents in MBRs. EPS are formed as a result of the biological activity in the mixed liquor and therefore their abundance and composition is strongly dependant on the microbial population developed in the reactor and its physiological state.

2D-fluorescence spectroscopy is a highly sensitive, selective and non-invasive technique that can provide rapid information about the composition of complex media such as biological systems. Due to the fact that all organisms contain natural intracellular fluorophores, such as aminoacids (e.g. tyrosine and tryptophan), vitamins, coenzymes and aromatic organic matter in general, fluorescence is a technique suitable to be used in bioprocess monitoring. Furthermore, since this technique is non-invasive, it can be used *in situ* and on-line without disturbing the biological system. To deconvolute the information obtained by the excitation-emission matrices (EEMs) obtained by scanning the spectra wavelengths statistical based modelling was used. Using PLS (Projection to Latent Structures), EEMs can be correlated with key operational and performance parameters of the studied system.

Fluorescence *in situ* hybridisation (FISH) and denaturing gradient gel electrophoresis (DGGE) are molecular techniques that enable to monitor the microbial populations developed in MBRs. FISH allows the microscopic observation and quantification of target microbial groups, whereas DGGE gives fingerprints of the microbial population, allowing e.g. the detection of shifts in the population profile with variations in the operating conditions. Both techniques can also be used to identify dominant species in the biomass, which can possibly be correlated with reactor performance.

Objectives

The objectives of this study were:

- To demonstrate the applicability of 2D-fluorescence for monitoring the activity and performance of MBRs, through statistical based models that correlate EEMs with the MBR output variables.
- To show the use of molecular techniques (FISH and DGGE) to characterise the microbial populations developed in MBRs in different WWTPs and compare the obtained profiles.

Materials & Methods

Fluorometric spectra were generated in a range of 250 to 700 nm (excitation) and 260 to 710 nm (emission). EEMs were obtained for influent wastewater, MBR sludge and permeate for a pilot plant operated in Lavis, Italy.

PLS models were developed using operating conditions, wastewater characteristics and the EEMs as model inputs, and permeate characteristics, sludge characteristics and membrane performance (measured as transmembrane pressure, TMP) as model outputs, i.e. the parameters to be described by them.

The microbial population structures of four full-scale (Monheim - Germany, Henvliet - The Netherlands, Schilde - Belgium and Nordkanal - Germany) and four pilot-scale MBR plants (Margaretenhohe - Germany, EAWAG - Switzerland, NTNU - Norway and Lavis - Italy) were characterised by FISH analysis and three of the full scale plants were also characterised and compared by DGGE analysis. FISH analysis targeted general phylogenetic groups (*Alpha-*, *Beta-*, *Gamma-Proteobacteria*) as well as phosphorus and glycogen accumulating bacteria (PAOs and GAOs), ammonia oxidising bacteria (AOB) and nitrite oxidising bacteria (NOB).

Results and discussion

The 2D-fluorescence measurements performed in feed wastewater, mixed liquor and permeate show that this technique is sensible to differences in composition of the three distinct media (Figure 1), resulting in three different spectra.

Fluorescence spectra not only combine physiological patterns of different microorganisms, but also reflect the variation in concentration of some substrate components and microbial by-products which possess fluorescence properties. In addition, some molecules can act as quenchers to fluorescence, by interacting with the excited fluorophores, resulting in alterations of fluorescence signal. Therefore, it was necessary to deconvolute the

contextual information contained in the fluorescence maps using PLS modelling. The statistical models in this study were obtained using the fluorescence maps and their corresponding process performance parameters measured for different operating conditions.

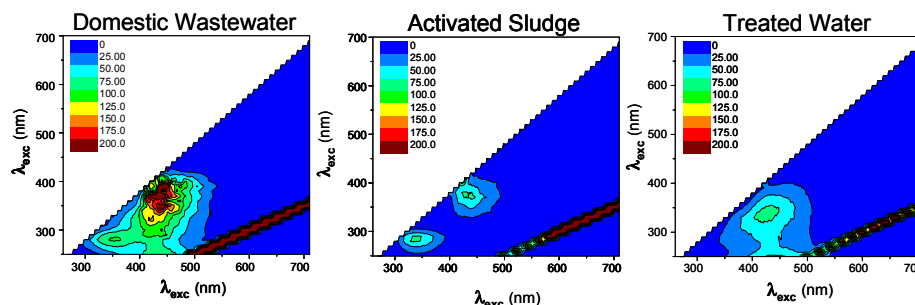


Figure 1: EEMs of wastewater, activated sludge and permeated water plotted as contour maps.

Figure 2 shows that, to describe the total COD in permeate, models using EEMs as inputs fit better the training points. Also the validation points (data not used to the model developing) are better described in PLS models using fluorescence data. Therefore the combination of the additional information provided by the EEM about the state of the biological system with the selected performance variables enhanced MBR modelling and performance prediction.

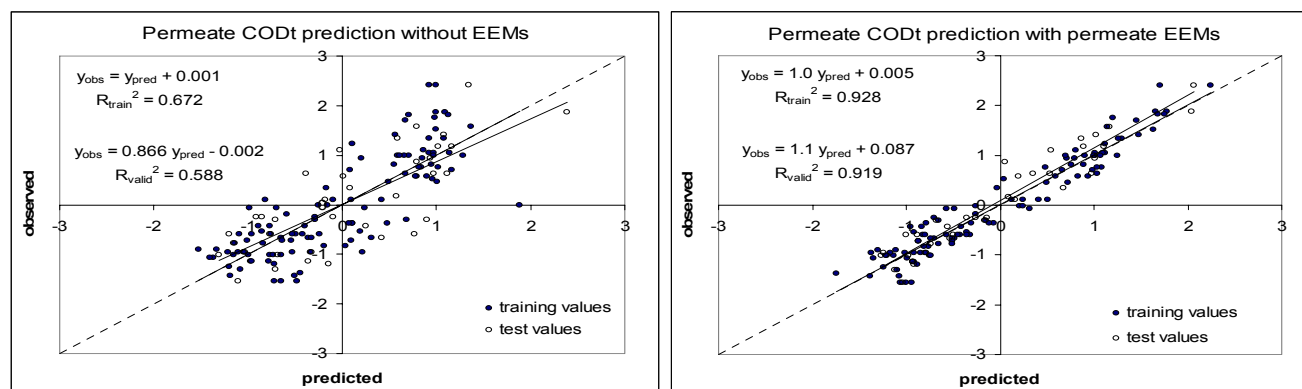


Figure 2: Predicted values of total Chemical Oxygen Demand (COD) in permeate represented against the observed values for two different PLS models, one without using fluorescence data and the other with permeate EEMs.

The microbial characterisation results showed that the dominant bacteria in all analysed plants belonged to the *Beta*- and *Gamma-Proteobacteria*, two bacterial groups that are often greatly represented in WWTPs. Most of the plants also contained relatively high numbers of PAOs (and their competitors GAOs) despite the fact that most of these plants were not designed for biological phosphorus removal. Most plants also contained representative numbers of nitrifiers, particularly AOB.

The DGGE profiles obtained from three of the studies full-scale plants displayed great differences in their microbial population structures, but they all seem to present similar levels of microbial diversity.

Table 1: Summary of FISH semi-quantificative profiles for the eight WWTPs assessed in this study.

Bacterial group	Nordkanal	Henvliet	Monheim	Schilde	Margeretenhohe	EAWAG	NTNU	Lavis
Dominant Bacteria	<i>β-Proteob.</i> (++++)	<i>β-Proteob.</i> (+++++)	<i>β-Proteob.</i> (++++)	<i>β-Proteob.</i> (+++++)	<i>β-Proteob.</i> (++++)	<i>β-Proteob.</i> (+++++)	<i>γ-Proteob.</i> (+++++)	<i>β-Proteob.</i> (++++)
PAO	++	+++	++	++++	++	++	++++	+++
GAO	+	++	+	++	+	+	++	++
AOB	+	+		+	-	+++	++	++
NOB	+	+	+	+	-	++	+	++

(+) 1-5%; (++) 5-15%; (+++) 15-30%; (++++) 30-45%; (+++++) >45%

Conclusions

The results obtained in this work supported the potential of applying novel techniques, such as 2D-fluorescence and molecular tools to characterise and monitor MBRs. 2D-fluorescence is a promising on-line monitoring technique that can accelerate decision taking as response to deterioration of MBR performance.

Biomass characterisation to a molecular level, e.g. using FISH and DGGE, can provide important information about the microbial population structure and dynamics. This information can be of great value in the understanding of biofouling, which can facilitate the development of process monitoring and optimisation strategies.

FOULANT DYNAMICS ON SUPPORTED MEDIA MEMBRANE REACTOR

R. Aryal*, S. Vigneswaran*, J. Kandasamy*, A. Grasmick **

*School of Engineering, University of Technology, Sydney, Broadway, 2000, NSW, Australia
 Rupak.Aryal@uts.edu.au, Vigid.Vigneswaran@eng.uts.edu.au, Jaya.Kandasamy@uts.edu.au,
 **Université Montpellier II, CC005, Place Eugène Bataillon; 34095, Montpellier Cedex 05, France
 alain.grasmick@univ-montp2.fr

Keywords: Aeration, transmembrane pressure, fouling, particle deposition

Introduction

Submerged membrane reactors are becoming popular for water and wastewater treatment as effluent standards are evolving in stringency and water conservation means that it is a strong demand for water reuse application. However, membrane fouling is still one of the main limitations in full-scale applications of membrane reactors in water and wastewater treatment. Several explanations have been advanced on the accumulation of fouling compounds on and within the membrane material [1].

Hydrodynamic and physico-chemical conditions are major factors affecting the performance of the membrane in separation. The most important operating parameters in membrane separation, which have an impact on fouling propensity, are the solids/particulates. One of the most common strategies to reduce and control fouling is to provide aeration (air sparging) close to membrane surface thereby inducing local shear stresses which control fouling by scouring and creates a favourable hydraulic distribution throughout the fibre network [2, 3]. Another method to reduce fouling is the use of support media [4].

Objectives

The objective of this investigation is to determine the impact support media at different aeration rates on the deposition of foulants on the membrane surface and the fouling propensity.

Materials & Methods

A membrane reactor tank with a total volume of 12 L was set up in the laboratory (Fig. 1). The tank equipped with flat sheet module containing 8 flat sheets, made of polyvinylidene (PVDF) with pore size 0.14 μm and filtration area 0.2 m^2 . Larger bubbles (2-4 cm in diameter) at an aeration rate of 2-4 $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ (200-400 l/h) were continuously injected from the bottom of the membrane tank to produce shear stresses and minimise particles accumulation on the membrane surface. Kaolin clay suspension (10 g/L) was added in the reactor as suspension. Anthracite (2 g/L) of particle size 640-2000 μm was added in suspension as a floating media. Membrane filtration was performed from outside to inside in a continuous mode. The experiments were carried out at different aeration rate and different permeation rate. Backwash and relaxation was not applied during the operation. The permeate flux was extracted by a peristaltic pump at a constant flux and discharged to the tank again to maintain the volume. The transmembrane pressure (TMP) was measured at intervals of 5 minutes with online data acquisition. Each experiment was run for 8 hrs and

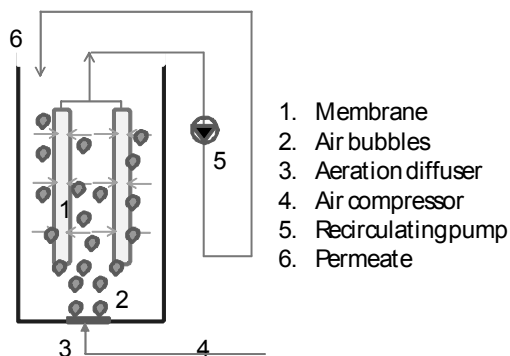


Figure 1: Schematic diagram of membrane unit

samples were collected from the tank (suspension) at a hourly intervals. The particle size distribution in suspension was measured using a particle size analyser (Malvern 2600). After each run, the membrane was cleaned with a sponge followed by ultrasonification for 3 hrs. The membrane was finally submerged in sodium hypochlorite solution (200 ppm) for 3 hrs. The membrane hydraulic resistance (clean membrane flux) was measured prior to each run and compared with a virgin membrane. In all runs the flux of the cleaned membrane was found to be virtually the same as a virgin membrane.

Results and discussion

In a cake filtration, the net accumulation of particles arises from an imbalance between the convective deposition and removal which is assumed to be proportional to shear stress:

$$\frac{dm}{dt} = A_t (J_t c - a \tau_t)$$

where, A_t is the surface area open to the permeation flow, J_t is the permeate flux, c is the mass concentration of the suspension, a is constant experimentally determined, τ_t is the shear stress and m is the mass of the cake.

Fig. 2 (a) shows the transmembrane pressure rise in absence of support media. In these experiments, the TMP development with time was rapid. The TMP at a higher aeration rate (400 l/h) was almost 6 folds lower than at a lower aeration rate (200 L/h). This shows the influence of aeration on membrane fouling. Fig. 2 (b) shows TMP rise in presence of a support media (anthracite). The rise in the TMP in the presence of support media was minimal. No distinct trend in the rise of the TMP was observed despite being operating at three different aeration rates. The similar rise in TMP at different aeration rates indicated that the support media helped not only to minimise the fouling propensity but also helped to change the nature of particles deposition. This could be a reason why TMP did not show distinct trend with time in presence of support media when operated at three different aeration rates.

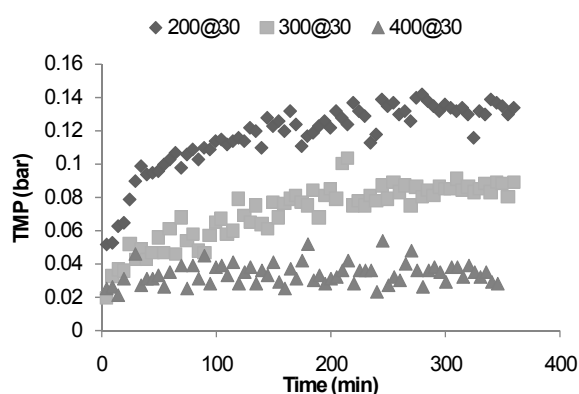


Figure 2 (a) : TMP variation at aeration rate 200, 300 and 400 l/h at constant flux 30 l/m/h in absence of support media

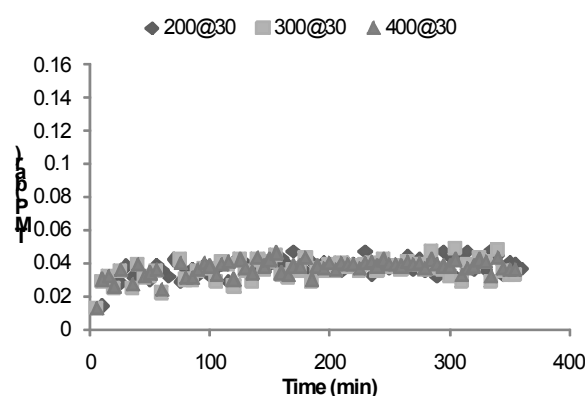


Figure 2 (b) : TMP variation at aeration rate 200, 300 and 400 l/h at constant flux 30 l/m/h in presence of support media

The mean particle diameter of the kaolin clay suspension at the beginning of the experiment was 4.1 μm . The deposited mass (foulant) on the membrane surface with time was calculated from the concentration remaining in the suspension. In the absence of a support media, the particle deposition pattern on the membrane was firstly fine particles followed by coarse particles as time elapsed. Similar pattern has been observed in literature [5, 6]. In the presence of a support media, the particle deposition on the membrane was almost four folds less. This showed that the support media helped to minimise membrane fouling. Moreover, the particle deposition pattern was random in the presence of the support media. Particles of smaller diameter as well as larger diameters deposited on the membrane at the same time. This behaviour could have helped to minimise the cake compactness and increased the porosity which in turn helped to minimise the rise in the TMP. Further experiments are required to understand the cake compactness and cake deposition pattern.

Conclusions

Effect of support media in membrane fouling was studied using kaolin clay suspension at different aeration rates. The trans-membrane pressure development was rapid in the absence of a support media. Higher aeration rates lowered the fouling propensity. The particle deposition pattern on the membrane was finer at the beginning followed by coarser particles. The presence of support media helped not only to reduce the fouling propensity by scouring the membrane surface, but also changed the particle layer formation pattern on the membrane surface. Simultaneous deposition of finer and coarser particles from the beginning might have helped to minimise the cake compactness and increased the porosity.

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ORGANIC MATTER IN MBR SLUDGE WATERS: FOULANT IDENTIFICATION AND CLEANING CONSIDERATIONS

Alessio Fenu*, Osi Braimah*, Jan-Willem Mulder*, Maria Kennedy*, Gary Amy*

*UNESCO-IHE Institute for Water Education, Delft, The Netherlands

**Waterschap Hollandse Delta, Ridderkerk, The Netherlands

Keywords: MBR, foulants, soluble microbial products, extracellular polymeric substances, cleaning

Introduction

This research study consisted of two phases: (i) role of membrane bioreactor operating conditions in the production of soluble microbial products (SMPs) in European pilot- and full-scale membrane bioreactors (MBRs) and (ii) fouling assessment and cleaning efficiency in a full-scale Dutch MBR.

Phase 1: Role of MBR operating conditions in the production of SMPs

Membrane fouling reduces permeability and increases operational costs in a membrane bioreactor (MBR) treating municipal wastewater. Organic colloids, extracellular polymeric substances (EPS), and NOM complexed with metals (e.g., Fe^{2+} and Ca^{2+}) have been implicated in fouling. Mixed liquor suspended solids (MLSS), sludge retention time (SRT), dissolved oxygen concentration and growth phase of bacteria all affect EPS production. The aim of this research was to elucidate the effects of these factors in fouling, and to characterise EPS using 3D-excitation-emission-matrix fluorescence spectroscopy (3D-EEM) and size-exclusion chromatography with a dissolved organic carbon detection (SEC-DOC). In EEM spectra, peak locations and intensities specify the concentration and type of EPS or its water-soluble fraction, soluble microbial products (SMP). Sludge water (0.45 μm pre-filtered MLSS) and MBR permeate samples were collected along with extracts of fouled membranes from two pilot plants (EAWAG and Trento) and two full-scale MBRs (Nordkanal and Schilde). Operational data were compiled and samples were analysed for SMP. EEM fluorescence of sludge waters exhibited the following peaks: Peak A (excitation-emission wavelength) Ex/Em, 270/320-350 nm, Peak B Ex/Em, 340/400-450 nm, and Peak C Ex/Em, 280/430-450nm. Peaks A and B are protein-like fluorophores retained by the membranes while Peak C represents humic-like fluorophores which are only partially retained.

The fluorescence intensities (arbitrary units) of the sludge-water supernatants were: A (30-35), B (15-70), C (30-40); corresponding permeate were: A (2-6), B (10-12) and C (14-16). Thus, there is a decrease in proteins and humic substances (HS) across the membranes. Using SEC-DOC, SMP retention by a Zenon membrane was determined to be 60-90% of HS and 92% of protein. The EEM spectra of membrane extracts showed fluorescence intensities for peak A (180) and peak C (80), levels higher than that in the corresponding sludge waters and thus confirming membrane retention and fouling by these components. At Nordkanal, DOC of the sludge water supernatant was 37.3 mg/L with EEM intensities of A (20-30), B (20-30) and C (40-50); corresponding permeate values were A (10-12), B (18-20) and C (25-30). At Schilde, the average DOC of the supernatant was 42.5mg/L, with peak intensities of A (140-180), B (60-80) and C (120-125); the corresponding DOC permeate of the permeate was 12 mg/L with peak intensities of A (1-2), B (10-15) and C (20-25). Correlations were difficult to make across different MBRs, however, at SRT of 20 days, high proteins and humic-fractions occur in the sludge supernatant. The production of EPS was seen to be weakly dependent on SRT <20 days, reaching an equilibrium value for specific MBRs. EEM spectra showed that HS are partly retained on the membranes, depending on molecular weight distribution. At the Trento MBR, using flux-stepping techniques (10, 18, 24-30 LMH), fouling rate was calculated, but an exponential increase in fouling due to colloidal materials masked the effects of other parameters.

Phase 2: Fouling assessment and cleaning efficiency in a full-scale Dutch MBR

This phase of the study focused on the identification of membrane foulants by characterization of the sludge water, and optimization of chemical cleaning to remove foulants in a full scale MBR plant in The Netherlands (Heenvliet) employing Toray flat-sheet membranes. Sludge water samples were collected from the full scale MBR system over a 6 month period. After prefiltration (0.45 μm), sludge water and permeate were analyzed. Employing a combination of DOC, SEC-DOC and EEM spectra, EPS was identified in the sludge water, and was strongly retained by the MBR membrane (up to the 70% for polysaccharides and the 59% for proteins). Moreover, the presence of biopolymers on the fouled membrane sheets was confirmed by SEC-DOC of extracted foulants during an autopsy campaign. EPS fouling was caused mainly by biopolymers, of a very high molecular size, on the feed side of the membrane. The ratio of proteins to polysaccharides in the biopolymer fraction of a sludge water sample was approximately 2:1, and this high ratio was attributed to the high SRT (29 days). Colorimetric methods confirmed the ratio of proteins to polysaccharides of 2:1, but also showed that the average protein retention (28-59%) was lower than the polysaccharide retention (66-70%). No clear correlation appeared to exist between permeability decrease and EPS concentration in the full scale MBR plant. Heenvliet data over the last two years were analyzed and a

weak correlation appeared to exist between permeability decline and MLSS concentration ($r^2 = 0.78$). Based on these results it was recommended to keep the MLSS concentration below 15 g/l in order to avoid severe permeability decline in the plant, but analyses should be confirmed with more sophisticated statistical tools.

Supersaturation of various sparingly soluble salts (expressed as % supersaturation or Langlier Saturation Index (LSI)) was estimated in the sludge water and MBR permeate using a commercial software package (4 AQUA) and by manual calculation. The sludge water and the MBR permeate were supersaturated with respect to $\text{Fe}(\text{OH})_2$ (114% and 133%, respectively) and CaCO_3 (average LSI of 0.06 and 0.27, respectively). The sludge water and MBR permeate was undersaturated with respect to BaSO_4 at 25°C. Manual calculations corrected BaSO_4 supersaturation for a temperature of 11°C, resulting in slight supersaturation (117%). However, the only real threat of precipitation on the sludge side was from $\text{Fe}(\text{OH})_2$ as CaCO_3 precipitation is unlikely to be a real threat when the LSI is 0.06. However, on the MBR permeate side, the supersaturation with respect to $\text{Fe}(\text{OH})_2$ and $\text{Ca}_3(\text{PO}_4)_2$ increased to 160 and 107%, respectively, during chemical cleaning with MBR permeate containing NaOCl at pH 11. In addition, the LSI of CaCO_3 reached 4.0 during chemical cleaning (pH of 11). The use of tap water for cleaning at pH 11 solves the precipitation of $\text{Fe}(\text{OH})_2$ and $\text{Ca}_3(\text{PO}_4)_2$, but leaves the CaCO_3 LSI at 3.05. Employing SEM EDX, the presence of Ca and Ba precipitates on the permeate side was confirmed, while no Ca and Ba precipitates could be observed on the feed side. Autopsies of the fouled membrane sheets revealed a loading of 25 $\mu\text{g}/\text{cm}^2$ for Ca. Cleaning optimization was performed with a bench scale MBR unit which was run with the same sludge water and raw waste water as the full scale plant. The pilot reproduces the full scale plant system in terms of membrane sheets, the cassette system, aeration, and the way cleaning is dosed. The bench scale unit was operated at the same F/M ratio and flux. Cleaning experiments were performed by measuring the permeability increase after cleaning. NaOCl showed a permeability recovery of 65 %, suggesting that EPS (biopolymers) were major foulants. Citric acid gave a permeability recovery of 33 % on the permeate side compared to 17 % on the feed side. Permeability recovery with HCl (27 %) was lower than permeability recovery by citric acid (33 %) when dosed on the permeate side at the same pH. The presence of inorganic fouling on the permeate side of the membrane was confirmed by supersaturation calculations, SEM-EDX analyses and cleaning experiments by measuring the permeability increase after cleaning. The NaOCl cleaning effect was improved by reducing the pH of the cleaning solution from 11 to 8. The concentration of NaOCl was reduced from 6 g/l to 1.5 g/l and the cleaning time was not modified (thus, CT was reduced by a ratio of 4, and the standard oxidation potential of the cleaning solution was reduced by a ratio of 3), however, the permeability recovery almost doubled from 43 % to 78 %. This phenomenon was attributed to the fact that a pH of 8 permits the formation of some HOCl (in the NaOCl solution) and the cleaning solution might benefit because of its higher reactivity compared to OCl⁻. NaOCl dosed at pH 8 significantly reduces the calcium carbonate fouling during cleaning since the maximum LSI in the permeate at pH 7.9 was 0.50, while the LSI was 4.00 when cleaning at pH 11. However, it is strongly recommended to run membrane aging tests (for PVDF membranes soaked in NaOCl at pH of 8) in order to evaluate the risk of membrane damage. In this study, batch tests conducted on a virgin PVDF membrane showed that the membrane matrix was damaged (permeability increased by >600%) after 3 days of soaking in a 6 g/l solution of NaOCl at pH 11 but no tests were conducted at pH 8. Caustic cleaning alone (on the permeate side) only provided a permeability increase of 11.6%. A presumed increase of membrane charge density provided by NaOH would increase repulsion among charged foulants but probably not sufficiently to detach them from the surface. However, NaOH clearly enhanced subsequent NaOCl effects; the permeability recovery of a NaOH step (0.1 M) followed by NaOCl (at pH 8) was 89 %. In conclusion, the Heenvliet membrane suffered from organic (biopolymer) fouling on the sludge/feed side and scaling on the permeate side due to the precipitation of sparingly soluble salts such as CaCO_3 , $\text{Fe}(\text{OH})_2$, and $\text{Ca}_3(\text{PO}_4)_2$ during chemical cleaning at a pH of 11. Therefore, chemical cleaning should be optimized to minimize damage to the membrane by careful selection of the cleaning conditions (pH, concentration and cleaning time) and to prevent scaling on the permeate side. A possible solution to the latter problem may be to use RO permeate to prepare cleaning solutions or to soften the water used for cleaning.

MBR AERATION AND FOULING, DIFFERENTS LEVELS OF OBSERVATION

J. Lebegue, M. Heran, A. Grasmick
 UMR 016 Génie des Procédés, Eau et Bioproduits (GPEB), UM II
 34093 Montpellier – FRANCE

julie.lebegue@univ-montp2.fr, marc.heran@univ-montp2.fr, alain.grasmick@univ-montp2.fr

Keywords: Membrane bioreactors, Hollow fibre, Aeration, Membrane fouling

Introduction

For a given SMBR system, membrane fouling is linked to the more or less reversible accumulation of macromolecules and solids on the membrane surface and to the irreversible sorption of soluble molecules inside the pores. If the reversible accumulation can be minimized by filtering in subcritical conditions, it is important to investigate the aeration effect on the irreversible sorption of soluble molecules.

Objectives

This paper shows how the suspension characteristics and membrane aeration intensity are link together. First the influence of membrane air flow rate on fouling during long term experiment was analysed. Then, a specific cleaning protocol was introduced in order to analyse the different fraction of fouling on the hydraulic resistance due to (i) the sludge accumulation, (ii) the irreversible thin biofilm onto the membrane surface and (iii) the role of adsorbed compounds.

Materials & Methods

Experiments were carried on in the lab scale submerged membrane bioreactor SMBR equipped with two hollow fibre bundles in parallel as described Fig. 1. The MBR was continuously fed with a synthetic substrate. Whereas

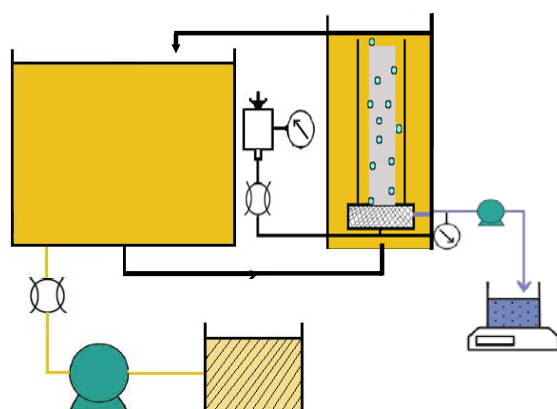


Figure 1 : Experimental set-up

different sludge concentration and permeate flux were tested to obtain different fouling rate (fig. 2) for the fouling slip up, the experiments were carried out again with a constant 20 LMH permeate flux with a range of variation of X_{SS} between 4-6 g/L. The filtration was then systematically stopped in both bundles as soon as TMP reached 0.3 Bar (R_T). Thus the resistance was calculated when the module was rinsed under tap water (until no sludge accumulation could be visually observed inside the bundle) : $R_T - R_S$, else each fibre was wiped to remove biofilm : $R_T - R_S - R_A$ (Fig. 3).

Results and discussion

a- Reversible fouling: Influence of membrane aeration on sludging control:

The results showed (Fig. 2) that membrane air flow rates appeared as a determining criterion to minimize sludging when filtering under intensive conditions. An air flow rate of 300 L/H allowed sustainable permeate fluxes operation, while an air flow rate of 100 L/H are only sufficient for low permeate flux (10 LMH). Under a specific amount of TSS which was dragged to the membrane due to the permeate flux ($70 \text{ gTSS} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$), the air flow rate has no effect on the fouling rate, later than, the influence of aeration must be introduced in the equation.

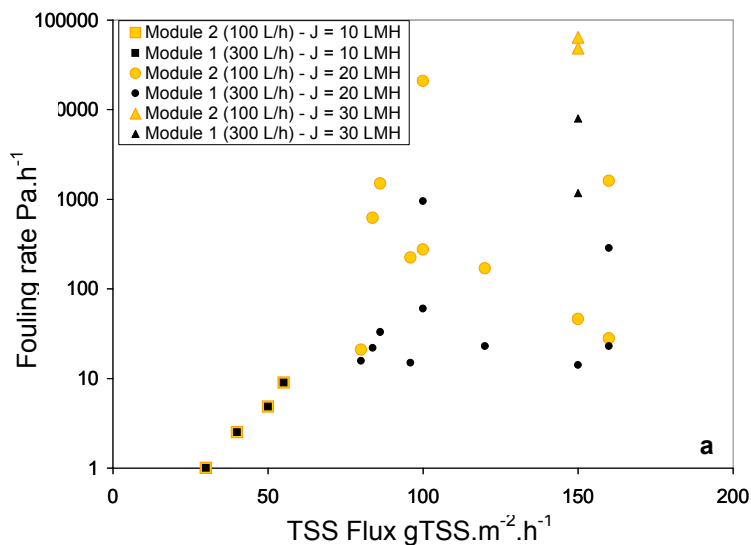


Figure 2 : Fouling rate versus TSS drag to the membrane due to the permeate flux

b- Zoom in on Fouling phenomena and Hydraulic resistances splitting up

The discontinuous line is marked for reference on each graphic at the value of 10^{12} m^{-1} . In the defined working conditions, the extent of sludging on the hydraulic resistance can be observed when operating with low membrane airflow rates. If sludging can be avoided by increasing aeration, the resistance due to biofilm and soluble adsorbed molecules are of the same order of magnitude. Nevertheless, membrane aeration also appears to have a positive effect on biofilm resistance. These results confirm the importance of good sludging control in the bundle. This is also largely dependant on the suspended solid concentration in the bulk

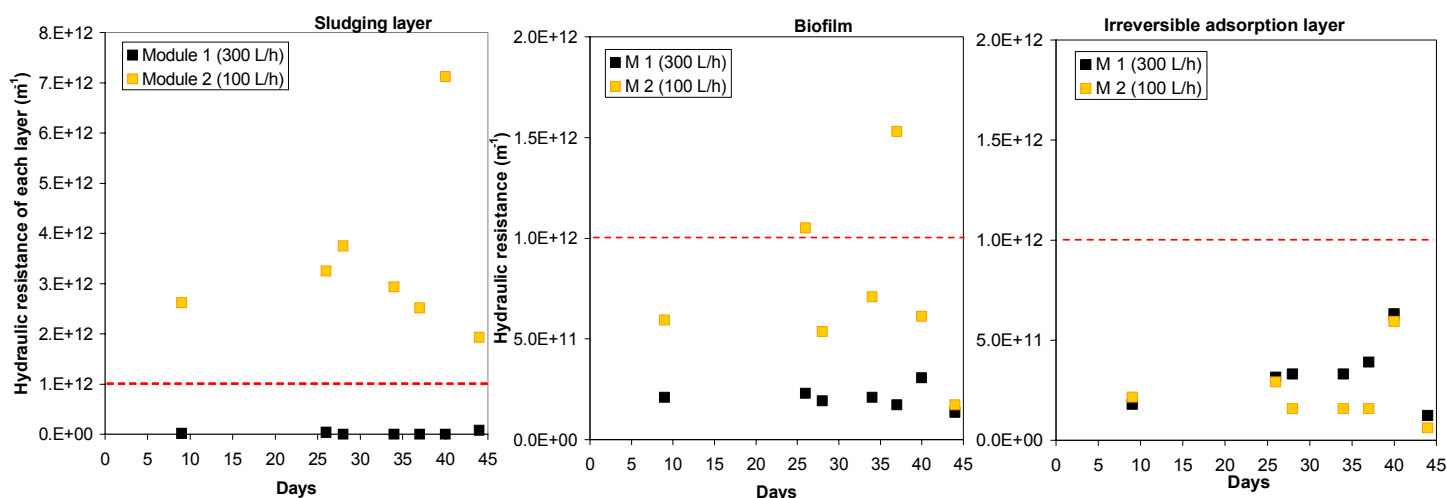


Figure 3 : Different levels of fouling observation : sludge accumulation, biofilm and adsorbed compounds

Conclusions

An appropriate aeration rate can avoid the resistance due to the sludge deposit. If the resistance due to biofilm and soluble adsorbed molecules are of the same order of magnitude, the aeration could also minimize hydraulic resistance due to the presence of biofilm. These observations provide important helpful information for the fouling modeling of SMBR. In fact, once the aeration is optimized, the effort must be concentrate on the biofilm evolution instead of modeling the sludge cake accumulation.

NEW ADVANCES IN MBR AERATION AND FOULING CONTROL

S. Pollet, B. Teychene, S. Khirani, M. Sperandio, C. Guigui, C. Cabassud
Université de Toulouse; INSA, UPS, INP, LISBP, 135 Avenue de Rangueil, F-31077 Toulouse, France
INRA, UMR792 Ingénierie des Systèmes biologiques et des Procédés, F-31400 Toulouse France
CNRS, UMR5504, F31400 Toulouse, France
Phone: +33(0)5 61 55 97 91 Fax: +33 (0)5 61 55 97 60
Corinne.Cabassud@insa-toulouse.fr

Abstract

Aeration in membrane reactors for waste water treatment is clearly a key issue as (i) it has shown to be an efficient way to prevent pressure increase in the system and (ii) it might represent one of the main operating costs.

In the frame of the development of sustainable technologies which will mean a very near future sparing non renewable energy resources it is important to enhance the knowledge in order to perform a scientifically based optimisation of the process.

Some of key questions are:

- what kind of flux controlling mechanism is really affected by aeration procedures?
- which is the contribution of particle and mainly of small size particles in fouling ?
- which are the mechanisms that make aeration efficient or non-efficient ?
- which are the pertinent parameters to characterise aeration effects, in terms of hydraulic changes? and in terms of fouling or clogging control or prevention ?
- which is the influence of module design (and mainly compacity) on aeration effects?
- What is the influence of aeration conditions on sludge properties? Are the flocs broken or restructured? Is the SMP production influenced?

The contribution of INSA Toulouse in the European project EUROMBRA aimed to propose a scientific strategy to study correctly these questions and to bring some elements for discussion. This paper introduces the principle of the methodology that was developed and some original results obtained thanks to this methodology in the case of semi-industrial scale outside-in external side modules. Each of these modules is tested independently and is aerated from the bottom and a very low liquid velocity ($<0,038$ m/s) is used in order to recycle the concentrate in the bioreactor

The methodology is based on different complementary methods: residence time distribution (RTD) analyses, gas hold-up measurements, two-phase flow modelling, video records were used to characterise the flow and fouling was characterised thanks to the flux step method and to constant pressure filtration for particle suspensions, supernatant and sludge.

Thanks to this methodology it was demonstrated that, for confined module geometry:

- two different areas exist in the module : one area with a good mixing which corresponds to the area in which hollow fibre are mobile, and one area with a plug flow compartment, which is the area where the fibres cannot move
- the relative proportion of these two areas is influenced by the module design (module compacity mainly) and by the liquid velocity. It might also be influenced by the technology used to build the fibre bundle (existence or not of a net around the fibres, for example)
- the flow inside the module can be an air-lift system: the air flow can make the liquid recirculating from the top to the bottom with a down flow going through and inside the fibre bundle. With the liquid flow, some particles are brought to the inside of the module at its top and then they flow down at the module core. The consequences of the airlift recirculation inside the fibre bundle can be positive or negative depending on the bundle properties (diameter, compacity and probably permeability) and on fibre mobility.
- In terms of particle fouling: for the precedent reasons, the choice of aeration conditions necessary to prevent or to control particle fouling will depend on module geometry (mainly compacity) : the more compact the module is, or the higher the number of fibres is, the lower permeate flux is obtained for the same aeration conditions used. Whatever the module, injecting a too high air velocity might have a negative effect on the permeate flux. This result is explained by the promotion of recirculation flows into the bundle deepness, which can enhance the clogging phenomenon.
- In terms of biofluid properties: The release of soluble microbial products is clearly influenced by aeration intensity in membrane bioreactor. Batch experiments demonstrated that SMP accumulation is more significant when dissolved oxygen decrease from 2.5 to 0.5 mg/L and if anoxic condition is maintained in the bioreactor. It means that contribution of both membrane aeration and bioreactor aeration on oxygen transfer should be accurately quantified.

- In terms of fouling by biofluids:

a) the fouling velocity is linked to both the presence of particles and of organics. Fouling due to a supernatant can be controlled by adjunction of some small particles (500 nm). Whatever the filtration cases or the nature of the chosen particles, the addition of a small amount of fine particles improves rejection and flux recovery by backwash. Filtration of the suspensions made of particles stabilised with OM leads to an incompressible and more porous fouling layer. It was also demonstrated that filterability, in terms of flux decline, is only improved when some adsorption mechanism occurs between particles and OM.

b) aeration velocity influences the proportion of OM that are found in backwash waters: the higher the gas velocity during filtration, the higher the concentration of proteins in TOC and of proteins in backwash waters. This shows that the way cake+clogging are built and their composition are influenced by the aeration conditions and that higher aeration conditions allow to enhance reversibility of limiting phenomena (fouling+ clogging).

c) Depending on the way it is operated, aeration can reduce long-term fouling phenomena during filtration of sludges. For a same global SADm, a discontinuous aeration mode (operated with two different levels of aeration rates) can be more efficient than a continuous one as it can decrease the irreversible compartment of TMP increase with time and enhance reversibility by backwash. This discontinuous operation induces the generation of two different alternative hydro patterns, which seems to be positive to deconcentrate the bundle inlet and to remove clogging.

Thanks to the methodology used and to the numerous results obtained, a module design and some recommendations for operating conditions have been proposed for a confined external geometry. The same approach can be applied to other module design or process options.

SLUDGE FILTERABILITY AND DEWATERABILITY IN MUNICIPAL MBR

G. Guglielmi*, D. Chiarani*, D.P. Saroj***, G. Andreottola*

* Department of Civil and Environmental Engineering, University of Trento, Via Mesiano, 77 – 38100, Trento, Italy – giuseppe.guglielmi@ing.unitn.it

** Department of Urban Water and Sanitation, UNESCO-IHE Institute for Water Education, Westvest 7, 2611 AX Delft, Netherlands- d.saroj@unesco-ihe.org

Keywords: MBR, dewaterability, filterability, filter-press

Introduction

Despite the widespread interest of scientists and practitioners towards the membrane bioreactor technology for the effluent quality, the retro-fitting/up-grading potential and fouling-related aspects, a relatively limited amount of information has been provided up-to-date regarding surplus sludge dewaterability and filterability.

Objectives

The aim of the abstract is to summarise the most salient outcomes coming from two years monitoring of surplus sludge filterability and dewaterability in a large-pilot scale MBR for municipal wastewater treatment. A statistical analysis has been carried out on experimental data to assess possible correlations between these parameters. Furthermore, results of 54 dewatering tests carried out on a pilot-scale fixed-volume chamber filter-press are reported, with comments on the impact of different operational parameters (polymer typology and dosage, pressure) on the final dry matter content.

Materials & Methods

A large pilot-scale plant has been operated for two years (see flow-scheme in Figure 1); the plant consists in an

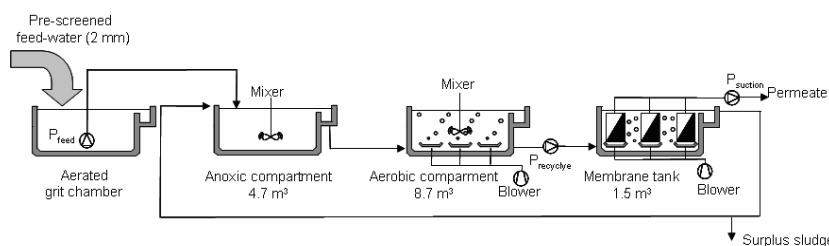


Figure 1: Flow-scheme of the large pilot-scale MBR installed at Lavis WWTP

an anoxic compartment (4.7 m³), an oxidation/nitrification tank (8.7 m³) and a membrane tank (1.5 m³) in which a 3-modules cassette supplied by GE Zenon is immersed. The overall installed membrane surface area is ~100 m² and the nominal pores size is 0.04 μm. The system has been fed with pre-screened sewage (2 mm) pumped from the aerated grit chamber of the

MWWTP of Lavis (Trento, Italy). A sludge age value ranging between 20 and 25 days was kept in the system by means of sludge wasting operations performed on a daily basis. The MLSS concentration in the biotank and the membrane tank were $6.8 \pm 0.9 \text{ kg m}^{-3}$ and $6.8 \pm 0.9 \text{ kg m}^{-3}$ respectively, with a recirculation ratio of approximately 3.5. Excess sludge was drained regularly from the membrane compartment and weekly monitored for capillary suction time (CST, s), specific resistance to filtration $\alpha_C \text{ (m}^{-2}\text{)}$, settleability (DSVI, mL g_{TSS}⁻¹), TOC content in the supernatant after centrifugation (4,000 g, 10 minutes) and subsequent filtration (1.5 μm fibreglass). The data collected were analysed with TANAGRA software for statistical interpretation, in order to determine the Pearson's coefficient and evaluate correlations. A pilot scale fixed-volume-chamber filter press was also used for batch filtration tests under different operational conditions. In particular, three pressure values (7 bar, 11 bar and 15 bar) and six polymers (powdered/liquid, linear/structured) were used for sludge pre-conditioning, with various dosages in the range 5-25 g_{polymer} kg_{TSS}⁻¹; the duration of each filtration trial was 2 hours.

Results and discussion

Trends of temperature, CST, and SRF, α_C and TOC in the supernatant are shown in Figure 2 and 3 respectively.

The statistical analysis highlights the crucial role of temperature on TOC in the supernatant, which is commonly assumed to be an indicator of free form of EPS. The increase of TOC at lower temperatures is responsible for the CST and α_C increase. This is in fair agreement with other studies which pointed out seasonal fluctuations of membrane permeability due to organic foulants in the liquid phase (Lyko *et al.*, 2008; Guglielmi *et al.*, 2007). Sludge settleability expressed as DSVI positively correlates with CST thus indicating that the filtration behaviour is somehow related to the settling properties. On the other hand, the absence of a significant correlation between DSVI and α_C would suggest DSVI not to be a clear indicator of sludge filterability. Interestingly, the MLSS concentration monitored

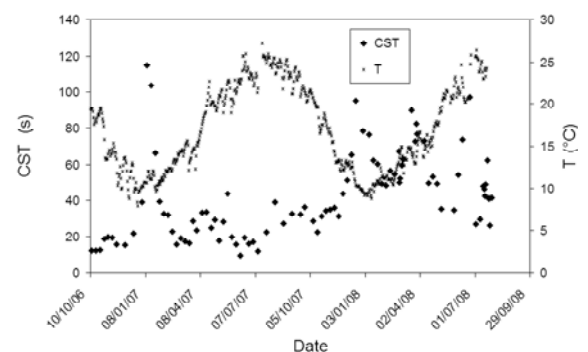


Figure 2: CST and sludge temperature during the experimental period

with an on-line probe in the membrane tank shows a poor correlation degree with the considered physical properties; this confirms that the suspended solids concentration only correlates with filtration properties at very high values (Rosenberger and Kraume, 2002; Wu *et al.*, 2007).

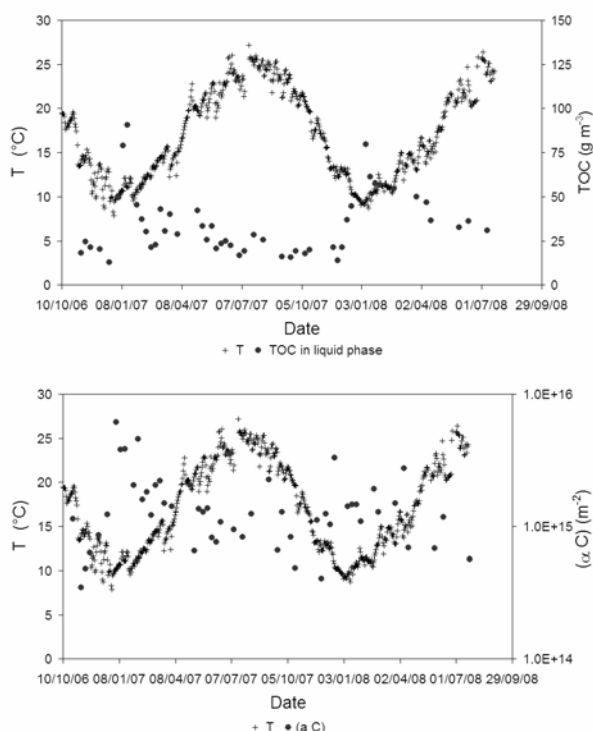


Figure 3: Trend of supernatant-TOC and (αC) with temperature over the experimental period

Conclusions

Excess sludge samples have been collected and analysed in terms of dewaterability, filterability and settleability over almost two years. All the above mentioned properties have been found to be negatively correlated with temperature; the reason of this is the negative correlation of temperature itself with concentration of organic compounds in the liquid phase of sludge. Tests on a pilot scale filter press demonstrated that MBR sludge can be dewatered with typical dewatering facilities used for CAS plants. Due to the high content of organic matter in the liquid phase ("free water"), a proper conditioning step is needed. In the adopted range, neither dosage nor pressure influenced the dry matter content of dewatered sludge; the type of polymer seemed to be the most important parameter, the N 77113 polymer being the best performing.

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All tests performed on the pilot filter-press indicated that the positive effect of sludge conditioning (polyelectrolyte dosage) is clearly evident even at extremely low dosages. Independently on the operational conditions and used polymer, the dry matter content is function of the dosage according to a power law trend with a weak effect in the considered dosage range. The structured polyelectrolyte Nalco N 77113 showed the best performances under all the operational pressures, with a percent dry matter content ranging between 19 and 25%; slightly less effective was the powdered polymer Zetag 72051. The lowest dry matter content was obtained with the linear polyelectrolyte Nalco N77164 and the liquid Ageclar KL3750; an example of %DM trend versus polymer dosage for the tested chemicals is shown in Figure 4. Temperature seems not to affect the test results, at least in the considered range (12-16 °C). Tests carried out on sludge samples collected from the aerobic digestion of the conventional activated sludge plant in Lavis did not differ from those obtained on MBR sludge. Possible improvements could be obtained with different filtering clothes and with an increase of the filtration duration, although this would result in a large installation at full-scale.

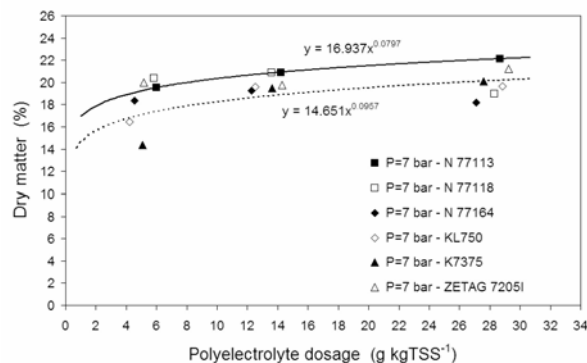


Figure 4: Effect of polymer dosage and typology on dry matter content (pressure: 7 bars; duration of filtration: 2 hours)

EFFECTS OF VARIOUS FLUX ENHANCERS IN MBR: LAB TESTS VS. PILOT SCALE OPERATION

Vera Iversen*, Stephanie Hermann*, Anja Drews*, Renata Mehrez**, Mathias Ernst**, Martin Jekel**, Boris Lesjean*** and Matthias Kraume*

*Chair of Chemical Engineering, Technische Universität Berlin, Straße des 17. Juni 136, MA 5-7, 10623 Berlin, Germany, sekretariat.vt@tu-berlin.de

**Chair of Water Quality Control, Technische Universität Berlin, Straße des 17. Juni 136, KF 4, 10623 Berlin, Germany

*** Berlin Centre of Competence for Water, Cicerost. 24, 10709 Berlin, Germany

Keywords: MBR, flux enhancement, fouling control

Introduction

Although approximately 30% of all MBR publications deal with fouling, the complex interactions of membrane material, sludge properties and operational conditions are not fully understood, especially since the filtration systems, applications and analytical methods vary widely. One promising strategy to reduce fouling in MBR is to modify the sludge filtration characteristics by the addition of flocculants or adsorbents. These additives may not only bind colloids and solutes onto the sludge flocs but can also cause an enlargement of the floc size. While this approach offers a variety of possibilities and advantages, systematic studies on the comparison of different flux enhancing chemicals are rare.

Objectives

Within the framework of AMEDEUS a comprehensive screening of 30 different chemicals (natural and synthetic polymers, metal salts, enzymes and powdered activated carbon) has been conducted. In a first step the potential to reduce SMP concentration in the sludge supernatant was determined for all additives at different concentrations. The optimum concentration was determined as the concentration with the highest or stagnant SMP removal. In subsequent experiments, the impact of selected additives at optimum concentration on sludge respiration, nitrification, denitrification and sludge characteristics (pH, viscosity, SVI, CST, particle size) were evaluated. Promising additives were then tested in different concentrations in lab tests. Furthermore, detrimental effects on the membrane were determined in residual fouling tests (water with 5% additive).

In addition, long term tests with three selected flocculants were conducted in a pilot-scale system.

Materials & Methods

The optimum concentration was determined via shaking flask tests. Respiration and nitrification / denitrification trials were conducted in parallel batch tests under defined conditions similar to the plant. The particle size was determined after defined shearing in a rotational viscometer in a Malvern mastersizer (laser diffraction). Further investigations concerning the fouling were made with a cross-flow filtration test cell designed at the department, representing the hydrodynamic conditions between two flat sheets in a module [1].

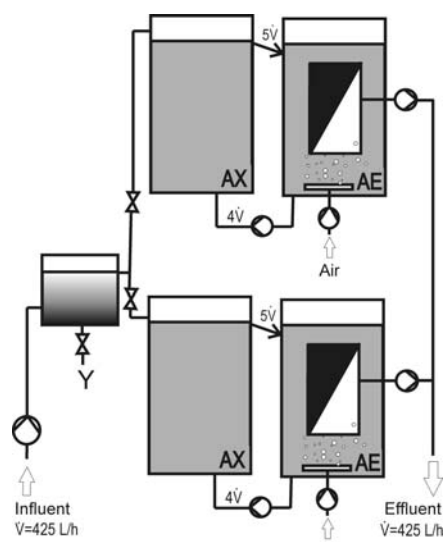


Figure 1: Flow sheet of the pilots

In order to investigate the long-term effects of flux enhancing chemicals in MBRs, two identical pilot plants were set up (Fig. 1). Each plant consists of two 1m³ tanks with a working volume of approx. 0.8m³ each. The pilot units are located in a 20' sea container on the grounds of a pumping station of Berliner Wasserbetriebe thus drawing combined municipal wastewater from Berlin city centre as influent. After the settler used as a sand trap for the removal of larger particles, the wastewater flows into a stirred anoxic chamber. The following tank is aerated and equipped with a 22m² membrane module (A3 Water Solutions, Germany, PVDF, nominal pore size 0.2 µm). TMP, flux, DO, T and pH in the membrane chamber are registered on-line. The systems have been in operation since October 2006. While different flocculants were dosed in one system, the other served as a reference.

Results

Several of the 30 initially screened substances were able to effectively reduce SMP concentration in the mixed liquor supernatant [1]. SMP-elimination at optimum concentration was generally in the range of 30-60%.

Batch tests showed that most of the tested substances did not inhibit oxygen uptake, nitrification and denitrification [2]. Only the tested polyaluminium chloride and one powdered activated carbon strongly influenced these biological parameters. The strong impact of the activated carbon can be explained by the shift of pH (from 7 to 5.7) if this

acidic activated carbon was added. It could also be shown that the expensive but effective biopolymer chitosan is highly biodegradable and thus not interesting for flux enhancing in MBR. On the other hand it strongly increased the particle size distribution as well as all the tested synthetic polymers [3]. The particle size is an important parameter for the filtration resistance in MBR; here, large particles are favourable. While strong effects on the volume based particle size distribution were found, the number based distribution was nearly unchanged if a cationic polymer was added to the activated sludge. Nevertheless, most additives strongly increased dewaterability (measured as CST).

In a last step of the screening, filtration test cell experiments were conducted with the most promising additives. Here, it was found that especially the synthetic polymers strongly enhanced the filtration, while the metal salts and natural polymers did not change or only slightly increased the critical flux values [1]. As already assumed from the particle size measurements the polymers mostly decreased the resistance due to the filter cake, but also decreased the internal fouling [4].

Three additives (two synthetic polymers and a starch) were then tested in the parallel pilot system [5]. As could be expected from the jar test, the additives did not disturb the biological performance of the MBR. While the synthetic polymers enhanced the filterability, the natural polymer starch worsened the filtration performance as can be seen in Fig. 2a. This was not expected as starch showed good results in the test cell experiments (Fig. 2b). In addition the starch permeated through the membrane to a large extent and caused problems with the measuring probes (pH and O₂).

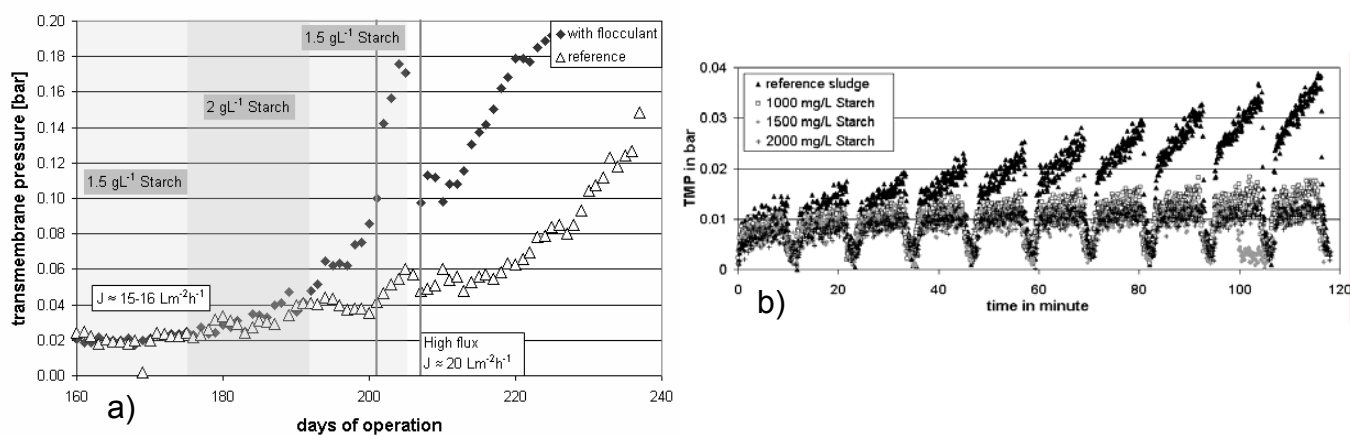


Figure 2: performance of starch in a) pilot tests b) filtration test cell

Conclusion

From a 3 year comprehensive screening of 30 additives taking into account effects on filterability, sludge characteristics and nutrient removal, it can be concluded that especially synthetic polymers are effective for flux enhancement, while showing no inhibiting effects on the biomass. The transferability of lab-scale results to pilot-scale is restricted. While biological effects can be easily evaluated in lab tests, results concerning filterability differed strongly between the short-time lab tests and the long-term pilot tests.

Acknowledgement

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FOULING ORIGIN AND CLEANING STRATEGIES IN MBR

A. Grélot*, C. Machinal*, A. Tazi-Pain*, A. Grasmick**

*Anjou Recherche, Water Research Centre of Veolia, Chemin de la digue BP 76, 78603 Maisons Laffitte Cedex, France

(E-mail : aurelie.grelot@veolia.com; claire.machinal@veolia.com; annie.tazi-pain@veolia.com)

**University of Montpellier II, Place E. Bataillon, 34 095 Montpellier Cedex 05 France

(E-mail: Alain.Grasmick@univ-montp2.fr)

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Introduction

Membrane fouling remains the most serious problem affecting the performance of a membrane bioreactor. Fouling leads to a decline in permeate flux, requiring more frequent membrane cleaning and replacement, which in turn increases operating costs. Therefore, MBRs remain more expensive than conventional processes. Fouling is due to physical and physico-chemical mechanisms related to the operation of membranes in filtration: concentration polarisation, particulate fouling (deposition of particles at the membrane surface), biological fouling (adhesion and growth of microorganisms onto the membrane surface) and organic fouling (adsorption of dissolved organic substances onto the membrane surface). The reversible fouling due to concentration polarisation and particles deposit can be partially removed by physical means (aeration, backwash, etc.). The irremovable fouling (not removed by physical means) due to biofilm and organic fouling, requires chemical cleanings. The degree of fouling is related to several parameters like the biological operating conditions (SRT, F/M ratio, MLSS concentration..), mixed liquor characteristics (EPS content, foam,..), the membrane design and material and the hydraulic parameters (aeration rate, filtration flux, backwash intensity,...). For the study, the biological operating conditions will be maintained constant through all the trials in order to study, above all, the influence of the membrane and the hydraulic parameters on the fouling behaviour. Reversible and irremovable fouling removal will be covered in this paper.

Objectives

In this study, the nature and the origin of the membrane fouling of three different membranes provided by A3 Water Solutions, Polymem and Inge were investigated in order to find best adapted hydraulic operating conditions and cleaning strategies for each technology. In addition, tests using different cleaning products were performed on fouled membranes in order to study the membrane regeneration capacity and identify alternative cleaning reagents to chlorine. This paper will concentrate on the results obtained using the A3 Water Solutions membrane technology.

Materials & Methods

A pilot platform was built to test successively at pilot-scale industrial modules provided by A3 Water Solutions, Polymem and Inge. The A3 Water Solutions technology, consisting in a block of microfiltration flat sheet membranes, was the first to be tested (12 months test period). The pilot was fed by urban wastewater from the town of Maisons-Laffitte (Yvelines, France) after pre-screening through a 1 mm drum screen (Table 1). Two modules were stacked on top of each other (140m² of membrane) and were immersed in the membrane tank. An aeration ramp with medium-size bubbles was installed below the filtration modules to minimise any mixed liquor accumulation onto the membrane surface. The filtration process operates in the so-called filtration/pause mode. The hydraulic performances of the membrane modules were monitored automatically by the supervision. Daily analyses were performed to check the raw water, permeate quality (TSS, COD, TN, TP, etc.) and the sludge filterability (soluble COD, CST, polysaccharides, etc.). The biological operating conditions were maintained constant during all trials (Table 1). The control of the reversible fouling was investigated during pilot trials which lasted around 1 year.

Table 1 Feed water quality and biological operating conditions

Feed water		Biological operating conditions	
TSS (mg/l)	170± 60	MLSS (g/l)	9.7± 2.4
COD (mg/l)	515± 165	SRT (d)	28± 2
TN (mg/l)	59± 14	F/M ratio (kg COD/kg MLSS/d)	0.13± 0.04
TP (mg/l)	9± 2	Volumetric load (kg COD/m ³ /d)	1.36± 0.42

At the end of the pilot-trials, the top module was first removed and the bottom module was subjected to an intensive cleaning with 0.5%ww at pH 11 hydrogen peroxide solution before to be removed. Both modules were cut and membrane pieces at various locations of both modules were taken off to analyse the irremovable fouling by:

- performing Scanning Electronic Microscopy (SEM) pictures and EDAX to detect elementary composition of specific particles on the membrane;
- estimating the irremovable fouling resistance from permeability measurements at lab-scale after having rinsed the fouled membrane with deionised water;
- analysing the remaining deposit after rinsing with deionised water. This deposit was extracted by soaking membrane samples (2771cm² by membrane sample) in deionized water and by cleaning using sonic

waves. The mineral part was investigated by Inducted Coupled Plasma (ICP) and the dissolved organic matter by Size Exclusion Chromatography (SEC).

The regeneration of the membrane with different cleaning products was also performed at lab-scale. Different chemical reagents were tested: sodium hypochlorite as reference, oxidizing reagents (caustic soda, hydrogen peroxide,...), enzymes products (Ecolab and Realco products), and acids products. A first selection was performed using membranes fouled at lab-scale and the best cleaning products were tested on membranes pieces fouled at pilot-scale. Intensive cleaning tests were also performed in the MBR pilot to validate the results.

Results and discussion

Reversible fouling:

During the pilot trials a cleaning strategy and operating conditions adapted to the A3 technology were developed to achieve a satisfying and reliable control of the fouling even during foaming events and during peak flows for a relatively low specific air demand of $0.2 \text{ Nm}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ corresponding to $8 \text{ Nm}^3/\text{m}^3_{\text{permeate}}$ when operating at a net flux of $25 \text{ L} \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ (at 20°C). Results showed, in addition, that the system can operate safely with MLSS concentrations up to 18 g/l . The quality of the treated water was according to all expectations, with COD removal of 96% and a 6 log coliform removal (Grélot et al., 2009). At the end of the trials, the modules were cut and showed very little sludge on the membrane surface except close to the module sides, proving that the module design was well adapted to MBR applications and the hydraulic operating conditions were effective.

Investigation of the irremovable fouling:

The membrane autopsy and characterisations performed at the end of the trials showed that irremovable fouling resistance remains low ($\sim 0.25 \times 10^{12} \text{ m}^{-1}$) but induces a higher resistance than the membrane itself ($\sim 0.10 \times 10^{12} \text{ m}^{-1}$). Moreover, the accumulated compounds onto the membrane surface modified the PVDF membrane characteristics such as the contact angle. The membrane deposit consisted of organic matter, mainly hydrophobic elements (Figure 1). Few mineral elements (Ca, Na, P, K, S, Mg and Si) were detected (Figure 2). Chlorine appears to be the best cleaning product to remove the irremovable fouling part. Hydrogen peroxide at 0.5% at pH11 gave satisfying results on membrane pieces fouled at pilot-scale during 5 months but the intensive cleaning performed with this product in the pilot plant remains less efficient than with chlorine at 1000 ppm (Figure 3) which can be explained by a different fouling and in particular the presence of an additional thin layer on the industrial modules (Grélot et al., 2008). Full-scale tests are therefore required to validate the results. The cleaning with hydrogen peroxide enabled however the removal of hydrophobic elements, biopolymers and some mineral elements at the membrane surface (Figure 1 and Figure 2).

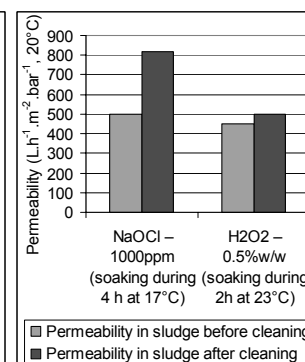
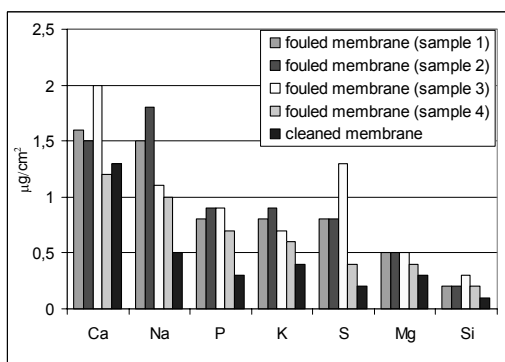
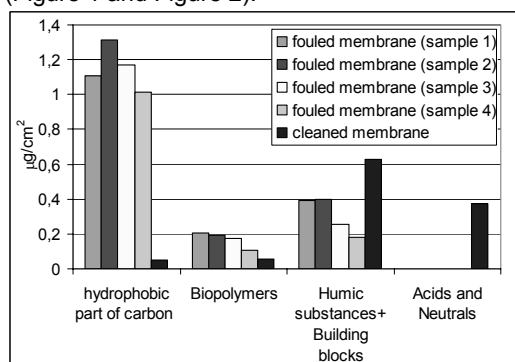


Figure 1 Composition of the dissolved organic fraction of the A3 membrane deposits

Figure 2 Composition of the mineral fraction of the A3 membrane deposits

Figure 3 Intensive cleanings at pilot-scale

Results from the other tested membranes showed that the irremovable fouling composition was different. In particular, these membranes were more sensible to mineral fouling ($\text{Ca} > 10 \mu\text{g}/\text{cm}^2$) and will require more frequent acid cleanings.

Conclusions

The design of the filtration system and adapted hydraulic operating conditions are first essential to prevent the membrane surface from sludge accumulation and use adequately the all membrane surface. The irremovable fouling modified the membrane surface characteristics and produces a higher resistance to the filtration. Regular cleanings with chemical reagents are required to control filtration resistance to a minimum. Chlorine appears for instance to be the most efficient reagent. Some other products like hydrogen peroxide could be envisaged but longer soaking could be required. Acids cleanings can be also required, especially for the membranes more sensible to mineral elements fouling.

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OPTIMISED ELECTROSPUN NANOFIBERS FOR MUNICIPAL WASTEWATER TREATMENT BY TEXTILE BIOREACTORS (TBR)

E. Fatarella*, L. Lombardi*, V. Iversen**, M. Kraume**, S. Paulussen***, U. Bruss**** and B. Lesjean*****

* Next Technology Tecnotessile, via del Gelso 13 59100 Prato (ITALY); e-mail: chemtech@tecnotex.it

**Technical University of Berlin – Department of Chemical Engineering (GERMANY)

*** VITO - Flemish institute for technological research (BELGIUM)

****A3 Water Solution GmbH (GERMANY)

*****Berlin Centre of Competence for Water (GERMANY)

Keywords: Membrane bioreactor, Textile, Filtration, Nanofiber

Introduction

(Membranes used in liquid filtration for particle and pathogens removal are generally microfiltration membrane (MF) or ultrafiltration membrane (UF). The membrane materials commercially used in membrane bioreactor (MBR) process include ceramics and both unmodified and surface modified polymeric materials, such as polyethylene, polypropylene and polysulfone¹. The pore sizes of these membrane materials are usually in the 0.02µm~0.5µm range. Therefore particles, bacteria, macro-colloids, and sometimes viruses are removed by the membrane.

Textile filtration media may be an economical option compared with polymeric micro- or ultrafiltration membranes, due to the lower cost per unit of surface and the potentially greater filtration flux². However, textile filtration media has some limitations, such as large pore size (> 1µm), controllable pore size distribution and easy design of fiber surface. Within this study, a functionalised nanocomposite membrane was produced in order to overcome the main limitations related with commercial textile membranes (BO2008A000197). First short terms filtration tests with real MBR mixed liquor showed promising results with high filtration fluxes.

Objectives

The possibility to replace conventional polymeric membranes with textile ones enabling to ensure good filtration performance at lower costs is the main objective of this study.

Materials & Methods

Nanocomposite textile were realised by the deposition of a nylon 6 nanofiber layer onto different commercial nonwoven membrane (Novatexx 2431N Polyester nonwoven and Novatexx 2471N Polypropylene nonwoven provided by Freudenberg – Germany). The nanofiber were produced by means of an electrospinning prototype design and constructed by Next Technology Tecnotessile by applying optimised production conditions: polymer concentration (range 10 ÷ 30%wt); distance between the electrode (range 5 ÷ 25 cm); voltage (range 10 ÷ 50 keV); flow rate (range 0.1 ÷ 5 ml/min); syringe distance (range 18 ÷ 24 mm). In order to increase the filtration fluxes, the permeability of the nanostructured textile membranes were enhanced by surface chemical modification induced by Atmospheric Plasma. Polar vinyl precursors – such as Acrylic acid and Allylamine – were selected to increase membrane superficial tension.

The nanocomposite membranes were characterized by means of:

- SEM (Scanning Electron Microscope) analysis, performed by means of a Joel JSM apparatus;
- Roughness measurements, assessed by a scanning topography measurement instrument, Altisurf 500. This device is based on the principle of chromatic aberration, the capacity of the gauge lens to focus different colors in different focal planes. The focusing wavelength (reflected by the sample) is analyzed by the probe spectrophotometer, which analyses the distance of the lens at the surface.
- Pore size analysis by means of capillary flow porometry, to verify the real pore size for the commercial and newly-realized membranes³.
- Contact angle measurements
- Tensile strength analysis according to standart test ASTM D638
- Adaptability to A3 MBR module, assessed by means of Cushion-Production tests and by means of Potting tests.

Filtration tests were done with a sludge from a small-scale MBR operated with synthetic wastewater under constant conditions at the department for Chemical Engineering of the Technical University of Berlin and several measurement series were conducted.

- Trans-Membrane Pressure (TMP) = constant. Tests were carried out under constant pressure conditions of approx. 0.6 ÷ 0.65 bar. Cross-flow velocity was constant at 0.2 m/s. A slightly higher TMP than during normal flat sheet operation had to be chosen to enable comparison of all textiles at the same conditions, i.e. to obtain a measurable flux even for very dense nonwovens. Flux decline was measured until constant flux was achieved.
- Critical flux. The critical flux was determined with the flux-step method. The test-cell was aerated in a vertical setup. For the determination of the critical flux, all data were plotted on same scale and the first flux for which a significant increase of TMP during one flux step occurred was defined as critical flux.

The performance of the nanocomposite membranes was compared with the one ensured by a conventional polyvinylidene fluoride (PVDF) polymeric membrane, currently used at A3.

Results and discussion

For the production of the high permeable nanocomposite textile the following parameters were used for the production of the nanofiber and for their functionalisation respectively.

Table 1 – Treatment optimal conditions for the production of functional nanocomposite textile membrane

ELECTROSPINNING		PLASMA	
<i>Parameter</i>	<i>Optimal value</i>	<i>Parameter</i>	<i>Optimal value</i>
Polymer concentration [%wt]	18	Power [W]	400
Distance electrodes [cm]	9	Frequency [kHz]	1.5
Voltage [kV]	30	Treatment time	6 passes at 4 m/min
Flow rate [ml/min]	0.25	Precursors	Allylamine

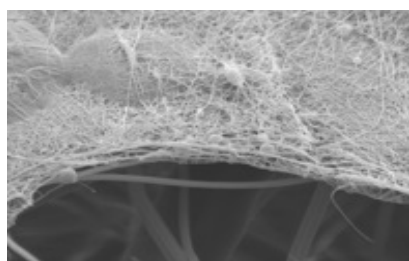


Figure 1: SEM analysis of NY6 nanocomposite

By applying these conditions an homogeneous functional layer is deposited onto the textile supports (Figure 1).

The diameter of the nanofibers is around 200 – 250 nm and its width is computed and it is around 12 – 18 μm . Mechanical performance of the nanocomposite textile was not affected; a slight increase in the tensile breaking strength and in the elongation at break was recorded: 0.1 MPa and 5%, respectively.

In the following table 2 the most significant characteristics of the functional nanocomposite textile are listed, in comparison with the same parameters achieved by conventional membranes.

Table 2 – Main characteristic of the nanocomposite textile membrane compared with conventional one

Parameter	Nanocomposite membrane	PVDF membrane
Roughness [μm]	1.5 – 2.5	1.5 – 3.3
Pore Size [μm]	0.6 – 0.8	0.3
Contact angle [$^\circ$]	< 5	> 90
Tensile strength [MPa]	15-25 MPa	21 MPa
Time TMP = constant	> 12	> 12 h
Critical flux [Lm/h]	215	120

Concerning Adaptability tests, it was found that Polyester support is more compliant than polypropylene with the A3 production line in terms of adhesion performance through melting and gluing processes. A nanoweb coated membrane, realised with 2431N nonwoven support, was designed and constructed.

Possibility to produce nanocomposite membrane with other materials has been investigated.

Conclusions

It has been demonstrated that a suitable electrospun nanofiber coating allows to reduce both the pore size and the roughness of commercial textile membranes, of which use has been limited so far to water and air filtration. This paves the way to the application of textile-based composites within MBR plants. Even if these composites may not feature the filtration performance of the traditional polymer membranes, thanks to their low costs they will be applied even by countries that are not able to support high wastewater treatment costs, such as the developing countries. Hence, these composites will allow the diffusion of the MBR technology all over the world, with major benefits for both the environment and the population. The authors would like to thank the EU Commission for funding this study within the AMEDEUS project (Contract n° 018320).

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Figure 2: Nanocomposite module

SPECIFICITIES OF ASM-BASED BIOLOGICAL MODELLING OF MBR PROCESSES

A. Fenu*, G. Guglielmi**, J. Jimenez***, B. Lesjean****, I. Nopens*****, J. Roels*, D. Saroj*****, M. Sperandio*****

*Aquafin NV, Dijkstraat 8, 2630 Aartselaar, Belgium - alessio.fenu@aquafin.be

**Department of Civil and Environmental Engineering, University of Trento, Via Mesiano, 77 – 38100, Trento, Italy – giuseppe.guglielmi@ing.unitn.it

***Anjou Recherche, Veolia Eau, julie.jimenez@veolia.com

****Kompetenzzentrum Wasser Berlin, Cicerostr. 24, 10709 Berlin, Germany - boris.lesjean@kompetenz-wasser.de

*****BIOMATH, Department of Applied Mathematics, Biometrics and Process Control, Ghent University, Coupure Links 653, 9000 Gent, Belgium – Ingmar.Nopens@UGent.be

*****Department of Urban Water and Sanitation, UNESCO-IHE Institute for Water Education, Westvest 7, 2611 AX Delft, Netherlands (Email: d.saroj@unesco-ihe.org)

***** (1) Université de Toulouse; INSA, UPS, INP; LISBP, 135 Avenue de Ranguieu, F-31077 Toulouse, France, (2) INRA, UMR792 Ingénierie des Systèmes Biologiques et des Procédés, F-31400 Toulouse, France, (3) CNRS, UMR5504, F-31400 Toulouse, France

Keywords: biological modelling, MBR, kinetic parameters, ASM

Introduction

Is the current knowledge about ASM-based modelling of conventional activated sludge (CAS) systems simply transferable to MBR systems? Although very similar, there are some differences between CAS and MBR that cannot be ignored in this context. A lot of efforts and results have been reported in literature, but this knowledge is somewhat scattered. Therefore, the liaison group on biological modelling of MBRs, initiated within the MBR-Network, has joined forces to compile these efforts and results into a review that transparently summarises the most important findings in literature and provides guidelines as to how ASM-based models should be used in a sound way.

Objectives

The effort is broken down in a couple of aspects that reflect some of the fundamental differences between CAS and MBR systems: (1) relevance of fundamental concepts of ASM with respect to MBR, (2) COD fractionation, (3) differences in bio-kinetic parameters and (4) integration of SMP-EPS concepts in biological models. Per aspect, the state-of-the-art and differences with respect to CAS modelling are summarised, shortcomings are highlighted and future needs proposed. This review should act as a future guide for the MBR system modeller.

Relevance of fundamental concepts of ASM with respect to MBR

Biological modelling of MBRs, in general, stems from the ASM-based modelling practices for wastewater treatment systems. Advanced wastewater treatment systems, and hence ASMs for their modelling have evolved through the course of years of developments in process understanding, notably during last four decades when the biological modelling ideas started - merely with two state variables (substrate and biomass) and based upon first order degradation kinetics - and furthered to robust ASM-based models (original ASM1, ASM2d, ASM3 or modified versions for MBRs etc). All of the background processes are based on theories and hypotheses, and some of these have been reasoned more relevant or less relevant for the specific case of MBRs. Accordingly, modified process descriptions have been reported for better description of MBR biological dynamics, for example, inclusion of SMP/EPS concept and/or adoption of new substrate uptake pathways. It has been reasoned in recent contributions that high SRT operation of MBRs is linked with corresponding influence on MBR specific sludge production and autotrophic biology etc. Throughout, it can generally be observed that all the recent efforts aiming at an accurate biological modelling of MBRs intend to focus on MBR specificities (e.g. high SRT operation, membrane retained microbial metabolites etc.) and corresponding required modifications in ASMs.

COD fractionation

Influent wastewater fractionation plays a crucial role in the application of ASMs. Together with operational conditions (sludge age, temperature, biokinetics), a detailed and reliable identification of different wastewater fractions is essential to optimise both design and operation. Fractionation consists of a simplification of the heterogeneous organic matter in the feedwater, which is therefore split into different fractions according to their physical status (dissolved, particulate) and biodegradability degree. COD fractionation is usually carried out by means of respirometry; experimental evidence suggests that, in the sludge age range of 10-30 days, conventional techniques used for COD fractionation can be successfully applied in membrane bioreactors. However, still a knowledge gap needs to be filled to get a proper protocol for COD fractionation in membrane bioreactors. Feedback fractionation carried out against experimental values of MLSS indicate that, at long SRT (> 50 days), neither ASM1 nor ASM3 are able to fairly predict excess sludge production. This is assumed to be due to the slowly but significant hydrolysis of influent “inert” particulate matter. Therefore, a different definition of “inert” is probably needed at long sludge ages, in order to fit the real data. Advances in COD fractionation (coupling particle size distribution and respirometry) could provide useful indications in such sense. One more open issue is linked to the high sludge age

operation: complete retention studies show that the longer the SRT the more significant is the solubilisation of the mineral fraction of influent wastewater. This aspect is not considered at all in the ASMs, where particulate inorganic matter is removed with surplus sludge on a SRT-basis.

Differences in bio-kinetic parameters

The quality of dynamic simulation basically depends on the quality of the set of kinetic and stoichiometric parameters included in the biological model. Determination of these parameters is based on specific experimental and mathematical procedures. MBR bio-kinetic parameters can apparently be different from CAS ones due to two main reasons: (1) floc structure modifies diffusion and local transfer of substrate (more dispersed growth due to shear stress and retention of free bacteria, high sludge age modifies the amount of EPS), (2) biomass microbiology could differ (floc-formers are no more selected, high sludge age favours slow-growing bacteria, protozoa enhance the predation and increase decay rate of bacteria).

In order to determine which modification of parameter has a significant impact on model prediction, sensitivity analysis should be considered specifically for MBR. Operating conditions in MBR significantly differs from CAS and consequently some parameters become more or less sensitive. As an example, high SRT make the MBR model more sensitive to slow kinetics (decay) and to the stoichiometric parameter controlling the inert fraction accumulation.

For each biological process (nitrification, denitrification, COD removal, phosphorus removal), several sets of parameters have been reported for MBR. Experiences showed for example that apparent affinity constants are generally reduced due to reduction of transfer limitation but identification of these parameters is sometimes influenced by the lack of homogeneity in bioreactors. Nitrification parameters (specific growth rate and decay rate) also showed significant differences in MBR compared to CAS. Little is known about the PAO kinetics in MBR and more data need to be collected to investigate this aspect.

Integration of SMP-EPS concepts in biological models

The main objectives for the incorporation of Soluble Microbial Products (SMP) and Exopolymeric Substances (EPS) concepts into biological models are to: (1) make a link to fouling prediction as SMP/EPS have been put forward as an important foulant in MBR systems, (2) improve the prediction of soluble COD as in ASM SMP/EPS are now part of the particulate fraction (X) that does not pass the membrane and (3) provide a better sludge production estimate at high SRT.

Efforts in literature have resulted in two types of models: (1) stand alone models describing SMP/EPS dynamics only and (2) models that incorporate SMP/EPS into ASM-based models. The former have focused mainly on the whereabouts of formation and consumption of SMP/EPS. Also, they were typically developed with a different objective in mind and not purely in the framework of MBR. An initial good overview of SMP in wastewater treatment systems is available in literature whereas the work on a unified theory for EPS, SMP as well as active and inert biomass can be regarded as another milestone. The latter type of models have attempted to incorporate these hypothetical pathways of production and consumption of SMP/EPS into ASM-based models. A first attempt was reported after which mainly minor modifications have been proposed. A major difference among these efforts is the use of experimental data to validate the proposed amendments. Some efforts are mainly restricted to simulation studies, which can be explained by the fact that measuring EPS/SMP is a tedious task. Recently, a model was successfully identified with experimental data. This current lack of data and measurement techniques causes the current shortcomings in this area of research: (1) what are the kinetics of these processes and (2) most models are overparameterised compared to the limited availability of data.

Conclusions

Although an MBR system is commonly described as an activated sludge system where the gravitational separation step is replaced by a membrane filtration, this simplicity can not be extended to the mathematical modelling of these types of systems. This contribution aims at showing what implications this “simple change” has with respect to fundamental concepts of activated sludge models (ASM), COD-fractionation and biokinetic parameters. Also, the concept of EPS/SMP has been studied extensively due to the believe that these components are closely related to the membrane fouling issue. The summary of all these differences in modelling approach and calibration should serve as guidance for people trying to model MBR-systems. This should keep them from merely applying the same concepts they have used in modelling conventional systems, which is bound to introduce errors in the decisions based on them.

BIOLOGICAL MODELLING OF MEMBRANE BIOREACTORS AND IMPACT OF PRIMARY SEDIMENTATION

J. Jimenez*, P. Grelier*, A. Tazi-Pain*

* Research Centre of Veolia Water, Anjou Recherche, Maisons-Laffitte, France
julie.jimenez@veolia.com, patricia.grelier@veolia.com, annie.tazi-pain@veolia.com

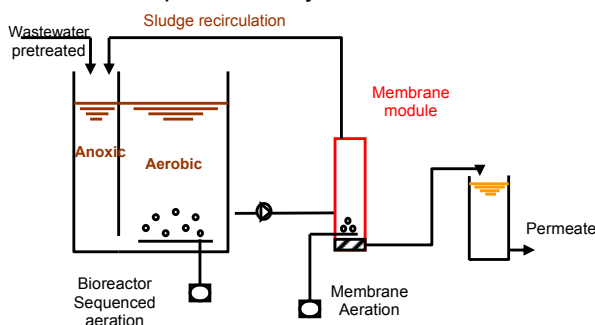
Keywords: biological modelling, ASM1, membrane bioreactor, sludge production

Objectives

Within the AMEDEUS European project, a work package is dedicated to the biological modelling of Membrane Bioreactors (MBR) processes and to the impact of a pre-treatment by primary sedimentation on the sludge production, the sludge characteristics and on the permeate quality. The supposed advantage of this pre-treatment is to decrease the sludge production and to improve the oxygen transfer by decreasing the sludge concentration. Two MBR pilots were operated side by side under the same operating conditions, one fed by screened (1 mm hole) raw municipal wastewater and the other fed by primary settled municipal wastewater. In the planning of this study, the sludge retention time SRT was fixed at 40 days and then modified at 15 days to calibrate the model on a broad range of operating conditions in order to validate and identify the biological ASM Activated sludge model limits.

Materials & Methods

Two identical MBR pilot plants of 0,795 m³ were set up at the water research centre of Veolia Environment in France. The schematic overview of process layout is given in figure 1. Each pilot is fed by two types of wastewaters. Pilot n°1 is fed with the wastewater of Maisons Laffite city after primary lamellar settler. This pilot is named “settled pilot” in this article. Pilot n°2 is fed with the same municipal wastewater after pre-screening through a diameter of 1mm hole. This pilot is named “screened pilot”. Sensors and transmitters are installed in order to provide sufficient on-line data to operate the system and calibrate the biological model.



Samples from the influent, the effluent and the sludge are extracted for daily analysis.

The biological model used is an activated sludge model ASM1 with Veolia internal modifications such as TSS fractionation of the influent (Lesouef, 1992). In order to represent the membrane, the model used is a secondary perfect settler. The simulation platform used in this study is WEST (MostForWater, Belgium). A first step was the validation of the systemic representation of the reactor with a lithium tracer test.

Figure 1: MBR pilot plant scheme

Results and discussion

- Wastewater characterization and experimental observations

The differences between both types of pre-treated water are: screened water has 35% more solids than settled water, and 16% more organic matter. Besides this first characterization, a fractionation of the COD of both influents has been performed, according with ASM definition. The main results obtained are the following: the global fractionation is closed to the default ASM1 for an urban wastewater, X_s fraction (slowly biodegradable fraction) is the easiest fraction to settle, X_i fraction has been estimated with this experiment but this variable is also a freedom degree of calibration for the sludge production of the biological tank.

Concerning the experimental results, the important results to underline concern the sludge productions comparison: at SRT 15 days, as expected, screened pilot has a sludge production Y_{obs} more important (0,23gMLVSS/gCOD) than settled pilot (0,18 gMLVSS/gCOD). The sludge production decreases for the screened pilot (0,15 gMLVSS/gCOD) when the SRT increases to 40 days, but not for settled pilot (0,21 g MLVSS/gCOD).

- Biological model calibration

The first model calibration is made with SRT 15 days measurement campaign. A steady-state calibration is first done in order to have a good fit of the level of organic and mineral solids in the biological tank.

The main results are that to calibrate the mixed liquor on settled pilot, X_i has to be decreased to 18% of particular COD of the influent, and to 22% for screened pilot (default value is about 25% of particular COD).

This explains why in settled pilot there is a lower sludge production: there is less inert organic particular COD in the influent; consequently, there is less inert solids accumulation in settled pilot.

Concerning the COD of the permeate, in order to calibrate this variable, the inert organic soluble fraction S_i is decreased to 8% for both pilots. That can be explained by the membrane retention which decreases the soluble

COD from permeate. Concerning the nitrification and denitrification kinetics, to calibrate the concentrations of nitrates and ammonium, and to create a dynamic change, a point load has been performed in each pilot with an addition of ammonium chloride to both influents. To calibrate the ammonium concentration obtained, the half-saturation constant of oxygen for autotrophic biomass K_{OA} has to be decreased to respectively $0,3 \text{ gO}_2/\text{m}^3$ and $0,25 \text{ gO}_2/\text{m}^3$ for settled pilot and screened pilot. A first explanation of these values is that the dissolved oxygen is lower in biological tanks (about $0,3\text{-}0,5 \text{ gO}_2/\text{m}^3$). Another hypothesis is the improvement of oxygen transfer by the floc granulometry. In fact, size distribution tests have been performed and compared with a classical activated sludge, and both pilots have the same average size about $64 \mu\text{m}$, and a classical activated sludge (SRT 18 days) has an average value about $140 \mu\text{m}$.

To calibrate denitrification, the half saturation constant of oxygen of heterotrophic biomass K_{OH} is decreased to $0,1 \text{ gO}_2/\text{m}^3$ (default value is about $0,2 \text{ gO}_2/\text{m}^3$) to decrease the "inhibition" of oxygen for anoxic biomass. Difficulties have been also found to calibrate this variable because of the dissolved oxygen brought by the return of aerated sludge from membrane tank.

Figures 2 (a) show the calibration of ammonia during the point load, and figure 2(b) nitrates calibration for settled pilot.

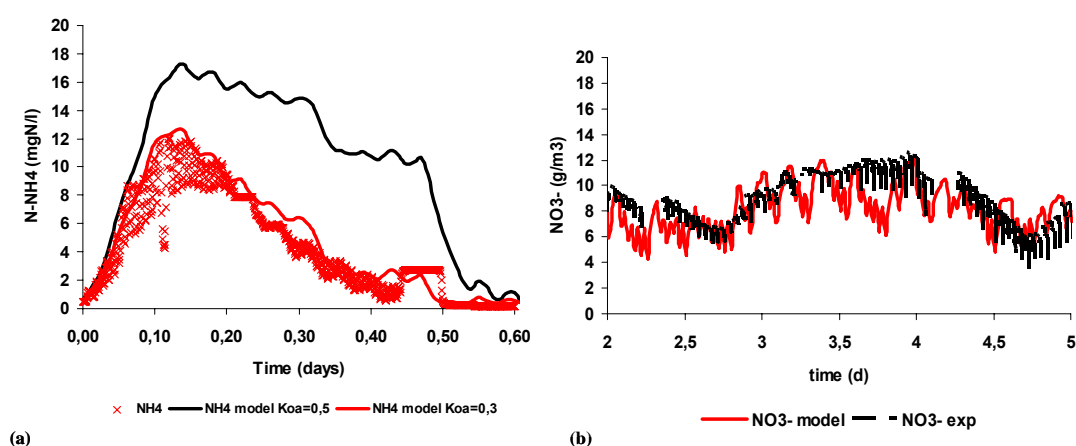


Figure 2: (a) Calibration of ammonia content in permeate for settled pilot after the perturbation, (b) Nitrates calibration for settled pilot.

At 40 days sludge age, the model calibrated at sludge age 15 days is not validated for variables such as the mixed liquor concentration.

For the settled pilot, the simulations underestimate the MLCOD and MLVSS concentrations and overestimate them on screened pilot. One interpretation is that inert organic matter X_i is accumulated in the settled pilot and biodegraded in the screened pilot. This phenomenon has been observed by several authors who decrease the X_i fraction to calibrate the MLVSS and the MLCOD at SRT higher than 30 days (Sperandio and al, 2005). With a high and sufficient SRT, the biomass can be acclimatized and then degrade the molecules larger than the membrane retention cut-off, which are EPS (exo-polymers substances), and SMP (soluble microbial products) (Massé and al, 2006).

- Sludge production and primary sedimentation interest

If a comparison of sludge production is made, it's important to consider the entire treatment line (primary sludge and biological sludge). As expected, concerning biological sludge production, settled pilot has an average sludge production of 281 g MLSS/d , lower than screened pilot with an average value of 327 gMLSS/d .

But if the pre treatment sludge production is added, the treatment line "sedimentation" reached a value of 423 g MLSS/d , value higher than the treatment line "screened" (343 gMLSS/d).

Considering the sludge treatment (anaerobic digestion of sludge), the file "sedimentation" becomes more interesting. In fact, if a comparison is made between anaerobic biodegradable components of both sludge (primary and secondary sludge for file "sedimentation and secondary sludge for file "screen"), there is more inert organic matter in sludge of screened pilot, and primary sludge bring supplementary biodegradable matter to the anaerobic digestion: so, an hypothesis is that the file "sedimentation" can bring a better quality of biogas, despite of the higher amount of sludge produced. This point has to be validated by experimental data and simulations thanks to an interface ASM/ADM (anaerobic digestion model) (Nopens and al, 2009).

Conclusions

The first results of this study shows that ASM1 model is able to predict correctly MBR performances for pilot fed by two different influents at 15 days sludge age with the same calibration kinetical parameters. One impact of the settler is that sludge production is lower than the screened pilot due to a lower level of organic inert in the influent. At high SRT, some biological phenomenon appear and the actual biological model does not considerate them. So, in this condition, the model prediction reaches its limits and need to be modified with a hybrid model ASM-SMP (Jiang, 2005). A positive impact of sedimentation is the sludge treatment improvement by anaerobic digestion in comparison with a classical MBR file.

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TECHNICAL FEASIBILITY AND OPTIMAL CONTROL STRATEGY OF DUAL (HYBRID) MBR-CAS CONCEPTS FOR PLANT REFURBISHMENT

W. De Wilde^{a*}, K. Moons^a, D. Bixio^a, C. Thoeye^a, G. De Gueldre^a

^a Research and Product Development Department, Aquafin; Dijkstraat 8, 2630 Aartselaar, Belgium; Tel. +32 (0)3 450-4841; Fax. +32 (0)3 458-3020; Email: wouter.dewilde@aquafin.be

*Corresponding author

Keywords: Process control, MBR, Hybrid, Dual

Introduction

More stringent effluent standards and increased biological and hydraulic loading trigger the need to extend existing treatment capacities at municipal wastewater treatment plants. Because of the limited footprint and enhanced treatment efficiency, among others, membrane bioreactor (MBR) technology is an attractive technology in the retrofitting of a WWTP. High investment costs are a major drawback to implement this technology in a refurbishment action. Dual configurations, combining (existing) conventional activated sludge (CAS) technology and (newly built) MBR-technology are a means to increase the cost-effectiveness of the refurbishment. Aquafin has determined the technical feasibility of 2 schemes following this concept: Dual 1 and Dual 2® (See Figures 1 and 2).

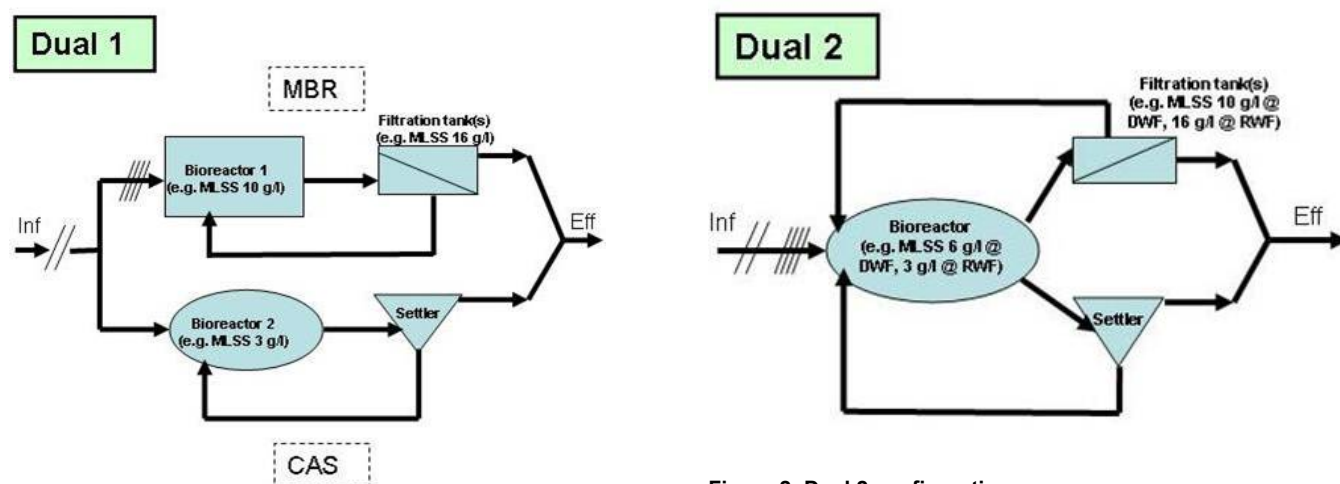


Figure 2: Dual 2 configuration

Figure 1: Dual 1 configuration

The main idea behind this Dual technology is to treat the average flow by the MBR and the peak flows by the final clarifier of the CAS. In this way the membrane area, which has a serious impact on the investment cost, can be reduced. The main difference between Dual 1 and Dual 2® is that in the former the CAS line and the MBR line have separate aeration tanks. In Dual 2® there is only one bioreactor feeding both the filtration tank and the final clarifier.

Objectives

Through extensive testing, a control strategy was determined to divide the influent between the CAS and MBR lane (Dual 1) and the final clarifier and the filtration tank (Dual 2). The Dual 1 concept was tested on full scale at the biologically overloaded WWTP of Schilde. The aim of this research was to fine-tune the control algorithm so as to minimize the risk of non-compliance with the maximum daily TN effluent norms. The Dual 2 scheme was tested on pilot scale. The goal was to determine the feasibility of the proposed flow scheme. This evaluation was done by monitoring the SVI and the SS concentration in the clarifier effluent. It was investigated if the settleability of the MBR sludge was sufficient to obtain a good settling during the operation of the final clarifier.

Materials & Methods

The Dual 1 control strategy experiments were performed on full scale at the WWTP of Schilde, an example of the Dual 1 flow scheme. This 28 000 PE treatment plant is biologically overloaded and is on the verge of non-compliance with the maximum daily effluent norms for total nitrogen (TN). A process model was developed using WEST® software, and calibrated with historical influent and effluent quality data of the Schilde plant. With this model, four different control strategies were evaluated: the flow repartition at start-up, the current flow repartition control, a pure feedback control and a combined feedforward/feedback flow repartition control. The analysis was extended to other WWTP refurbishment scenarios. In the next phase, the feedback/feedforward control algorithm was implemented and evaluated in full-scale operation. Simultaneously, the effect of enhanced primary clarification by means of coagulation with ferric chloride was evaluated. The feedforward action in the full-scale evaluation is

based primarily on two water quality signals in the influent, namely the ammonium and the suspended solids concentrations. The effluent results of the new feedforward algorithm are compared to the results for the previous flow repartition algorithm.

The Dual 2 control strategy was tested on pilot scale. The experiments were performed in three periods. In period 1 only the clarifier was working, in period 2 filtration tank and clarifier were operated in parallel with constant influent conditions, in period 3 filtration tank and clarifier were operated in parallel with dynamic influent conditions (dry weather flow/rain weather flow experiments). In this last and most important experimental period the Dual 2 concept is tested according to the patent application WO 2007/065956 A1.

Results and discussion

Because of the strong fluctuations in the influent load and the very narrow operational margin, feedforward control has a high potential as opposed to feedback control. The feedforward/feedback control indicates the improvement margin that can be offered by upgrading the system with control options only. The advantages of this combined control strategy can only be fully seized if the primary clarification is enhanced by the use of coagulants. In this way peak flows can be temporarily relieved and the risk of non compliance with the daily TN norm is reduced. Including the dosage of the coagulants in the control strategy leads to a more efficient use. This also counts for the use of external carbon source for denitrification. In this way the control algorithm can help to limit the operational costs. The dosage of coagulant would cost 6000-15000 € in a representative year. Other refurbishment scenarios, all comprising infrastructural changes, were put on hold for being more expensive.

The signals from the water quality sensors proved to be very reliable, on the condition that regular inspection and maintenance was performed. Due to the choice of conservative parameters for the estimation of the influent load and the kinetic parameters, the algorithm overestimated the effluent nitrogen concentration initially. When these parameters are relaxed, Nitrogen removal efficiencies can be increased by 5 % on a yearly basis due to the new control strategy. Theoretically, an additional 8 % removal efficiency can be achieved when an external carbon dose is added in the CAS-lane during the non-aerated phase. Dosage of ferric chloride is effective as temporary expedient to relieve the overloaded CAS lane. With a dosage of 50 µL/L it is realistic to attain 65 % removal of particulate matter. In a representative year, this mode of operation causes a rise in sludge production of 7 %. The newly developed controller seems promising and its use was extended beyond the evaluation period.

The Dual 2 experiments yielded fairly regular values for the sludge volume index, in the same range as the values in the full-scale plant. The effluent quality of the clarifier during rain weather flow was assessed and was dependent on the sludge concentration in the bioreactor. Higher sludge concentrations yielded lower effluent suspended solids concentrations. This was attributed to sludge blanket filtration. In most experiments the turbidity of the effluent of the clarifier was acceptable, guaranteeing a combined effluent (from clarifier and filtration tank permeate) with turbidity below the effluent norms.

Conclusions

The implementation of the Dual 1 algorithm yielded a good and economically feasible optimisation for the Schilde WWTP. While the control algorithm developed here is definitely site-specific, a similar analysis can be done for basically every plant designed according to the Dual 1 concept. To make the control algorithm universally applicable, the objective of the controller is to be expanded to account for additional elements such as cost functions/cost optimisation.

The Dual 2® flow scheme (patent application WO 2007/065956 A1) has proven to be adequate to treat dynamic dry weather/rain weather flows on pilot scale. The good effluent results were partly due to the formation of a high sludge blanket and subsequent sludge blanket filtration. This might not be generally the case. More research is therefore necessary to evaluate the practical potential of the Dual 2® concept.

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ADVANCED CONTROL OF MBR SYSTEMS USING ON-LINE FOULING SENSOR MEASUREMENTS

Brauns, E. Van Hoof, C. Huyskens, H. Elslander, F. Vanhoof, P. Lens, H. De Wever
 VITO, Unit Separation and Conversion Technology, Boeretang 200, B-2400 Mol, Belgium, E-mail: Etienne.brauns@vito.be, heleen.deweever@vito.be

Keywords: membrane fouling, fouling sensor, advanced control, fuzzy, dynamic parameter setting

Introduction

It is well known that fouling is a major problem during pressure driven membrane filtration. The control of the filtration process by an operator therefore requires knowledge (expertise) in that respect as to try to optimize the filtration conditions. A standard control system is mostly present, often being based on PLC control. The actions of the PLC are linked to the stabilization of basic parameters such as transmembrane pressure (TMP) or permeate flow. In the case of e.g. an intended stable permeate flow value, the set-points involved are dictated by the human operator. Such set-points could eventually be adapted by the operator when process conditions are changing. In practice however, a frequent supervision is rare and many filtration processes thus run in a suboptimal mode. With respect to process optimization and energy savings the potential advantages of a system, which would allow to implement the operators knowledge in an advanced control system (ACS) and which supervises automatically 24hours/7days the set-points of the lower-level PLC driven control system, are obvious.

Objectives

With respect to process optimization and energy savings the potential advantages of a system, which would allow to implement the operators knowledge in an advanced control system (ACS) and which supervises automatically 24hours/7days the set-points of the lower-level PLC driven control system, are obvious. In this presentation, the concept behind the ACS based on fuzzy set logic, its application for membrane bioreactors (MBR) and its validation and fine-tuning during MBR pilot testing are elaborated.

Materials & Methods

The ACS is meant to be able to change the values of the set points in an automatic way and in response to the actual condition of the MBR. As such, it supervises the functioning of the hierarchical lower level basic PLC or PC software oriented control system (see Figure 1). The ACS was developed as a separate software in Labview and was conceptually based on fuzzy set logic (FSL). Since in Labview a Fuzzy Toolbox was available, this was a very large advantage and the implementation of the Labview FSL blocks in the ACS software could be done in a very flexible and compatible way.

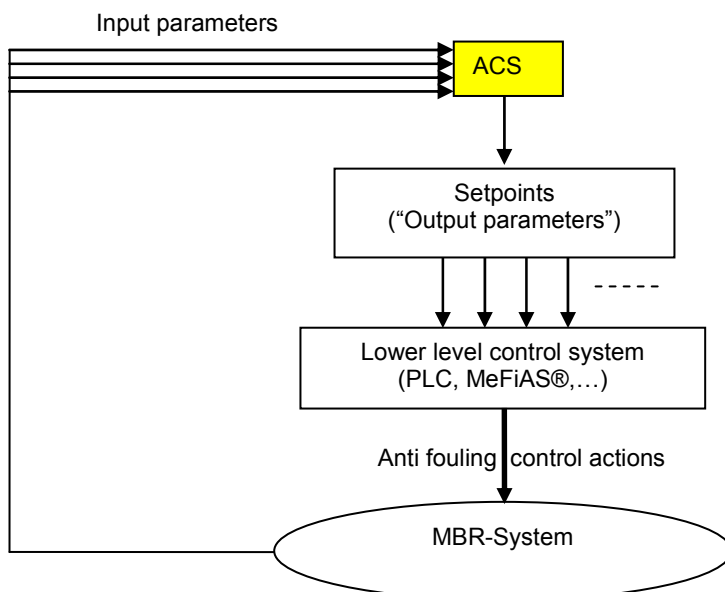


Figure 1: Advanced Control System (ACS) scheme

In total, 13 candidate ACS input parameters and 17 candidate output variables were defined. A crucial input parameter is the reversible and irreversible fouling propensity of the MBR mixed liquor. A specific fouling sensor was developed to enable the measurement of both fouling components. For details on this MBR-VFM (VITO Fouling Measurement) concept, we refer to Huyskens et al. [1]. Other potential input parameters are temperature, Mixed Liquor Suspended Solids (MLSS), extracellular polymeric substances (EPS), etc. Output parameters are mechanical actions counteracting reversible fouling, such as aeration, relaxation and backwash, or irreversible-fouling related actions.

In the context of the pilot tests reported here, the focus was on reversible, and not on irreversible fouling. The input parameters considered were the reversible fouling potential, temperature and flux. Due to the use of flat sheet membranes in the pilot unit, the adjustable reversible-fouling related output

parameters were aeration and relaxation. Backwashing was not compatible with the selected membranes. This results in the input-output matrix presented in Table 1.

Table 1: MBR filtration process input parameters and set points considered for the pilot tests.

Output variable set-point	Output variable (ACS generated set-point)		Input parameters		
			Primary input MBR-VFM	Temp	Flux
1	Aeration	flow			
2		duration			
3		interval			
4	Relaxation	duration			
5		interval			

The pilot demonstration tests were performed in various test blocks which consisted of a reference period with only lower level data acquisition and control and a test period with ACS control on top of the lower level control. The pilot MBR was an outside submerged MBR, equipped with an A3 doubledeck module.

Results and discussion

In the first test block, two input parameters – ‘temperature’ and ‘reversible fouling potential’ measured by the MBR-VFM - were considered to calculate the output parameter ‘aeration flow’. This served as a demonstration of the ACS and it could be concluded that the ACS software was functional and operational. In the following tests, the complexity was gradually increased and the system fine-tuned. In the second ACS test, a third input parameter ‘temperature’ was included to calculate the output parameter ‘aeration flow’. The permeability was constant in the reference period with a membrane aeration of 18 Nm³/h, but showed a gradual decrease in the ACS test period, where average aeration to the membranes amounted to 11 Nm³/h in filtration and 10 Nm³/h in relaxation mode. It was therefore concluded that the ACS settings, obtained in response to the measured fouling behaviour, strongly reduced the energy consumption of the MBR, but that this implied an increase in TMP. In ACS test 3, an even more complex ACS approach was tested. The input parameters ‘temperature’ and ‘reversible fouling potential’ measured by MBR-VFM were first used to calculate the output parameter ‘relaxation duration’. The relaxation duration value then determines the actual flux during the filtration phase, since the net hydraulic throughput should be kept constant. In a second step and similar to ACS test 2, the input parameter ‘flux’ was considered together with ‘temperature’ and ‘reversible fouling potential’ to determine the output parameter ‘aeration flow’. The observations confirmed the earlier conclusions that the gain in energy consumption obtained from the ACS settings leads to a TMP increase. In addition, the third test learnt that more fine-tuning of the fuzzy set rules was needed to optimize e.g. the range of aeration rates, the flux ranges, etc. Furthermore, the more challenging conditions in terms of fouling at lower aeration rates may require the combination with maintenance membrane cleaning. In the final long-term test period, maintenance cleanings were therefore included to be able to make the trade-off with the gain in energy consumption and the ACS was evaluated under dynamic operating conditions.

Conclusions

An ACS based on fuzzy set logic was developed as a supervising level on top of lower level MBR control system. It envisaged the dynamic generation of set-points related to anti-fouling control actions with the aim to optimize MBR operation. Demonstration tests at pilot scale highlighted the potential of the system to reduce energy consumption for membrane scouring.

Acknowledgment

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CFD ANALYSIS OF MBR-UNITS RECOMMENDATIONS FOR SYSTEM DESIGN AND OPERATION

Jan Saalbach*, Michaela Hunze**

*FlowConcept GmbH, Vahrenwalder Straße 7, D-3065 Hannover, saalbach@flow-concept.de

**FlowConcept GmbH, Vahrenwalder Straße 7, D-30165 Hannover, hunze@flow-concept.de

Keywords: CFD, MBR-unit, 3-d flow simulation, operation conditions

Introduction

MBR-units have been used in waste water treatment more frequently the past years. In order to guarantee an optimum and energy efficient operation, system design of the unit in combination with the chosen membrane modules as well as the operation conditions as e.g. aeration type, air-load and MLSS-concentration are to be harmonized. In this context, CFD can be regarded as a helpful tool to give a detailed insight within the system and to find the best combinations for the given boundary conditions. Within this abstract, recommendations will be given for the design and the operation of MBR-units developed on the basis of a number of CFD studies.

Objectives

The general aim of this research work was to find universally valid recommendations for system design and system operation with respect to the position of inlet and outlet construction, the influence of additional mixers, the type of aeration as well as the air-load.

Materials & Methods

All studies were carried out using the program system FLUENT (Ansys, 2006). The flow conditions were calculated using the Algebraic-Slip-Mixture-model (Manninen et al., 1996), which allows the computation of the two-phase-flow of water and air. The turbulence is modelled by means of the $\text{rng-k-}\epsilon$ -model (Orszag et al., 1996), a modified version of the standard-k- ϵ -model but better qualified for density influenced currents.

The use of a two-equation-turbulence-model is necessary in order to approximate the heterogeneity of the turbulence intensity within the systems of interest. Modelling sludge transport, the third phase – the activated sludge – and its influence on the flow field is approximated by a transport equation taking into account the sink velocity of the sludge. The interactions of sludge and water phase are realised by a density function as well as a function for the fluid viscosity. In order to investigate a complete MBR-unit, it is necessary to simplify modelling of the membrane modules. In the present investigation the modules are assumed as porous zones with a defined flow resistance. Studying the conditions in the vicinity of a single module, e.g. the influence of aeration on the conditions on flat-sheet membranes, the membranes themselves need to be modelled (Saalbach and Hunze, 2008).

Results and discussion

Recommendations were developed on the basis of a number of studies for different MBR-units equipped with hollow-fibre as well as flat-sheet membrane modules.

The studies for MBR-units equipped with hollow-fibre membrane modules comprises on the one hand investigations of a nitrification basin in which membrane modules are directly inserted (WWTP Nordkanal) and on the other hand investigations of pure filtration tanks (WWTP Sobelgra). The first system type includes near-bottom fine bubble aeration, cross-flow aeration as well as mixers for generating a circulation flow and for avoiding sedimentation below the modules. Cross-flow aeration exists within the second system type only, additionally to the membrane modules.

The studies for these systems were carried out with a focus on:

- the operation of mixers (only for system I),
- the design of inlet and outlet,
- the type of aeration mode.

Operation of mixers

As result of the studies it can be stated that the operation of mixers highly influences the flow behaviour as well as the sedimentation of sludge within the lower part of the basin below the modules, whereas their influence within the upper part is marginal, due to the strong impact of cross-flow aeration. Reaching a process stable mode of operation, the position of mixers, their thrust as well as their quantity are relevant. All three parameters need to be investigated if a tank of this type is planned. A mode of operation of four mixers but with a reduced thrust compared to the original one can be recommended for the nitrification basin of WWTP Nordkanal.

Design of the inlet

A simple design of the inlet is often used in order to receive a cost-efficient construction. The question is, however, how the inlet design affects the process behaviour within the system.

Several inlet types were evaluated with their influence on the systems behaviour in the present studies. Two inlet designs were compared for system I. At WWTP Nordkanal the inlet is designed as one opening at the front side of the nitrification basin. In order to evaluate the influence of a modified inlet construction, the inlet was extended into the basin.

It can be shown that this modification has no significant influence on the system behaviour because of the high turbulence and especially due to the operation of mixers.

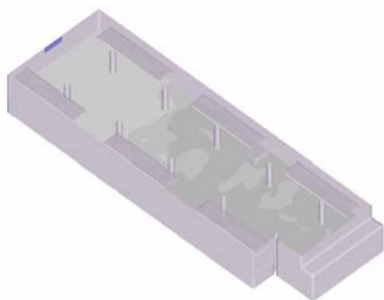


Figure 1: Tracer distribution – opening at the front.

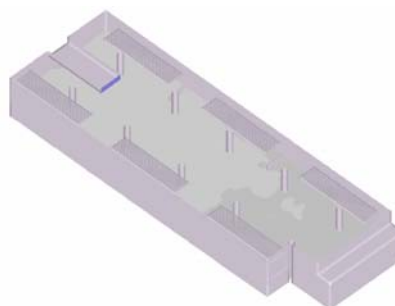


Figure 2: Tracer distribution – modified inlet.

The inlet constructions of system II comprises a distributed inlet system of three pipes with several openings distributed over the bottom, a very cheap and simple modification given by one opening at the side wall and a variant with four openings at the length side.

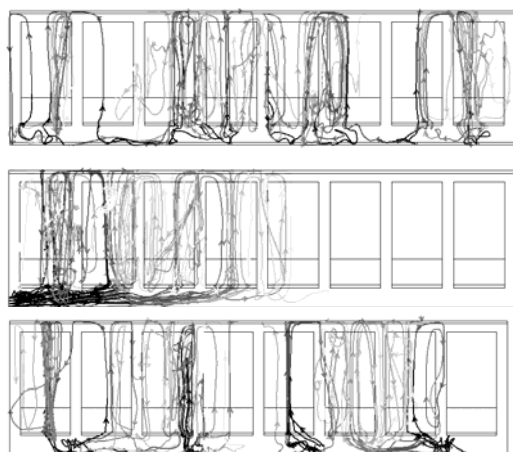


Figure 3: Pathlines – distributed inlet (above), one opening (middle), four openings (below).

Figure 3 illustrate the high influence of the inlet construction on the system behaviour. In order to guarantee a uniform load of all modules a distributed inflow is necessary.

Design of the outlet

The studies demonstrate that the outlet type plays a less important role compared to the inlet construction.

Type of aeration mode

As result of the studies it can be shown that – as expected – continuous aeration leads to a continuous upwards directed flow within a module. Using the air-cycle mode, the duration of aeration and no aeration is relevant for the flow field. For example, a mode of aeration to no aeration of 1 : 3 causes a system that almost comes to complete rest.

Studies for the filtration tank of WWTP Heenvliet were carried out in order to receive information about MBR-units equipped with flat-sheet membrane modules. Additionally to questions about air-load and air-cycle mode, the construction of the modules themselves were of interest. With respect to these investigations it can be stated that modules with closed sides around the membranes - including the aeration elements - will help to keep the rising air within the modules, where it ought to be used to reduce clogging and fouling.

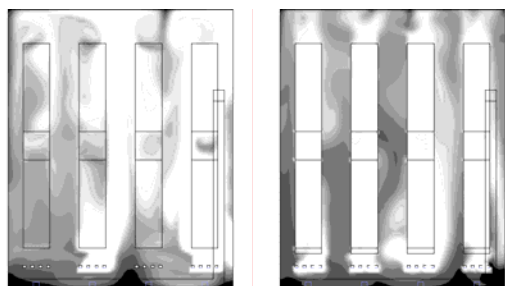


Figure 4 : Air-phase distribution – modules without (left) and with (right) closed sides.

Conclusions

The present investigations show that CFD is a helpful tool to get a detailed insight within MBR-units. On the basis of a number of practical relevant studies, recommendations for system design and operation were developed.

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EVALUATION OF MIXING EFFICIENCY & NUTRIENT REMOVAL IN MEMBRANE BIOREACTORS VIA CFD MODELLING WITH EXPERIMENTAL VALIDATION

Yuan Wang, Matthew Brannock, Greg Leslie*

UNESCO Centre for Membrane Science & Technology, University of New South Wales, Sydney 2052, Australia

* Corresponding author, contact details: Tel: +61-2-9385 6092; Fax: +61-2-9385 5966

Email: yuanw@student.unsw.edu.au; matthew.brannock@worleyparsons.com; g.leslie@unsw.edu.au

Keywords: MBR, Mixing, CFD, RTD

Introduction

The major disadvantage of current membrane bioreactor (MBR) design tools such as BioWin® [1] is that the mixing characteristics are assumed to conform with either complete mixing (CSTR) for aeration tanks, or plug flow (PFR) for some anoxic channels. Empirical techniques are then used for sizing reactor or position mixers, to achieve complete mixing [2, 3]. This often leads to an overestimate of the actual mixing energy for large installations, and hence the inaccurate estimation of biological nutrient removal.

Objectives

The purpose of this research is to develop a model using computational fluid dynamics (CFD) to account for how membrane configurations (i.e. hollow fibre vs. flat sheet) affect hydrodynamics at a set level of nutrient removal and subsequently allowing optimisation of the overall MBR performance.

Materials & Methods

The MBR vessel features can affect flow regimes which can be expressed by residence time distributions (RTDs). CFD modelling formulates and solves the fundamental mass and momentum balance equations using numerical

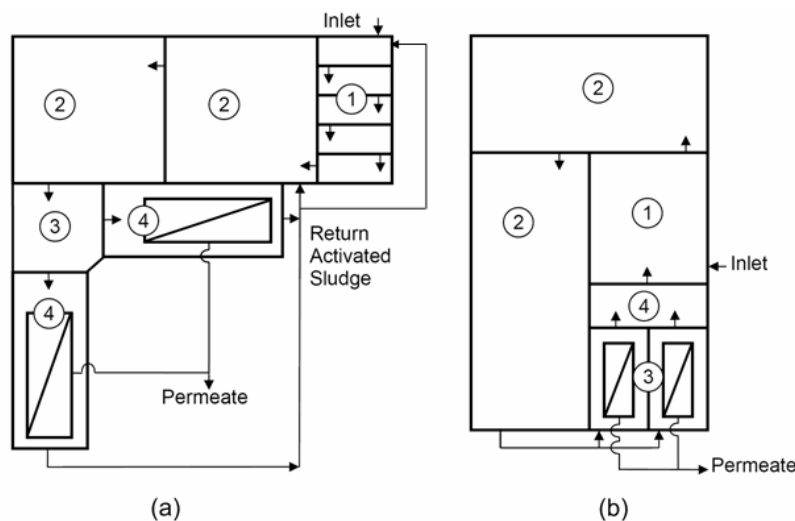


Figure 1 Overview of the full-scale MBRs' process setup; (a): FS MBR – 1. Bioselector, 2. Swing aerobic/anoxic zones, 3. Aerobic zone, 4. Membrane filtration vessel; (b): HF MBR – 1. Anoxic zone, 2. Aerobic zones, 3. Membrane

techniques and can be used for the prediction of RTDs of full-scale MBR plants. Two Australian full size MBRs were selected for RTD assessment, one having hollow fibre (HF) membranes and the other having flat sheet (FS) membranes (Figure 1).

To describe flow of the liquid and gas components of the multiphase flow, the Euler-Euler model was implemented [4]. The continuous phase was the water/sludge mixture and the dispersed phase was air. The assumptions made for the dispersed phase were: i) the bubbles are spherical; ii) the bubbles have constant diameter; iii) no collisions, coalescence or break-up of bubbles. The Morsi-Alexander drag force coefficient for the bubbles was used along with the mixture $k-\epsilon$ turbulence

model. The free surface was considered to be symmetry plane for the liquid phase and an outlet for the dispersed phase (i.e. degassing effects). The liquid phase fluid properties were that of water and for the gas phase were that of air. A simplification here was that the liquid phase viscosity is that of water which is valid for the majority of shear rates/stress experienced in the system. The CFD model implemented here only includes the liquid-gas phases, as the positive buoyancy forces from rising bubbles is much greater than the negative buoyancy forces from settling sludge [5]. The mean bubbles size used was 5 mm as calculated from the correlation by Akita and Yoshida [6]. The liquid outlet for the membrane module was assumed to be a negative source term for mass. Species transport equations with bioreactions were incorporated from Activated Sludge Model No. 1 (ASM1) [7]. Mass transfer of oxygen from the gaseous phase into the liquid phase was incorporated using the model proposed by Higbie [8] which is based on the slip velocity and diameter of the bubbles. The developed MBR CFD model was compared against field measured RTDs for hydrodynamics and against the COST Simulation Benchmark [1] for the biological nutrient removal component of the model.

Results and discussion

RTDs were generated at both sites with high reproducibility and tracer recovery (>96%) and were successfully reproduced by the CFD model (Figure 2). The FS MBR has a Peclet number of 0.29 and number of completely

mixed tanks in series of 1.10, while the HF MBR has a Peclet number of 0.68 and 1.24 of completely mixed tanks in series, which showed that the two MBRs were both close to completely mixed conditions. However, it was found that FS MBR required 20% more mixing energy than the HF MBR to achieve the completely mixed conditions (Table 1). The energy consumption of an MBR is usually characterised using specific energy consumption, which is the total energy consumed per m³ of permeate. The specific energy consumption of FS MBR and HF MBR was 1.23 and 0.98 kWh/m³ respectively. Among these, higher mixer power input of the FS MBR is resulting from its larger reactor volume. The aeration energy required for the bioreactor of the FS MBR was 3.3 kW, significantly lower than that of the HF MBR due to its simultaneous nitrification-denitrification design. However, the energy usage due to the aeration of flat sheet membranes is more than twice of the hollow fibre membranes.

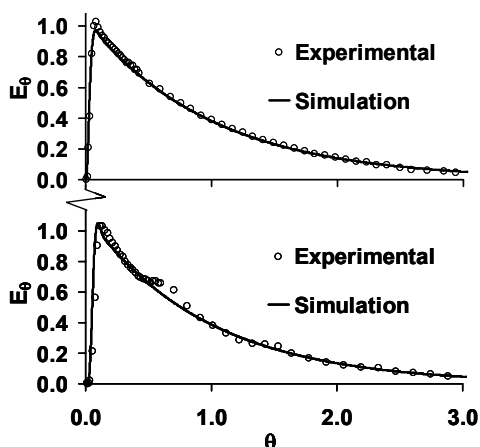


Figure 2: Experimental & CFD Modelled RTDs, Top: Hollow Fibre MBR; Bottom: Flat Sheet MBR

(anoxic and aerobic) were compared (Table 2). The differences between the benchmark & CFD simulation outlet concentrations for the anoxic tank were minimal (i.e. <1%). For the aerobic tank the largest difference was ~10%. Further work needs to be undertaken to correct this discrepancy.

Power Sink	FS MBR	HF MBR
Mixer	7.1 kW	2.2 kW
Bioreactor Aeration	3.3 kW	8.5 kW
Membrane Aeration	29.5 kW	13.8 kW
Recirculation Pump	16.0 kW	18.5 kW
Total	55.8 kW	42.9 kW
Specific Energy Consumption	1.23 kWh/m³	0.98 kWh/m³

Table 1 Comparison of energy usage of two MBRs

Pollutant Species	Units	Anoxic Tank 2		Aerobic Tank 3	
		B'mark	CFD	B'mark	CFD
S_S	g/m ³	1.46	1.47	1.15	1.30
X_S	g/m ³	76.4	77.1	64.9	68.0
$X_{B,H}$	g/m ³	2553	2554	2557	2557
$X_{B,A}$	g/m ³	148	148	149	148
S_{NO}	g/m ³	3.66	3.69	6.54	5.70
S_{NH}	g/m ³	8.34	8.34	5.55	6.24

Table 2: Comparison of selected parameters between COST Simulation Benchmark & the MBR CFD Model

Conclusions

A CFD model was developed to assess the implications of membrane configurations on MBRs' hydrodynamics and mixing efficiency and was successfully validated using field measured RTD data of full size MBR plants. Hollow fibre membrane module was found to be more energy efficient than the flat sheet membrane module. The biological reaction component of the CFD model was also successfully benchmarked against the COST ASM1 Benchmark. The development of this model improves the MBR design with the view of achieving the optimum mixing at lowest possible energy inputs at a set level of nutrient removal.

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ASSESSMENT PRINCIPLES FOR MEMBRANE AND MEMBRANE MODULE DEVELOPMENT: A CASE STUDY

S. Buetehorn*, J. Kochan*, C.N. Koh*, T. Wintgens*, D. Volmering**, K. Vossenkaul**, T. Melin*

*Chemical Process Engineering, AVT, RWTH Aachen University, Turmstr. 46, 52056 Aachen, Germany, Steffen.Buetehorn@avt.rwth-aachen.de.

**Koch Membrane Systems GmbH, Kackerstr. 10, 52072 Aachen, Germany, k.vossenkaul@kochmembrane.com.

Keywords: Membrane characterisation, surface modification, cake layer formation, (computational) fluid dynamics.

Introduction & Objectives

Membrane bioreactor (MBR) processes are affected by a number of parameters such as membrane fouling, hydrodynamic conditions and membrane module design. While the fouling propensity is linked to both biological characteristics of the activated sludge and characteristics of the membrane, hydraulic conditions and the module design are influencing the formation and removal of the layer of deposited matter (i.e. the cake layer). Therefore, efforts have been made within EUROMBRA WP 2 "Membrane module" to further investigate the impact of membrane and membrane module characteristics as well as operating conditions on the filtration performance of the system. Out of these activities, the outcomes of a collaboration of RWTH Aachen University and Koch Membrane Systems GmbH (KMS) are presented within this paper. Overall objectives of this study are to identify analytical tools to evaluate the impact of (i) membrane production conditions and (ii) membrane coating on pore structure and surface characteristics of the membrane. Furthermore, hydrodynamic conditions have been investigated by means of (iii) lab- and pilot-scale filtration experiments as well as (iv) computational fluid dynamics (CFD) simulations.

Materials & Methods

For the majority of investigations, PES hollow-fibre membranes in the microfiltration range out of the PURON[®] system supplied by KMS have been used. In the first stage of experiments, five different membrane samples have been characterised and compared with each other by means of pure water filtration tests, molecular weight cut-off (MWCO) measurements, scanning electron microscopy (SEM), atomic force microscopy (AFM), contact angle measurements, X-ray photoelectron spectroscopy (XPS) [Buetehorn *et al.*, 2008 a] and zeta-potential measurements. In parallel, long-term activated sludge filtration studies were conducted to evaluate the fouling propensity of the above-mentioned membrane samples [Buetehorn *et al.*, 2007 a + b].

Furthermore, a surface modification with a layer-by-layer polyelectrolyte assembly has been performed [Kochan *et al.*, 2008 + 2009]. Alterations in pore structure and material properties due to the surface modification were investigated by using the above-mentioned methods for membrane characterisation. Moreover, initial coating layer stability tests with respect to mechanical and chemical stresses were conducted and differences in the affinity to fouling were analysed.

Besides these membrane characterisation and modification studies, more fundamental filtration tests have been carried out to investigate the cake layer formation and removal mechanism. In addition to rather simple filtration experiments in both cross-flow and submerged mode with 1 up to 228 fibres, more complex methods like nuclear magnetic resonance (NMR) tomography or direct observation (DO) have been used. While NMR was used to visualise the filtration process, DO is based on an image processing of video sequences to characterise the bubble induced fibre movement [Buetehorn *et al.*, 2008 b]. For all filtration studies, a model suspension consisting of silica (SiO₂) particles in water (respectively in aqueous xanthan solutions showing shear thinning characteristics) was used to ensure stable and reproducible conditions. Prior to the filtration tests, the rheological properties of the model suspension were investigated and compared to the ones of activated sludge [Buetehorn *et al.*, 2008 c].

Lastly, computational fluid dynamics (CFD) simulations have been performed to investigate the impact of packing density and fibre arrangement on the (multiphase) flow pattern inside a single hollow-fibre bundle [Buetehorn *et al.*, 2007 c]. For this purpose, two different geometry models based on x-ray computer tomography (CT) scans have been identified and implemented into the CFD code. Besides this, model calibration experiments were conducted to determine a correlation of pressure loss, packing density and Re number for a liquid flow through hollow-fibre bundles.

Conclusions

The corresponding presentation to this paper will give an overview about the outcomes of an evaluation of assessment principles which have been applied to the module system of KMS as part of their membrane and membrane module development. Since most of the relevant results have been published earlier (see references listed below), only major conclusions will be drawn in the following:

- In the framework of membrane development studies, it was found that a significantly decreased residence time in combination with a decreased concentration of a key component of the chemical post-treatment are leading to higher pure water permeabilities (PWP), higher MWCO values and more open pore structures as observable in cross-sectional SEM images. However, a further reduction of these parameters was leading to

opposed trends, so that an optimal parameter combination exists with respect to highly permeable and cheap membranes [Buetehorn *et al.*, 2008 a]. Long-term activated sludge filtration tests in pilot-scale using the same membrane samples have consistently shown that membrane characterisation studies are capable of predicting the performance in activated sludge filtration properly. This was observable since the most favourable membrane according to the characterisation tests has shown the highest permeability over a piloting period of 15 months [Buetehorn *et al.*, 2007 a + b].

- Surface characteristics of virgin and modified flat-sheet and hollow-fibre membranes have been investigated using different polyelectrolyte coating agents and membrane materials. It was observed that all selected polyelectrolytes (PEI, PDADMAC, PAH) adsorb sufficiently on PS, CA, PES and PVDF membranes without any prior plasma treatment, resulting in initial permeability decreases, a shift of MWCO, slight changes of the contact angle and a better NOM removal. However, the maximal long-term filtration enhancement was observed for PEI coatings on PS membranes [Kochan *et al.*, 2008 + 2009].
- Rheological measurements have indicated that a suspension of silica particles in xanthan solutions are representing the shear-thinning characteristics of activated sludge properly. In this model suspension, the viscosity range is adjusted via the xanthan concentration to model a certain mixed liquor suspended solids (MLSS) concentration in real activated sludge, whereas the silica content can be adjusted almost independently [Buetehorn *et al.*, 2008 c].
- Cross-flow filtration studies at constant transmembrane pressure (TMP) have shown that the permeate flux is rapidly decreasing during the first stage of experiment until an equilibrium of particle deposition and entrainment is reached, which is characterised by a constant permeate flux over time. This long-term permeate flux is increasing with an increasing cross-flow velocity, a decreasing solids concentration, a decreasing average particle size and a decreasing dynamic viscosity, whereas the long-term permeate flux is independent of TMP variations [Buetehorn *et al.*, 2008 c].
- Submerged filtration studies at constant permeate flux have shown consistent trends compared to the above-mentioned cross-flow filtration tests. It was observed that the TMP rise during the filtration of a silica suspension in water is less pronounced at higher aeration rates and in case of significant fibre movement. The intensity of fibre movement was characterised by means of a direct observation technique which is based on an image processing of video sequences under different aeration conditions and module configurations. The results have proven that the intensity of fibre motion (e.g. expressed as average amplitude and frequency) is increasing with an increasing aeration rate respectively a decreasing packing density of the bundle [Buetehorn *et al.*, 2008 b].
- Initial NMR measurements have proven that the cake growth on the surface of a single hollow-fibre during a submerged filtration of silica particles can be visualised and the thickness of the cake layer can be quantified. Moreover, it was found that NMR is capable of visualising the liquid flow pattern at the membrane lumen, which in turn facilitates estimating the permeability evolution along the fibre.
- CT scans are a useful tool for mapping the instantaneous distribution of not-moving fibres in a hollow-fibre bundle properly. On the basis of these measurements, the geometry was modelled accurately (importing a CAD file into the simulation software) respectively as a heterogeneous porous medium (implementation of a porosity matrix into the CFD code). Although the settings of the simulation are to be further improved and calibration experiments to be initiated, both models are expected to be beneficial with respect to membrane module development in terms of optimised fibre arrangement and packing density [Buetehorn *et al.*, 2007 c].

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DEVELOPPEMENT OF NEW HOLLOW FIBER MODULES FOR MBR APPLICATION

W. BOSQ*, F.SAUX*, J. M. ESPENAN*, O. LORAIN*

*Polymem, Impasse de Palayre 31100 Toulouse France,
o.lorain@polymem.fr

Keywords: MBR; Dead-End filtration; Hollow fiber, External module localisation

Introduction

Regarding the membrane bioreactor development, the first MBR generation (1970) is based upon an external tangential filtration over tubular membranes. This generation, still available, required a high energy consumption and a high implementation cost of the tangential filtration which are not compatible with low treatment costs required in wastewater treatments. The second MBR generation, appeared in 1985, is constituted of membranes immersed in the bioreactor. Filtration is achieved in a dead-end suction mode with continuous air scouring and periodic backwashes removing the high energetic circulation loop. This system limits the membrane fouling and is more cost effective, allowing its implementation for urban wastewater treatment, however, maintenance (integrity tests, chemical cleaning, membrane reparations) and replacement of the membranes, submerged in bioactivated sludges, are laborious and unhealthy for the workers. Polymem is developing a new concept of membrane bioreactor which would incorporate the advantages of the two previous MBR generations. The driven idea is to still use the cost effective dead-end filtration of the second generation while the membranes are located outside the bioreactor as encountered in the first generation. This is performed by housing the dead-end hollow fibres membranes in an external carter which is fed by gravity or by a feed pump if needed. The main advantages of this concept are the easy maintenance of the external modules, the total independence of the bioreactor and the membrane filtration part which facilitates plant retrofitting and upgrading and a better efficiency of membrane scouring thanks to a dedicated coarse bubbles agitation system inside the module vessel. The polysulphone membranes are 0.08 μm (300 kDa) pore size.

Objectives

The objectives of the research performed were first to find the appropriate hollow fiber in term of material, pore size distribution and geometry, secondly the optimal module configuration in term of geometry, bundle assembly and packing density, and finally to estimate the optimal process operations of this particular configuration. In this last part, focus was made on the strategy of membrane aeration management by sequencing aeration cycles.

Materials & Methods

The demonstration plant was fed with a real municipal wastewater degraded at 6 mm, desanded and degreased. The wastewater comes from the left of the pilot through a thin screener of 1.5 mm punch holes, to the bioreactor divided into two parts, an anoxic area and an aerobic area. The activated sludges is carried to the module via the feed pump. The flow rate entering the module is 400% of treated flow rate Q , so 300% of Q is returned to the bioreactor. This slight renewing allows working at a stabilized concentration of the suspended solids inside the module and return with a ratio of 300 % to the anoxic area.

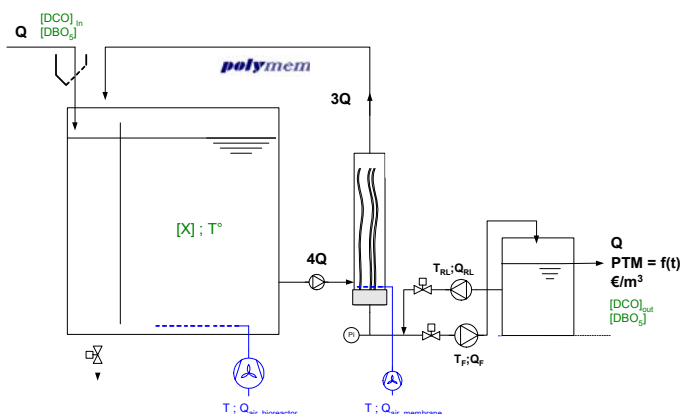


Figure 4 : Immem, MBR pilot PID

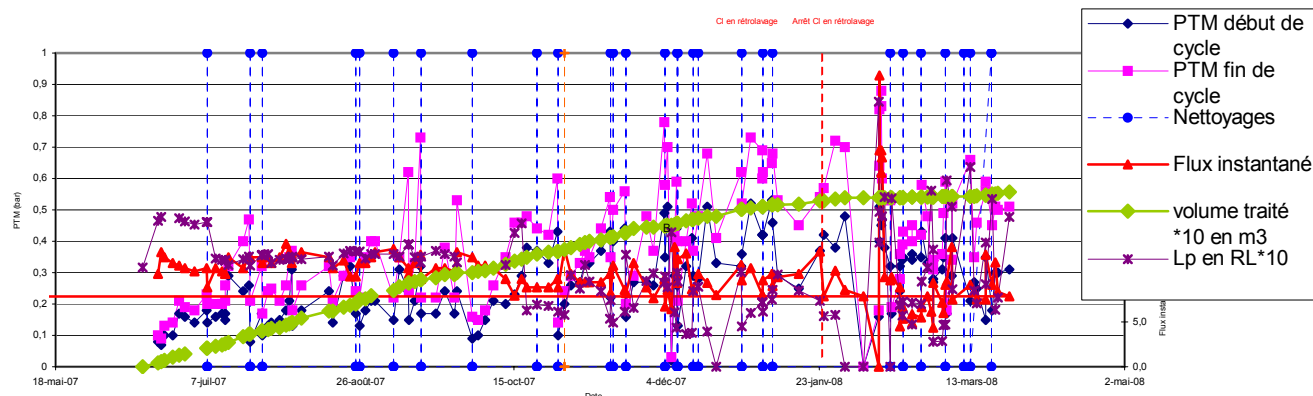
The module length was fixed at 1.3 m with a carter diameter of 0.135 m. Hollow fibers are potting in one end at the bottom of the module and are free and sealed off at the other end in the top of the module. The fibers are gathered in 4 bundles. 3 fiber dimensions were tested with an OD of 0.72 mm ; 1.4 mm and 2.5 mm. It was chosen to not work with reinforced fibers in order to limit the cost of the module. Various packing density were tested from 15 to 35%. Between the bundles, aeration blowers are disposed to provide the coarse bubbles for the scouring of the

membranes. Various air flow rates expressed in SAD_m , were tested from 500 $NI/h.m^2$ to 190 $NI/h.m^2$. A check valve was installed on the air entrance of the module for the sequencing and controlled by the PLC.

Biological process parameters were fixed during all the experiment with a SRT of 40 days and the Suspended solids concentration between 8 and 10 g/l. A suction pump was used for the filtration. The permeate goes to the storage tank and the overflow constitutes the production. The permeate storage is used to backwash the membrane thanks to the backwash pump. The pilot was controlled by an automatic device.

Results and discussion

Hydraulic performances from 5 $l/h.m^2$ to 15 $l/h.m^2$ have been validated for long term trials with a chemical cleaning frequency comprised between 2 weeks and one month. High effluent quality was achieved i.e. a biodegradation of carbon and nitrate of 95% and 98%. Suspended solids, as well as bacteria, have been completely removed of the treated water.



The optimal hollow fiber was a UF and not a MF because UF was easier to clean chemically, fouling was essentially surface deposit. Its OD was 1.4 mm, however a biggest fiber, 2.5 mm seems to be more resistance to mechanical stresses induced by air scouring. An important concern during all the experiment was the ageing of the membrane essentially due to an erosion active layer. Many impacts were observed which were probably caused by particles which passed through the screener. Integrity was checked frequently but it was difficult to maintain by fiber repair especially with a PDT limit fixed at 1 bar which correspond to no hole greater than 3 μm (size of bacteria). Whatever, the MBR can work with it but the treated water was not a UF water quality. SDI measurements have been made and they were not often lower than 3 which is the recommendation of the RO membrane supplier.

Conclusions

A new concept of membrane bioreactor was demonstrated with success. The results are promising with an average flux of 10 $l/h.m^2$. The maintenance steps during this pilot trial (cleaning, integrity checking, fiber inspection) were facilitated with the localisation of the module outside the bioreactor. Optimization of the filtration cycles and chemical cleaning strategy was made. Strategy of low aeration during filtration and high aeration during backwash have shown good tendencies of fouling control and reduce the aeration demand to 190 $NI/h.m^2$. However, ageing of the membranes surface was shown and this point must be improved in the next future for reuse purposes.

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DEVELOPMENT OF A NOVEL FIBRE SHEET MEMBRANE FOR MBR: THE FISH

M. Heijnen*, R. Winkler, M.Vogg, G. Roeder, P. Berg
 *inge AG, Flurstrasse 27, 86926 Greifenberg, Germany, mheijnen@inge.ag

Keywords: MBR, FiSh, Membrane, Fibre Sheet

Introduction

The world of waste water treatment has been viewing the arrival of the Membran Bioreactors with a lot of anticipation. The MBR market as a consequence has seen a healthy growth. However this growth has been hampered by a few factors, most notably the relatively high energy costs associated with coarse bubbling of air in order to prevent the membranes from clogging.

Objectives

Within the Amedeus project, inge AG has been working on developing a radically new design for membrane geometry. The proposed technology combines the advantages of the more common hollow fibre configuration with those of the flat sheet membrane. The result is a planar membrane which consists of hollow fibres that are combined. This leads to the term Fibre Sheet, or FiSh.

The FiSh membrane when developed successfully, will not have the problem of clogging like hollow fibres have, and as a consequence the pre-treatment filtration can be coarser. On the other hand, unlike flat sheet membranes, this FiSh can be backwashed at a high backwash rate, reducing the amount and/or frequency of coarse aeration. These advantages can lead to a significant reduction in overall energy demand.

Materials & Methods

The principle of the membrane as proposed by inge is depicted in Figure 1. The membrane developed here has Polyethersulphone (PES) as the base material. Of course some additives have been used in order to increase the membrane permeability, hydrophilicity and strength. Several spinning heads have been used for the production of the FiShes. The spinning process is similar to the process used for standard hollow fibres from PES (phase inversion through non-solvent), wherein this FiSh membrane is produced in 1 stage, so there is no necessity to glue the fibres together. A new membrane production unit has been build specifically to make enough of these membranes to be able to supply the modules necessary for testing at Anjou Recherche.

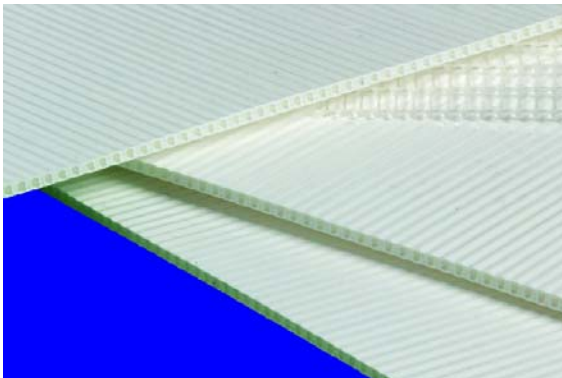


Figure 1: FiSh membrane showing the structure of connected hollow fibres

Results and discussion

Over the course of the last 3 years many different membranes were produced, and several challenges encountered. One of the main challenges was the formation of a membrane that had an uneven surface. The surface would show wave-like formations. It was found this was due to the expansion of the membrane due to the build-up of higher

levels of porosity. When producing membranes with a UF character, ie poresize under 50 nm, this wave formation could be prevented. However, these UF membranes brought other unforeseen problems, and it was decided to just pursue with MF membranes. The wave formation can lead to a suboptimal distribution of air during the aircouring due to the air being able to follow preferential paths, although on the other hand, the uneven surface could lead to a higher degree of turbulence which could then aid the scouring effect.

Several batches of FiSh membranes have been used to produce modules. The last membranes that were tested by Anjou Recherche had a clean water permeability around 5000 l/(m²hrbar) and a poresize distribution around 0,2 micrometer.

The module development has been particularly interesting, going from a small mini module with 0,2 m² to a size that can be used for small applications, 5 m².



Over the course of the Amedeus project, many small changes were made, and especially after the first module tests at Anjou Recherche showed a number of plate breakages, some more drastic changes were necessary. These included changes in the membrane, the potting procedure as well as the module endcaps. These latter were at first produced as 1 part per side, but this meant that any necessary repairs were difficult to perform. In the latest version, these caps have been divided in 2 parts which can be easily taken apart. Below these modules, a simple aerator was placed, which also was connected to the same tie bars. The total system can be seen in Figure 2. This system can be lifted into the MBR tank by a crane or hoist. Several novel aerator designs have been thought out, but due to time constraints only a standard design based on Oxytube aerator tubes was used.

Because of the membrane breakages that occurred during the initial testing at Anjou Recherche, also the membranes were adjusted. Different additives were tested in various compositions,

and in the end a 30% increase in elasticity was achieved compared to previous membranes with a similar porosity.

Figure 2: 4 module system as build-up at Anjou Recherche

Conclusions

It can easily be recognised that the FiSh (Fibre Sheet) membrane structure has great potential, especially in the MBR market. As a coming together of two proven technologies that eliminates the inherent weaknesses of both, this FiSh technology can reduce the energy needs for an MBR system, thereby giving the waste water market a significant push further towards complete 'membranisation'. The Amedeus project allowed inge to develop the FiSh technology up to a level that allows for successful pilot trials. A membrane with very good characteristics (porosity, permeability and fouling resistance) has been developed, together with a solid base for a module and an initial useable system design.

INNOVATIVE EUROPEAN MADE FLAT-SHEET MODULE SYSTEM FOR MBR APPLICATION

B.Kreckel*, U.Bruess*, A. Grélot**, A. Tazi-Pain**

*A3 Water Solutions GmbH, Magdeburger Straße 16a, 45881 Gelsenkirchen, Germany
(E-mail: bernd-kreckel@a3-gmbh.com, ulrich-bruess@a3-gmbh.com)

**Anjou Recherche, Chemin de la Digue BP76, 78603 Maisons Laffitte Cedex

Keywords: MBR, Flat-Sheet Membrane, Multi-Module

Introduction

During the past years, A3 water solutions, as a supplier of MBR plant technology, improved a flat sheet module concept for the use in MBR applications. Summarized, the advantages of this concept are the simple modular design that allows to arrange the modules very easy, a good filtration performance and an easy manageability. By using the experiences of planning, mounting and operating MBR plants, several improvements were done to module design and even to operation concept for MBR applications in the past time period.

Objectives

This paper deals with the optimisation of the A3 water solutions filtration system. The following described trials were accomplished in collaboration between the manufacturer of membrane technology, A3 water solutions GmbH, and Anjou Recherche, the research centre of Veolia Water within the framework of the AMEDEUS project. The trials cover three aspects of the novel flat-sheet MBR filtration system:

- Impact of the double deck and triple deck configuration, 2-3 modules stacked on top of each other;
- Optimization of the hydraulic performances to achieve high filtration performance and minimise the aeration demand;
- Membrane performances after biological stress and during peak flows.

Materials & Methods

The A3 water solutions membrane filtration concept shown in Figure 1 is based on flat sheet microfiltration membranes (PVDF or PES) that are fixed in a parallel configuration in a defined distance. The sheets are moulded in square based modules, so they are easy stackable as shown in Figure 2. An aeration system operating with medium-size bubbles is installed below the filtration modules. The resulting turbulence in the gas-liquid mixture ascending through the spaces between the membrane plates enables to detach the deposits. The aeration channel is fixed directly to the membrane modules. Filtration occurs from inside to outside of the plates.

The A3 module system allows the combination of modules to form so called "Multimodules" which contains up to nine 70 m² modules.

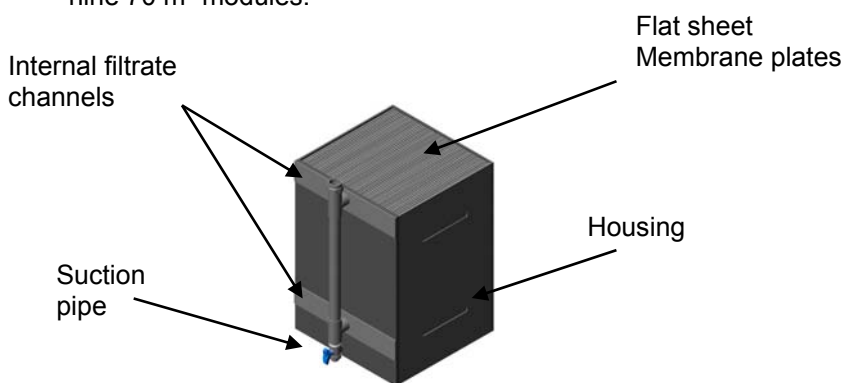


Figure 1: A3 membrane module M70-002

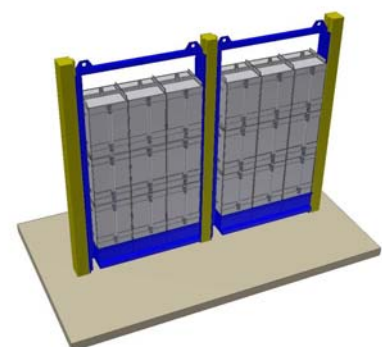


Figure 2: A3 Multimodule (630 m² each)

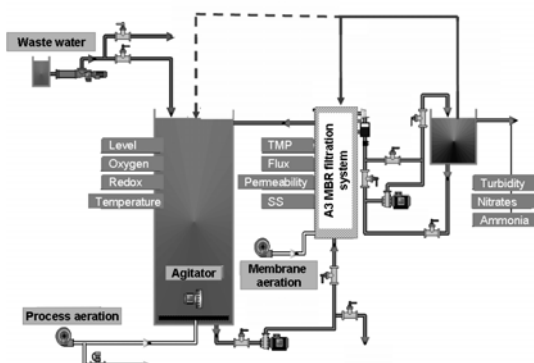


Figure 3: Pilot Plant Design of Anjou Recherche

A flexible platform (Figure 3) was built by Anjou Recherche (Research center of Veolia Water) to test the A3 Water Solutions technology under typical biological operating conditions (MLSS=11 g/l ; F/M= 0.12 kgCOD/kgMLSS/d; SRT= 28 days). The trials with the A3 water solutions filtration system lasted 12,5

months. The pilot was operated with municipal wastewater of the city of Maison-Lafitte. Pre-treatment was carried out by screening with a 1mm drum screen. The feed water characteristics are given in Table 1. Two tanks were used for the pilot plant: a 1.6 m³ tank for biological treatment and a 2.6 m³ tank for the membrane module. The wastewater enters the system in the biological tank, where nitrification and de-nitrification occur. To guarantee a sufficient oxygen supply for the biological process, the biological tank was aerated and stirred by a mixer. The activated sludge was pumped to the filtration tank. Inside the filtration tank two membrane modules with 70 m² membrane surface each, were arranged in a double stack configuration. Filtrate is collected in a storage tank. Concentrate was re-circulated back to the biological tank. Hydraulic and biological performance of the system was monitored. An installed data acquisition allowed continuous measurements for TMP, flux rate, temperature, and several filtrate and wastewater parameters, like redox- potential, turbidity, nitrogen-compounds, MLSS and oxygen. Wastewater and filtrate were analysed every day to monitor the trend of the treatment performance. Once a week the sludge characteristics were determined to detect possible interactions between biological stress situations of the sludge and fouling of the membranes.

Table 1. Wastewater characteristics

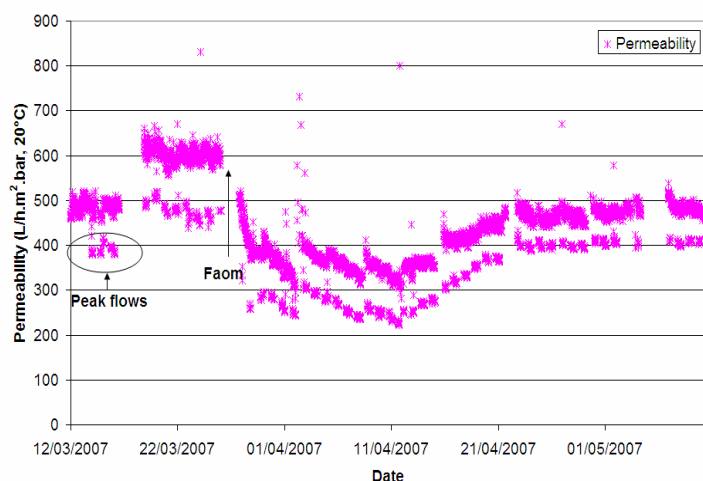
Parameter	COD (mg/l)	TN (mg/l)	N-NH ₄ ⁺ (mg/l)	TSS (mg/l)	pH
Municipal waste water	515 ±165	59±14	40±7	171±60	7.7±0.2

A3 water solutions GmbH, as a constructor and deliverer of turn-key MBR plants, validated the operation concept developed at Anjou Recherche at full-scale in Xanten. Further tests with triple-deck configuration were also performed at pilot-scale.

Results and discussion

The results obtained at Anjou Recherche showed that the biological treatment was according to the expectations: COD in average 16.7 mg/L and turbidity below 0.1 NTU.

Initial permeability of the membrane in water was about 1,600 L/(h*m²*bar). During the trials, a new cleaning strategy was developed which permits the permeability to stabilize during the pilot plant operations to 500-600 L/(h*m²*bar) with a membrane air flow rate of 0.2 Nm³/(h*m²) and a flux of 25 L/(h*m²). Moreover, the results show that the system can support fouling due to biological stress and peak flows (programmed to occur twice a day during 2h with an instantaneous flux 1.5 times higher) for a MLSS concentration up to 18g/l (Figur 4) (Weinrich and Grélot, 2007; Grélot et al., 2009).



Figur 4: Operation after biological stress and with peak flows

The trials at Xanten confirmed the beneficial of the new cleaning strategies at full-scale and first tests showed the feasibility of the triple-deck configuration.

Conclusions

Under typical biological operating conditions (MLSS: 11 g/L; SRT: 28 days; F/M ratio: 0.12 kgCOD/kgMLSS/d), an optimum flux rate was at 25.5 L/(h*m²) for a relatively low membrane air flow rate of 0.2 Nm³/(h*m²) corresponding to a specific aeration demand of 8 Nm³/m³_{permeate}. The new operation mode of the A3 module outperformed the current market leaders presenting specific aeration demands higher than 14Nm³/m³_{permeate} for MBR applications according to the data indicated by Judd et al. (2007)

By applying an adapted cleaning strategy for flat sheet membranes a high permeability of around 500-600 L/(h*m²*bar) can be maintained.

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DEVELOPMENT OF CONTAINERISED TURN-KEY MBR PLANTS

D. Vilim *, P. Hlavinek **, J. Kubik **, P. Hlustik **

* Envi-pur Ltd., Wilsonova 420, 392 01 Sobeslav, email: vilim@envi-pur.cz

** Brno University of Technology, Zizkova 17 602 00 Brno, email: hlavinek.p@fce.vutbr.cz

Keywords: MBR, membrane, containerised, wastewater

Introduction

Turn-key MBR plants can be completely constructed at the factory and shipped as containerised modular plants or factory components can be installed in tanks (concrete or steel) constructed on-site. Containerised plants are delivered pre-wired and pre-assembled and minimize field installation labour and they are easily relocated. A detailed MBR design considers variables including influent and effluent criteria, climate, and other operating methodology.

Objectives

This article presents technical information, which is used for detailed design and operation of containerised turn-key MBR plant of Envi-pur Ltd Company in the frame and support of EU project AMEDEUS. The work on the development of MBR Plant was divided into the next parts: overview of existing containerised MBR's, wastewater pre-treatment, buffer tank, bioreactor, physical and chemical cleaning of the membranes and control and measurements.

Overview of existing packaged MBR Plants

We've found more less 16 applications during the exploration of the containerised MBR plant market. The most important producer of these plants is A3 Water Solutions with own membrane module (70 m² module). These plants aren't standardised and are developed for certain application (Xanten - extension of the existing WWTP, Kunduz - German Forces, Afganistan, Weßling – wastewater from textile industry).



Figure 1: A3 Water Solutions - Kunduz

The next important producer of containerised MBRs is Smith & Loveless which introduced a product called "Titan MBR". This package plant is equipped with flat-plate module with fine bubbles diffusers for efficient operation and oxygen transfer. Smith & Loveless also provided complete PLC controls for each unit.

Good example of containerised MBR is Puron pilot plant (KOCH membrane). The difference is in type of membrane module. The membrane module is hollow fiber with single header design fixing the fibers at the bottom of the module and allowing them to float freely at the top.

Another pilot plant is located in Berlin-Margarethenhöhe and it's developed in the frame of ENREM (Enhanced Nutrient Removal in Membrane Bioreactor) project. This pilot plant is equipped with

Martin System siClaro® membrane module.

Eflo International Ltd. is the producer of containerised MBR with their flat sheet membrane module. Typical applications for EFLOMBR include municipal and domestic sewage treatment, mobile or temporary sewage treatment, industrial wastewater biological treatment, and grey water treatment.

The last well described producer of containerised membrane bioreactor is Suido Kiko Middle East. They produce containerised MBR plants fitted into 20' and 40' ISO containers.

Envi-pur containerised MBR plants

One of important aspects for containerised plants is kind of used container. In concept of containerised plants we intend to use two kinds of containers, standard ISO containers (20', 40') and plastic containers from Envi-pur production. The technical solutions of plastic and ISO containers are little different in the reason of target expedition countries. The ISO containers will be mostly sold to foreign countries contrary to plastic containers which are developed to be sold mainly in the Czech Republic.

There are four possible sizes of MBR containers according to population equivalent (50, 100, 200 and 500). The volume demands on ISO containers will be satisfied by full fill approach. This approach means to design volumes of tanks to full fill the total volume of the ISO container. This is the reason why the number of population equivalent is

slightly different from plastic containers. The approach for designing of plastic containers is using of Envi-pur plastic containers product line utmost.

Wastewater pre-treatment

Wastewater pre-treatment plays important role in municipal wastewater treatment using MBR technology. Design of wastewater pre-treatment relates to type of membrane module. Generally producers of flat sheet membranes recommend mesh size 2-3 mm, producers of hollow-fibre modules recommend mesh size 1-2 mm.

There are three main technical solutions of mechanical pre-treatment for containerised MBR:

- Integrated facility (sieves and sand trap)
- Screw drum screens
- Rotary drum screens

Buffer tank

From the literature review we supposed that the size of the buffer tank installed before membrane bioreactor has to come from 12 h HRT, in order to minimize hydraulic and concentration load variations. Volume of the buffer tank can be calculated as two hours of Q_h (design flow).

Bioreactor

The membrane bioreactor works as a classic activated sludge process where the sludge is removed on membrane modules. The bioreactor is divided into two tanks denitrification tank (anoxic zone) and nitrification tank (aerobic zone). The membrane modules are submersed in nitrification tank and the reclaimed water is pumped out by permeate pumps.

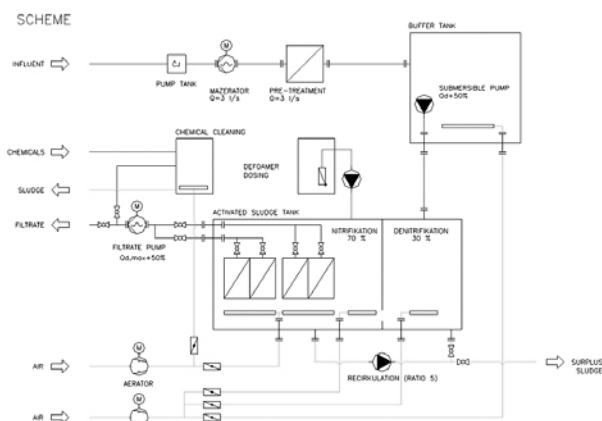


Figure 2: Scheme of Envi-pur containerised MBR Plant

The membrane permeate is pumped by permeate pumps. Part of permeate is stored in permeate storage tank where membrane modules are cleaned with addition of cleaning chemicals.

Defoamer chemicals are stored in defoamer dosing tank and are applied manually after higher formation of foam.

Control and monitoring

Entire equipment of containerised MBR plant is monitoring and control unit. We've tried to find a solution for measuring of dissolved oxygen, flow rate, water level, F/M ratio etc. and unit for control and operating of pumps, blowers and mixing facilities.

Conclusions

Containerised MBR plant is innovative technology in wastewater treatment. The company of Envi-pur is developing new product line of wastewater treatment plants which can give comfort of operation and money saving to costumers. The best value of this technology is high removal efficiency which take a possibility to reuse reclaimed water for flushing toilets, park or garden irrigation and of course to satisfy EU water framework directive 2000/60/EC.

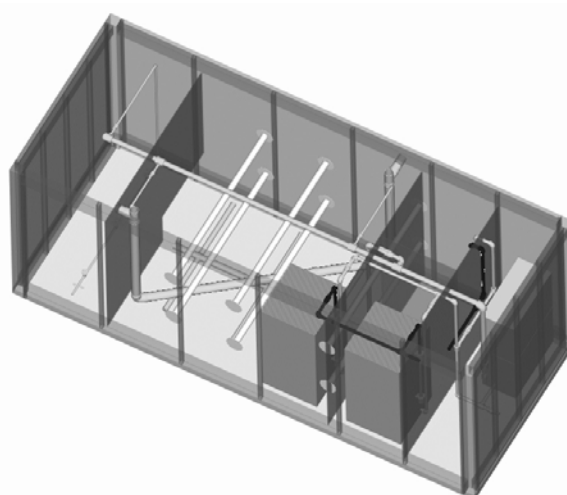


Figure 3: 3D model of Envi-pur containerised MBR Plant

THE EFFECT OF ORGANIC PEAK LOADS ON MEMBRANE BIOFOULING IN A PILOT SCALE MBR TREATING MUNICIPAL WASTEWATER

Ben Zwickenpflug, Marc Boehler, Adriano Joss, Hansruedi Siegrist
 Eawag, Swiss Federal Institute of Aquatic Science and Technology, Ueberlandstr. 133, 8600 Duebendorf, Switzerland

Keywords: MBR, permeability, biofouling, peak loads, F/M ratio

Introduction and Objectives

Organic peak loads are supposed to have influence on membrane permeability (membrane fouling) and effluent quality. For testing the interrelationship between fouling and peak loads at a pilot scale MBR plant, different kinds of organic substrates have been dosed, in order to bring a massive load of biodegradable C-components directly in contact with the membrane to thus provoke membrane fouling.

Materials & Methods

The peak load experiments have been conducted at a pilot scale plant treating municipal wastewater from a the local sewer after primary clarification. The pilot is equipped with three submerged filtration units operated in parallel (fig. 1): one flat sheet module (*Kubota FS50*) and two hollow fibre modules (*Puron A-30-HS*, *Zenon ZW500A*). The plant has been dimensioned for carbon removal and nitrification. In order to simulate high organic peak loads, 3 dosing experiments have been carried out using 3 different substrates. **Acetate** and **sugar solution** have been applied to obtain an increase regarding the **soluble** COD-fraction ($COD_{sol.}$) and **wheat flour** to increase the **particulate** COD-fraction ($COD_{part.}$)

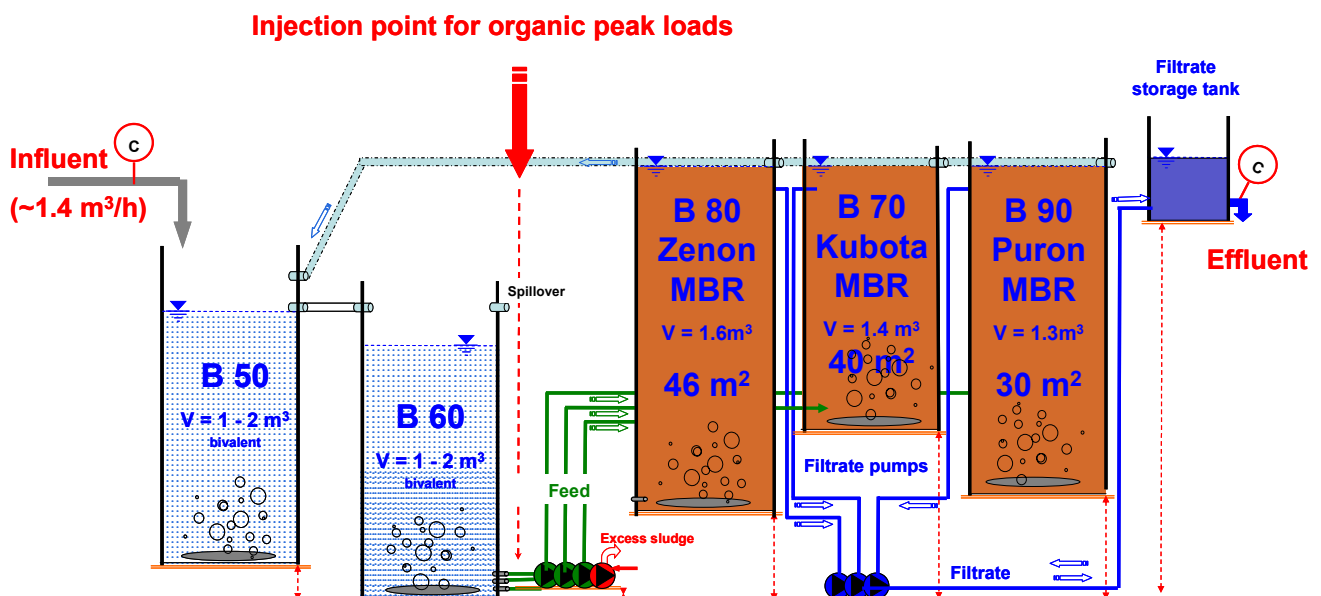


Figure 1: Scheme of the MBR pilot plant

Each peak load experiment was carried out for 7 days in a row with one daily peak load in the morning. The peak load was dosed during regular operation of the plant with flow proportional feed to the flow rate in the sewer. Each peak dosing lasted only 6-12 minutes but added 50 % of the daily influent COD load. With the scope of testing the worst case, the peak load solution was dosed directly into the membrane chambers. In between the experiments there has been at least 2 weeks without peak load dosing and normal chemical maintenance cleaning of the membranes (done every two weeks as a combined hypochlorite and acid clean).

Results

The impact of the peak load dosage on membrane permeability of the modules was rather small (fig. 2), although high COD concentration in the permeate reached peak concentrations up to 800 mgCOD/L during acetate and sugar dosing, while under normal operating conditions was in the range of 15 to 20 mgCOD/L. During flour dosing no increase of the permeate COD was observed although, the supernatant in the membrane chamber was around 200 mgCOD/L while under regular operating conditions it was in the range of 50 to 100 mgCOD/L: this shows, that the sludge layer covering the membrane during regular operation can contribute to organic removal. During the dosing time of both acetate and sugar only one of the three modules showed a reaction on permeability (permeability decline of ca. 35% in each case), whereas the performance of the other 2 modules remained unaffected. The flour peak loads showed no impact on the permeability of none of the modules.

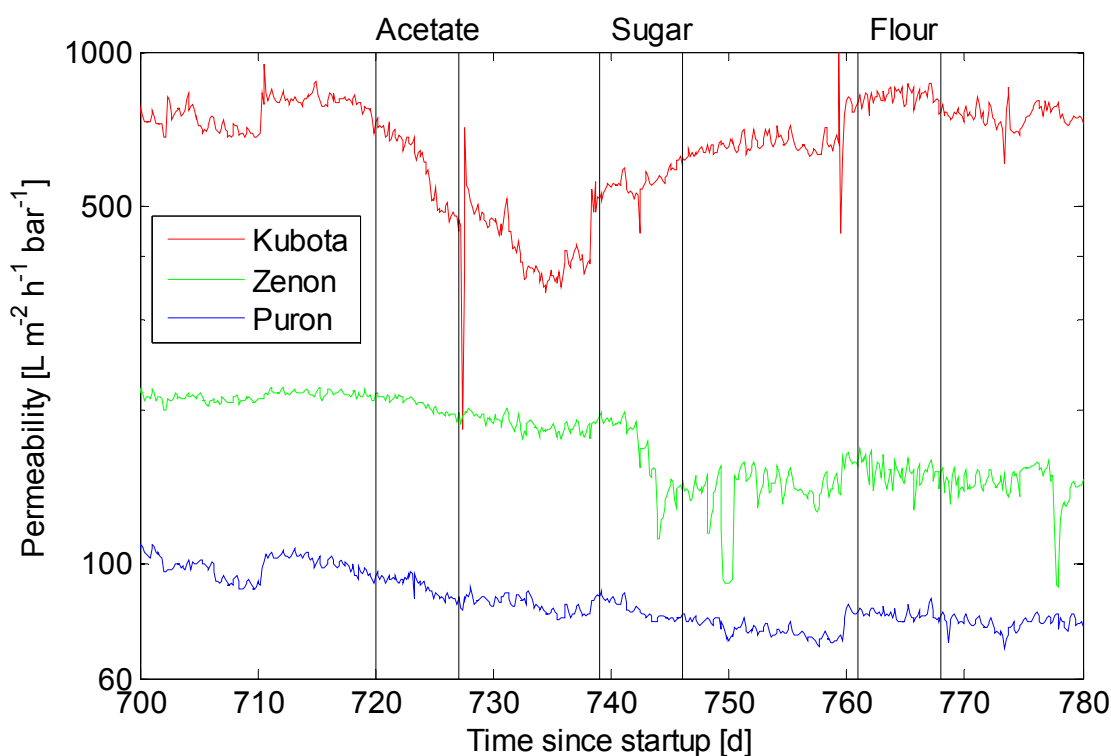


Figure 2: Permeability of the three modules during the peak load experiments with three different organic substrates. The permeability is compensated to 20°C for water viscosity.

Conclusions

High organic peak loads causing high F/M ratios seem to have only minor influence on membrane permeability compared to other unidentified factors, e.g. sludge charistics or seasonal variations. Literature findings that predicted high fouling rates (massive decrease of permeability) could not be confirmed in our experiments. Fouling caused by high F/M ratios seems to be mostly reversible. Decline of permeability has been observed only for dosage of COD_{sol.} not for COD_{part.}. The membrane permeability is influenced simultaneously by many factors and the physico-chemical interactions between membrane and sludge are rather complex. Nevertheless our study shows that very high peak loads of easily degradable soluble or particulate substrate directly into the membrane chamber do not result in high fouling rates: MBR systems seem to cope well with peak loads.

DECISION TREE FOR FULL-SCALE SUBMERGED MBR CONFIGURATIONS

De Wever, H.* , Brepols**, C., Lesjean, B.***

*VITO, Unit Separation and Conversion Technology, Boeretang 200, B-2400 Mol, Belgium, E-mail: heleen.dewever@vito.be

**Erftverband, Paffendorfer Weg 42, 50126 Bergheim/Erft, Germany, E-mail: christoph.brepols@erftverband.de

***KompetenzZentrum Wasser Berlin, Cicerost. 24, 10709 Berlin, Germany, E-mail: boris.lesjean@kompetenz-wasser.de

Keywords: submerged MBR, inside configuration, outside configuration

Introduction

Submerged membrane bioreactors (MBRs) exist in two configurations. In the outside configuration, membrane modules are placed outside the bioreactor. A pump circulates the mixed liquor from the bioreactor to the membrane module or back at a flow rate of 100 to 500% of the influent flow. In the inside configuration, membrane modules are immersed directly into the bioreactor. The main difference in design of an inside and outside submerged MBR is therefore the presence of an extra pump to recirculate the mixed liquor between the bioreactor and the membrane filtration tank and compartmentalization through a separate filtration tank.

Objectives

In this investigation, we want to give an overview of the perceived advantages and disadvantages of both submerged MBR design options and of the trends in submerged MBR design for full-scale systems treating municipal wastewater. From this information, a decision tree for submerged MBR configurations was constructed.

Results and discussion

In literature several advantages and disadvantages are claimed for the inside and outside submerged MBR configurations.

With separate membrane tanks, the membrane module can easily be separated from the biomass and is easily accessible for inspection, maintenance or cleaning interventions. Particularly at high cleaning frequencies, this leads to reductions in energy, time and resources. In addition, the outside layout allows improved chemical cleaning [1].

Membrane fouling in outside submerged MBRs is lower. On the one hand, this is related to the fact that hydraulics and fluid dynamics can be independently optimized in the separate filtration tank. Sludge distribution in the vicinity of the modules can for instance be better controlled [2]. On the other hand, the biological system can be separately optimized.

The outside submerged MBR configuration is said to yield better effluent qualities. First, this is related to the hydraulic retention times (HRT). Since outside submerged MBRs usually have lower MLSS concentrations in the bioreactor system, their specific volume is larger and this increases their hydraulic buffer capacity. Second, this is attributed to the fact that the separate filtration tank leads to cascading of the total reactor volume, which makes this type of configuration less susceptible to strong fluctuations in feed flow or loading conditions [2, 3].

Particularly when stringent nutrient discharge norms have to be reached, MBRs with a separate filtration tank are recommended [3]. This is not only due to their larger buffering capacity, but also to the possibility to better optimize the denitrification and the biological phosphorus removal.

Outside submerged MBRs show a higher operational flexibility when operating in several parallel lanes. As stated by Brow [4], one aeration tank can be isolated and flow may continue from the remaining aeration lanes to all filtration tanks. In an inside layout, both the biological capacity of the tank and the hydraulic capacity of the membranes in that lane would not be available.

An analysis of trends in full-scale submerged MBR design for municipal wastewater treatment in Europe indicated that outside submerged MBRs are a more recent development, which is preferred for retrofitted plants, for plants with medium to large capacity or flow and for sites with high peaking factors or with stringent nutrient discharge consents. Smaller plants, MBRs equipped with flat sheet membranes with lower packing densities and systems where only C removal needs to be achieved, typically take the inside lay-out. When alternating anoxic/aerobic cycles are applied in the bioreactor, the outside configuration is the only option.

The outside submerged MBR configuration provides the highest flexibility in operation and allows independent optimization of biological and membrane processes. From comparison of 2 full-scale plants, this goes with a higher investment and operational cost. In spite of higher manpower requirements to operate an inside MBR, its operational costs were 30% lower than for the outside MBR. Capital costs were also around 70% of those for an outside MBR but this may have been related to a difference in size and hence economy of scale.

Conclusions

Advantages associated with the outside submerged MBR implementation are among others easier maintenance and cleaning, improved chemical cleaning, better control of clogging and foaming, better effluent quality, and higher operational flexibility. This probably explains why outside submerged MBRs quickly became the favored MBR

design for municipal plants in Europe. However, the inside configuration is strongly preferred for smaller plants, for flat sheet membrane applications or for systems where only C removal needs to be achieved.

Based on literature data, expert inputs and current trends, a decision tree was tentatively compiled which indicates the major factors affecting the choice for an inside or outside MBR configuration (see Figure 2).

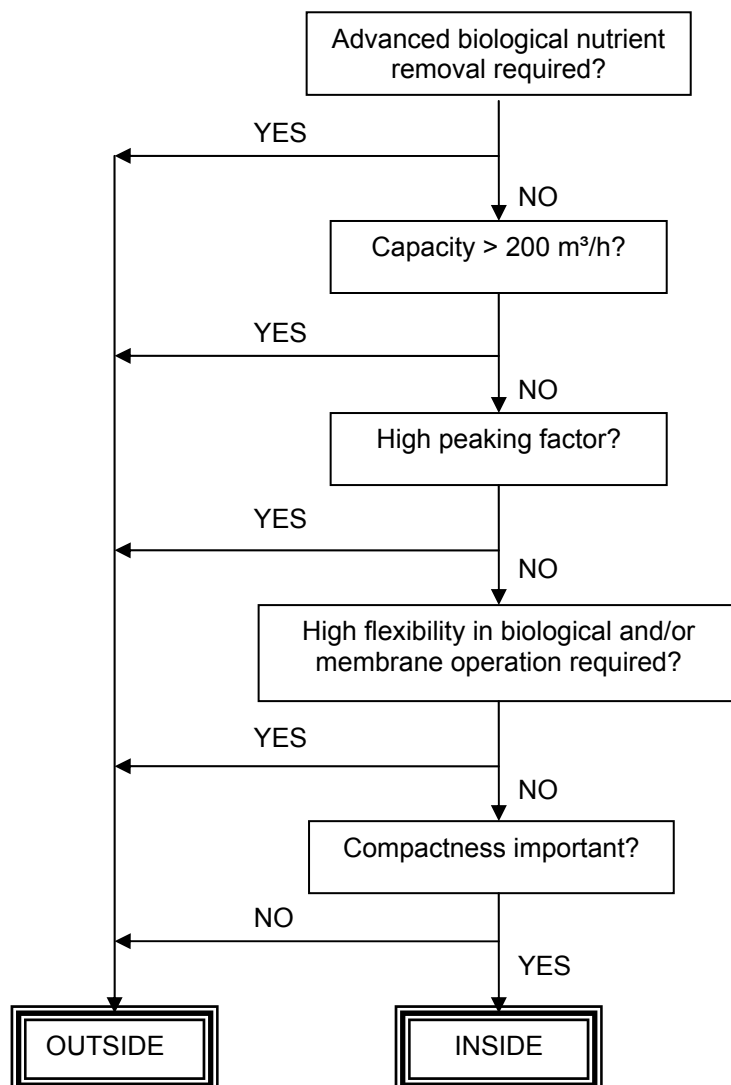


Figure 2: Decision tree for submerged MBR design.

Acknowledgment

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OPERATIONAL EXPERIENCE OF MBR DEMONSTRATION PLANT WITH POST DENITRIFICATION IN BERLIN-MARGARETENHÖHE (ENREM-PROJECT)

Carsten Lüdicke¹, Johan Stüber², Regina Gnirss¹, Boris Lesjean², Matthias Kraume³

¹Berliner Wasserbetriebe, Cicerost. 24, 10709 Berlin, carsten.luedicke@bwb.de

²KompetenzZentrum Wasser Berlin, Cicerost. 24 10709 Berlin

³TU Berlin, Fachgebiet Verfahrenstechnik, Straße des 17. Juni 136, 10623 Berlin

Keywords: ENREM, MBR, EBPR, Post-denitrification

Introduction

Some of the suburban areas (approx. 33.000 inhabitants) of Berlin are not connected to the central sewer system. Wastewater is usually collected in cesspits and regularly trucked away. This is not only an inconvenient and expensive way of wastewater treatment but also bears the risk of uncontrolled discharge of wastewater in groundwater due to leaks in old cesspits.

Objectives

Within the 3.5 years lasting ENREM project (Enhanced Nutrient REmoval in Membranebioreactors) in Berlin-Margaretenhöhe a novel and patented process was investigated to demonstrate the feasibility of a semi-decentralised solution reaching the high effluent requirements of the water authority of Berlin. The biological process combines the enhanced biological phosphorus removal (EBPR) with a post denitrification in MBR technology without dosing of any carbon sources (Figure 1). The waste water nutrients C, P and N are removed with high elimination rates.

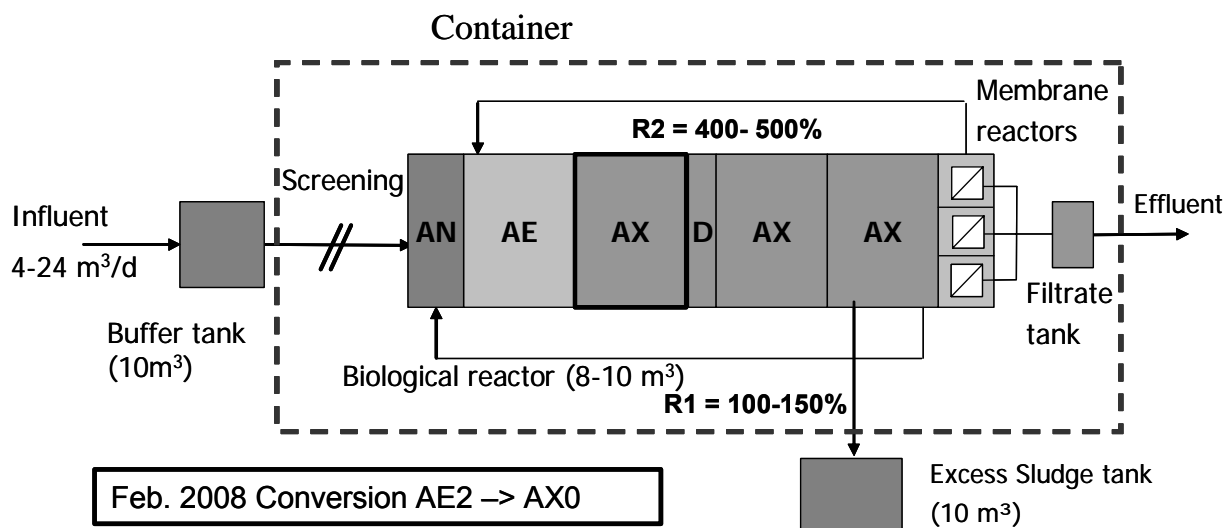


Figure 1 Process flow sheet of MBR plant

Materials & Methods

The catchment area of the plant includes approx. 250 p.e. A low pressure drainage system is implemented for the sewage disposal of the domestic wastewater. The small catchment area and the absence of rain water and industrial discharge results in high concentrated waste water which is heavily fluctuating in concentration and amount. To guaranty a stable biological process and low effluent concentrations, it is worthwhile to homogenize the influent volume flow and the concentration peaks. Because there is no possibility for a bypass at the MBR plant too, the concept was extended with a buffer tank [1]. There is no sludge treatment on site.

Results and discussion

The operational experience within the first years showed that there is a possibility for process stabilisation by changing the ratio of the process steps. For this reason the volume of the anoxic zone was enlarged by reducing the aerobic volume in Feb 2008. The positive effects could be seen on the basis of the effluent concentrations after a short period of adaptation.

The potential of the process becomes apparent in Figure 2. With the post denitrification there are TN-elimination rates possible up to 98% with effluent concentrations for nitrate-N below 1 mg/l, in average of 6 mg/l. Without dosing of external carbon sources the measured denitrification rates were up to 1.2 mgN/h/gVSS and higher which are above the endogenous denitrification rates. At this the impact of stored substrate in the anaerobic zone is supposed [2].

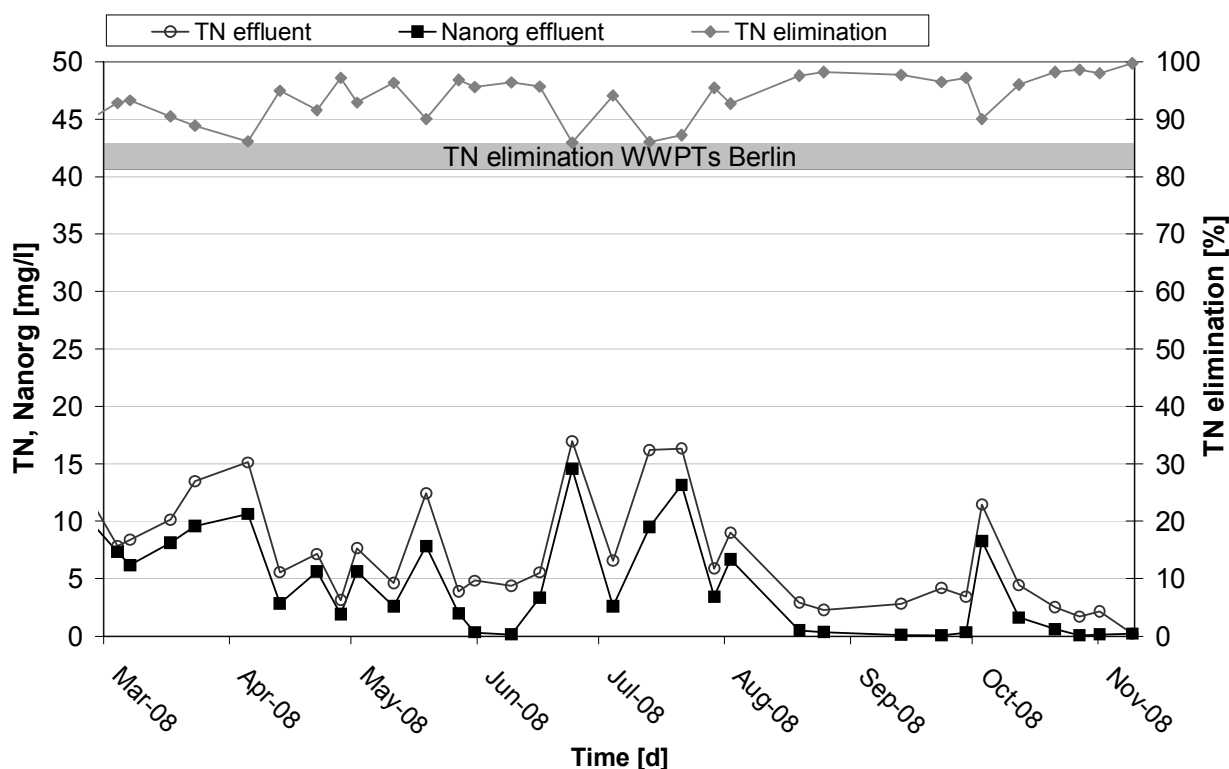


Figure 2 Effluent concentration and elimination rate for TN and Nitrate-N

Only with the EBPR process and without dosage of ferric precipitants a phosphorus elimination rate of more than 99% could be reached. By installing of a co-precipitation with a minimal amount of ferric precipitants (4 g Fe/ m³ waste water) in the 2nd term of 2008, the effluent concentrations could be reduced once more with a further stabilisation of the process. The effluent concentration for this period was in average 0.02 mg/l for o-PO₄-P and 0.09 mg/l for TP resulting in a high phosphorus content in the biomass between 4.3 - 4.7 %.

The filtration performance was very satisfying with a new implemented cleaning strategy: Two membranes were operated alternating with an operational flux of 16 – 20 l/m²/h and a maintenance cleaning with different cleaning agents for each membrane with low chemical concentration. One membrane was operated while the other was in stand-by in cleaning solution, every month the membranes were switched. It was observed that the cleaning with 500 ppm reactive chlorine as well as 1000 ppm hydrogen peroxide at pH 11 is a practical way for a long-term good filtration performance. Approx. every 6 month there was a 2 step cleaning with 5000 ppm citric acid for each filter.

Conclusions

The operated plant shows high elimination rates for COD (>95%), phosphorus (>99%) and nitrogen (up to 98%) when operated within the appropriate range of design conditions. The membrane performance was very reliable with the new implemented cleaning strategy.

Acknowledgment

This study was conducted in the frame of the demonstration project ENREM, with subventions of the European LIFE-program (LIFE 04 ENV/DE/058). The project partners are grateful for this support and the financial support from Veolia Water and Berliner Wasserbetriebe.



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OPERATIONAL EXPERIENCES WITH THE HYBRID MBR HEENVLIET, A SMART WAY OF RETROFITTING

J.W. Mulder
Water Authority of Hollandse Delta

The wastewater treatment plant of the village Heenvliet (the Netherlands) was originally designed to treat 8,950 p.e. of domestic wastewater. The capacity increased to 13,000 pe and 390 m³/hr by upgrading to a hybrid membrane bioreactor system. The newly installed MBR treats approximately 25% of the maximum hydraulic capacity, which is equal to the dry weather flow. During storm weather events the remaining effluent is discharged by the conventional clarifier. The biology of both systems has been integrated to one activated sludge system. This hybrid concept allows for optimisation of both sub-systems in terms of hydraulics and biological loading rate as illustrated in figure 1. During dry weather the complete wastewater flow can be treated by the membranes. (figure 2).

Figure 1. MBR in series with conventional aerobic tank

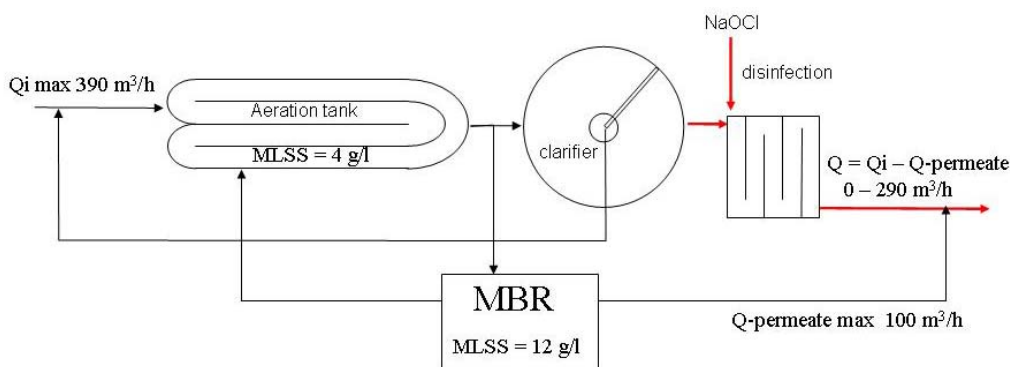
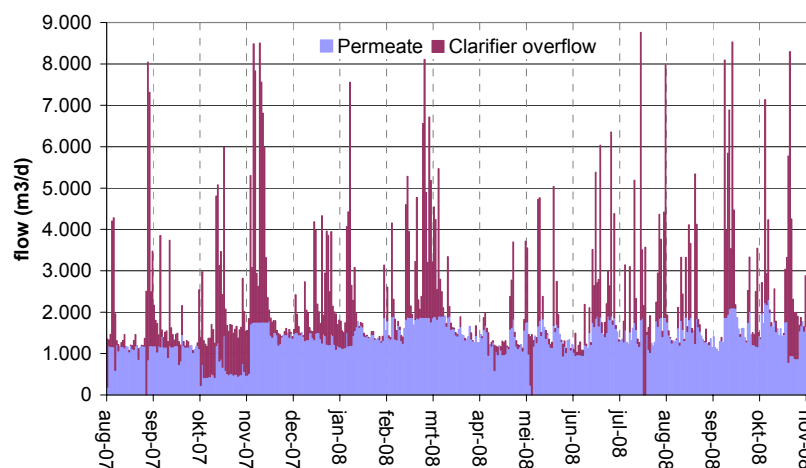


Figure 2: flow distribution of the wastewater over membranes and clarifier.



The MBR is equipped with flat sheet membranes of Toray. In total 3,000 membrane elements are installed in 16 modules in a double deck system. The maximum hydraulic capacity of the membranes amounts to 100 m³/h at a net flux of 23.4 l/m²*h. The MBR was started up in March 2006. During the first year of operation leakages were detected based on analyses of E-Coli. Inspection of the membranes showed malfunctions of the connection of the membrane material on the frame. Based on these experiences Toray improved the production process. In 2007 the membranes have been replaced.

One of the advantages of the hybrid concept is a more economic use of the membranes. Unlike normal domestic MBR applications the membranes can be operated at the design capacity continuously. One of the research topics

is the development of the membrane performance under these high loaded conditions and the frequency of chemical cleaning. Initially the permeability appeared to drop rapidly, followed by a period of a slight decrease. After 2.5 years of operation 5 recovery cleanings were needed with citric acid and hypochlorite. No maintenance cleanings have been done in between.

The hybrid concept requires activated sludge with good characteristics for both membrane filtration and sedimentation. The SVI varied between 90 and 120 ml/g. Membrane filtration characteristics have been very well during the entire period of operation.

The performance of the biology was good. The average BOD concentration in the permeate was 1 mg/l. Nitrogen concentrations in the permeate are very low, specially during summer seasons (figure 3). Nitrogen in the combined effluent of permeate and clarifier overflow was slightly higher, but mostly below 5 mg/l (figure 4). Removal of phosphorus hasn't been optimised yet.

Figure 3: nitrogen in permeate (monthly averaged)

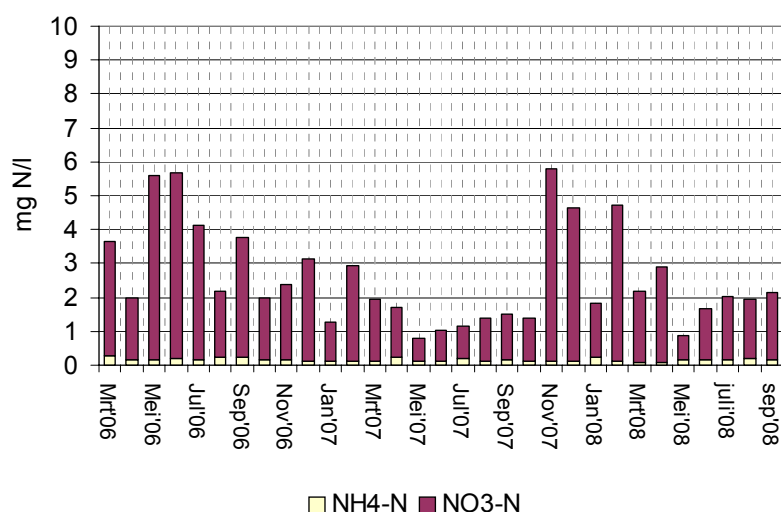
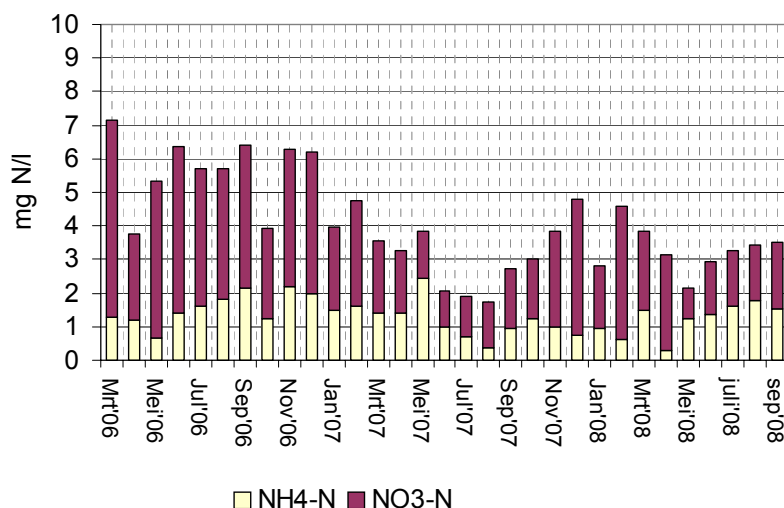


Figure 4: nitrogen in the combined effluent (monthly averaged)



One of the future optimisations is the energy consumption. MBR requires more energy than conventional treatment, specially for air scouring of membranes. After initial clogging of membrane sheets the specific air flow capacity was increased from 0.14 to 0.43 Nm³/m²*h. The total energy consumption varied between 0.8 and 1.2 kWh/m³ and is still under optimisation. The optimal air flow is topic for further research.

After 3 years of operating experience it can be concluded that the first experiences with the hybrid concept of the wwtp Heenvliet have been successful. The membranes have been operated more economically compared to other domestic MBR plants treating combined sewage and rainwater runoff. The sludge quality was good for both membrane filtration and sedimentation. Point of attention in the further optimisation will be reduction of the energy consumption.

CHALLENGES AND POTENTIALS OF BIOFILM-MBR FOR MUNICIPAL WASTEWATER TREATMENT.

T.O. Leiknes, J. Phattaranawik, I. Ivanovic

Department of Hydraulic and Environmental Engineering, NTNU- Norwegian University of Science and Technology, S.P. Andersens veg 5, N-7491 Trondheim, Norway, Tel.: +47 7359 4758; Fax.: +47 7359 1295; email: torove.leiknes@ntnu.no

Keywords: Extractive biofilm membrane bioreactor, Suspended solid control, Process design, Membrane clogging

Introduction

Coupling biofilm reactors with membrane processes as biofilm membrane bioreactors (BF-MBR) is an interesting development as an alternative technology to activated sludge membrane bioreactors (AS-MBR). Biofilm technology for wastewater treatment can provide substantially lower suspended solid (SS) environments for membrane filtration and may overcome problems from high viscosity and membrane clogging in AS-MBR. The extractive BF-MBR processes with moving-bed biofilms have been investigated in the EUROMBRA project. Attachment of biofilms on moving carriers provides many different process characteristics from AS-MBR such as i) much lower SS concentration and low liquid viscosity in the biofilm reactor, and ii) different method to control solids retention time (SRT) in the system. Low SS environments created in BF-MBR may offer a number of advantages such as i) lower energy consumption from the aeration due to lower liquid viscosity, ii) potentially less problems of cake deposition & clogging in modules, and iii) potentially less biofouling, and iv) when clogging of modules is not an obvious problem, higher membrane packing densities can be obtained, leading to lower space requirement for the installation. In addition, membrane cleaning would possibly become easier when membrane clogging is not an issue, and amounts of cleaning chemicals and chemical wastes may be lower. However, these benefits of BF-MBR can only be obtained if SS in the system is well controlled. Therefore, this study aims to present challenges and potentials of the extractive BF-MBR for municipal wastewater treatment. Development in BF-MBR process design is focused. Three different designs of BF-MBR process configurations to control suspended solid in the systems are described. Management of the suspended solids in the systems may be a key to reduce amount of sludge waste and the sludge disposal cost.

Materials & Methods

Three different process configurations and designs of BF-MBR systems are included in this investigation. The BF-MBR designs were evaluated for SS control, and membrane filtration performances. Table 1 shows details of the process characteristics of the biofilm reactors and process configurations.

Table 1. Characteristics of the BF-MBR configurations for systems I, II and III.

Characteristics	System I	System II	System III
Numbers of bioreactor	1 (2 parts)	1 (2 parts)	2
Aerobic digestion	Upper chamber: 73 L, Lower chamber: 42 L, Aeration: 9 L/min	107 L, Aeration: 17 L/min	142 L, Aeration: 20 L/min
Anaerobic/anoxic digestion	-	Size: 71 L, floating bed biofilm, Role: anoxic digestion	Size: 285 L, activated sludge Role: Sludge digester and anaerobic digestion
Membrane module	A3 flat-sheet modules. Surface area: 0.5-0.6 m ²	0.97 m ² Puron, external-submerged configuration	3 m ² Polymem, submerged-side stream configuration
Total HRT	7.2 hours	8.3 hours	8.7 hours

System I is the double-deck aerated biofilm reactor with external membrane filtration unit. The biofilm reactor had two biofilm chambers, each confined by a partially perforated sloping plate on the top of the chambers and a grid plate at the bottom. The K1 media as biofilm carrier were used. Two different designs of a flat-sheet membrane module were tested; i) standard module for AS-MBR, and ii) new module designed for the BF-MBR. The BF-MBR module had smaller gaps between the membrane surfaces which allowed higher superficial air velocities for fouling control. The configuration in the system II is the vertical biofilm reactor consisting of two chambers. The lower chamber is used for an aerobic digestion and the upper chamber is for anoxic digestion. The design of this configuration is aimed to make use of the excess energy in air flow used in the aerobic chamber to provide some mixing in the anoxic chamber. The excess sludge trapped at the bottom of the biofilm reactor and membrane tank were removed. The benefit of this design was to utilize the excess aeration energy for energy optimization. The configuration in system III is composed of aerobic moving-bed biofilm reactor and anaerobic sludge reactor. The supernatant from the anaerobic tank is pumped to the module. The sludge waste from the aerobic tank is digested

anaerobically and the amount of the sludge waste would be significantly reduced. SRT in the system III was approximately 45 days. Smaller space volume in the side-stream module can give some benefits such as i) higher shear rates and high bubble velocity for the fouling control, ii) large reduction of total amounts of chemical waste and cleaning membrane chemicals.

Results and discussion

For system 1, average TSS concentration in the biofilm reactor effluent was relatively low at 44.6 mg/L throughout the experimental period, which implies that the alternative biofilm reactor design was able to control the suspended solids. A filtration performance comparison was carried out between the A3-AS-MBR membrane module and the A3-BF-MBR module under permeate flux of 17.9 L/m².h and aeration of 32 L/min. The BF-MBR module with smaller gaps had lower fouling rates (slower increase in TMP), and the superficial air velocity in the BF-MBR module was approximately 50% higher than that in the AS-MBR module for the same aeration rate. Average rates of transmembrane pressure (TMP) increases over time (d(TMP)/dt) were 0.086 and 0.046 bar/day for the AS-MBR module and the BF-MBR module, respectively. The new BF-MBR module also occupied approximately 35% less space than the AS-MBR module. The experiment at flux of 12.93 L/m².h and aeration of 32 L/min over 3 weeks was performed for monitoring long-term membrane clogging problem. Linear increases in the TMP were found with the average d(TMP)/dt at 0.016 bar/day. No clogging was observed in the BF-MBR module during 3 weeks operation. Low SS condition had overcome the clogging problems in the membrane module which was often observed in the AS-MBR. For system II, the sludge traps provided a concentrated sludge with concentration of 15 g/L. The bubbling system in the unit of excess aeration energy recovery was able to drive the propellers with speed of about 55 rpm for the mixing in the anoxic chamber. The effect of membrane aeration on the fouling rates was tested at permeate flux of 20.95 L/m².h and aeration rates of 9.5 and 19 L/min. When the aeration rate was increased two times, the TMP rate was reduced 45%.

For system III, the experimental results show that the solids concentration of the sludge waste removed from the anaerobic tank was 26 g/L which was significantly higher than in system II. The effect of membrane aeration on membrane fouling rates was tested at 11 and 17 L/min with the permeate flux at 12 L/m².h. No solid accumulation or membrane clogging took place in the Polymem module. Fouling rates obtained from the system with the Puron module were significantly lower than those from the system with the Polymem module. The Puron module can be operated under lower aeration rates and higher permeate flux. At the superficial air velocity of 4.1 cm/s, the fouling rate from the Puron module was only 0.091 bar/day which was much lower than that from the Polymem module with the same aeration. However, major advantages of the Polymem module was on the membrane cleaning as a small internal volume can imply that the amount of cleaning chemicals and chemical waste from the cleaning are significantly lower than that of the Puron module. Total amount of chemical waste was experimentally found at 8 L for one cleaning activity for this 3 m² module, which was very low.

Conclusions

Three different process designs and configurations of BF-MBR were developed and experimentally evaluated for suspended solid control, energy optimization method, and sludge waste management. System I was configured by a double-deck aerated biofilm membrane bioreactor with sludge control. System II was configured by an aerobic moving biofilm - anoxic biofilm MBR with unit of excess aeration energy recovery. System III was configured by a two-stage aerobic moving biofilm - anaerobic activated sludge MBR. Systems II and III managed to control the suspended solid better than System I because of anoxic and anaerobic conditions integrated in the system. The TSS concentrations in the effluent from the biofilm reactor in Alternative II were lower than 30 mg/L. Problems of membrane clogging were not observed in the proposed BF-MBR systems. The effects of membrane aeration on membrane fouling rates were investigated at various superficial air velocities. System II showed a possible way to use an excess aeration energy in which the unit for the energy recovery was used for mixing in the anoxic chamber. System III managed to reduce amount of excess aerobic sludge from the aerobic biofilm reactor which may be a possible way to reduce a cost for sludge disposal.

MBR STANDARDISATION IN EUROPE: MARKET INTEREST, TECHNICAL POTENTIAL AND INITIATION OF FORMAL ACTIONS.

W. De Wilde^{a*}, A. Tazi-Pain^b, M. Richard^b, B. Lesjean^c, G. de Guedre

^a Research and Product Development Department, Aquafin; Dijkstraat 8, 2630 Aartselaar, Belgium; Tel. +32 (0)3 450-4841; Fax. +32 (0)3 458-3020; Email: wouter.dewilde@aquafin.be

^b Anjou Recherche, Chemin de la Digue, BP 76, 78603 Maisons-Lafitte, France

^c Berlin Centre of Competence for Water; Cicerostr. 24, 10709 Berlin, Germany,

*Corresponding author

Keywords: CEN workshop; Filtration systems; MBR; Membrane characterisation; Standardisation

Introduction

Today, the European municipal membrane bioreactor (MBR) market is very fragmented and exhibits many membrane characterization methods and MBR filtration products with diverse dimensions, capacities and operational modes. This situation without standardisation is a bottleneck in the selection of MBR technology and its broad application. In the context of the European funded STREP project AMEDEUS ('Accelerated Membrane Development for Urban Sewage purification') a research was performed to assess the market expectations and technical potential for standardisation.

Objectives

Based on an extensive survey of the MBR industry, a comprehensive analysis was performed of the market interests/expectations and technical potential of going through a standardisation process of MBR technology in Europe. The report of this study, the White Paper [1], is considered as a public discussion document on MBR standardisation in Europe. It should increase awareness and interest in the subject and, according to the outcome and in agreement with the European MBR industry, initiate a formal procedure of standardisation together with the CEN.

Materials & Methods

Due to the predominance of submerged filtration systems in municipal applications, the study has focused only on this configuration. Two different aspects of standardisation were considered:

- MBR filtration modules (standardisation towards interchangeable modules in MBRs)
- Characterisation methods for membrane acceptance, fouling, integrity and ageing (standardisation towards uniform quality assessment methods)

An extensive questionnaire on MBR standardisation was sent to the chief players on the European MBR market. These include companies, institutions, research institutes, ... with relevant MBR know-how and experience. In total, 80 companies and institutions active in all areas of the European MBR market were identified after a thorough market review and individually contacted. The response rate was spectacular and demonstrated the interest of the industry in this initiative: 45 contacts cooperated in this study. The questionnaire inquired about both the market expectations and technical potential of a standardisation effort. After collecting and processing the data, the results were written in a draft version of the White Paper. During an international workshop, this draft version was presented to MBR industry representatives. Their recommendations were added to the final version of the White Paper.

Results and discussion

Market interests and expectations

MBR filtration modules

The analysis of market interests and expectations for MBR filtration module standardisation indicates that there is a specific interest in guidelines or standards on interchangeable filtration modules in MBRs from both sides of the market. The majority of the MBR operators, constructors, consultants and knowledge institutions are convinced this is the right time to initiate a process of MBR module standardisation. On the other hand, some of the module suppliers think that initiating a module standardisation process now would be too early and would hamper the technological innovation in the field. Most market players expect that interchangeable MBR filtration modules will increase the willingness of decision makers to invest in MBR technology and will contribute to a growth of the municipal MBR market - although they do not believe this standardisation process to be one of the top three driving forces.

About twenty potential technological, financial, economical, or environmental advantages/opportunities and disadvantages/threats of MBR filtration module standardisation for suppliers and operators were identified and mapped. It appears that the number of advantages and disadvantages is quite balanced for both sides of the

market, the main advantage perceived by the industry being that standardisation should contribute to the growth of the MBR market. Main advantages/opportunities for the end-users are the reduction of dependency on one supplier, price decrease and increased trust and acceptance. Main disadvantages for the module supplier seem to be the higher competition, lower profit margins and a limitation for innovative module producers to enter the market. Main disadvantages/threats for the end-user are over-dimensioning of civil constructions and supplementary works and costs to the peripherals for module replacement.

Membrane characterisation methods

The market players mainly agree that it is time to initiate a process of standardisation for membrane characterisation tests. The majority of the MBR operators, consultants and knowledge institutions, except the plant constructors, believe that harmonisation of membrane acceptance tests at module delivery, will probably have a positive impact on municipal MBR market growth. The majority of the respondents feel that standard acceptance tests during plant commissioning can lead to an increase of MBR market growth. Module suppliers are ambiguous about a possible positive impact of standardised tests either at module delivery or during plant commissioning. While several advantages are mentioned, one real concern appears: the difficulty to find the right methods applicable to all types of membranes.

Technical potential

MBR filtration modules

The technical potential for standardisation of MBR filtration modules in Europe was evaluated based on a unique analysis and comparison of nine commercially available MBR filtration modules in Europe, completely different in terms of design and mode of operation. More than thirty technical factors hampering or interfering with a standardisation process were identified, quantified and compared for the surveyed modules, and their relative potential in hampering module-standardisation was evaluated. Four factors with a high to extremely high interference are mainly the result of a totally different geometry and dimensions of the filtration module. Discussions for the standardisation of MBR filtration systems should in essence focus on these factors. Sixteen factors with a moderate to high interference are mainly the result of the fact that either a number of products are still in the early development phase of their life cycle, or because they will (drastically) increase total costs of module replacement due to required adaptation works to the peripherals. Sixteen other factors with a low to moderate interference will only be a minor issue, for example because they are part of the common knowledge or practice. It was also revealed that it would be easier and technically wiser to consider two separate standardisation groups: one for flat sheet modules and one for hollow fiber modules.

Membrane characterisation methods

End-users and module suppliers were questioned on existing membrane fouling, ageing and deterioration measurements. The main operating techniques applied were assessed, and some parameters were identified for integration in a standardisation process. This study emphasizes some important parameters for which a common definition and measurement protocol can be helpful. Harmonisation of parameters definition and measurement methods could precede, or accompany the harmonisation of the technologies: this will encourage trust in the technology, and will also reduce the risk of lower quality. Establishing guidelines and characterisation protocols can be a second step in the standardisation process. The production of such common definitions and characterisation protocols can reply to a real need in the European MBR industry.

Recommendations by the industry

The outcomes of this study were presented to and discussed with representatives of the European MBR industry at a workshop organised together with the Centre Européen de Normalisation (CEN) in Berlin on 24/11/2006. 35 MBR representatives from 9 countries and 29 different companies accepted the White Paper by plebiscite as a reference document to initiate a procedure of standardisation within the MBR industry. A large majority of the companies argues that their company would be interested one way or another to commit/participate in a process of standardisation of submersed MBR filtration systems (75%) and membrane characterisation methods (90%) in the coming years. The representatives of the MBR industry present at this workshop decided to initiate a standardisation process on submerged MBR technology through a CEN Workshop Agreement (CWA).

Conclusion

The enormous reaction to this call for standardisation indicates the need and concern of the parties involved. With the reactions coming from operators, suppliers, plant constructors and academic experts, the White Paper can be considered as a representative discussion document concerning the standardisation of MBR technology.

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MAJOR ITEMS AND OUTCOMES OF THE CEN WORKSHOP AGREEMENT N° 34 ON SUBMERGED MEMBRANE BIOREACTOR (MBR) TECHNOLOGY

F.B. Frechen

Department of Sanitary and Environmental Engineering (DESEE), University of Kassel,
Kurt-Wolters-Str. 3, 34125 Kassel/Germany, frechen@uni-kassel.de

Keywords: submerged membrane bioreactors; CEN; interchangeability; wastewater pre-treatment

Introduction

As an outcome of a questionnaire held within the EU financed AMEDEUS project it was agreed by the majority of the participants that it is time now to move on towards standardization of MBR systems. However, it was decided as a first step to restrict activities to a CEN Workshop Agreement (CWA), which is a public discussed document but does not need formal approval by the CEN members. Instead, the final agreement of the workshop members is sufficient. It must be stressed upon here that a CWA is of pre-standardisation character and is not binding in any way.

Objectives

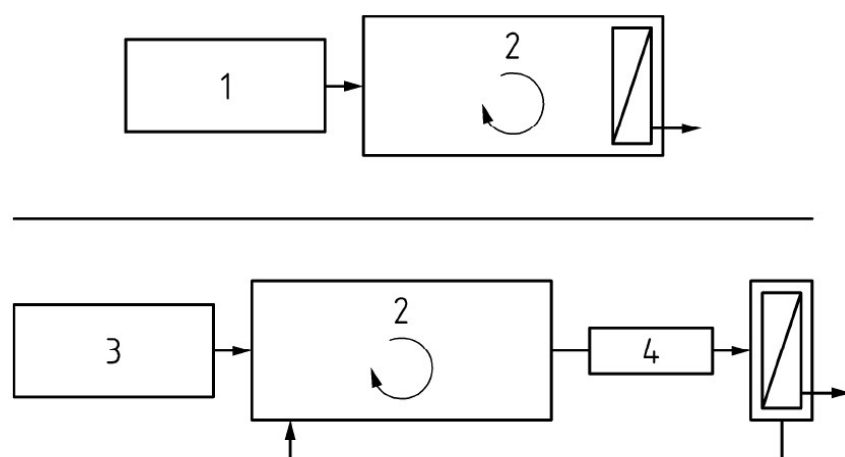
Main reason for the decision to undertake this activity was to accelerate the implementation and overall market growth of the MBR system as well as to increase acceptance of this high-tech process as the „best available technology“. The aim of this CWA document is to improve the basis for communication and understanding of MBR technology by increasing the comparability and transparency of products defining common terms and definitions, to increase the comparability and transparency of products and the end-user’s confidence in them by specifying acceptance and monitoring tests, to increase the end-user’s reinvestment opportunities and to decrease the MBR filtration module investment costs by specifying guidelines to facilitate interchangeability of MBR filtration systems.

Outcome of the Workshop

After several meetings of the task groups, the final text was agreed upon by the participants of the Workshop and issued under the date of 20th November 2008.

The document emphasizes on several topics including, but not restricted to General System Requirements, the membrane system itself (MBR Integrated System vs. MBR Separate System), wastewater pre-treatment, acceptance, commissioning and monitoring tests, necessary documentation and interchange ability issues and has one normative and four informative Appendixes.

Special attention was devoted to the prevention of membrane damage due to unsatisfying pre-treatment of the incoming wastewater, which was found to be a severe problem in early days of membrane installations. It was stressed upon that an advanced pre-treatment is a vital and essential part of any MBR plant, regardless of the type



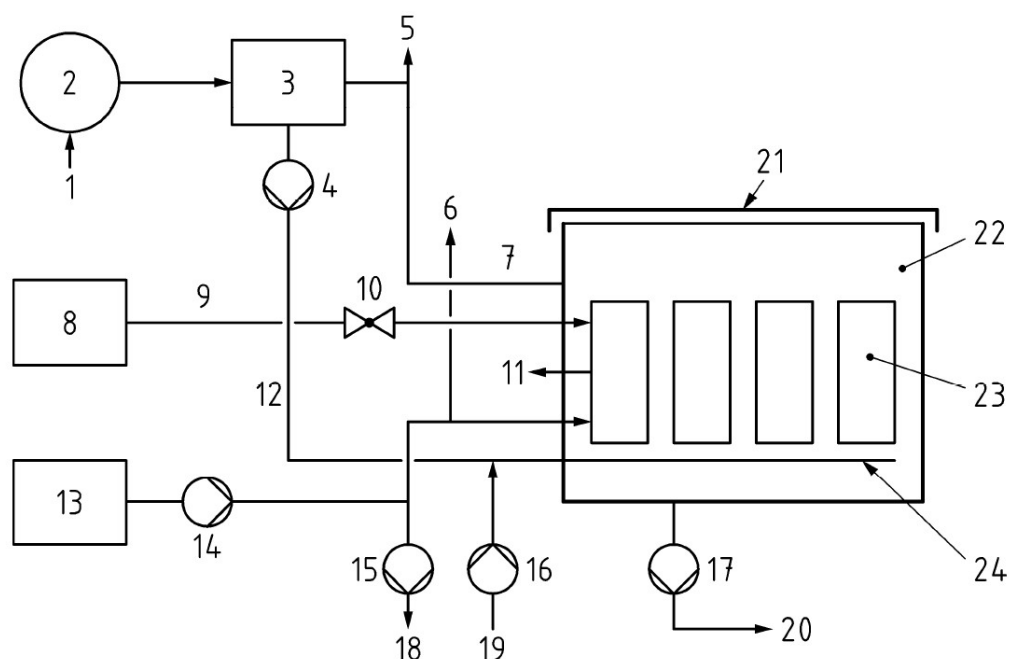
Key

- | | | | |
|---|------------------------|---|---------------------|
| 1 | advanced pre-treatment | 3 | conv. pre-treatment |
| 2 | Aeration tank | 4 | sieve |

Figure 1: Possible design of mechanical treatment

of membrane module. Alternatively, according to Schier et al. (2008), the design as shown in figure 1 is possible.

One more or less unexpected outcome was that interchangeability focussed on an interface quite far away from the membrane modules themselves, as can be seen from the Process Flow Diagram shown in figure 2.



Key

1	wastewater	13	chemicals
2	pre treatment	14	chemicals pump
3	AT	15	permeate pump
4	feed pump	16	effluent pump
5	process air release	17	drain pimp
6	air release	18	permeate
7	overflow	19	effluent
8	air compressor	20	activated sludge
9	process air	21	cover
10	process air valve	22	MT membrane tank
11	sample	23	modules
12	activated sludge	24	feed distribution pipe

Figure 2: Typical PFD MBR Separate System

As can be seen, the interface between the WWTP itself and the MBR part consists of merely 6 streams (air and water), leaving still a broad variety of MBR realizations themselves to the suppliers. This also induces that the membrane filtration tank is supplied as part of the membrane system. This philosophy surely does not fully regard integrated systems and thus a follow-up of the document, either as a second issue as CWA or as a document of a higher level concerning standardisation, will be valuable in the future.

However, this philosophy has the advantage of being a quite holistic approach, avoiding very restrictive regulations and thus allowing a broad diversity of membrane-specific and proprietary technical solutions and design.

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AN AERATION ENERGY MODEL FOR AN IMMERSSED MEMBRANE BIOREACTOR

Verrecht, B.* , Judd, S.* , Guglielmi, G.** , Brepols, C.*** , and Mulder, J.W.****

*Cranfield University, Beds. UK

**Trento University, Trento, Italy

***Ertverband, Germany

****Water Authority of Hollandse, the Netherlands

Keywords: aeration, energy, flat sheet, hollow fibre

Introduction

Together, membrane and biology aeration generally account for 60-70% of the total energy demand of an MBR (Judd, 2006). Reducing the energy demand in a conventional MBR thus relies on an understanding of the total aeration requirements of the process, and the balance between the aeration demanded by the membrane compared to that of the biology.

Methods

In this paper, a simple mathematical model is presented for MBR aeration and available data from two full-scale plant used for benchmarking. Benchmarking in this way produced a match to within 20% of all key process plant operational parameters. It is suggested that a key parameter representing membrane aeration in MBRs is the mean in-module air upflow velocity U , since this gives a reasonable representation of the shear applied through membrane aeration. U was found to vary between 0.04 and 0.1 m/s across a number of modern large pilot and full-scale plant.

Results and discussion

An analysis reveals that significant reductions in energy demand are attained through operating at lower MLSS levels and membrane fluxes. Evidence provided from recent controlled pilot trials (Guglielmi 2007, 2008) implies that halving the flux can reduce the aeration is suggested whereby the number of membrane tanks on line and/or the membrane aeration intensity is adjusted according to the flow, and thus flux, so as to reduce the overall aeration energy demand.

There are important implications of flux and SRT reduction. Reducing the flux commensurately increases the required membrane area and thus the capital cost. Decreasing the MLSS increases the sludge production, and can also increase the fouling propensity (Trussel et al, 2007). There is therefore a direct financial penalty for operating under more conservative conditions, unless the latent energy of the sludge can be recovered on site. On the other hand, there is a direct financial benefit to be gained through the adoption of a membrane aeration device and/or regime which (a) enhances oxygen transfer to increase its utilisation for aerobic treatment and/or (b) adjusts in intensity according to the hydraulic load.

Enhancing oxygen transfer may only be achievable through creating smaller air bubbles which would then be to the detriment of membrane scouring. Adjusting the intensity of aeration, however, would appear to be more viable. Flows through sewage treatment works vary significantly both diurnally and seasonally, yet the current practice is to provide membrane and membrane aeration capacity for the highest flows and, generally, provide little buffering capacity. A rudimentary analysis using, assuming a reasonable conservative flux:aeration relationship of based on full-scale observations reveals that the energy demand can be reduced by around 20% if the membrane aeration is applied proportional to the flow and the latter is at half the plant capacity for half of the time. This figure increases as the sewage strength decreases. A protocol can thus be envisaged whereby the number of membrane tanks in line and/or the membrane aeration intensity (in effect the number of blowers in service) can be adjusted according to the flow.

Figure 1 demonstrates that the impact of the increased biological aeration demand at longer HRTs due to endogenous respiration is countered by the decrease in membrane aeration demand at the lower SAD_m values required at lower fluxes incurred. Thus, a decrease in specific membrane energy demand could be expected if membrane aeration can be adjusted according to the feed flow rate and the blower energy demand decreased proportionately. Overall, the change in total aeration energy demand with HRT is negligible .

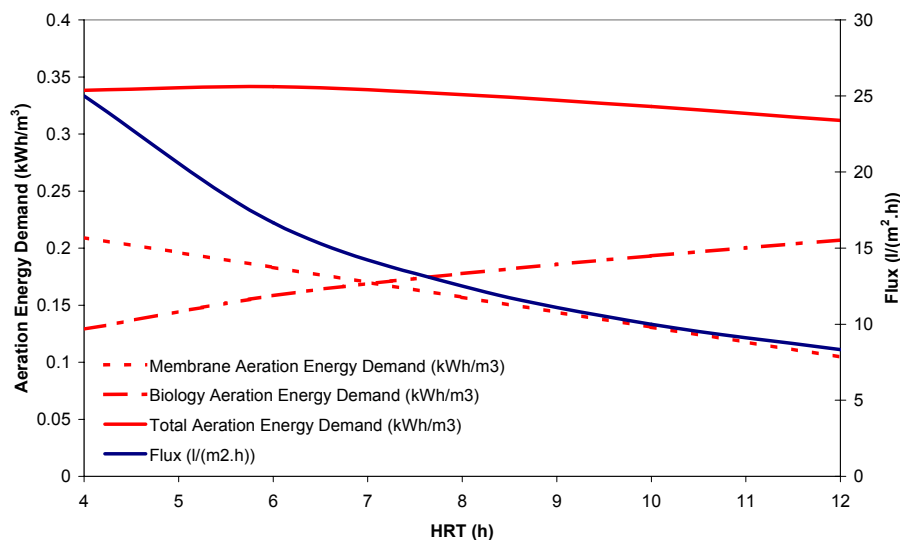


Fig 1: Projected aeration energy demand with HRT for Hollow Fibre modules: Contribution from predicted Membrane and Biological aeration energy demand to Total Aeration Energy Demand

Conclusions

The model demonstrated that significant reductions in aeration energy could be obtained through operation at lower flux and reducing the membrane aeration requirement accordingly, so-called “proportional aeration” at lower flows. Similarly, increasing oxygen transfer from membrane aeration would also be expected to decrease energy demand. A sensitivity analysis of some of the key parameters revealed that, of the key operating parameters, loading, SOTE and MLSS concentration remain the most critical in determining energy demand.

Acknowledgements

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POTENTIAL FOR MBR APPLICATIONS FOR WASTEWATER TREATMENT IN THE MIDDLE EAST AND NORTH AFRICAN REGION

Murad J. Bino *, Shihab N. Al-Beiruti **, Matthew Wade ***

* Executive Director of the Inter-Islamic Network on Water Resources Development and Management (INWRDAM), muradinw@nic.net.jo

** Head of Services and Programs Section, INWRDAM, shihabinw@nic.net.jo

***Puratreat project coordinator, mwade@tz-bremerhaven.de

Keywords: WWTP, MBR, reuse, wastewater, feasibility

Introduction

The MENA region is defined by the World Bank as consisting of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, United Arab Emirates, West Bank and Gaza and Yemen. The population of the MENA is now more than 300 million and average per capita renewable water resources in the region, which in 1950 were 4,000 m³ per year, are currently 1,100 m³ per year. Projections indicate that they will drop by half, reaching 550 m³ per person per year in 2050. This compares to a global average of 8,900 m³ per person per year today and about 6,000 m³ per person per year in 2050, when the world's population will reach more than 9 billion (World Bank, 2007) and, if climate change affects weather and precipitation patterns as predicted, the MENA region may see more frequent and severe droughts and floods.

Treated wastewater reuse can contribute to large savings in water sources. It can be considered as an important water resource especially in urban and peri urban areas. Drinking water quality is not required for all kinds of reuse kinds of use such as toilet flushing and landscape irrigation. Membrane bioreactors (MBR) are gaining popularity for greywater and sewage treatment due to the low footprint compared to conventional treatment processes and can produce high quality effluents without disinfection (Rosenberger, 2002).

Objectives

MENA region is facing continued decline of per capita water availability due to high population growth rates that demand extra water for food production and due to improved living standards, industrialization. Many attempts to improve water management and increase efficiency and water use by all sectors is being made in the region. Reuse of treated wastewater for irrigation and other non potable uses is considered as priority for all MENA countries. This is reflected in water policies and strategies of many countries such as Jordan, Egypt, Yemen and Palestine. These policies encourage the involvement of the private sector in the wastewater treatment since national governments are unable to carry the financial and technical burdens of expanding sewerage services to the population.

Cost of sewer services are now priced in many MENA countries as 30% of value of the water bill of households and at 100% of water bill for commercial users. This results in good incentive for private sector to invest in construction of wastewater treatment plants. Water authorities consider quality of treated water as main concern because higher quality treated wastewater provides more opportunities for water demand management and saves scarce fresh water. In this regard, MBR based wastewater treatment technologies has an edge with respect to quality of effluents produced compared to most other available wastewater treatment technologies.

The aim of the paper is to discuss and present Puratreat project findings with regards to feasibility of a full scale decentralized packaged MBR wastewater treatment plant for peri urban areas in MENA countries. The paper will present case of benefit cost analysis of practical situation of a MBR plant installation in Samoa Village in Jordan with estimated population equivalent of 500 and moderately strong sewage characteristics as an adaptive measure to water scarcity situation relevant to MENA region.

Materials & Methods

A summary of Puratreat findings with respect to sanitation services requirements in Jordan indicate that about 40% of the population are not connected to sewer systems and these rely on local facilities for wastewater disposal mainly on-site sanitation management systems. When the need arises to empty these systems septage tankers transport their wastewater to municipal wastewater treatment plants and other disposal sites. According to the National Water Master Plan of Jordan, it is expected that the nationwide connection rate to sanitary sewer system will increase to about 69% by 2020.

A peri urban community in Jordan was selected as a possible site for installation of an MBR based sewage treatment plant. housed in a prefabricated container. Data relevant to community sewage disposal and reuse of treated wastewater was conducted. Estimation of costs and benefits of sewerage treatment and sale of sewerage connection and sale of treated wastewater for irrigation and sale of sludge as fertilizer were conducted. The B/C ratio was estimated based on present worth value of 20 years project life.

Results and discussion

The present worth value formula was used to estimate the present value of costs and benefits of the MBR. The equivalent present worth value of the total costs of the MBR plant for treatment of wastewater from 500 population equivalents was found to be US\$207,500 and the equivalent present worth of benefits over 20 years of MBR plant operation was estimated to be US\$245,500. Thus, the B/C for the MBR plant will be 1.18. This means that for each dollar invested in the construction and operation of the MBR plant, 1.18 dollars will be accrued as profits.

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POTENTIAL AND IMPLEMENTATION OF FULL-SCALE DUAL (HYBRID) MBR-CAS CONCEPTS IN NEWLY ACCESSED COUNTRIES

D. Bixio^a, L. Maes^{a*}, W. De Wilde^a, J. Deurinck^a, C. Thoeye^a, G. De Gueldre^a

^a Research and Product Development Department, Aquafin; Dijkstraat 8, 2630 Aartselaar, Belgium; Tel. +32 (0)3 450-4126; Fax. +32 (0)3 458-3020; Email: lucas.maes@aquafin.be

*Corresponding author

Keywords: MBR, hybrid, dual, full-scale

Introduction

Transposition of the Water Framework Directive into national legislation is a difficult challenge to be tackled by newly accessed EU countries in the coming decade. Actions taken to meet the European standards will implicate thorough changes of the existing wastewater treatment policy and infrastructure in these countries. Adequate refurbishment techniques which combine high quality effluent and a minimal cost can facilitate this process. Hybrid (Dual) forms of conventional activated sludge (CAS) and membrane bioreactor (MBR) technologies yield a high quality effluent and are more cost-efficient than classic MBR technology. The Aquafin team has dedicated a lot of effort to assess the technical feasibility of two hybrid technologies: Dual 1 and Dual 2®. The results of these efforts and further technical details about these process schemes can be found in Deliverables 52, 53 (Dual 1) and Deliverable 54 (Dual 2®). In this part of the research, a detailed description of the state of the wastewater treatment in the different newly accessed EU countries is given. Secondly, a rough assessment of the market potential of different refurbishment scenarios is assessed. Finally, a tailor made refurbishment plan is made for an existing plant. This analysis is meant to give a better view of the economic potential of the abovementioned Dual technologies.

Objectives

The aim of this research is to determine the conditions in which MBR Dual technology can be an economically feasible option for WWTP refurbishment in newly accessed EU countries.

Materials & Methods

The elaboration of the work is carried out in 3 stages: an inception stage, a strategic screening stage and a detailed scenario analysis for a specific case study.

In the inception stage, the Aquafin team defined both the scope of the evaluation and the key assumptions, based on a literature review on the status of implementation and typical infrastructure of municipal wastewater treatment. These review results are reported in *Deliverable 55*.

The strategic screening analysis stage evaluated cost implications for the most common WWTP upgrading scenarios with the Aquafin CIS-software. The territorial reference framework of Bulgaria and Cyprus are taken as an illustration, as these markets lie at the extremes of the application spectrum: Bulgaria matches the minimum requirements, while Cyprus has the strictest compliance requirements, as known from *Deliverable 55*. CIS is a dedicated, in-house developed Cost Integrated Sizing software, where several design options can be compared and optimized. An imaginary biologically overloaded plant of approximately 11000 p.e. was considered and refurbished after Bulgarian standards (introduction of nutrient removal) and Cypriot standards (inclusion of tertiary treatment to reach water reclamation and reuse standards), using different technologies: classic CAS retrofitting, classic MBR retrofitting, Dual 1 and Dual 2® refurbishment. As a form of sensitivity analysis, optimistic and pessimistic parameter-values were considered and compared to the baseline scenario. The result of this analysis is reported in *Deliverable 56*.

Finally, a tailor-made analysis of refurbishment options for a specific WWTP in a EU newly accessed country is performed. The elected plant was located in Veliko Tarnovo, Bulgaria. The analysis encloses 3 phases. At first, specific data about the receiving waterbody, the agglomeration, the state of the existing treatment facilities etc. are collected and summarized in an inception report. Based on these data, different refurbishment scenarios are constructed by means of the CIS software. Considering the CIS output, constructional constraints etc., the optimal scenario is being selected after consultation of the local parties. This optimal scenario is then further elaborated in a technical plan of the renovation. The results of these three stages are summarized in *Deliverable 57*.

Results and discussion

The literature review reveals that MBR technology can be relevant in the following areas, which should be given primary consideration:

- Areas with severe water stress where wastewater treatment is not only envisaged for meeting environmental targets but it can also serve as an asset to increase the reliability of the water supply

through appropriate reclamation and reuse. These areas are mainly the Mediterranean coastal areas and islands and the coastal areas on the Black sea.

- Wealthier areas with specific geographical properties such as for instance ski resorts, where features such as the seasonal extremes in climate and population, the low footprint for plant upgrading and the cost of the ground provide definite competitive advantages to plant upgrading scenarios based on MBR technology. These areas are situated mainly in Slovenia, but also in some developing areas of Slovak republic, Macedonia, Bulgaria, ...
- Sensitive areas to eutrophication in highly urbanised environments (mainly: in the Danube, the Elbe and the Baltic region), and particularly those areas with legislation requirements about wastewater treatment exceeding those laid down in the EC Directives (e.g. the Baltic states and Cyprus).

Within each of those areas, the plant upgrading potential is very diverse mainly because of the large differences existing from country to country, especially regarding the level of wastewater treatment and the timing of the investment cycles. The dominant technology present in the newly EU accessed countries is activated sludge.

The CAS refurbishment scenario had the highest market potential in a Bulgarian context. The net present value of Dual 1 and Dual 2® refurbishment options were respectively 20 and 25 % higher. Classic MBR retrofitting was found to be 50 % more expensive. In the Cypriot context, where water reclamation standards have to be met, MBR alternatives become financially more attractive. Here the MBR alternatives yield 8 % (classic MBR retrofitting) to 24 % (Dual 2®) less extra costs. Key determinants at the planning level are the assumptions on the replacement costs, the energy consumption and the economies of scale. Also, the choice of conservative/less conservative parameter values can alter the results significantly.

After the phase of data collection, the actual state of the WWTP in Veliko Tarnovo, Bulgaria could be assessed together with the bottle-necks that need extra attention during refurbishment. The plant discharges into the Yantra river, which has been designated as a sensitive stream by the European Union. Therefore the need of adequate nutrient removal is high. The main part of the infrastructure dates from 1983. Although some minor renovation efforts were done in the past, a lot of compartments of the treatment process are in need of renovation/reconstruction. Momentarily, the plant is both hydraulically and biologically overloaded. Besides, future influent estimations foresee a rise in influent load, partially because of a renovation of the sewer system in the near future. In all scenarios, the construction of an anaerobic tank for biological phosphate removal and the reconstruction of the aeration basins were found necessary. As expected, the full MBR retrofitting scenario is found to be the most expensive option, because of high investment and operational costs. The investment cost of both dual scenarios comes closer to the cost associated with a conventional CAS retrofitting scenario.

Conclusions

The efforts that have to be done by the newly accessed EU countries to meet the European wastewater treatment standards, create a big market potential for cost-efficient retrofitting technologies. Dual WWTP refurbishment scenarios yield a better effluent quality than conventional CAS technology and are more cost-efficient than full MBR retrofitting scenarios. The market potential of the dual technology increases when more stringent effluent norms or guidelines concerning water reuse are imposed.

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ECONOMIC ASPECTS OF LARGE SCALE MEMBRANE BIOREACTORS

Christoph Brepols, Heinrich Schäfer, Norbert Engelhardt
 Erftverband, Am Erftverband 6, 50126 Bergheim / Erft, Germany, christoph.brepols@erftverband.de

Keywords: investment, energy consumption, operation, membrane lifetime

Introduction

As a water association under public law the Erftverband pursues innovative and integrative approaches towards water related issues in three key operational areas: water supply management; maintenance of surface waters; and treatment of wastewater.

The Erft river, after which the association is named mounds into the river Rhine northwest of Cologne. The Erftverband regionally owns and operates 44 municipal wastewater treatment plants (WWTP) with a total capacity of 1.06 million population equivalents (PE). Many of these plants employ tertiary treatment to meet stringent discharge criteria. The increasing investment cost for wastewater treatment spurred the companies interest in innovative technologies.

Objectives

Since 1999 the Erftverband has commissioned three full scale membrane bioreactor (MBR) plants (see table 1). Actual investment and operational expenses are compared to that of conventional activated sludge (CAS) plants. Practical experiences of design, construction and operation of the plants are described. An example of a cost comparison between a MBR plant and a CAS plant with additional treatment is given.

Table 1. Main technical data of the Erftverband's MBRs

	Rödingen, 3,000 PE	Glessen, 9,000 PE	Nordkanal, 80,000 PE
Commissioned	1999	2008	2004
Dry-/ rain weather inflow	300 / 3200 m ³ /d	2000 / 6500 m ³ /d	12000 / 45000 m ³ /d
Bioreactor	400 m ³ + 80 m ³ (filtration tanks)	1,600 m ³ + 320 m ³ (filtration tanks)	9,300 m ³
Membrane	5,280 m ² hollow fibre modules, separate filtration units	12,100 m ² hollow fibre modules, separate filtration units	84,480 m ² hollow fibre modules, integrated filtration
Effluent requirements	COD < 30 mg/L NH ₄ -N < 4 mg/L P _{tot} < 1.5 mg/L	COD < 30 mg/L NH ₄ -N < 1.5 mg/L P _{tot} < 0.6 mg/L	COD < 90 mg/L NH ₄ -N < 10 mg/L P _{tot} < 1.5 mg/L

Investment Cost

On average the investment cost of an MBR can be comparably lower than that of a conventional activated sludge (CAS) plant with additional treatment steps. Figure 1 shows the actual specific investment cost of 26 municipal WWTPs the Erftverband has commissioned during the years 1989 to 2008.

MBRs show a trade-off between constructional cost and the cost for mechanical and electrical equipment that is mainly driven by the membrane cost and the more complicated process control. The example in table 2 shows a significantly higher share for mechanical and electrical equipment for the MBR. The investment cost of the CAS in this example include an additional sand filtration and a disinfection step. The footprint of the MBR is 50% lower than of the CAS.

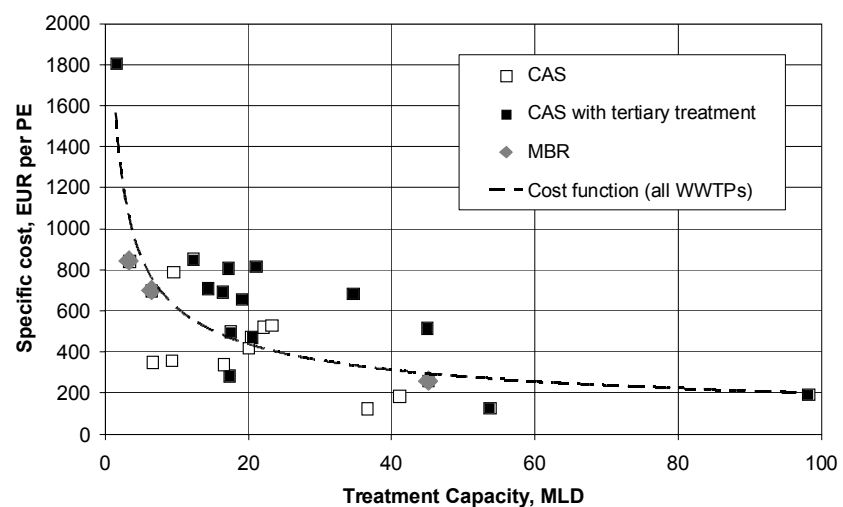


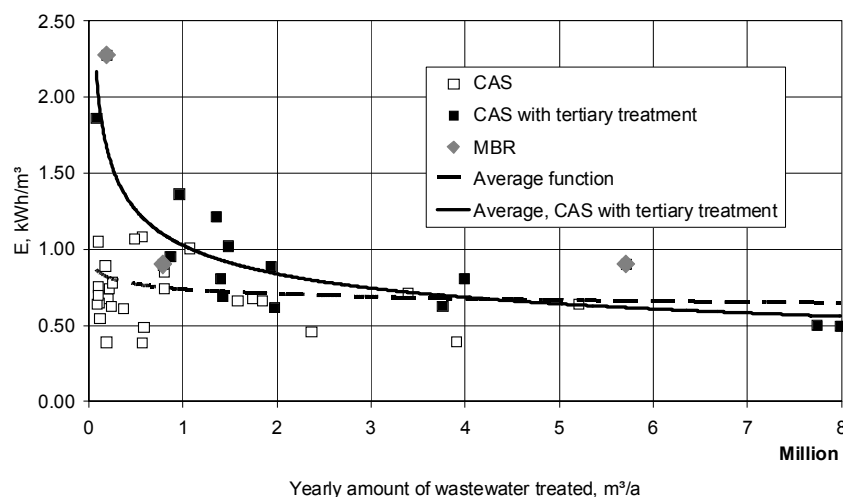
Figure 1: Specific investment cost for municipal WWTPs in the Erftverband association area

Table 2: Example of the investment cost structure of CAS with additional treatment and MBR

	Construction	Mechanical equipment	Electrical equipment	Membranes
CAS	63%	28%	9%	-
MBR	46%	31%	13%	10%

Operational Cost

A MBRs energy consumption is often higher than that of comparable a CAS plant. Figure 2 shows the energy demand of the Ertverband's WWTPs including the MBRs. Energy cost add up to approximately 30 % of the operational cost. Other main cost factors like personnel and sludge disposal are similar to conventional technologies. The cost for membrane cleaning chemicals contributes only to less than 3 % of operational expenses. Nevertheless membrane cleaning is important for the success of long-term operation. (Brepols et al., 2008)


Figure 2: Specific energy demand per cubic metre wastewater treated

wastewater pre-treatment and proper plant design and operation. These efforts should aim at reducing the effects of clogging and sludging of membrane modules. The end of the membrane lifetime may be indicated by mechanical failures of the membranes or of the module construction or an unrecoverable loss in permeability. The specific reasons for replacing the membranes need to be assessed individually. De Wilde et al. (2007) have projected a possible lifetime of 13 years. At the Rödigen MBR a membrane lifetime of eight years was reached even under unfavourable conditions. A change of the module type or the membrane supplier is likely to trigger additional changes in the plants peripheral equipment.

The example of a MBR for 10,000 PE compared to a similar CAS with additional treatment by sand-filtration and a UV disinfection shows that the break even point for the discounted present values of the two options comes at a membrane lifetime of seven years.

Conclusions

The life cycle cost for MBR plants can be competitive against CAS plants for municipal wastewater treatment as soon as the conventional technology is upgraded by means to achieve a similar effluent quality. Due to the lower property demand and the possible savings in construction the initial investment for the MBR can be equal or less to that of the CAS. The keys to long term economic efficiency then are (a) increasing the energy efficiency, (b) maintaining a sufficient membrane lifetime and (c) limiting membrane replacement cost.

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Membrane lifetime and reinvestment

Membrane lifetime and the required reinvestment strongly influence the life-cycle-cost of an MBR. Membrane lifetime can be prolonged by a sufficient

THE EUROPEAN MBR MARKET: SPECIFICITIES AND FUTURE TRENDS.

E. Huisjes¹, K. Colombel² and B. Lesjean
 Berlin Centre of Competence for Water
 Cicerostrasse 24, 10709 Berlin Germany
 boris.lesjean@kompetenz-wasser.de

Keywords: MBR, market, municipal, industrial, Europe, Middle-East

Introduction

Within the FP6 Amedeus project, the Berlin Centre of Competence for Water performed a market survey of the MBR technology in Europe and Middle-East by the end of the year 2005, complemented 3 years later to observe the evolution and trends of the market.

Objectives

The market study was thought to compile an exhaustive and detailed database of all MBR units constructed in order to provide a snap-shot of the market with regards to the countries, to the installed capacity, and to the different MBR technologies commercially available. The complete inventory of all MBR plants with an installed capacity greater than 20 m³/d for industrial applications and 100 m³/d for municipal applications (i.e. roughly > 500 p.e.) was performed (Lesjean et al., 2008a). In addition, a more detailed study on the 37 MBR plants built up by the end of the year 2008 with a capacity greater than 5,000 m³/d was carried out (Lesjean et al., 2008b).

Materials & Methods

The market study was performed while contacting all companies supplying MBR modules in the European and Middle-East market, and the market analysis was performed only with this “product source” perspective; i.e. the other contributors in the overall MBR market were not accounted for.

Results and discussion

The main results of the MBR market survey are as follows:

- By the end of the year 2008, about 800 MBR plants of the considered size were commissioned in Europe, of which 566 were built up for industrial applications and 229 for municipal applications (Fig. 1), for a total installed capacity reaching in 2008 the threshold of 1,000 MLD. The wastewater of about 2 millions of citizen is handled by MBR treatment, i.e. about 0.5% of the European population.
- The annual market volume has been steady in the past 5 years for the industrial sector with about 65 new references per year, demonstrating the maturity of the MBR technology for the industrial market. In contrary, the municipal market really kicked off in 2002 with an increasing volume since: 30 new references per year were inventoried in the years 2004-2005, and 45 in the years 2007-2008, highlighting that the market has not reached full maturity yet.
- The size of municipal MBR units is about one order of magnitude greater than the size of systems for industrial applications (Fig. 2): the core 60% of the industrial MBR references (20-80% cumulated repartition) are in the range 60-600 m³/d, whereas the equivalent range for municipal applications lies within 200-5,000 m³/d (i.e. about 1,000 to 20,000 p.e.), without any significant evolution of the size repartition in the last decade.

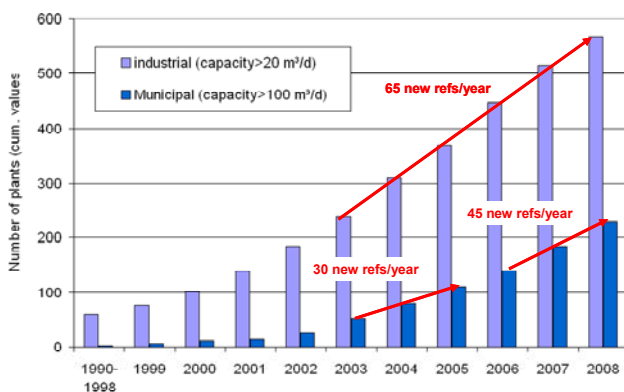


Figure 1: Evolution of MBR market in Europe

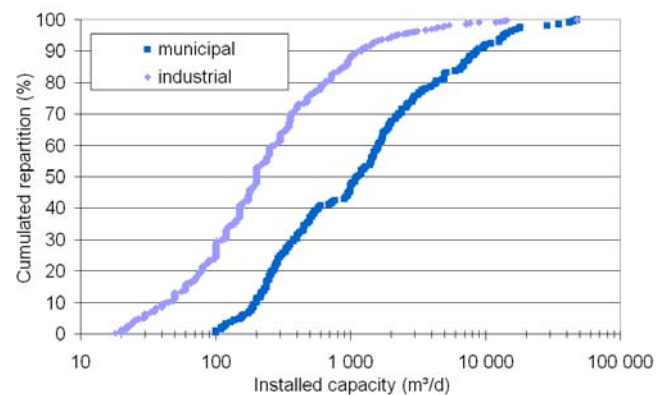


Figure 2: Capacity distribution of European MBR plants

- Consequently, the municipal sector drives the MBR market in terms of capacity and installed membrane surface: if the municipal market represented already approximately 2/3 of the total installed capacity in 2004-

¹ Now in Technology University, Delft, The Netherlands

² Now in UTC, Compiègne, France

2005, it covered about 3/4 of the market in the years 2007-2008. The eleven larger municipal MBR plants (> 5 MLD) which were commissioned during this same period contributed to more than half of the total installed capacity across the entire market.

- The countries leading the European MBR market in terms of reference numbers are Italy, Germany, United Kingdom, Spain, France and The Netherlands, the most dynamic countries being currently Spain followed by Italy who have together doubled their parks of MBR units in the past 3 years, in particular through the sudden development of water reuse projects (Fig. 3).
- The MBR technology is also a competitive technology for upgrade or refurbishment of existing wastewater treatment plants: one third of the municipal applications, whatever the considered size, refer to retrofitting project using existing infrastructure.
- Key industrial applications are food industry, landfill leachate, cleaning / textile / laundry wastewater, and wastewater treatment aboard ships. The larger industrial applications are found in the petrochemical sector and also for processing of water from sludge treatment.
- The Middle-East market showed a step increase in the last 2 years with 44 new plants (from a total of 66 inventoried by the end of 2008). It is characterised by an extreme concentration on the municipal market with the construction of very large plants: as example, when commissioned in 2009, the plant of Jumeirah Golf Estates (United Arab Emirates), will be the larger MBR plant worldwide with a total installed capacity of 269,000 m³/d.

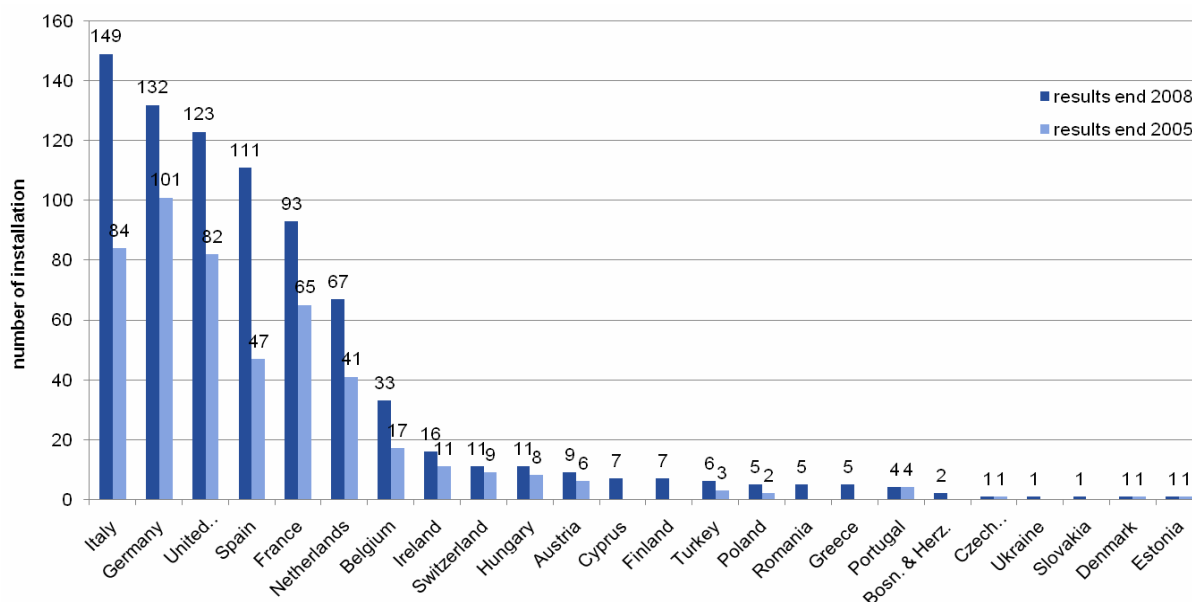


Figure 3: Geographical distribution of MBR market in Europe

Conclusions

Since the development of the submerged MBR technology, and its commercial deployment in the first years of the new millennium, the European MBR market has witnessed a growth rate greater than 10% per annum. This growth was driven essentially by the municipal sector, and in particular by the construction of the larger plants with an installed capacity above 5,000 m³/d. In contrast, the industrial market is very mature and competitive, and exhibits a constant market volume with about 65 new plants being constructed per year in the past 5 years.

The MBR technology is now a cost competitive option for industrial wastewater treatment, or for municipal projects with exceptional specifications such as enhanced water quality (for bathing water, water reuse), reduced footprint or upgrade of existing plants. Following the observed trend in countries such as Spain, Italy, or Cypress, the technology is expected to be embraced in the coming years by new countries facing water-scarcity such as Greece, Croatia, Turkey etc.

Acknowledgment

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SUBMERGED MBR TECHNOLOGY: AN UNFINISHED INTERNATIONAL ADVENTURE OF 20 YEARS

Kazuo YAMAMOTO

Environmental Science Center, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, yamamoto@esc.u-tokyo.ac.jp

Keywords: Membrane Bioreactor, submerged MBR, next generation MBR

Introduction

Vulnerability of water on the earth is becoming more serious due to the global climate change. Water reclamation is one of the most promising countermeasures reducing the vulnerability on the condition that it is recognized as safe and secure by the public and also cost and energy effective. Any technology must contribute to the sustainability of our society from the viewpoints of low-carbon oriented, material-cycle oriented and ecological oriented.

MBR (membrane bioreactor) is a hybrid wastewater treatment process in nature, i.e. a physico-biological combination. The membrane gives a physical barrier for hygienically safe and clean water with the help of microbial-ecological treatment that can achieve good public perception. It is also well recognized by experts that the clear membrane permeate gives post-treatment easy, then a variety of hybrid systems composing of MBR can be considered depending on various needs of the reclaimed water. These advantages make the MBR as a good device in water reclamation and/or advanced wastewater treatment systems. However, judging from the aforementioned criteria, there is still much room for improvement in order to fully use of the potential of the MBR. Adventure of research and development of MBR technologies remains unfinished.

Before birth of submerged MBR

The original terminology of Membrane Bioreactor (MBR) used to show that a membrane device itself acts as a biological reactor, where enzymes or biological cells are fixed, for example. Although this is still an adventure to develop a mimetic biological membrane process for a real world, the first MBR technology that was successfully realised in wastewater treatment is a side-stream MBR where polymeric membrane was used as a solid-liquid separation device replacing a final sedimentation tank of an activated sludge process. Ultrafiltration membrane (UF) of MWCO (molecular weight cut-off) of tens of thousand was usually used. A complete oxidation process was aimed and applied to a small-scale on-site wastewater treatment in the United States in 1960's. It was pointed that the membrane could keep a high MLSS (mixed liquor suspended solids) concentration making a process compact together with a long SRT (Solids Retention Time) operation, thus resulting in negligibly small excess sludge wastage. This type of MBR was introduced as a wastewater reclamation process, since then there are many applications for building water reuse in big cities in Japan. It is noted that the cost-saving by reduction in water consumption was larger than the cost of wastewater reclamation especially for a large consumer due to a step-wise increase tariff for water and wastewater.

The higher MLSS makes the more compact process. This is advantageous to treat a high-strength wastewater. For example, the two-step MBR process was developed and applied for night soil treatment, where the organic and nitrogen removal was achieved in the first step and the phosphorus and colour removal was done in the second step. Because the oxygen supply limits the maximum MLSS in aerobic MBR, anaerobic MBRs were also developed and practically applied in South Africa. It is also worthwhile to mention that the Ministry of International Trade and Industry (MITI), Japan launched a six year R&D project named "Aqua-Renaissance '90" in 1985 with the particular objective to develop energy-saving and smaller foot-print water treatment processes utilizing side stream anaerobic MBR to produce reusable water from industrial wastewater and sewage. However, a high crossflow velocity and frequent physicochemical cleaning was required to maintain the performance of such a high rate MBR. It was difficult to significantly reduce energy consumption by adopting the side stream operation using a big recirculation pump. Nevertheless the anaerobic MBRs are still on the list of the unfinished international adventures.

Submerged, why?

In order to reduce energy consumption, which was 3 – 5 kWh/m³ of the filtrate of typical side stream MBRs applied to building water reuse system, the elimination of the recirculation pump was worth thinking. This led to the idea of submerged MBR where hollow fiber module was directly immersed in an aeration tank and a suction pump was used to get filtrate. After several unsuccessful trials including use of rigid fibers a prototype submerged module using soft hollow fibers had been tried by the author in laboratory scale experiments in 1985. This finally gave the findings of the feasible operation of a low pressure operation and intermittent filtration. Aeration was utilized both biological reaction and air scrubbing of the fibers. However, this was just a fundamental research that had shown the concept and potential feasibility of submerged MBR. We needed to wait R&D by MBR industries to make the submerged MBR practically applied.

20 years international progress in submerged MBR

Last 20 years, R&D of submerged MBRs made a significant progress utilizing both flat sheet type and hollow fiber type module by the MBR industries, research institutes and universities in Europe, North America, Australia, and Asia (especially China, Korea, Singapore, Taiwan, Thailand, and Japan). Their application becomes wider and wider from municipal wastewater to a variety of industrial wastewaters as well as surface waters, and larger and larger from household on-site treatment in the order of magnitude of 1 m³/d to large-scale municipal wastewater treatment in the order of magnitude of 100,000 m³/d. The achievements of the present submerged MBR technologies will be summarized in this lecture. It is noted that a recent remarkable progress has been done by the EU projects including the MBR Network.

Unfinished adventure, challenges for next generation of MBR

As mentioned earlier, advanced treatment is a key for water reclamation. However, it is necessary to change the concept of 'advanced wastewater treatment' in the context of sustainable water system, i.e., the advanced treatment must compose of a coupling technology of water production of required quality and material conversion from waste. Required quality does not always mean 'high quality'. The quality comes from necessity. Membrane technology has potential to be an on-demand quality distributor just by separation. The conversion mainly comes from biological reaction in MBR. Three types of advanced wastewater treatment are classified into energy saving (or productive), material productive, and ecological oriented, depending on the weights for three aspects of sustainable society, i.e. low carbon society, sound material cycle society and ecological society. The MBR technology might match more in the first two. Together with the new definition of 'Advanced Treatment', the change of the concept will be proposed from 'organic wastewater treatment' to 'water/biomass production' by developing next generation of MBR where the membrane act as a separator of water and biomass. Some examples of advanced MBR systems are illustrated in Figs. 1 and 2.

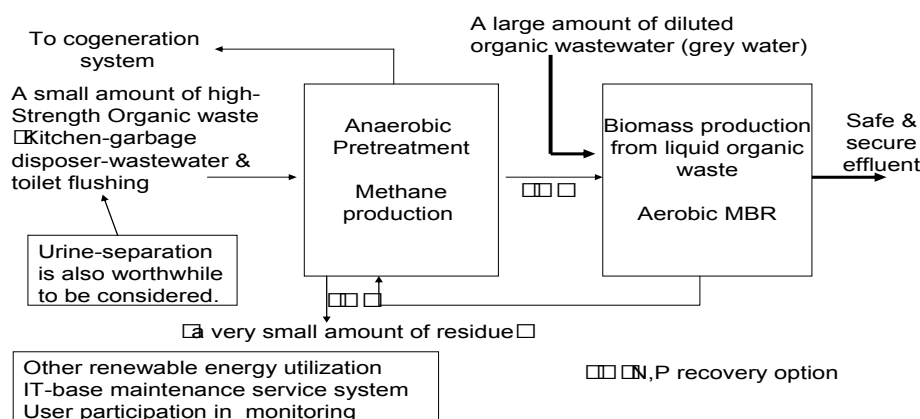
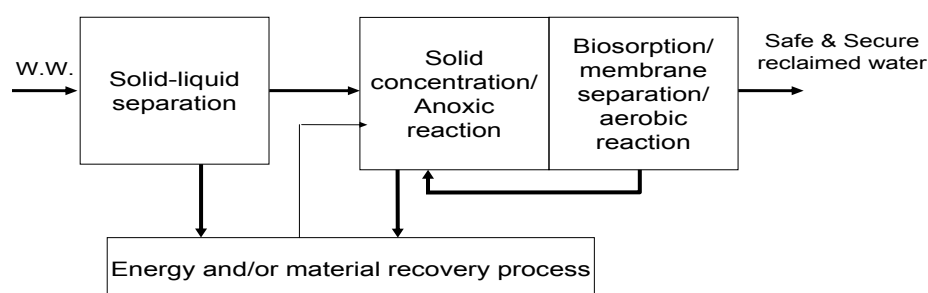


Fig.1 An example of anaerobic combination for on-site advanced MBR



Other than biogas production, physicochemical treatments are also candidates for energy recovery, e.g., supercritical water gasification of sludge-water mixture where the biomass sludge is utilized as energy source to produce hydrogen from water molecules (coupling clean energy production).

Fig.2 Another example of Advanced MBR (Renovation of existing wastewater treatment plants)

PERFORMANCE ASSESSMENT OF MBR APPLICATIONS FOR METROPOLITAN WASTEWATER TREATMENT IN THE UNITED ARAB EMIRATES

Raafat Alnaizy*, Vikrant Sarin**

*Chemical Engineering Department, American University of Sharjah, PO Box 26666, Sharjah, UAE; Tel. (971) 6-515-2710; Fax (971) 6-515-2979; email: ralnaizy@aus.edu

**Huber Technology Middle East

Extended Abstract

With growing nations, the demand for a better and more efficient treatment of domestic wastewater is growing inexorably. In addition, there is always a need of new treatment options, which guarantee very stringent standards but that combine low energy consumption, low maintenance and management costs, low environmental impact, and that, should not imply higher capital costs than conventional treatment options. Hence, new and innovative technology for more efficient and effective treatment of raw municipal wastewater is always desired. One of these new and emerging technologies is membrane microfiltration or ultra filtration systems of activated sludge that are a crucial part of the bioreactor process used for raw municipal wastewater treatment.

A pilot-scale of the new and innovative Huber Vacuum Rotation Membrane (VRM 20/36) bioreactor is made available and installed at the Sharjah Municipality Drainage Department (SMDD) main sewage treatment plant (STP), United Arab Emirates (UAE), since March 2008 for a period of 12 months in a working and active environment. The Huber MBR system consists of individual rotating VRM plates installed around a stationary hollow shaft. The VRM membranes are configured in plates (3-m² filter surface area per plate) that contain permeate channels, spacers, and permeate discharge nozzles. The membranes are flat sheets with a nominal pore size of 0.038 µm submerged in a designated membrane tank. Scouring air is introduced into the interspaces between the plates via two centrally arranged tubes. Permeate is drawn from each plate via permeate tubes that collect permeate to a common pipe. These horizontal pipes meet at a center manifold, from which the permeate exits the system. The VRM bioreactor uses a 2-horsepower motor for rotation at a constant rotation of 1.8 rpm which allows the membrane plates to be air scoured alternatively by just two centrally placed air tubes, thereby reducing the scouring air requirements, Figure 1.

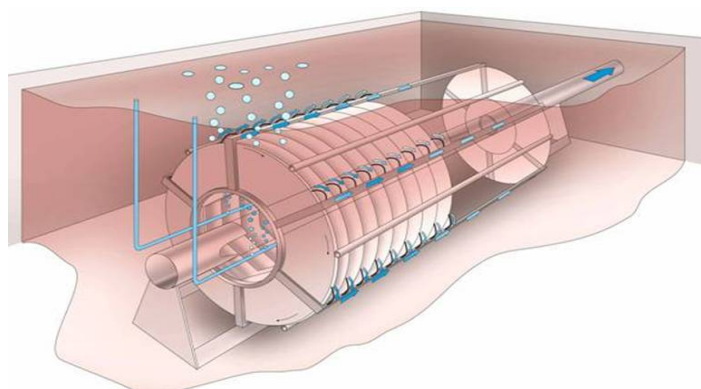


Figure 1. HUBER Vacuum Rotation Membrane (VRM[®])

We effectively evaluate the performance of the pilot-scale membrane process with respect to removal efficiencies for most important macro pollutants (COD, BOD, and others) and fouling. Investigation and optimization of filtration by means of short term and long term trials under steady-state conditions are in progress. Heterotrophic and Autotrophic biomass are characterized with respirometric trials. A Model of sludge production under steady-state conditions is developed. The efficiency of membrane process, as compared to the conventional biological secondary treatment processes of a typical STP is evaluated. The pretreated influent of the crude sewage is high in suspended solid, but low in oil and grease content. The average concentration of COD is 620 mg/l, BOD is 239 mg/l, ammonia is 37 mg/l, pH is 7.5, total suspended solids (TDS) is 304 mg/l, TKN is 46 mg/l, phosphate is 10.2 mg/l, and the turbidity is 225 NTU, Table 1. The VRM bioreactor is found to provide a very high quality final effluent. Results has shown the permeate from the VRM to have on the average 3 mg/l BOD, 3 mg/l COD, TKN 8 mg/l and 2 mg/l Ammonia. The turbidity is less than 3 NTU and virtually no suspended solids, Table 1.

Table 1. Inlet and final effluent conditions of the VRM bioreactor

	Influent Crude Sewage	Effluent	% removal
COD	620	3	99.5%
BOD	239	3	98.7%
TKN	46	8	82.6%
Ammonia	37	2.4	93.5%
Suspended Solid	304	□ 1	□ 99.7%
Phosphate	10.2	8.8	13.7%
Turbidity (NTU)	225	3	98.7%

The rotating mechanism of the membrane panels in the Huber VRM permits the entire membrane surface to receive the same intensive degree of air scouring leading to longer durations between the chemical cleaning cycles. Experience on site with hollow fiber membrane systems has shown that the fixed orientation results in more air scouring in the lower portion of the membranes and less at the top. The Huber VRM overcomes this by rotating the membrane panels such that the entire membrane surface receives the same intensive degree of air scouring - leading to longer durations between the necessity for chemical cleaning. It is anticipated that in the near future more STPs to employ MBR processes. The MBR process holds a promising future because it occupies smaller footprint compared to conventional systems, virtually no sludge, its effluent is suitable for reuse for irrigation, and it has high loading rate capacity. However, more work is needed to minimize fouling and to reduce operational (energy) cost.

Acknowledgements

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EFFECT OF AERATION AND VISCOSITY IN SUBMERGED MEMBRANE REACTOR

R.K. Aryal, S. Vigneswaran*, J. Kandasamy

*Faculty of Engineering, University of Technology, Sydney, P.O. Box 123, Broadway, NSW 2007, Australia
Tel. +61(2) 9514 2641; Fax +61(2) 9514 2633 E-mail: Rupak.Aryal@eng.uts.edu.au, vigid@eng.uts.edu.au, jaya.kandasamy@eng.uts.edu.au

keywords: submerged membrane, particles deposition, viscosity, aeration

Introduction

Submerged membrane filtration is an effective way for purification or separation of microbes and particles from mixed liquor. Two major drawbacks in membrane filtration are membrane fouling and high energy consumption [1, 2]. It is generally accepted that membrane characteristics, hydrodynamic and operational conditions play important roles in the control of membrane fouling [3, 4]. The hydrodynamics of the membrane system have been intensively studied. The results show that increasing aeration rate improved particle back transport and reduced membrane fouling [5, 6].

Objectives

This research study aims to investigate the role of aeration, flux rate and viscosity on particle deposition in the membrane as it evolves with time. Different hydrodynamic conditions were maintained and the particle deposition patterns were investigated with evolution of time at different flux rate and viscosity. The particle deposition behaviour was studied by transmembrane pressure measurement, particle size analysis gravimetric method, and turbidity.

Materials & Methods

A membrane reactor tank with a total volume 12 L was set up in the laboratory (Fig. 1). The tank equipped with flat sheet module. The flat sheet membrane module (PVDF with pore size 0.14 μm with filtration area 0.2 m^2) was submerged in the membrane tank. The mixed liquor of Larger bubbles (2-4 cm in diameter) at an aeration rate of 1-4 $\text{m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ were continuously injected from the bottom of the membrane tank to produce shear stresses that can minimise particles accumulation on the membrane surface. Membrane filtration was performed from outside to inside in a continuous mode, with no relaxation or back-wash procedure. The effluent was extracted by a peristaltic pump at a constant flux and discharged to the tank again. During the experimental period the transmembrane pressure (TMP) was measured at intervals of 20 minutes with online data acquisition. To have identical to mixed liquor (wastewater), experiments were performed at three different viscosities 1×10^{-3} , 3×10^{-3} , $5 \times 10^{-3} \text{ kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$.

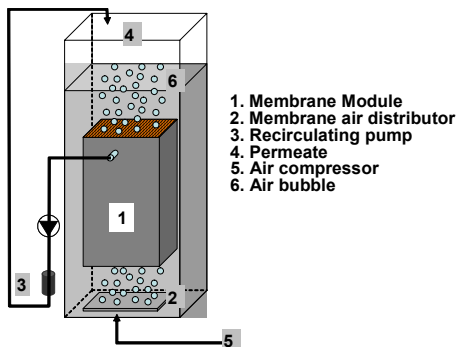


Figure 1: Schematic diagram of membrane unit

Results and discussion

The colloid used in this study was kaolin clay (Sigma, USA) of particle diameter 0.1-4 μm in diameter. The suspension was made by adding 10 g of kaolin clay in 1 L of water. The suspension was agitated for several hours. The suspension showed non-Newtonian behaviour and characterised by power rheological model $\eta = k\dot{\gamma}^n$, where η viscosity, k is consistency coefficient, $\dot{\gamma}$ is shear rate and n is the power law index.

Figure 2 shows a typical curve of a filtration of kaolin at constant flux ($70 \text{ l} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) at aeration rate $2 \text{ m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$. With the growing layer, the transmembrane pressure increased and the layer height reached the steady state very quickly. This typical behaviour could be observed in all experiments. Forces on streamline particles were calculated by considering drag force F_d , gravity force F_g , interparticle force F_i and Brownian force F_B . The rate of deposition of the particle on the membrane can be expressed as

$$m_p \frac{dv_p}{dt} = F_d + F_g + F_l + F_i + F_B$$

where m_p is the mass of the particle and v_p is the velocity of the particle and t is time.

Particle deposited on the membrane surface was considered release by sliding. At the low flux rate, both large and small particles found deposit on the membrane surface indicating the higher drag force to drive the particles on the surface where as at higher flux rate the larger particles deposited followed by smaller particles.

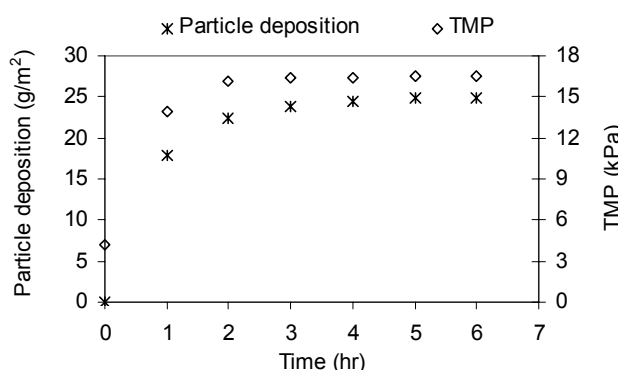
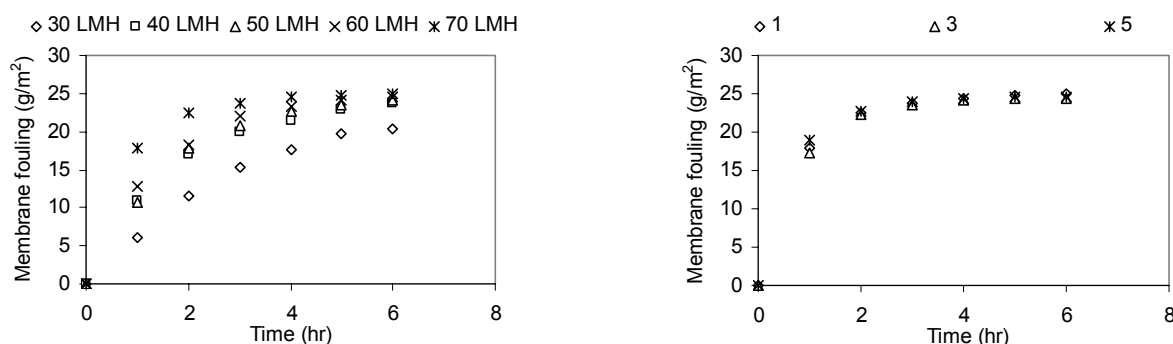


Figure 2: Particle deposition and transmembrane pressure with time at aeration 2 m³/h/m²

At the higher flux rate the drag force was higher than the tangential force, the particles with effective diameter were supposed to be entrained with the flowing suspension. At higher flux rate, membrane fouling was considerably higher from the beginning. Increase of viscosity increased membrane fouling propensity (Figure 3). With increasing viscosity, deposition of particles on the membrane surface was homogeneous at the low flux but with increasing the flux rate larger particles deposited on the membrane surface followed by smaller particles. Effect of aeration decreased the fouling propensity (Figure 4) and particles deposition behaviour also. At higher aeration rate, the larger particles deposited on the membrane surface from the beginning which was believed due to well scouring and mixing of suspension.



*Note: 1, 2 and 3 refers to viscosity 0.001 kg·m⁻¹·s⁻¹, 0.002 kg·m⁻¹·s⁻¹, and 0.003 kg·m⁻¹·s⁻¹, respectively.

Figure 3: Effect of flux rate and viscosity in membrane fouling at aeration 2 m³/h/m²

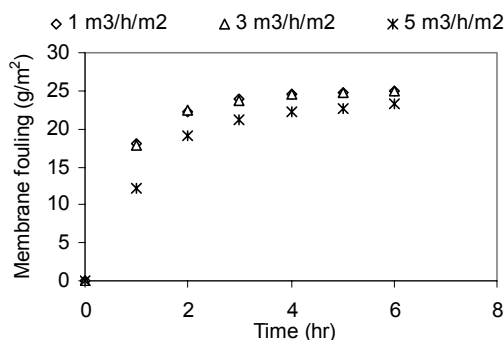


Figure 4: Effect of aeration rate in membrane fouling

Conclusions

Membrane microfiltration experiments were carried out with kaolin clay solution. Aeration, flux rate and viscosity were altered and their effects were studied. The suspension followed power law rheological property. Particle deposition on the membrane surface was affected by various forces acting on the particles. Membrane fouling propensity increased with increasing flux rate. The fouling propensity was more pronounced with increasing viscosity. Increase of aeration rate decreased membrane fouling.

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DEVELOPMENT AND EVALUATION OF A DISCONTINUOUS REACTOR OF MOVING BED AND SUBMERGED MEMBRANES FOR THE WASTE WATER TREATMENT

Julio Alberto Ávila-Arias, Irma Paola Delgado-Luna, Arodí Bernal-Martínez,*Germán Cuevas-Rodríguez

Faculty of Civil and Environmental Engineering. Guanajuato, University
 Av. Juárez No. 77, Guanajuato, Gto., México. Tel.+52 (473) 1020100 ext. 2292
 *E-mail: german28@quijote.ugto.mx

keywords: Wastewater, moving bed, MBR, flat membranes, nutrients

Introduction

Nowadays, the application of the biological reactors with membranes (MBR) for the wastewater treatment is one of the technologies that has took a good place in the market, mainly because with this technology is possible to obtain effluents with very high quality allowing its reuse in different activities that demand this water resource. However, there still exist some problems in the operation of these systems as the bunging (caused due to the fouling that grows over the surface of the membranes), and economical (high cost of the membranes that are part of the filtration modules). Even so, this haven't been an impediment for the continuous increase in the application of the technology of MBR in the domestic and industrial wastewater treatment at a world level. In Latin America, the application of the MBR in the domestic and industrial wastewater treatment is still low due to the high cost that represents the membranes that are used for the extraction of the permeate and the high oxygen requirements that are necessary to reach a high efficient treatment. That is why the search of materials for the elaboration of membranes with low cost and operation strategies that allow reducing the treatment costs is a necessity to increase the application of the MBR in developing countries.

Objectives

The main objective of this reseach was to design, construct and evaluate a discontinuo reactor with moving bed and filtration membranes of low cost to carry out the elimination of the nutrients present in domestic wastewater.

Materials & Methods

The research was made in a pilot reactor, constituted by 4 main parts: supporting media, module with membranes, air circulation system and reactor with active sludge. The total volume of the reactor was 29 L. The supporting material for the fixation of biofilms were 500 cubes of polyester with an specific surface of 6 cm² each one. The membranes module was constituted by 2 hydrophilics commercial membranes of polyuretano with a surface of 100 cm² each one. In the figure 1 shows a diagram of the pilot reactor with each one of the parts.

The feeding was carried out with domestic wastewater generated in the City of Silao, Guanajuato, México. The reactor was operated in a discontinuous way with cycles of 8 hours (filling, anaerobic reaction, aerobic reaction, extraction of the permeate). The experimentation was made into three stages: (1) with activated sludge only, SBR,

(2) SBR with the moving bed and activated sludge, (3) SBR with moving bed, activated sludge, and the module submerged with filtration membranes.

The parameters determined were CODD and CODT, P-PO4³⁻, N-NO3⁻, TSS and VSS. The COD, the nitrates, the nitrites and the phosphates were measured by Hach [Hach, 1997]. The TSS and VSS were determined according to the Standard Methods [APHA, 1998].

Results and discussion

The operation of the reactor was carried out in a discontinuous way during 286 days. In the figures 2 and 3 is shown the behavior of each one of the analyzed parameters during the experimentation time. It can be observed that it exist variability in each one of them during this time in the influent as much in the effluent, this is because the feeding was made with real wastewater and the operation conditions changed during the three stages of the work.

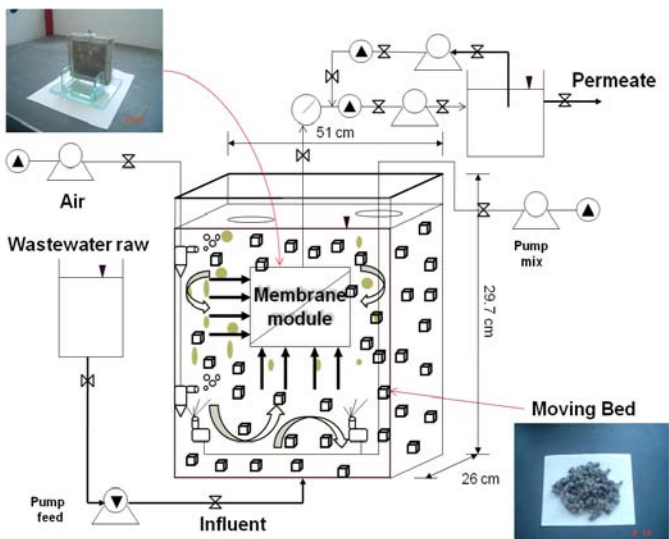


Figure 1: Membrane biological Reactor (MBR).

Solid removal

The percentage of removal for TSS and VSS in the MBR was of 95% during all the experimentation. This a good percentage compared with the bibliographical (Laera et al. 2005). The average concentration of TSS in the effluent was 20 mg/L throughout the time that were used membranes to extract the permeate.

COD removal

The Figures 2 y 3 shows the concentrations of the COD in the influent and the effluent of the bioreactor during the experimentation. It can be observed that the quality in the effluent increased with the time of experimentation. During the first stage, when the reactor was operated as a conventional discontinuous reactor, the average concentration in the effluent was 106 mg/L (72.7% of elimination), 94 mg/L (79.8% of elimination) in the second stage (with the insertion of the moving bed) and in the third stage, when it was placed the module with submerged membranes, the average concentration of COD obtained is very similar to the reported in other researches made in MBR (Rosenberger, et al., 2002, Cote, et al., 1997).

Phosphate Removal

The phosphorus concentration detected in the raw wastewater was varying between 23.7 and 30.6 mg/L during all the experimentation. These concentrations are typical in domestic wastewater. In figures 1 and 2 is shown the behavior that presented this compound during all the experimentation. It can be observed that in the effluent, the phosphates concentration decreased with the time of experimentation and with the operation way of the reactor. During the first stage, the average concentration detected in the effluent was 6.5 mg/L (equivalent to the 70.3% of elimination) while in the second stage the concentration decreased up to 3.8 mg/L (86.7% of elimination efficiency). However, when it was carried out the extraction through the membranes, the concentration decreased up to 1.1 mg/L (96.7% of elimination). This indicates that introducing membranes inside the bioreactor as well as the operational conditions applied favors the elimination of the phosphates present in the crude waste waters.

Nitrification

In figures 1 and 2 it is shown the behavior of the N-NO₃⁻ concentrations in the influent and effluent of the discontinuous bioreactor during the experimentation. It is observed that the nitrates concentration in the influent were low, this is common in the crude waste waters. Nevertheless in the effluent, the N-NO₃⁻ concentration increased, detecting values of 1.7, 2.6 and 3.1 mg/L in each experimentation stage. This behavior indicates that the nitrification took place in the system.

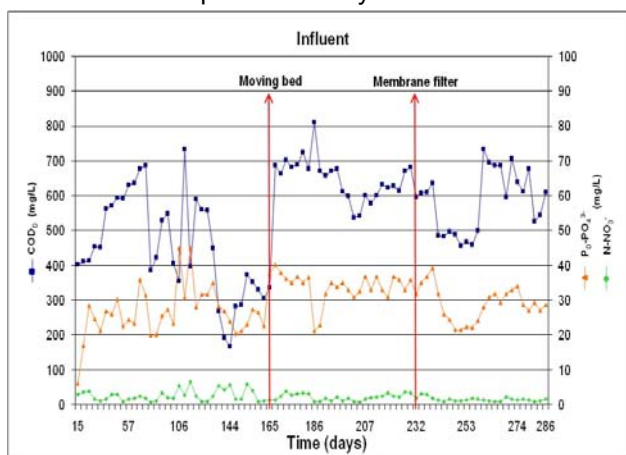


Figure 2: COD, P-PO₄₃⁻ and N-NO₃⁻ in the influent.

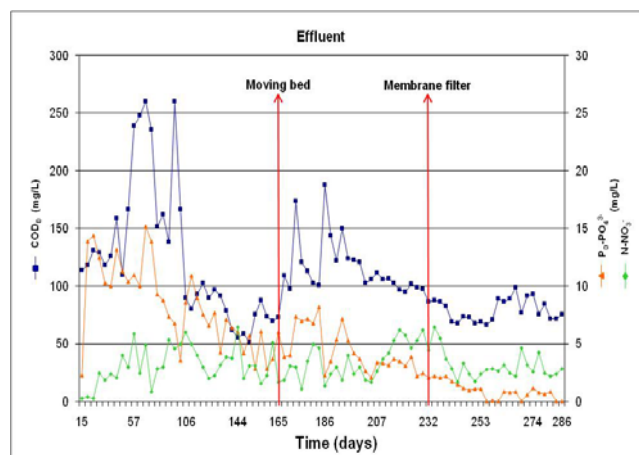


Figure 3: COD, P-PO₄₃⁻ and N-NO₃⁻ in the permeate.

Conclusions

The results show that the application of the bioreactor with moving bed and submerged membranes of low cost for the domestic wastewater treatment allow to carry out the elimination of nutrients present in the wastewater in an efficient way. However, it is necessary to keep experimenting in this unit of treatment for making able to determine the optimum operation conditions, with which is possible to increase the elimination efficiencies of COD and nitrogen present in the influents of the raw wastewater.

Acknowledgments

To the CONCYTEG for the economic support given to carry out this project.

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DEVELOPMENT PERSPECTIVES OF ON-SITE MBR TREATMENT PLANTS IN THE MUNICIPAL WASTEWATER SECTOR OF CHINA

Christian Binz*

*Eawag, Swiss Federal Institute of Aquatic Science and Technology. E-Mail: binz@giub.unibe.ch

keywords: MBR, On-site wastewater treatment, China

Introduction

Wastewater infrastructures in Western European countries are relatively well established and path dependencies in the respective wastewater sectors are typically strongly biased towards centralized wastewater collection and treatment. Therefore, in the European context only few development opportunities exist for radical innovations like on-site wastewater treatment facilities using MBR technology. It is thus argued that China represents a promising location for assessing the potential of a transition of the wastewater sectors towards more decentralized configurations: The construction of the wastewater infrastructure in China is supported by large governmental investment programs as the country struggles with severe water shortages in the northern regions and skyrocketing urbanization in major cities with both factors revealing the limits of centralized approaches of wastewater treatment. Windows of opportunity are thus open in China for the application of alternative, more decentralized and potentially more sustainable wastewater treatment technologies like on-site wastewater treatment plants using MBR technology.

Objectives

The objective of the presented study was to assess the driving and hindering factors for an implementation of on-site MBR package plants in Chinese urban centres and the description of socio-technical combinations in which these applications are valued as realizable by Chinese experts. A further objective of the study was to identify potential actor networks inside China that could produce on-site MBR plants in large quantities and in standardized industrial production, which in turn could lead to decreasing costs for on-site MBR plants and enhance their application potential.

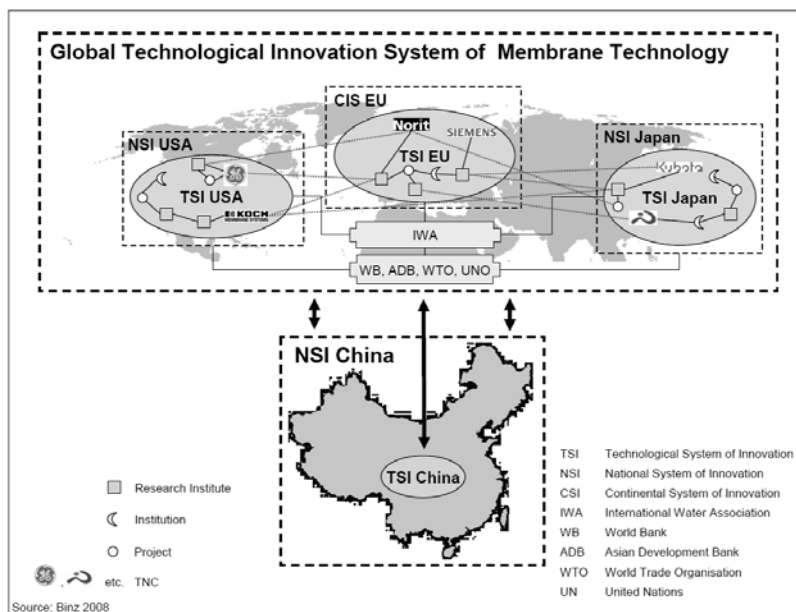


Figure 1: Global and Chinese innovation systems and their interactions

Materials & Methods

The study relies on a total of 31 expert interviews which were realized in 2007 and 2008 in China, Germany and Switzerland. 23 Chinese stakeholders (representing membrane companies, universities, associations and authorities) were interviewed in China, 3 relevant German experts and 5 Swiss experts for on-site wastewater treatment were interviewed in Germany and Switzerland respectively. A system of innovation perspective was applied to identify and compare relevant institutional contexts, actor structures and innovative networks in China and on a global scale (see Figure 1).

Results and discussion

The empirical results show that China hosts a dynamic technological innovation system for MBR technology but that international linkages between actors of the different innovation systems represented in Figure 1 mainly lead to an import of

Institutional factors	Expected influence on development perspectives of on-site MBR plants
ds	On-site MBR plants get economic feasible in regions with high water prices
rds	On-site MBR plants can fulfil the recently implemented severe discharge quality standards
	On-site MBR plants are not yet integrated in national design standards
National infrastructure investment	- - National infrastructure development plans favour investments in centralized wwtp
Rising demand for water recycling	+ High potential for on-site water reuse provided by MBR package plant systems
Building construction technique	- Dominant building construction technique not compatible with on-site MBR plants
Public awareness/acceptance	- Lacking knowledge about on-site MBR plants leads to low public acceptance
Landscape factors	
Strong water scarcity	+ On-site MBR plants combined with water reuse can strongly reduce urban water consumption
Rapid urbanization	+ On-site MBR package plants as interesting option for fast growing satellite cities
Privatization reforms	+/- New opportunities and new challenges for the application of on-site MBR wwtp

Table 1: Institutional and landscape factors influencing the development perspectives of on-site MBR plants in China

foreign perceptions about adequate wastewater technologies and thus to a strengthening of centralized wastewater treatment approaches in the Chinese wastewater sector. Table 1 summarizes some further key findings about the institutional context of the innovation of on-site MBR package plants in China: Some factors such as rising water prices and wastewater treatment tariffs in most water scarce cities of China potentially favour the future implementation of on-site MBR plants even as an economical attractive alternative to centralized wastewater treatment. At the same time, low public awareness about the technological potential of on-site MBR plants and governmental policy focussing on a rapid build-up of centralized wastewater treatment capacity strongly hinder the diffusion of the discussed innovation.

Figure 2 provides a picture about the organisational role models in which the operation of decentralized MBR facilities is generally imaginable in China. Table 2 combines these role models with different sizes of MBR package plants ranging from systems designed for one single household up to systems that can be applied for semi-centralized or even centralized wastewater treatment. The evaluation of these socio-technical variations shows that Chinese experts assign the biggest future development potential to applications of on-site MBR plants in big units such as apartment buildings, "Prestige" buildings (airports, sport stadiums, big hotels, etc.) or even residential areas with semi-decentralized wastewater recycling systems. Furthermore, organizational role models are strongly favoured that keep the main responsibility for installation, operation and maintenance of installed on-site plants concentrated in the hands of only few professional actors.

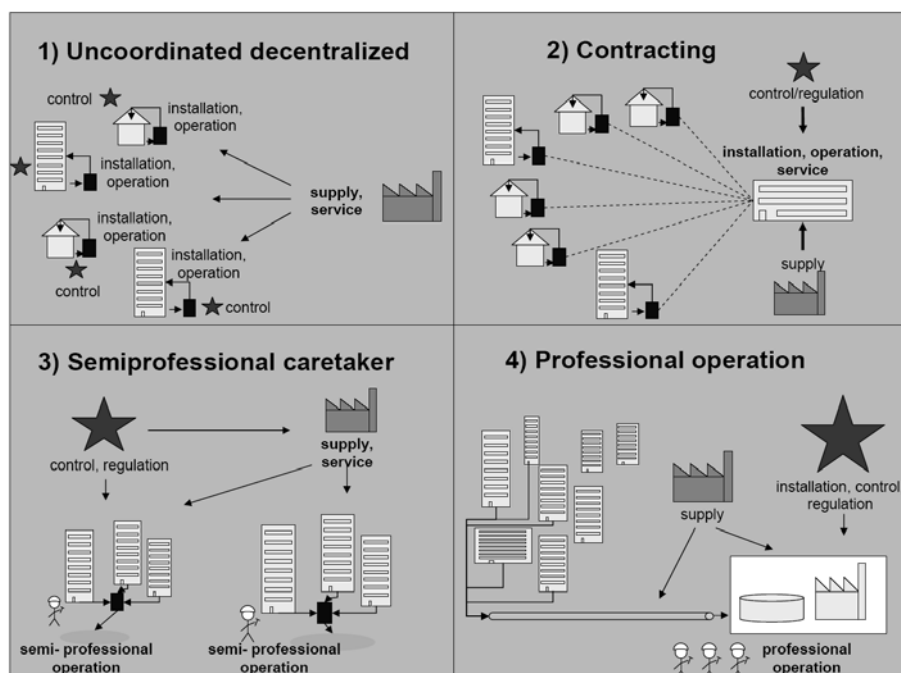


Figure 2: Organizational role models for the operation of MBR plants in China

		Organizational role model			
		Uncoordinated decentralized	Semi-professional caretaker	Contracting model	Professional operation
Plant size	Household	- - -	-	+/-	
	Apartment building	- - -	+/-	+++	
	"Prestige" building	- -	+++	++	++
	Residential area	-	-	+	+++
	City district				+++

Source: Binz 2008

Table 2: Evaluation of plant size and organizational role models for the operation of MBR plants in China

keep the main responsibility for installation, operation and maintenance of installed on-site plants concentrated in the hands of only few professional actors.

Conclusions

The development perspectives of on-site MBR plants in the municipal wastewater sector of China depend on a complex interplay of supporting and hindering institutional factors. At the moment, a diffusion of the technology in a large scale is rather unrealistic as the relevant governmental programs for infrastructure development strongly favour centralized approaches of wastewater treatment. Nevertheless, strong landscape factors support the application of the technology and there exist some very dynamic application niches in water scarce areas of China that could be the basis for a future spreading of the technology. The strongest future potential for applications of on-site MBR plants can be anticipated for installations in fairly big buildings such as hotels, department stores, apartment buildings or airports, which are operated by actors in highly centralized organizational role models.

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CLEVELAND BAY WASTEWATER TREATMENT FACILITY RETROFITTING MEMBRANES WITHIN EXISTING STRUCTURES

Travers Boland*, Ken Hartley**

*GHD Pty Ltd, 61 402 296 572, tboland@ghd.com.au

**Ken Hartley Pty Ltd, 61 7 3278 8400, kenhartleypl@bigpond.com

Keywords: Membrane, Bioreactor, Retrofit, Innovation, Sustainability

Introduction

The Cleveland Bay Wastewater Treatment Facility (CB WTF) located in Townsville, Australia, is a new 75 ML per day (126,000 EP) Biological Nutrient Removal (BNR) and Membrane treatment system delivered by the **Water Matters Alliance**. Members of the Alliance included the **New Townsville City Council, GHD Pty Ltd, Abigroup Contractors Pty Ltd, United Group Infrastructure Pty Ltd** and **Aquatec-Maxcon Pty Ltd**.

Objectives

The overall strategy for management of the product water from the CB WTF is one of maximising reuse of this treated water. The reuse from this plant is targeted at industry, parks, gardens and irrigation surrounding Townsville, Australia.

To achieve a very high effluent quality, state-of-the-art BNR processes were utilised by combining an oxidation ditch to achieve a high level of nutrient removal with the superior solids separation offered by membranes. This retains the simplicity and flexibility of the oxidation ditch while adding the exceptional solids separation capability of the membranes.

The adopted process treatment solution offered the flexibility of effluent from the plant to be treated in a water reclamation facility, which includes Reverse Osmosis (RO), to produce high quality reuse water suitable for industrial and irrigation applications.

Materials & Methods

The **Water Matters Alliance** looked at more traditional BNR treatment technologies but the process reviews and preliminary cost estimates quickly identified that there were significant capital investments associated with these larger footprints. The high surface area of Hollow Fibre Membranes offered a significant reduction in infrastructure size and through a series of innovation workshops also offered the opportunity to retrofit the membranes within existing plant infrastructure.

Of further cost benefit was that the membranes provided ultra-filtration; a step in the proposed downstream RO plant that would no longer be required. This in turn reduced future capital expenditure and offered the most advantageous triple bottom line to the community at large.

As a direct result of the innovation workshops, the **Water Matters Alliance** successfully completed one of world's first and largest retrofit of existing Clarifiers to house the BNR and Membrane treatment process trains. This in-turn significantly reduced the project capital expenditure and construction program. Furthermore, re-use of existing infrastructure offered a staged approach to construction meaning that high quality treated effluent could be introduced to the environment earlier and also offered process optimisation during this earlier phase of the project.

The CB WTF is viewed by the **Water Matters Alliance** as an innovative example of integrating membrane technology into existing treatment facilities and adapting these processes to offer ongoing sustainable solutions. This is illustrated through the following:

Maximum Reuse of the Existing Infrastructure

1. Hydraulic & structural refurbishments to the existing primary screening and aerated grit removal structures.
2. Conversion of the existing flat floor Clarifier No. 1 into a sloping floor Primary Sedimentation Tank.
3. Conversion of the existing Clarifier's No. 2 and 3 into hydraulically linked but separate Membrane trains complete with Biological Nutrient Removal.



Figure 1: Hollow Fibre Membranes



Figure 2: Clarifier Converted into MBR



Figure 3: Permeate & Air Pipes on MBR

4. Reuse of the existing sludge thickening and digester's prior to the new Biosolids Handling Facility.

Energy Recovery

1. Digester Methane Energy Recovery
2. Membrane Backpulse Pumping Energy Recovery
3. Membrane Train Low Flow Shutdown and Aeration Oscillation

Chemicals

1. Maximum use of Biological Nutrient Removal to lessen the plants reliance on chemicals.
2. Use of GHG friendly Ethanol in lieu of other non-sustainable solutions as the carbon source for the plant process.
3. Use of Lime Slurry (a by-product from a local gas manufacturer) for chemical P removal for the sludge system return flow.

Speed and Efficiency of Construction

To hasten the release of high quality treated effluent and to reduce the project overhead costs, a number of construction techniques were initiated, including:

1. A staged approach to retrofitting the Clarifiers allowing advanced commissioning and process optimisation. The success of the first stage allowed the second clarifier to be decommissioned ahead of program through process improvements to the existing plant.
2. The use of Stainless Steel Membrane tanks and pipework allowed off-site centralised fabrication for a large portion of the works using contractors with specialist equipment increasing quality and reducing fabrication and erection times (ie. Fabricate whilst making the necessary structure modifications).
3. Prefabricated tanks and pipes were erected on-site quickly reducing construction costs, waste materials such as formwork and significantly reducing the overall project time.

Results and discussion

The plant is producing exceptional quality effluent that has exceeded the design targets. To provide the greatest level of treatment at the lowest possible operating cost, the *Water Matters Alliance* team is currently optimising the biological processes to minimise the consumption of chemicals and energy.

Table 1: CB WTF Performance Data

Final Effluent Characteristic	Licence Requirement	Achieved Median	Plant Energy Consumption	Design Target	Achieved Average
COD	< 200	24	Power (kW)	1480	760
SS	< 30	0.5	Specific Energy (kWh/kgCOD)	3.1	1.6
NH3-N	< 3	0.7			
Total N (mg/L)	< 5	3.8			
Total P (mg/L)	< 1	0.8			
F. cols / 100mL	1000	2			

Conclusions

Membrane technology offered the Project Team a smaller footprint, which in-turn allowed an innovative solution to integrating the membranes and biological nutrient processes within the existing plant infrastructure.

Reusing the existing infrastructure reduced the on-site construction and therefore the overall project capital costs.

Long-term energy savings will be achieved through on-site power generation and this will be further amplified by savings in downstream pre-treatment prior to the planned Reverse Osmosis system.



Figure 4: MBR During Conversion



Figure 5: Side View of MBR



Figure 6: Biological Aeration

COMPARISON OF PHARMACEUTICAL SUBSTANCES REMOVAL BETWEEN A FULL SCALE CONVENTIONAL ACTIVATED SLUDGE PROCESS AND A MBR PILOT PLANT

H. Bouju*, G. Buttiglieri*, F. Malpei*

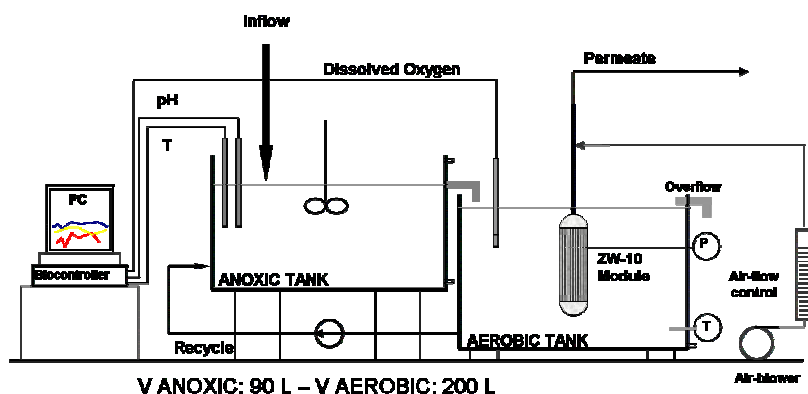
Politecnico di Milano – DIIAR sezione ambientale – Piazza Leonardo da Vinci 32 – 20133 Milano - Italy
 helene.bouju@polimi.it, gianluigi.buttiglieri@polimi.it, francesca.malpei@polimi.it

Keywords: Pharmaceutical substances, MBR, Domestic wastewater treatment

Introduction and objectives

Pharmaceutical substances, and on a more general basis, persistent micropollutants removal from wastewater is an important issue since their discharge into the environment might damage ecosystems. Nevertheless, knowledge about their fate in wastewater treatment plant is still scarce and pharmaceuticals discharge has not been regulated in Europe yet. In the last years, some studies have presented MBRs as a process that leads to higher removal rates of micropollutants, encompassing pharmaceutical substances in comparison to conventional processes (Bernhard et al. 2006), (Kreuzinger et al. 2004). However, those compared CAS working at standard SRT and MBR working at much higher SRT. Hence, when comparing both processes working in comparable conditions, it appeared that for some compounds, MBRs might achieve a slightly higher removal, while for those which are either well removed in CAS or not removed at all, no difference was observed (Clara et al. 2005), (Weiss and Reemtsma 2008). These results tend to show that the tertiary treatment is also a key step in micropollutants removal. This work presents results obtained when comparing a 290L anoxic-aerobic MBR pilot plant running in parallel of the full scale CAS of Nosedo, Milan, Italy (1.250.000 pe). Both processes are working with the same aerobic/anoxic volume ratio and the MBR has been studied at two different SRTs (35 and 15 days). Treated wastewater from the Nosedo treatment plant enters the canal Vettabbia with a low dilution ratio after a tertiary treatment including sand filtration and disinfection with peracetic acid, and is then largely reused for agriculture. Therefore the monitoring of water contamination is of particular interest for a reliable assessment of environmental risks.

Materials & Methods



The anoxic-aerobic MBR pilot plant (90L anoxic – 200L aerobic) is working at an average concentration of 6gTSS.L⁻¹ in the aerobic tank. It is equipped with a hollow fibres microfiltration module from Zenon®, Zee-Weed-10, which has a surface area of 0.93m² and a characteristic pore size of 0.2µm.

Figure 1: Scheme of the MBR pilot plant

Results and discussion

In order to compare removal efficiencies of both processes, two sampling campaigns have been performed on both processes, at the same period of the year to limit differences due to external variations such as human consumption of pharmaceuticals and temperature. Analyses have been performed by means of HPLC/MS/MS. A total of 35

Ciprofloxacin	COF	Lincomycin	LIN	Enalapril	ENA
Ketoprofen	KET	Dehydroerythromycin	DHE	Estrogen	EST
Ofloxacin	OFL	Atenolol	ATE	Gemfibrozil	GEM
Diclofenac	DF	Bezafibrate	BZF	Ibuprofen	IBU
Furosemide	FUR	Clarithromycin	CLA	Naproxen	NAP

pharmaceutical substances have been analysed, in which respectively 27 and 28 were detected and 15 were present at relevant concentrations during both campaigns (Table 1).

Table 1: List of selected substances and abbreviations.

On Figure 2, one can see measured influent and effluent concentrations as well as removal rates for the different campaigns.

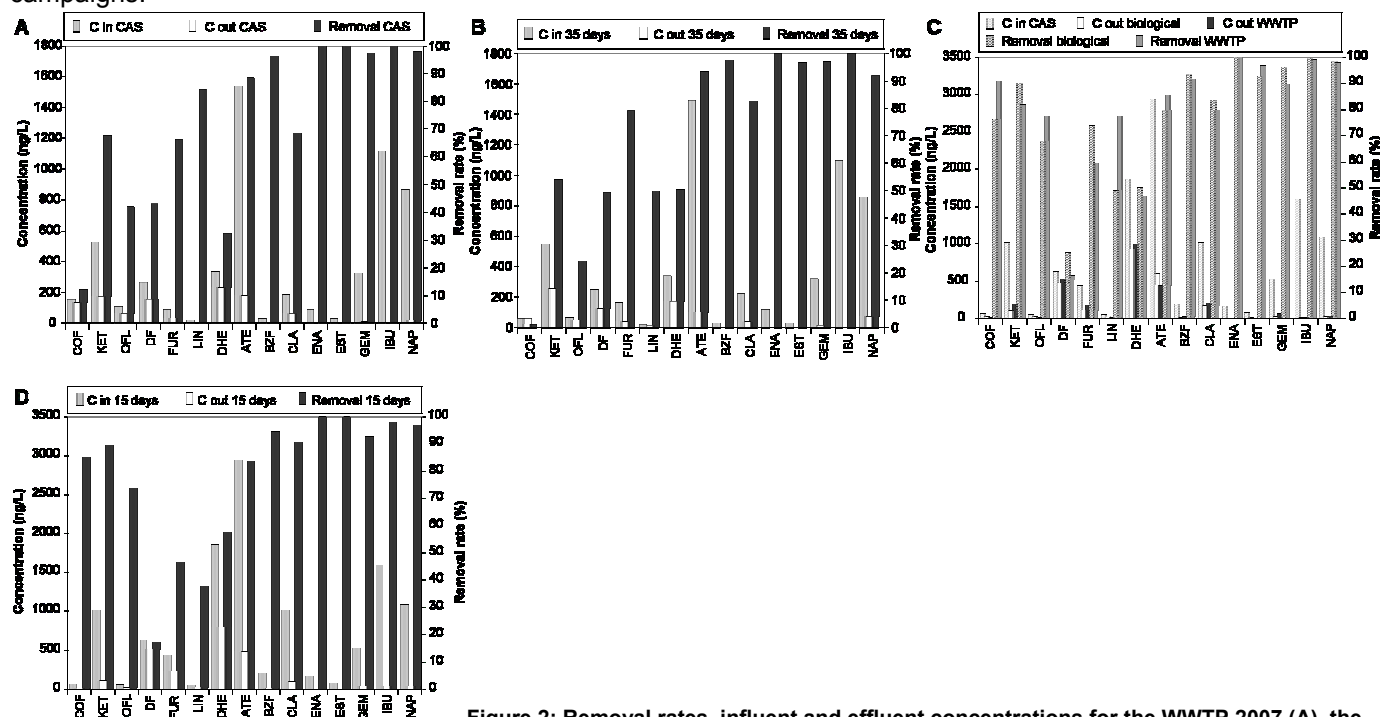


Figure 2: Removal rates, influent and effluent concentrations for the WWTP 2007 (A), the MBR working at 35 days SRT – 2007 (B), the biological reactor and the whole WWTP 2008 (C) and the MBR at 15 days SRT – 2008 (D)

Conclusions

These results clearly show that there is no significant difference between the two processes. Indeed, the three substances which display a slightly higher removal rate in the WWTP at comparable SRT (Ciprofloxacin, Ofloxacin and Lincomycin) display also a slightly higher removal rate during the tertiary treatment. Moreover, when comparing results from the MBR pilot plant at two different SRT, most of the substances display similar removal rates. Whereas three of them exhibit a slightly higher removal at 15 days (Ciprofloxacin, Ofloxacin and Ketoprofen); the difference can not be considered as significant for Ciprofloxacin and Ofloxacin, due to their really low influent concentration. Regarding Ketoprofen, this might be due to a higher removal with the excess sludge. For those which are better removed at higher SRT (Diclofenac, Furosemide and Lincomycin) there might be a slight effect of the SRT on their biodegradation rates, while for Lincomycin, the influent concentration is too low to draw such conclusions. Therefore, it seems that MBRs do not exhibit such a higher potential in removing pharmaceutical substances. Hence, research should rather focus on tertiary treatments.

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THE FATE OF ¹⁴C-RADIOLABELLED DICLOFENAC AND 4'-HYDROXYDICLOFENAC IN A LABORATORY SCALE MBR

H. Bouju*, G. Hommes**, T. Wintgens**, P. Corvini**

* Politecnico di Milano – DIIAR sezione ambientale – Piazza Leonardo da Vinci 32 – 20133 Milano - Italy
helene.bouju@polimi.it

** Institute for Ecopreneurship, School of Life Sciences, University of Applied Sciences Northwestern Switzerland, 40 Grundenstrasse, CH 4132 Muttenz, Switzerland

gregor.hommes@fhnw.ch, thomas.wintgens@fhnw.ch, philippe.corvini@fhnw.ch

Keywords: Diclofenac, MBR, Radiolabelling, Domestic wastewater treatment

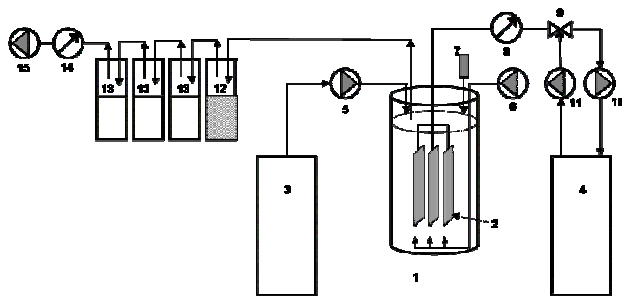
Introduction

Diclofenac is one of the most extensively used non-steroidal, anti-inflammatory and non-prescribed drugs (NSAIDs). Indeed, diclofenac concentration levels of up to 15 µg.L⁻¹ were reported in water and wastewater samples (Stülten et al. 2008).

However, wastewater treatment plants (WWTP) hardly remove such substances in those low concentrations and removal pathways are still to be identified or better understood. The fate and transport of diclofenac in sewage treatment systems is difficult to study and analyse due to its low concentration in effluent and the presence of the complex organic matrix of the latter. Hence, by using ¹⁴C-radiolabelled substances, it is expected to be easier to determine removal pathways, especially to distinguish between biodegradation, adsorption and volatilization. Moreover, radiotracing is the method of choice for the detection of any metabolites. Indeed, various studies have been carried out on diclofenac removal in WWTPs. Although a slight removal has been detected most of the time, in average 30%, the observed range is wide, from 0% (De Wever et al. 2007) to 70% (Ternes 1998).

Therefore, the assessment of the fate of diclofenac and 4'-hydroxydiclofenac, its main metabolite expressed in humans, during the wastewater treatment process is necessary to better appraise the reasons of their persistence in treated effluents.

Objectives



1 - Bioreactor vessel; 2 - Membrane plate modules; 3 - Influent tank; 4 - Effluent tank; 5 - Influent peristaltic pump; 6 - Air pump; 7 - Level controller; 8 - Digital pressure control; 9 - Controlling valve; 10 - Effluent peristaltic pump; 11 - Backwashing peristaltic pump; 12 - Mono ethylene glycol base for VOC trapping; 13 - NaOH traps for CO₂ trapping; 14 - Digital pressure control; 15 - Vacuum pump

The aim of this project was to assess the fate of diclofenac and its main metabolite in membrane bioreactor (MBR), which represents a promising method for the elimination of persistent organic pollutants during sewage treatment. In order to circumvent problems related to the analysis of trace concentrations in complex matrices such as activated sludge a radiomonitoring approach was implemented. ¹⁴C-labelled diclofenac and 4'-hydroxydiclofenac were applied to a lab scale MBR, which has been developed to run under radioactive conditions (Figure 1).

Figure 1: Scheme of the laboratory scale MBR

Materials & Methods

For this purpose, a 1.15L MBR was operated under continuously mixed aerobic conditions at a SRT of 30 days and a HRT of 7.1 hours. The reactor was fed continuously with a sterilized synthetic medium.

The filtration unit consists of 6 flat sheet membranes for a total surface area of 40 cm² (4x10) with a pore size of 0.2 µm (MV020; Microdyn-Nadir GmbH).

¹⁴C-radiolabelled 4'-hydroxydiclofenac was produced by incubating ¹⁴C-labelled diclofenac with S9 mix from human liver containing the NADPH depending enzyme P450.

COD, total Nitrogen, Nitrate and total Phosphorus analyses were carried out daily using test kits (Dr. Lange), the total solids concentration, on average 9.5 g.L⁻¹, was determined gravimetrically. Radioanalyses were carried out using a LC-MS coupled to a LSC radiodetector.

Results and discussion

Bioproduction of ¹⁴C labelled human metabolite of diclofenac

¹⁴C-labelled 4'-hydroxydiclofenac could be synthesized under lab conditions. Diclofenac and its main metabolite were analyzed by HPLC/LSC radiodetector. Our results indicated an almost complete transformation of diclofenac into 4'-hydroxydiclofenac after one hour of incubation with the liver extract (Figure 2).

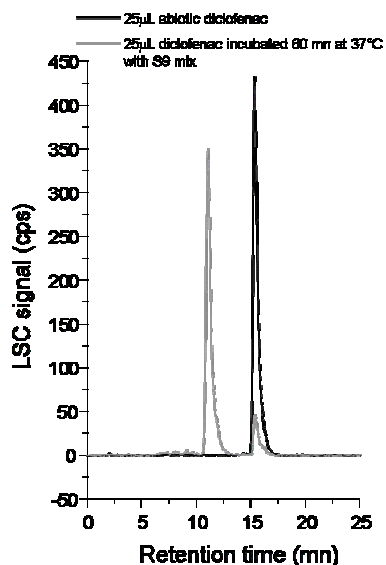
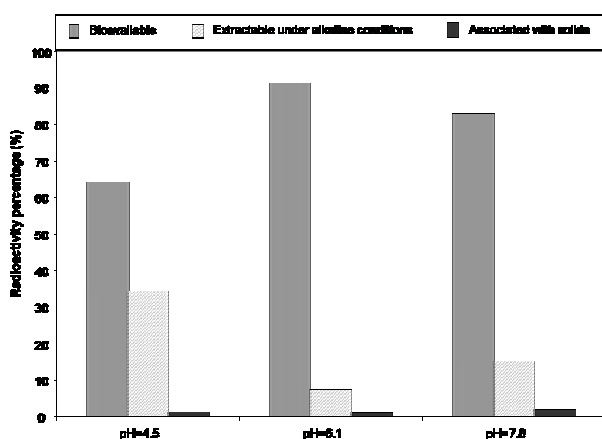


Figure 2: Radiochromatogramm of ¹⁴C-diclofenac incubated with cell liver extracts

Distribution of diclofenac in the different phases of MLSS



In order to estimate the distribution of diclofenac in the different phases of the MLSS at different pH, 2.5 µg.L⁻¹ of radiolabelled diclofenac was spiked to MLSS samples and incubated overnight. Subsequently, samples were centrifuged to separate the bioavailable phase, then washed with a solution of sodium hydroxyde at 0.5% to estimate the fraction which is extractable from the biomass pellet under alkaline conditions. Finally the remaining biomass pellets were combusted to determine the percentage of diclofenac that remains associated with solids (Figure 3).

Figure 3: Distribution of diclofenac in the different MLSS phases

The results showed a dependance of the distribution according to the pH. Indeed, due to a pKa of 4.15, diclofenac was almost completely deprotonated at a pH of 6.1, therefore, more soluble and bioavailable at such a pH. Moreover, it confirms a priori the low effect of adsorption on its overall removal during the activated sludge processes.

Conclusions

After completion of the stabilization period, the MBR will be spiked with a relevant mixture of radiolabelled diclofenac and 4'-hydroxydiclofenac. This will enable the assessment of the partitioning of radioactivity in various fractions (e.g. effluent and activated sludge), the radioactivity balance, the mineralization and the identification of diclofenac and 4'-hydroxydiclofenac residues.

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INTEGRATION OF SOLAR PHOTOCATALYSIS AND MEMBRANE BIOREACTOR FOR PESTICIDES DEGRADATION

Casas López, J.L.* , Sánchez Pérez, J.A.* , Ballesteros Martín, M.M.* ,
García Sánchez, J.L.* , Malato Rodríguez, S.**

* Department of Chemical Engineering, University of Almería, 04120 Almería, Spain

** Plataforma Solar de Almería-CIEMAT, Carretera de Senés km 4, 04200 Tabernas, Almería, Spain

Keywords: Toxic pollutants, Advanced Oxidation Processes, photo-Fenton, biodegradation.

Introduction

Wastewater containing toxic and biorecalcitrant compounds can be treated by solar photo-Fenton achieving a complete mineralization of pollutants. Nonetheless, the cost of AOPs is very high (Comninellis et al., 2008) compared with biological treatments. Therefore, an alternative to reduce the cost of the process is to carry out a partial mineralization of toxic compounds with an AOP in a first step, increasing wastewater biodegradability and generating intermediates that can be ultimately treated in the biological plant. A large number of studies have shown the potential of these coupled systems to treat different contaminants in wastewater from various sources. Membrane bioreactors (MBR) have demonstrated to be particularly suitable for advanced biological treatment of wastewater containing emerging contaminants (ECs) (Kimura et al., 2005). Moreover, the operational flexibility of this technology allows its integration with other processes (such as AOPs) resulting in optimized treatment performances. Previous research reported much better ability of MBR in removing ECs with respect to conventional activated sludge (Bernhard et al., 2006). Nonetheless, there is a lack of research about the integration of photo-Fenton oxidation process with biodegradation in MBR.

Objectives

The present work tries to demonstrate the viability of combine photo-Fenton process with biodegradation in a MBR to treat industrial wastewater containing a non-biodegradable pesticide mixture.

Materials & Methods

The industrial wastewater effluent contained a mixture of Vydate, Metomur, Couraze, Ditimur and Scala, pesticides whose active ingredients are oxamyl, methomyl, imidacloprid, dimethoate and pyrimethanil, respectively. The initial dissolved organic carbon concentration was 200 mg L^{-1} .

Photo-Fenton experiments were carried out in a solar wastewater detoxification plant with compound parabolic collectors (CPC) able to treat up to 50 L of water (2.25 m^2 irradiated surface, 22 L irradiated volume).

Determination of the minimum treatment time has been carried out following the variation in biodegradability with cultures of the bacteria *Pseudomonas putida* on the pesticide derivatives from the photo-Fenton reaction (García-Ripoll et al., 2009).

Biotreatment was carried out in a 20L-membrane bioreactor provided with three flat sheets (Kubota A4) working in a sequential way, with a total filtration area of 0.3 m^2 . The influent of the MBR was a mixture of a partly oxidized pesticide solution from the photo-Fenton reaction (132 mg L^{-1}) with a synthetic urban wastewater with biodegradable carbon sources and mineral salts. The influent flow was 1.8 L h^{-1} (11 hours of hydraulic residence time) with a total dissolved organic carbon concentration of 500 mg L^{-1} .

Figure 1 represents the setup of the photoreactor combined with the MBR.

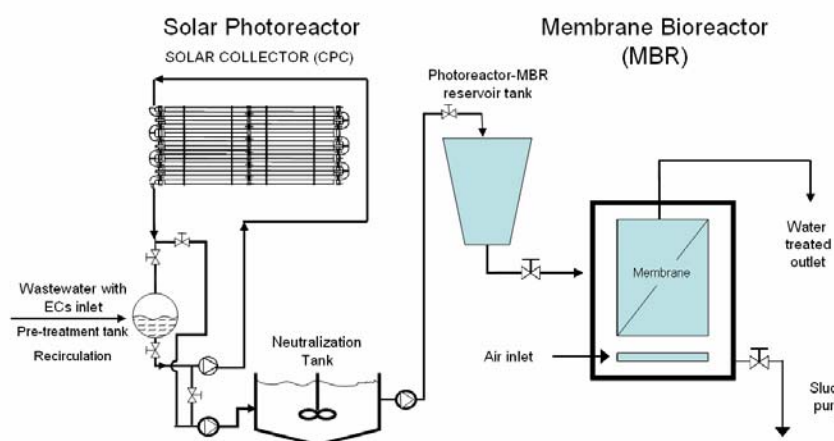


Figure 1. Solar Photoreactor – Membrane Bioreactor setup.

Results and discussion

There are previous studies (Oller et al., 2007) that show toxicity and non biodegradability of the selected pesticides. Thus, a pre-treatment with photo-Fenton is adequate to diminish the toxicity and increase biodegradability before a biological treatment. Complete pesticide degradation and dissolved organic carbon removal by photo-Fenton oxidation is shown in Figure 2 at 200 mg L⁻¹ of initial DOC. At early stages of the photo-Fenton reaction, molecules of pesticide are attacked by hydroxyl radicals giving rise to organic intermediates without a strong decrease in DOC concentration. In the present work, the beginning of the biological treatment was carried out just after the total pesticide degradation, when a mineralization degree of 35% had been reached.

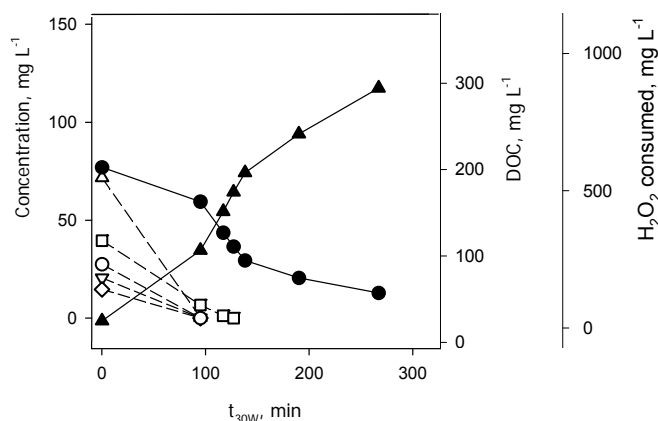


Figure 2. Complete pesticides degradation by photo-Fenton treatment.
(DOC—●, hydrogen peroxide—▲, oxamyl—△, methomyl—▽, imidacloprid—◇, dimethoate—○ and pyrimethanil—□)

Pre-treated water with 130 mg L⁻¹ of dissolved organic carbon given by pesticide intermediates of the photo-Fenton reactions was neutralized to pH 7 and enriched with a biodegradable C-source as previously described to simulate mixing with an urban wastewater. Consequently, the integrated process is carried out under more pragmatic conditions like in a WWTP, where different sources of carbon are present. DOC concentration at the start of biotreatment was 500 mg L⁻¹ (26 % from pesticide wastewater pre-treated by photo-Fenton). Steady state DOC concentration in the outlet of the biological treatment in the MBR was 49 mg L⁻¹, the biomass concentration (VSS) inside the MBR was 12.3 g L⁻¹, giving a C-uptake rate of 810 mg DOC L⁻¹ h⁻¹ and a specific uptake rate of 65.85 mg DOC mg VSS⁻¹ h⁻¹. Similar experiments were carried out in previous works using a sequencing batch reactor. In this case, for 7.8 hours of cycle, the steady state DOC concentration in the outlet of the biological treatment with adapted sludge was 55 mg L⁻¹, the biomass concentration (VSS) inside the reactor was 2.5 g L⁻¹, giving a C-uptake rate of 45.5 mg DOC L⁻¹ h⁻¹ and a specific uptake rate of 18.2 mg DOC mg VSS⁻¹ h⁻¹.

Conclusions

Combined solar photo-Fenton and membrane bioreactors is an effective approach for the treatment of wastewaters polluted with pesticides. The higher carbon removal rate obtained with MBR compared with conventional biotreatment points out the presented integrated process as an alternative for toxic wastewater treatment.

Acknowledgments

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TECHNO-ECONOMIC STUDY OF A PILOT-SCALE MBR PLANT FOR PHARMACEUTICAL WASTEWATER TREATMENT

Chia-Yuan Chang*, Che-Jung Chang*, Jing-Song Chang*, Saravanamuthu Vigneswaran** and Roger Ben Aim***

*Department of Environmental Engineering and Science, Chia Nan University, Tainan 71710, Taiwan. Email : mcychang@mail.chna.edu.tw

**Faculty of Engineering, University of Technology, Sydney, Australia. Email: Vigid.Vigneswaran@eng.uts.edu.au

***International Filter Testing Services (IFTS), France. Email: RBenaim47@aol.com

keywords: membrane bioreactor, pharmaceutical wastewater, economic assessment

Introduction

The use of membrane bioreactor (MBR) in wastewater treatment is becoming increasingly important, because they offer several advantages, i.e. high biodegradation efficiency, smaller footprint, and less sludge production [1]. However, the application of the MBR in treatment of pharmaceutical wastewater is still in its infancy and various aspects of techno-economic evaluations still received little or no attention to date [2,3]. This paper presents the technical and economic assessment of a pilot-scale MBR plant for the treatment of pharmaceutical wastewater in Southern Taiwan Science Park (STSP).

Objectives

A pilot-scale MBR plant for pharmaceutical wastewater treatment was designed, installed and has been run for a period longer than 1000 days. Regulation requires the COD of the wastewater should be reduced to below 450 mg/L in order to be discharged into a tertiary treatment plant in the STSP Administration which has an effluent COD limit of 50 mg/L. This paper presents the performance of the MBR pilot based on the initial 140 days of on-site experience. On the other hand, an economic assessment was conducted based on the results obtained from the test operation to determine the investment and operating costs required for the pilot.

Materials & Methods

Figure 1 shows the pilot scale MBR plant used to treat wastewater from a pharmaceutical company. The influent to the MBR system consisted of real pharmaceutical manufacturing wastewater and septic tank effluent. The characteristics of the wastewater are indicated in Table 1. The system consisted of two tanks with a total volume of 20 m³. The first tank is a biological tank (10 m³) and the second tank has a dual function of biological reaction with solid-liquid separation. The suction pump was stopped for 30 seconds after 4 minutes of filtration to allow membrane relaxation. Two modules of membrane (Motimo Co., China) were employed in the second tank to alternatively accommodate the pumping and relaxation mode exchange operating mode. For each membrane, 54 minutes of membrane operation (12 cycles of suction-relaxation) was followed by 6 minutes of backwash by permeate. Table 2 shows the characteristics of the membrane. The operating parameters are shown in Table 3.

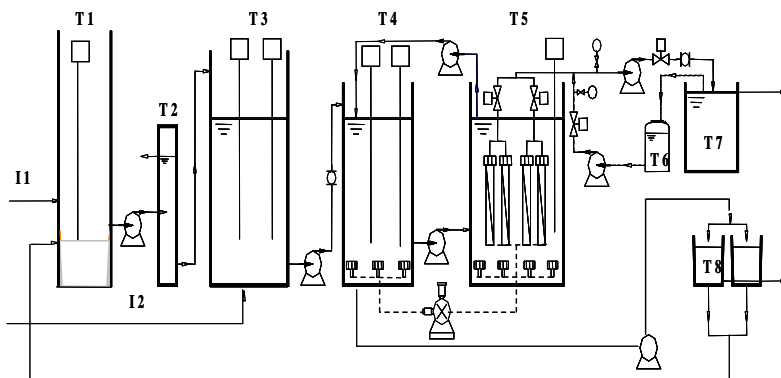


Figure 1: Schematic diagram of the MBR pilot system for pharmaceutical wastewater treatment. I1 influent from pharmaceutical manufacturing processes I2 influent from septic tank effluent T1 wet well T2 solvent-liquid separation T3 equalization tank T4 biological tank T5 membrane bioreactor T6 backwash tank T7 effluent tank T8 sludge drying bed

Table 1 Characteristics of the raw wastewater

Characteristic items	Range
Temperature (°C)	18.5 ~ 25.1
pH	6.6 ~ 9.4
SS (mgL ⁻¹)	60 ~ 360
COD _{Cr} (mgL ⁻¹)	800 ~ 11800
BOD ₅ (mgL ⁻¹)	100 ~ 6350

Table 2 Characteristics of hollow fiber membrane*

Characteristic parameter	module
Material	PVDF
Internal/outer diameter (µm)	650/1000
Pore size (µm)	0.1
Fiber length (cm)	90
Number of the hollow fibers	4220

Results and discussion

Figure 2 illustrates the influent and effluent quality of the MBR in terms of COD. COD effluent was remarkably stable and with a highest removal efficiency of 96%. This result may be attributed to the mass loading in MBR tank which was generally low and in the range of 0.003~0.079 kg CODkgMLVSS⁻¹d⁻¹. Moreover, COD organic loading to the biological tank was in the range of 0.099~6.844 kg CODm⁻³day⁻¹ and 0.011~0.408 kg COD m⁻³day⁻¹ to the membrane tank. Figure 3 shows that the plant can be operated with a high biomass concentration by using membranes for sludge separation. MLSS concentration in MBR tank was maintained in the range of 6000~17000

mg/L and excess sludge was wasted in accordance with the sludge growth rate (average SRT > 40 days). As shown as Figure 3, the variation of MLSS could be classified into two stages. The trend in the MLSS growth rate during the first stage (day 1 to day 60) was slowly rising followed by a sharp increase during the second stage. This is partly attributed to the influent COD concentration during stage 2 being on average higher than during stage 1. The average sludge production during stage 1 and 2 were 0.035 kgSS/kgCOD and 0.072 kgSS/kgCOD respectively, which is much less than the conventional activated sludge process (0.2~0.3 kgSS/kgCOD). Although the MLSS concentration was higher than 6,000 mg/L, the treated water was free of suspended solids due to the complete rejection by the membrane. Figure 4 illustrates the variations of TMP and flux during the monitoring period. The membrane module was withdrawn for cleaning on days 43 and 92 to remove clogging. Chemical cleaning was carried out on day 102 by inside-out type washing (as shown in Figure 4). It was found that the clogging occurred periodically within about 40 days. It can be seen that there was an abrupt raise of TMP from 10 to 38 kPa prior to the second manual cleaning and the same phenomena was observed before the first manual cleaning. The TMP varied from 9 to 55 kPa with the flux change from 16-64 Lm⁻²h⁻¹. However, the TMP kept within a range of 10-25 kPa over most of the period of operation. It demonstrated that less power consumption is needed for the immersed membrane system than for the pressure driven type of membrane. Based on the results obtained from the pilot-scale operation, the treatment costs were evaluated. The values for different cost categories are shown in Table 4. Depending on the throughput, the specific running costs was calculated to be within the range of 1.27 to 1.75 €/m³ (including capital costs and cost accounting depreciation).

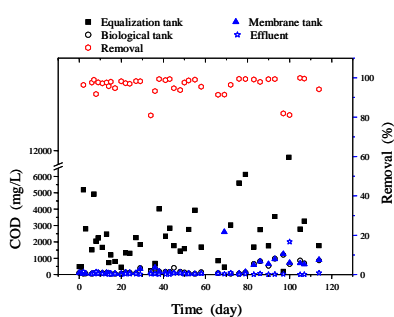


Figure 2: Variations and removal of COD

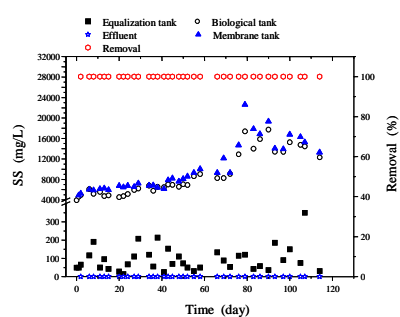


Figure 3: Variations of MLSS and SS

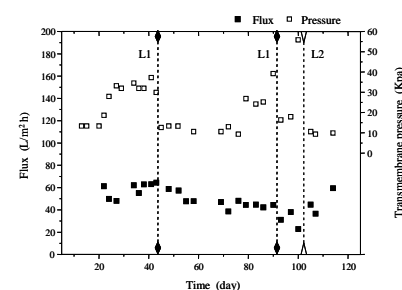


Figure 4: Variations of flux, TMP and the cleaning of membrane (L1 manual cleaning, L2 chemical cleaning)

Table 3 MBR pilot plant operating conditions

Item	value
Design flow (m ³ d ⁻¹)	10
Biological tank volume (m ³)	10
Membrane tank volume (m ³)	10
SRT (days)	> 40
Mixed liquor recycle ratio	5
pH range	6-8
Temperature (°C)	16-28
F:M ratio of biological tank (kg COD kg ⁻¹ MLVSS ⁻¹ d ⁻¹)	0.014~0.65
F:M ratio of membrane tank (kg COD kg ⁻¹ MLVSS ⁻¹ d ⁻¹)	0.003~0.079
Volumetric loading rate of biological tank (kg COD m ⁻³ day ⁻¹)	0.099~6.844
Volumetric loading rate of membrane tank (kg COD m ⁻³ day ⁻¹)	0.011~0.408
Flux (m ³ m ⁻² d ⁻¹)	0.384~1.536

Table 4 Economic evaluation of the treatment costs of the pilot-scale MBR plant

General information:	
Plant capacity, m ³ h ⁻¹	0.417
Maximum COD, mgL ⁻¹	11,800
Annual operating time, h	8,280
Flow, m ³ /a	3,453
Total investment, €	10,400
(Plant including membranes)	
Annual operating costs, €:	
Depreciation	2,080
Energy	1,680
Chemicals	290
Excess sludge disposal	310
Maintenance	580
Membrane replacement	125
Interest	52
Annual costs, €:	5,117
	1.48

Conclusions

The test operation for the treatment of pharmaceutical wastewater with a pilot-scale MBR plant to meet the effluent standard was successfully completed. This investigations carried out demonstrated clearly the benefits and economical feasibility of membrane bioreactor applications for pharmaceutical industry.

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ADVANCED ANALYSIS OF POLYSACCHARIDES IN MBR FOULING BY CHROMATOGRAPHY

Charlery, C.*, Drews, A.*^{****}, Kraume, M.*, Kroh, L. W.**

*TU Berlin, Fachgebiet Verfahrenstechnik, MA 5-7, Str. des 17 Juni 136, 10623 Berlin, matthias.kraume@tu-berlin.de

**TU Berlin, Fachgebiet Lebensmittelchemie und Analytik, TIP 3/4-1, Gustav-Meyer-Allee 25, 133355 Berlin, lothar.kroh@tu-berlin.de

***now working with: University of Oxford, Dept. of Eng. Sci., Parks Rd, Oxford OX1 3PJ, UK, anja.drews@eng.ox.ac.uk

keywords: polysaccharides, oligosaccharides, thin layer chromatography, SEC, ion exchange chromatography

Introduction

Membrane fouling is a major cost factor in MBR operation. Despite about a decade of worldwide research, many fundamentals of fouling are still poorly understood. This can be partly attributed to the complexity of the interacting phenomena but also to the fact that in foulant identification, mostly surrogate parameters are used to analyse the potentially relevant group of so-called "polysaccharides (PS)" although they also contain oligo and monomeric carbohydrates. In addition, influent carbohydrate concentrations and the effect of partial carbohydrate retention by the membrane are surprisingly often overlooked. Real feeds obviously contain very different amounts and types of carbohydrate depending on the origin of the wastewater and the residence time in the (anaerobic) sewers. This neglect of influent values and membrane retention on the accumulation of soluble microbial products (SMP) in the tank might have led to the general perception of SMP production or release whenever an increase in SMP concentrations is observed. A simple mass balance, however, reveals a net carbohydrate or SMP elimination of typically about 80 %, and that only under extremely adverse conditions a net release can be observed (Drews et al. 2006, 2008). Wang et al. (2009) found a wider molecular weight spectrum in the biomass than in the feed. Hence, it is appropriate to speak about net elimination because apparently the disappearance of SMP by adsorption, biodegradation etc. can be accompanied by the release of a smaller amount of different products and thus cause a shift in the molecular weight spectrum. This, on the other hand, can also be brought about by partial retention.

Objectives

In this work, more detailed analyses of carbohydrates in the feed, biomass, permeate and on the membrane are applied to identify specific groups. For these, paths through the plant shall be sketched and their individual fouling relevance shall be determined.

Materials & Methods

Size exclusion chromatography, thin layer and ion exchange chromatography were used to analyse carbohydrates in the feed, supernatant and permeate from a municipal MBR pilot. Filtration trials with the same biomass were carried out to obtain membrane samples from which could be extracted for further chromatographic analysis. To identify individual monomers, samples were hydrolysed by sulfuric or hydrochloric acid and analysed by ion exchange chromatography.

Results and discussion

Size exclusion chromatography showed that the biomass supernatant contained more high and less low molecular weight components than the feed. All samples contained D-glucose derived compounds with a degree of polymerisation (DP) equal to three, with more of these three D-glucose-units (DP₃) compounds present in the feed

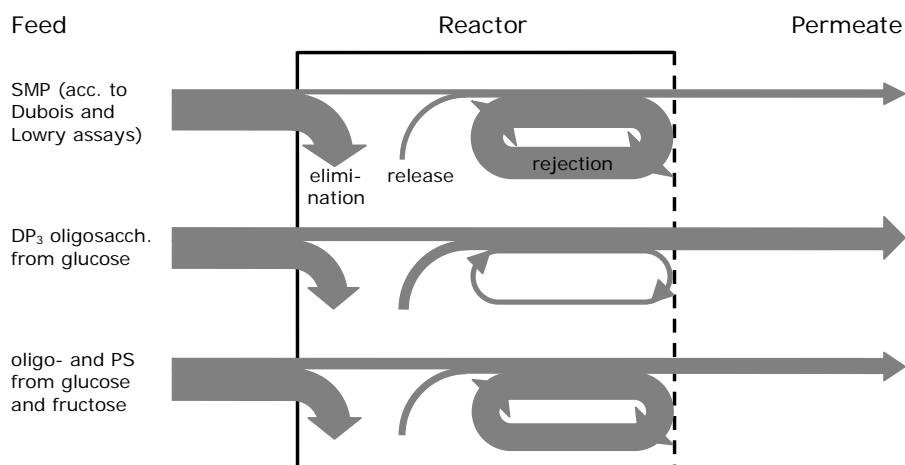


Figure 1: Schematic Sankey diagram to illustrate the potential flow and fate of various (groups of) compounds

and similar amounts in the sludge and permeate. Ion exchange chromatography of hydrolysed samples revealed that in contrast to the sludge and feed, very little D-glucose and D-fructose derived oligo- and polysaccharides are present in the permeate. Thin layer chromatography of hydrolysed membrane extract confirmed that D-glucose derived oligo- or PS are retained, as well as D-xylose and to a lesser extent D-arabinose, L-rhamnose and D-fructose derived compounds. In Fig. 1, a half-quantitative summary of these findings is illustrated. If similar amounts are present in the feed and

in the supernatant but only very little in the permeate, this can only mean that a large amount is eliminated, which is apparently especially true for SMP as a whole but also for D-fructose and D-glucose derived oligo- and polysaccharides. Oligosaccharides with three D-glucose-units on the other hand easily pass through the membrane and thus seem to play a minor role in fouling. Typical surrogate analysis, however, would include them which shows that the Dubois method cannot be used as a measure for fouling.

Conclusions

Detailed chromatographic analyses of oligo- and polysaccharides in MBR feed, supernatant and permeate showed that commonly used surrogate parameters cannot reflect membrane rejection and fouling propensity. A considerable amount of oligosaccharides can be present which would contribute to an overall carbohydrate or "polysaccharide" concentration, but passes the membrane almost completely.

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LONG TERM OPERATING EXPERIENCE WITH PILOT PLANT MBR USING SUBMERGED HOLLOW FIBER MEMBRANE

J.H. Chung *, Y.R. Heo*, J.H. Lee*, E.S. Lee*

*Daewoo Institute of Construction Technology, 60 Songjuk-dong, Jangan-Gu, Suwon, Gyeonggi-Do, Korea
(E-mail : detangle@dwconst.co.kr; rocky@dwconst.co.kr; janghlee@dwconst.co.kr; euisin@dwconst.co.kr)

keywords: wastewater reuse, Submerged Membrane Bioreactor(SMBR), ferric chloride, SAD_p

Introduction

Wastewater reclamation and reuse has been a center of recent research for water resources preservation and water pollution control. Adoption of membrane bioreactor(MBR) has enhanced for wastewater reuse because of its benefits such as higher effluent quality in terms of organic and nutrients. Especially, SMBR(Submerged Membrane Bioreactor) process has been recognized as important alternative for conventional activated sludge process due to its less space requirements, perfect solid-liquid separation and stable operation & management. But common submerged MBR process which installed membrane within aeration tank has defect in terms of cost and effectiveness because of excess air consumption for membrane fouling control. And in the view of effluent quality, extra carbon sources are needed to reuse treated water as high quality reclamation water because of low raw water C/N ratio in Korea.

Objectives

This study was conducted for high quality effluent water production not only for river stream restoration, but also for various application of reclaimed water. This study has focused on minimum injection of extra carbon source and minimum air injection into aeration tank by isolated membrane tank from aeration tank. And organization of low cost, high efficiency process was possible with minimized tank volume by installing highly - integrated membrane module in the membrane tank.

Materials & Methods

100 □/day scale pilot plant in “A” STP of Gyeonggi province was operated to investigate effluent quality and membrane fouling condition. The schematic diagram of the submerged membrane bioreactor (SMBR, Process B) which was used in this study is presented in Figure 1. The system consisted of hydra-sieve screen which has 1.0mm diameter, bioreactor, and membrane filtration and the bioreactor was divided into pre-denitrification, nitrification, post-denitrification and membrane reactor. MBR process (Process A) consisted of membrane – coupled MLE process (anoxic-oxic tank) was operated in same condition for comparison with objective process. HRT, SRT was 8 hrs, 35days each, internal recycle ratio for denitrification was 1Q and sludge was recycled by 1.5Q to maintain equally microorganism concentration in membrane tank and other reaction tanks. Ferric chloride was directly added to solve difficulty in phosphorus removal due to long SRT. Ferric chloride injection rate was calculated 1 ℓ/d with equation by Yoon *et al.*. Every measurement was conducted by Standard Methods and HACH DR/2800 was used.

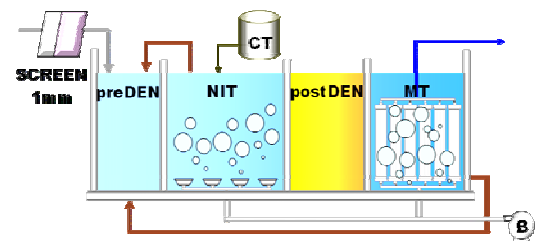


Figure 1: Schematic diagram of SMBR(Process B).
preDEN=pre-denitrification, NIT=nitrification,
postDEN=post-denitrification, MT=membrane tank,
CT=chemical tank.

As shown in Table 1, Membrane used for the study was hollow fiber PTFE (poly-tetrafluoroethylene) MF membrane with nominal pore size 0.25 □ and 10 □/module of surface area. Flux and transmembrane pressure (TMP) was continuously monitored and CIP was periodically conducted once a week with 500 mg/ℓ NaOCl and 40 mg/ℓ NaOH mixed solution. The specifications of the two MBR systems used in this study are shown in Table 1.

Table 1. Operating and design conditions of the two MBR systems

Item	Process A (Control)	Process B (This study)
Flow rate		100 m ³ /d
HRT		8 hr
SRT		35 day
MLSS	8,000 ~ 10,000 mg/ℓ	
Internal Recirculation Rate		100 %
Sludge Recirculation Rate	-	150 %

Material	Hydrophilic poly-tetrafluoroethylene (PTFE)
Pore size	0.25 μ
Membrane Module type	Hollow fiber
O.D./I.D.	2.0/1.0 mm
Flux	25 L/m ² /hr

Results and discussion

Figure 2 shows T-N concentration variation during operation. Average T-N concentration of process A effluent was 8.2(5.0 ~ 12.3)mg/l with 76.4% of removal rate but in case of process B, average T-N concentration was 5.6(4.1 ~ 7.1)mg/l with 84.5% of removal rate which is less 2.6 mg/l than process A. This is assumed because remained nitrate which is almost perfectly (99%) nitrified without recycling, was denitrified by endogenous respiration in post-denitrification tank due to low average 3.7(2.9 ~ 5.3) C/N (BOD/TKN) ratio in influent water.

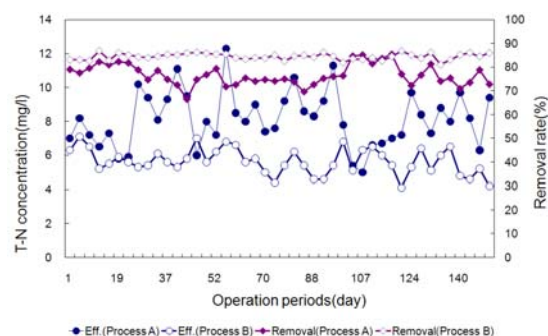


Figure 2: The variation of T-N effluent concentrations and removal efficiency in process A and process B

Figure 3 shows T-P concentration variation during operation. From the start of operation to 65 days, Influent T-P concentration, average T-P concentration and removal rate was 5.4 mg/l, 2.3 mg/l and 59.8%, each. But after 65 days with ferric chloride injection, average concentration of T-P and removal rate was 0.5 mg/l, 90.7% each which is better than previous operation.

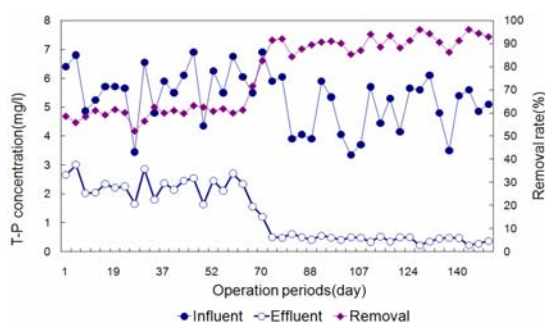


Figure 3: The variation of T-P influent and effluent concentrations and removal efficiency in process B

And average BOD, T-N concentration was 1.6, 5.5 mg/l each with ferric chloride injection which is better than 2.0, 6.0 mg/l without ferric chloride injection. This result shows that direct ferric chloride injection brought not only chemical phosphorous removal but also better effluent quality with reaction of metabolic microorganism byproduct. Isolated membrane tank from aeration results minimization of Bio-Process Air consumption for nitrification by concentrated blowing of Cleaning Air into limited area. During operation, 24% of air consumption was reduced in terms of SAD_p(m³ air/m³ permeate) which is 25 in process A and 19 in process B.

Conclusions

In this study, 100 m³/day pilot scale application of low cost and high efficiency MBR process with high quality effluent and air consumption reduction was estimated and the conclusions are as follows.

In comparison with process A, process B with post-denitrification tank shows better T-N removal rate by 2.6 mg/l of difference. Direct injection of ferric chloride brought better result in comparison with no injection of ferric chloride in terms of nitrogen, phosphorous and organic matter removal. And isolated MBR tank from aeration tank shows 24% lower SAD_p value.

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INDUSTRIAL XENOBIOTICS REMOVAL FROM URBAN WASTEWATER IN MEMBRANE BIOREACTORS: PILOT AND FULL SCALE EXPERIENCES IN ITALY

Di Fabio S.*, Fatone F.*, Bolzonella D.*, Cecchi F.*

*Department of Biotechnologies, University of Verona. Strada Le Grazie 15, Cà Vignal 1, 37134 Verona, Italy
sildifa@yahoo.it; francesco.fatone@univr.it; david.bolzonella@univr.it; franco.cecchi@univr.it

keywords: membrane bioreactors, micropollutants, pilot and full scale

Introduction

Anthropogenic inputs of industrial xenobiotics to aquatic systems has led to relevant chemical pollution of natural waters which has already become a major public concern (Schwarzenbach *et al.*, 2006). In contrast to the long-term strategies which aim at reducing the use of critical chemicals and to treat the existing contamination, the end-of-pipe pollutant mitigation is occurring at much shorter time scale. Dealing with urban wastewaters, the membrane bioreactors (MBRs) were widely indicated as one of the most promising modification to intensify the conventional activated sludge process (CASP) also in relation to micropollutants removal (Cecchi *et al.*, 2003; Innocenti *et al.*, 2002; Fatone *et al.*, 2005; Joss *et al.*, 2008). However, notwithstanding the huge and valuable lab-scale research carried out MBRs and micropollutants removal, there is still a lack of information regarding removal of trace xenobiotics from urban wastewater in pilot and/or full scale MBRs. Therefore, the actual convenience of MBRs for xenobiotics removal from urban wastewater can be considered almost unknown.

The poster will summarize the main result of our 9 years-long studies carried out on pilot and full scale MBRs for urban wastewater treatment focusing on the removal of industrial xenobiotics such as heavy metals, industrial (petro)-chemicals (BTEX and PAHs) and products (PCBs and HCB).





Objectives

This paper shows the results of 9 years of activity on MBRs (pilot, demonstration and full scale Membrane Bioreactors) treating real urban wastewater of different composition. The objective of the activity carried out is twofold: to know the presence and the form (i.e.: dissolved or associated to suspended particulate) of industrial xenobiotics in the urban wastewater and, contemporary, estimate the MBR contribute to their removal (in particular the direct sieving effect and the influence of process parameters as sludge age and solid content). Moreover, the comparison with CASPs operating in parallel with the pilot and demonstration MBRs will allow to globally quantify the actual process intensification linked to the MBR application. These will be evaluated in the different experiences so to find out if different cases would have had similar behaviour. Target compounds were more than 80, among them are heavy metals, PAHs, Volatile Organic Solvents (BTEXs), PCBs, HCB.

Materials & Methods

The experimentations considered for this study were carried out through MBRs equipped with hollow fibre UF membranes (ZeeWeed®500) and the main details are given in Table 1.

Table 1: different studies carried out on MBRs

			
<p><i>When:</i> 1999-2002 <i>Reaction volume:</i> 1,4 m³ <i>Flowrate:</i> up to 20 m³/d <i>Influent:</i> mixed urban/industrial wastewater</p> <p>AND</p> <p><i>When:</i> 2003-2005 <i>Reaction volume:</i> 4,3 m³ <i>Flowrate:</i> up to 20 m³/d <i>Influent:</i> urban wastewater and municipal landfill leachate</p>	<p><i>When:</i> 2004-2007 <i>Reaction volume:</i> 22 m³ <i>Flowrate:</i> up to 75 m³/d <i>Influent:</i> mainly domestic wastewater</p>	<p><i>When:</i> February 2005 on <i>Reaction volume:</i> 2200 m³ <i>Flowrate:</i> up to 6000 m³/d <i>Influent:</i> urban wastewater</p>	<p><i>When:</i> October 2007 on <i>Reaction volume:</i> 4,3 m³ <i>Flowrate:</i> 6÷7 m³/d <i>Influent:</i> industrial (petrochemical) pre-treated wastewater</p>

In order to evaluate the actual differences and possible advantages with respect to the CASP, the occurrence of a number of the same industrial xenobiotics in wastewaters entering to Italian urban WWTPs was investigated monitoring seven urban full scale plants with treatment capacity from 12 000 to 700 000 Population Equivalent (PE) and with different fractions of mixed civil and industrial wastewaters, coming from industries located in the catchments area. The monitoring was carried out also analysing the xenobiotics in the main sections of the CASPs plants, so to find the final destiny of the pollutants and possible differences in the MBRs (i.e.: due to the different pretreatments).

Results and discussion

The study of the micropollutants in the different main sections of the full scale plants allowed us to evaluate the role of the different operation units, so to estimate, for instance: (1) the xenobiotics (i.e.: metals and PAHs) adsorbed to larger suspended particles (grit and sand); (2) the influence of the membrane as solid/liquid separator; the function of MBR, as more flexible way to manage the activated sludge process. As a result, pre-treatments (degritting and sand removal) played an important role, in fact metals (up to 10÷20%, depending on the metal adsorption capacity), PAHs (in the range 20÷40%) and BTEXs (40÷60%) were significantly removed in this step, so to demonstrate the actual xenobiotics contamination of the grit and sand removed in WWTPs. As expected, the activated sludge section was responsible for the additional major removal of metals (9÷90%), while PAHs were removed for additional 20÷50% and BTEXs for 10÷50%. As for the role of the MBR, with respect to the conventional activated sludge system, MBRs enhanced the removal of Cr, Cu, Ni. Hg and Cd were effectively removed also in the conventional system followed by gravitational final secondary clarifiers. Major problems were found for the As removal, while the Pb underwent similar removals both in the conventional and in the membrane system. This major performances were attributed to the enhanced sieving effect rather than to operating biological parameters (i.e.: sludge age more than 1000 days). On the other hand, no significant improvement of the removal of PAHs and VOCs were found in MBRs, which were already under the limit of quantification in the secondary effluent from conventional plants.

Conclusions

The paper deals with the occurrence, removal and final fate of heavy metals, PAHs and BTEXs in urban conventional WWTPs and MBRs, evaluated through pilot, demonstration and full scale experiences. The main evidences point out the important role of the pretreatments, which remove a large fraction of xenobiotics adsorbed to the suspended particles. The MBRs played a relevant role for heavy metals removal, while PAHs and BTEXs undergo to comparable removal in conventional and membrane assisted activated sludge plants. As for the metals: (1) respect to CASP, MBRs are not effective to enhance the Hg removal Except for Ni, the metals removal in MBRs for “municipal” applications is mostly dependent on chemical/physical aspects; (2) The further membrane effect was stable and permanent for Cu, Cr, Pb, while the effect on Ni was less remarkable. This gives ideas on the possible binding sites preferred for the metals and the capacity of the membrane to retain them; (3) Further investigations are needed for Ni which removal seemed metabolism dependent and favoured by high SRTs The main advantage from MBRs seems to come from the enhanced sieving effect, rather than the different operating parameters of the biological process. This is probably due to the fact that biodegradation/biotransformation was considered a minor removal mechanisms for the analyzed compounds.

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INFLUENCE OF NITRIFIERS ON SMP CONCENTRATION, REJECTION AND FOULING IN MBR

Drews, A.^{****}, Charlery, C.^{*}, Kroh, L. W.^{**}, Kraume, M.^{*}

^{*}TU Berlin, Fachgebiet Verfahrenstechnik, MA 5-7, Str. des 17 Juni 136, 10623 Berlin, matthias.kraume@tu-berlin.de

^{**} TU Berlin, Fachgebiet Lebensmittelchemie und Analytik, TIP 3/4-1, Gustav-Meyer-Allee 25, 13355 Berlin, lothar.kroh@tu-berlin.de

^{****}now working with: University of Oxford, Dept. of Eng. Sci., Parks Rd, Oxford OX1 3PJ, UK, anja.drews@eng.ox.ac.uk

keywords: SMP, proteins, polysaccharides, nitrite, nitrifiers

Introduction

The compounds currently most often mentioned in relation with fouling are the so-called soluble microbial products (SMP), which depending on the applied sample preparation and analytical technique contain soluble and colloidal biopolymers, mostly polysaccharides (PS) or carbohydrates, and proteins. Mainly colloidal PS have been blamed to cause fouling (e.g., Rosenberger et al. 2005). One gets the impression that the responsibility of SMP or PS has already generally been agreed on, however, there has always been some contradiction on their fouling properties and the factors governing their occurrence. E.g., SMP fouling propensity was found to be higher under severe limitations or under fluctuating feed conditions (Evenblij et al. 2005, Drews et al. 2006). It therefore seems advisable to further differentiate under which conditions they can be held responsible. Like bound EPS, SMP can be present in varying amounts and have no fixed composition, i.e., two samples with equal net SMP concentration can exhibit largely different behaviour. A variety of operating and ambient conditions like temperature or the availability of oxygen sources for PS mineralisation can influence both occurrence and properties of SMP, especially in a heterogeneous system like activated sludge where population dynamics are also subject to changes. Besides DO, nitrate concentrations appear to have an impact on SMP elimination and thereby on SMP concentration with SMP elimination being lower at low availability of these oxygen sources (Drews et al. 2007). On the other hand, this could also be an indication of a particular role that nitrifiers play in SMP formation/elimination.

Objectives

By uncoupling some of the interrelated effects of several ambient conditions, the relevance of nitrifiers and of nitrogen compounds for SMP formation/elimination, rejection and fouling propensity shall be investigated.

Materials & Methods

A number of well defined lab trials were carried out with municipal MBR sludge using a 1 L stirred bioreactor with a UF membrane (PAN, 37 nm) placed around the inside of the wall (Drews et al. 2007). This reactor was continuously fed with domestic wastewater at HRT = 3.6 h to represent a typical residence time in aerobic MBR tanks which was chosen because aerobic elimination of SMP was thought to be completed there. DO concentration and temperature were controlled, and to study the effect of nitrate concentration, defined amounts of sodium nitrate were dosed to the feed. In order to decrease nitrate concentration in some runs, allylthiourea (ATU) was added which inhibits ammonia oxidation and thus prevents nitrate build-up.

Results and discussion

Temperature was found to impact on SMP retention and on temperature corrected fouling rate; both were higher at low temperatures. DO concentration showed no unambiguous influence on rejection. However, the concentration of nitrogen compounds did. Lowering temperature caused an immediate rise in supernatant SMP concentration accompanied by an increase in rejection. Apparently, large molecules were produced or – maybe more likely considering the effect of temperature on reaction rates – less large molecules entering the plant were eliminated. This effect was reversible when temperature was increased again. Inhibiting nitrifiers by ATU addition, too, immediately increased rejection. While temperature caused a rejection change mainly through a change in sludge supernatant concentration, the addition of ATU changed both sludge and permeate concentrations. Since rejection was almost unaffected by temperature in the presence of ATU, it is concluded that temperature only has an indirect effect on rejection by decreasing nitrification rates at low temperatures. In further runs with ATU addition to different municipal sludge, an increase in PS and SMP rejection was repeatedly observed, however, unlike observed previously (Drews et al. 2007), sludge PS concentration did not always increase.

A slight correlation between ammonia oxidation rate and rejection could be observed. In three lab trials, however, no dependence of protein rejection on ammonia oxidation rates was found. In these runs, in contrast to the others, significant amounts of nitrite were detected, i.e., apparently nitrite oxidation was somehow inhibited. A roughly linear correlation between protein rejection and nitrite concentration was observed (see Fig. 1) in these three trials. Rejection increase was mainly due to a decrease in permeate concentration. W.r.t. PS, elevated rejection and very high concentrations of up to 150 mg/L were found in a pilot plant during a period of low nitrification activity (and increased nitrite concentrations), however, at the same time, fouling was rather low (Drews et al. 2008). This could indicate that under these conditions SMP were mainly too large to cause internal fouling but rather formed a loose

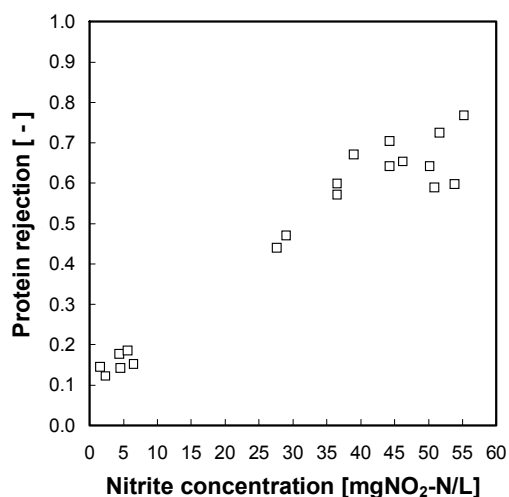


Figure 1: Protein rejection vs. nitrite concentration in a lab-scale MBR trial with inhibited nitrite oxidation (Drews et al. 2007)

2009). While it is yet unclear if this only accidentally happened in parallel, it gives another indication of the potential importance of N-components even at full scale. One reason for lower nitrate concentrations could be an inhibition of nitrite oxidation, which, as mentioned above could cause a lack of small SMP which could penetrate and thus block the pores. More investigations, however, are necessary to support this hypothesis.

Conclusions

Especially protein rejection was found to be influenced by nitrification activity and thus by temperature. Nitrite oxidisers seem to be responsible for the formation of smaller SMP compounds that can pass the membrane. The build up of nitrite might thus be used as an indication of increased SMP rejection or lower permeate concentration. Further microbiological investigations and more detailed analyses of individual compounds or biopolymer spectra are necessary to confirm this hypothesis.

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cake. The inhibition of nitrite oxidisers therefore seems to be the most relevant one for the lack of SMP molecules that are small enough to enter and block the pores and to pass through the membrane. The typical influence of pH on protein retention which increases with pH was found to be completely opposite in the presence of nitrite, which supports the hypothesis that nitrite oxidisers play a significant role in determining the properties of SMP.

By fractionation, Geilvoet et al. (2006), too, showed that proteins and PS present in denitrification, nitrification and membrane tanks, i.e., in different environments in terms of DO but also N-compounds concentration, can have rather different sizes.

In the full size MBR Monheim (Wedi et al. 2005), high fouling occurred during periods of high nitrate concentrations. Over 3 years, temperature corrected permeability followed the nitrate profile closer than it followed the temperature profile (Kraume et al.

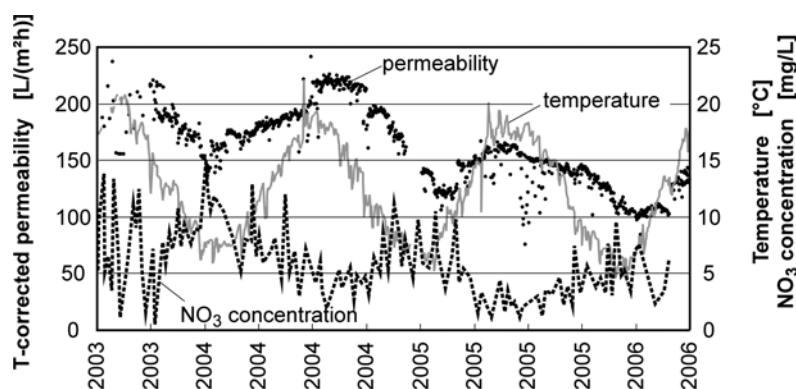


Figure 2: Permeability, temperature and nitrate concentration in 9700 p.e. MBR Monheim (Kraume et al. 2009)

OPTIMIZATION OF SUBMERGED MEMBRANE BIOREACTOR PROCESS FOR WASTEWATER TREATMENT BY MINIMIZING THE FOULING PHENOMENON

Javier Etxebarria, Deiene Iturbe, Ana Urkiaga

GAIKER Technological Centre

Parque Tecnológico, Edificio 202, 48100 Zamudio, Spain

Tel: +34 946002323, Fax +34 946002324, E-mail address: etxebarria@gaiker.es

Keywords: Activated sludge, Membrane, Membrane fouling, Submerged Membrane Bioreactor (SMBR), Ultrafiltration

Abstract

Submerged membrane bioreactor (SMBRs) processes for wastewater treatment are restricted by the membrane fouling. This fouling phenomenon during ultrafiltration is due to the interaction between the membrane material and the mixed liquor components. In fact, the process is strongly influenced by three factors: biomass and wastewater characteristics, operational conditions and membrane characteristics [1].

In this work, a design of experiments was carried out in order to optimize a submerged membrane bioreactor process. For that, the sludge retention time (SRT), mixed liquor suspended solids (MLSS), the ratio of soluble COD and particulate COD in the influent and the aeration process were studied as well as the influence they have in the membrane fouling as a result of the interaction between them. Table 1 shows the working range of each variable. As a response of all these experiments, the concentration of extracellular polymeric substances (EPS) and the permeate flux were measured. EPS concentrations were determined as carbohydrate and protein, both measured colorimetrically by the methods of Dubois and Lowry, respectively [2].

Table 1. Working range of variables like SRT, MLSS, CODs/CODp and the aeration flux.

Variable	Working Range
SRT, d	5-20
MLSS, mg/L	8000-15000
CODs/CODp	0.5-3
Aeration flux	Low-high

All the experiments were performed with PVDF hollow fiber membranes which have an area of 1m² and a pore diameter of 0.4 μm (Figure 1). A synthetic wastewater was prepared to be used as the food source throughout this study, depending on the ratio of soluble COD and particulate COD. The pilot plant where all the experiments were carried out is shown in Figure 2.



Figure 1. PVDF hollow fiber membrane module.



Figure 2. Pilot plant of the submerged membrane bioreactor (SMBR) for wastewater treatment.

Finally, after having all the information, it was performed a statistical analysis in order to determine which variables or interaction of variables were the most significant for the membrane fouling.

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PURIFAST PROJECT

“ADVANCED PURIFICATION OF INDUSTRIAL AND MIXED WASTEWATER BY COMBINED MEMBRANE FILTRATION AND SONOCHEMICAL TECHNOLOGIES”

E. Fatarella*, I. Cioni*, I. Ciabatti **, E. Venturini degli Esposti*

* Next Technology Tecnotessile, via del Gelso 13 – 59100 Prato (ITALY), e-mail: chemtech@tecnotech.it

**current address: : European Commission, Research Executive Agency

keywords: textile wastewater; mixed wastewater, Ultrafiltration, Ultrasound

Introduction

With the need to safeguard the quality of freshwater supplies and reduce freshwater usage for potable purposes, there is the need to develop and demonstrate innovative technologies to increase the applications of wastewater reuse, in line with the objectives of the Environmental Technologies Action Plan (ETAP). This particularly concern both wet industries and municipalities where there is a high number of such industries, such as the textile industrial areas. In fact, the textile sector plays a critical role in this context, because textile companies are large users of water - typically 0.2-0.5 m³ are needed to produce 1 kg of finished product (Marcucci, 2001) – and they are historically concentrated in districts (e.g. Prato in Italy) located in Southern Member States, such as Italy, Spain and Portugal, which are facing more and more longer periods of drought and therefore are strongly in the need to preserve the availability of water for potable use. The finishing processes (i.e. pre-treatment, dyeing, printing and special finishing) are especially polluting and resource consuming in terms of water, energy and chemicals. Almost the entire of water used in textile production is discharged and, on average, the effluents volume covers 90-95% of the water used (Mattioli et al., 2002). Because it is a chemically intensive industry, the effluents contain significant amounts of a wide range of residues. Effluents from the dyeing and finishing processes usually contain: 50-5000 mg/L of COD; 200-300 mg/L BOD; 50-500 mg/L suspended solids; 18-39 mg/L organic nitrogen; 0.3-15 mg/L total phosphorus; 0.2-0.5 mg/L total chromium. Dyes are usually present in these effluents in concentrations of 10-50 mg/L. Colour is usually noticeable at concentrations above 1 mg/L and has been reported in effluent from textile manufacturing at concentrations exceeding 300 mg/L (Gonçalves et al., 2000).

Objectives

The main aim of the PURIFAST project is to demonstrate an innovative and efficient advanced wastewater treatment system for both textile and mixed municipal and textile effluents, in order to reduce the environmental impact of the “wet processes” implemented in the textile industry and to promote the wastewater reuse. Therefore, the application of this system, featuring ultrafiltration and sonochemical treatment, will allow to safeguard the water sources for potable use. The innovative process will be highly efficient in pollution degradation and therefore, in quantitative terms, it will offer the possibility to achieve high levels of reuse for industrial purposes – at least 60% when dealing with textile effluents and at least 80% when dealing with mixed effluents - with lower costs in comparison with the conventional AOP processes (e.g. ozonisation). In details, the following objectives will be targeted within this project:

- Demonstration of the technical and economical feasibility of an advanced wastewater treatment system based on ultrafiltration and an innovative AOP process (sonochemical treatment) for industrial effluents and mixed municipal and industrial effluents, especially textile effluents. The application of this system will allow preservation of the natural water resources in the European Union in terms of both quality and quantity, as wished by the EU environmental legislation. More specifically, the following reduction of pollutant content is expected to be achieved considering the effluents before the treatment: >75% as COD; >90% as BOD₅; >90% as TSS; >95% as colour, at costs competitive to other advanced treatment systems (0.60 Euro/m³ as operative cost).
- To build up and test pre-industrial scale prototypes for in situ validation of the advanced purification system applied to real textile wastewater from a representative industry and to real effluents of an industrial and municipal wastewater treatment plant, obtaining results that are transferable to other textile districts in the EU and other industrial districts such as those of the leather and pulp industry, e.g. Santa Croce sull'Arno (leather) and Lucca (paper) districts that are located in Tuscany as Prato. This will allow to fully exploit the wastewater potential reuse of several wet industrial sectors (see figure below).
- To enlarge and optimise the application of the ultrafiltration processes as tertiary treatment for mixed and textile effluents by: (1) comparing two different technologies (multibore membrane technology of Inge and hollow fibre membrane technology of Polymem), allowing to define the optimal configuration for the target effluents; (2) the application of an innovative control system based on neural nets.

- To enable the reuse of purified wastewater in textile production processes, with a significant reduction in freshwater consumption (at least 60% when dealing with textile effluents and at least 80% when dealing with mixed effluents) for industrial purpose. Hence, the project will also allow to define long-term and viable (on the economic and social efficiency viewpoint) Performance Targets for wastewater purification and reuse for industrial purposes by industries and municipalities in areas with an intensive textile production, as promoted by the EC through the objective “Performance Targets” of the ETAP.
- Dissemination of the results to industrial, institutional and research actors at national and international level to promote the use of purification plant for reuse of industrial effluents, meeting the objective “Awareness Raising and Training” of the ETAP.
- Reduction of the toxicity of the purified effluents compared to other AOP technologies.

Project structure

The work programme of the proposed project is composed of the following Actions:

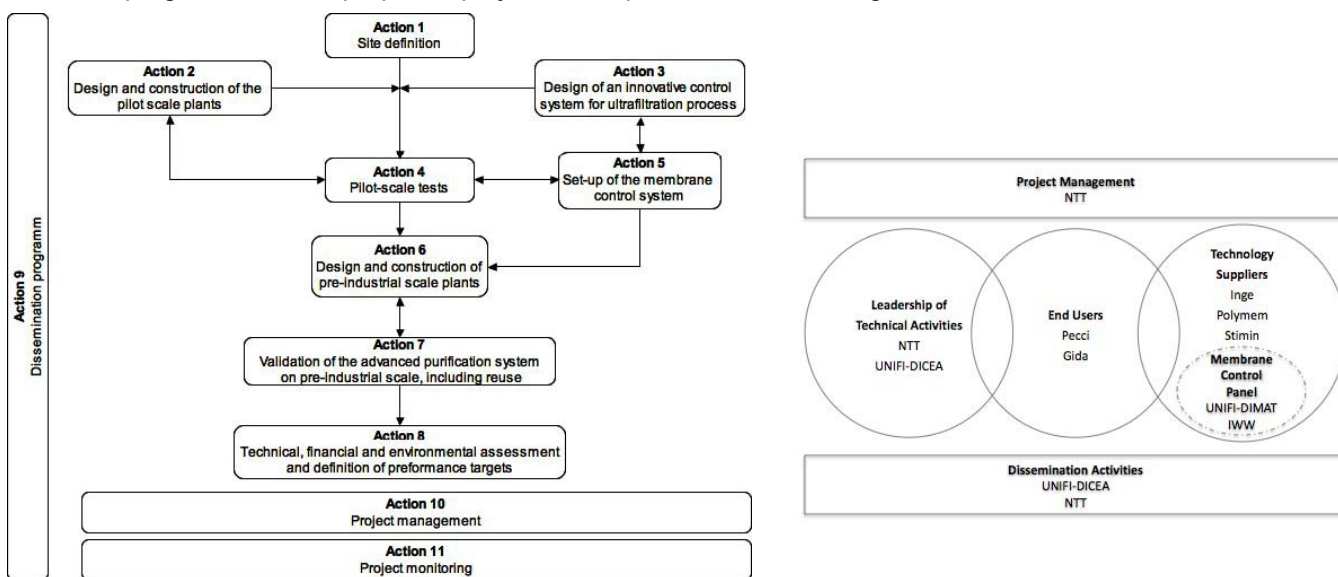


Figure 1 – Project Activity structure (PERT diagramm)

Figure 2 – Beneficiaries' role: NTT (Next Technology Tecnotessile); UNIFI-DICEA (University of Florence- Department of Civil Engineering); UNIFI-DIMAT(University of Florence- Department of Mathematic) Inge; Polymem; Stimin; Gida; IWW (IWW Rheinisch-Westfälisches Institut für Wasserforschung gemeinnützige GmbH)

The different actors involving in the project will have direct interest in the implementation of the innovative combined process for the wastewater treatments.

In fact, the implementation of the target technologies (Ultrafiltration and Ultrasound) can solve the problem related with the environmental and economical aspects related with the industrial wastewater and the combination of the experiences of the end-users and of the technology provide can help the textile industry to achieve the environmental target imposed by the European commission in terms of reuse and preservation of the primary water. The stakeholders involved in the project are composed by the different actors aimed to the definition of an efficient strategy for the preservation of the environment and for the optimisation of the water consumption at textile industry. The different partners will have an important role in the development (technology suppliers) and optimisation (management of technical activities and membrane control system) of the different technologies (Ultrafiltration and Ultrasound) that will be implemented at the end-users.

The benefits in the implementation of the target technologies, according to the environmental legislation, will be promoted to the industry by the presence of public institution interested to comply the international statements for the reduction of environmental pollutions.

Acknowledgment

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USE OF MBR FOR TREATMENT OF EFFLUENT FROM LIQUEFIED NATURAL GAS INDUSTRY

Céline FAUVEAU

VWS Oil & Gas, 10 place du Général de Gaulle BP 90172

92163 Antony Cedex (France),

+33 (0)140836452. Email: celine.fauveau@veoliawater.com

Keywords: Membrane Bio Reactor (MBR), Liquefied Natural Gas (LNG), Reuse, MEG (Mono Ethylene Glycol)

Introduction

Veolia is a very experienced company in Building and Operation of MBR worldwide for industrial effluent treatment. In 2008, for the first time, Veolia designs a MBR dedicated to MEG treatment of LNG industry effluent. The characteristics of this treatment are here described.

Choice of treatment line

When extracted, LNG contains substantial quantities of MEG (C₂H₆O₂; 1.29 gCOD/gMEG) and produced water which have to be removed in dedicated unit. The wastewater requires treatment prior to disposal or reuse as service water.

In this case, MBR has been chosen to secure treatment and decrease cost associated to downstream reuse even if inlet COD load is low and so represents an unusual MBR application.

After pretreatment consisting in separation of free oil and BTEX (Benzene, Toluene, Ethyl Benzene, Xylene), MBR has to remove biodegradable COD (mainly related to MEG) before discharge to sea or polishing steps for reuse.

For reuse, effluent is fed into polishing steps (ozonation and (Biological) Activated Carbon) where non biodegradable COD is removed.

MBR and all treatment steps must comply with the petroleum specifications because effluent treatment plant will be implemented in the petrochemical industry facilities.

Influent characteristics & outlet specifications

Characteristics of influent and required outlet concentrations are shown hereunder:

INFLUENT MBR DATA		
Parameters	Units	Values
Q	m ³ /d	1152
	m ³ /h	48
Temperature	°C	20 - 28
pH	u. pH	6 - 8
soluble BOD5	kg/d	91
	mg/l	79
soluble COD	kg/d	168
	mg/l	146
SS	kg/d	22
	mg/l	19
TKN	kg/d	0.5
	mg/l	0.4
TP	kg/d	0.2
	mg/l	0.2
MEG	kg/d	58
	mg/l	50
BTEX	kg/d	0.6
	mg/l	0.5

Table 1: MBR inlet data

EFFLUENT SPECIFICATIONS FOR REUSE AFTER POLISHING STEPS		
Parameters	Units	Values
Turbidity	NTU	5
BOD5	mg/l	< 5
pH	u. pH	6 - 9
MEG	mg/l	< 15
BTEX	mg/l	< 0.1

Table 2: Effluent specifications for reuse

We must take into account the above specifications for reuse to design the MBR. MBR has been chosen for its reliability and efficiency. It has to allow low COD concentration to be reached by removing MEG.

Results: treatment line and MBR design

The designed treatment line is the following:

- 1- Corrugated Plate Interceptor to remove free oil (90%) and TSS (50 ppm outlet).
- 2- Cooling and chilling to maintain influent MBR temperature between 20 and 28°C.
- 3- Macro Porous Polymer Extraction to remove BTEX (98%).
- 4- MBR to remove biodegradable COD (70% removal on soluble COD) mainly related to MEG (85% removal).
Then effluent is either sent to polishing steps or discharged to sea.
- 5- In case of reuse: Tertiary Membrane Filtration – Ozonation – Activated carbon filters (1 out of 3 is biological) to remove non biodegradable COD.

MBR design:

MBR is composed by 2 identical trains each composed by an aeration tank (75 m³) and a membrane tank (membrane surface = 3000 m²) to treat 28.8 m³/h (60% of inlet flowrate).

FIGURES FOR ONE TRAIN		
Biological parameters		
Concentration in AS	gMLSS/l	10
MLVSS/MLSS	%	60
F/M ratio	kgBOD/kgMLVSS/d	0.14
Volumic load	kgBOD/m ³ /d	0.8
Sludge Retention Time	days	22 @ 20°C (⇔ 40 @ 12°C)
Actual Oxygen Transfer Rate	kgO ₂ /d	100
Membranes parameters		
Type of membranes		Hollow fibers
Modules per train	units	6
Module surface	m ²	500
Net flux	l/h/m ²	9.6

Table 3: Design of one MBR train

EXPECTED MBR OUTLET VALUES		
Parameters	Units	Values
Soluble COD	mg/l	43
Soluble BOD	mg/l	8
TSS	mg/l	5
MEG	mg/l	8
BTEX	mg/l	0.05
pH	u. pH	6 - 8

Table 4: Expected MBR outlet values

Even though the MEG treatment is a new application, MBR is designed according to usual standards since MEG is quite easily biodegradable.

No specific MBR operation is expected: cleaning procedures are foreseen with usual cleaning reagents (sodium hypochlorite and citric acid) and frequency (maintenance cleaning once a week and recovery cleaning twice a year).

Conclusion

The plant is expected to be commissioned at beginning of 2010. It will represent the first VWS Oil & Gas reference for LNG effluent treatment.

2D-FLUORESCENCE SPECTROSCOPY AS A NOVEL MONITORING TOOL IN MBR MODELLING FOR WASTEWATER TREATMENT SYSTEMS

Claudia F. Galinha¹, Carla Portugal^{1,2}, Gilda Carvalho^{1,3}, Giuseppe Guglielmi⁴, Daniele Chiarani⁴, Gianni Andreottola⁴, Rui Oliveira¹, Maria A. M. Reis¹, João G. Crespo¹

¹REQUIMTE/CQFB, Chemistry Dept., FCT-UNL, 2829-516 Caparica, Portugal

²CEBAL, R. Pedro Soares, Apt. 6158, 7801-908 Beja, Portugal

³IBET/ITQB, Apt. 12, 2781-901 Oeiras, Portugal

⁴Department of Civil and Environmental Engineering, University of Trento, Via Mesiano, 77, 38050 Trento, Italy

E-mail: claudia.galinha@dq.fct.unl.pt

Keywords: MBR, Statistical Modelling, 2D-Fluorescence Spectroscopy, Monitoring.

Introduction

In membrane bioreactors (MBRs) for wastewater treatment the progressive membrane fouling due to deposition of cells and cell products on the membranes reduces the permeability of the system, resulting in substantial maintenance costs and shortening membrane life span. The major biofouling agents in MBRs are Extracellular Polymeric Substances (EPS), and thus EPS monitoring and control in MBR operation is essential. EPS contain large amounts of proteins and aromatic organic substances that possess natural fluorescence properties, making fluorescence a powerful technique to monitor their production in MBRs.

2D-fluorescence spectroscopy is a highly sensitive, selective and non-invasive technique that can provide rapid information about the composition of complex media such as biological systems. Due to the fact that all organisms contain natural intracellular fluorophores, such as aminoacids (e.g. tyrosine and tryptophan), vitamins, coenzymes and aromatic organic matter in general, fluorescence is a technique suitable to be used in bioprocess monitoring. Furthermore, since this technique is non-invasive, it can be used in situ and on-line without disturbing the biological system. The excitation-emission matrices (EEMs) obtained by scanning the spectra wavelengths can cover a wide diversity of natural fluorophores. The maps obtained from the EEMs can thus correspond to a fingerprint of the physiological activity of a biological system.

The richness and complexity of information contained in EEMs should be taken into account when interpreting fluorescence results. Fluorescence fingerprints not only combine physiological patterns of different microorganisms, but also reflect the variation in concentration of some substrate components and microbial by-products which possess fluorescence properties. In addition, some molecules can act as quenchers to fluorescence, by interacting with the excited fluorophores, resulting in alterations of fluorescence signal. Therefore, it is necessary to deconvolute the contextual information contained in the fluorescence maps. Using chemometrics, EEMs can be correlated with key operational and performance parameters of the studied system. When using chemometric modelling techniques, fluorescence spectra are viewed as multivariate descriptors of performance parameters and treated with statistical approaches such as Principal Component Analysis (PCA) and Projection to Latent Structures (PLS). The statistical models are obtained by this approach using on-line fluorescence maps and their corresponding process performance parameters measured for different operating conditions. Through these calibrated models, the EEMs obtained on-line can be used to monitor the status of the process, as well as for prediction, allowing rapid correction of operational parameters for process optimisation.

Objectives

This work aims at demonstrating that 2D-fluorescence spectroscopy can be applied as a monitoring tool for MBR modelling and performance prediction. This goal is achieved combining the fluorescence EEMs with other analytical data using statistical models to improve the prediction of MBR performance.

Materials & Methods

In the current work 2D-fluorescence is applied to monitor a pilot scale MBR for domestic wastewater treatment located by a full-scale Wastewater Treatment Plant in Lavis, Italy. The MBR system consists in submerged hollow-fibre membranes immersed in a tank containing suspended activated sludge and several products resulting from wastewater feeding and microbial activity, which are liable of possessing fluorescence properties. This study was performed by closely monitoring the pilot MBR by physical-chemical analysis while operated under controlled permeate flux. PLS models were developed for this system in for the attempt to establish a correlation between inputs and outputs that would enable us to predict the system's behaviour. Operating conditions, wastewater characteristics and EEM were used as inputs of the models. Permeate characteristics, sludge characteristics and membrane performance (measured as transmembrane pressure, TMP) are the parameters predicted by these models (outputs).

Results and discussion

The model description of the output variables, with and without the integration of fluorescence EEMs, was compared in order to assess the relevance of using 2D-fluorescence for monitoring of such a complex systems.

Six criteria were used in the selection the number of principal components of PLS models, to compare different models and to infer about models fitting and prediction ability. These parameters are: the variance captured, the root mean square error of prediction (RMSEP), the regression coefficients between prediction and experimental data for training and test sets (R^2_{train} and R^2_{test} , respectively), chi-square (χ^2) and AIC. Based on these parameters, it was possible to compare and select the best models with and without fluorescence EEMs for each output prediction.

Table 1: Calculated parameters for best PLS models for total COD in permeate prediction.

Outputs	Modelling strategy	PC used in PLS	Variance (%)	RMSEP	R^2_{train}	R^2_{test}	χ^2	AIC
CODt-p	Without EEMs	12	58	9.62 mg/L	0.58	0.72	28.6	67.3
CODt-p	With permeate EEMs compressed with 8 PC	13	84	4.19 mg/L	0.84	0.95	5.4	53.4

It was proved that the combination of the additional information provided by the EEM about the state of the biological system with the selected performance variables enhanced MBR modelling and performance prediction. Table 1 and Figure 1 show that, for total COD in permeate, models using EEM as inputs fit better the training points. Also the validation points (data not used to the model developing) are better described in PLS models with fluorescence data. Similar results were obtained for other outputs. Regarding TMP prediction, both types of modelling, with and without fluorescence data, proved to be able to model its variation.

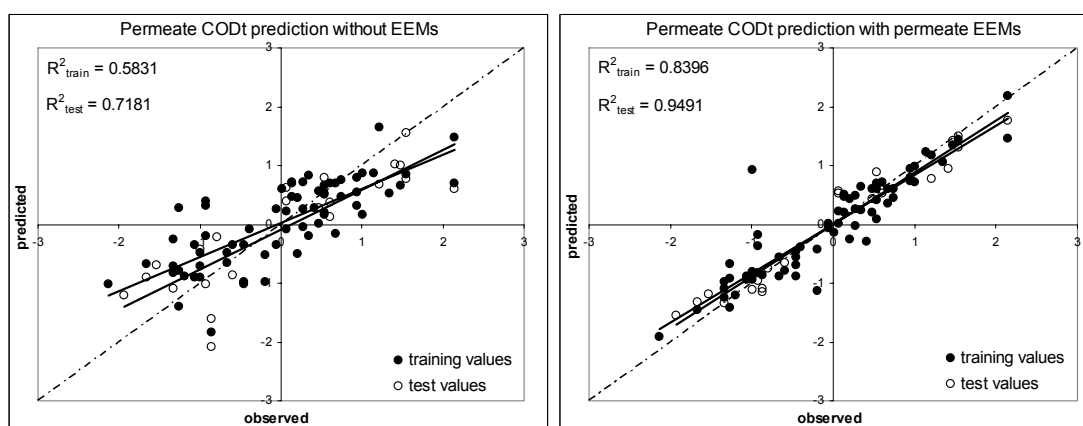


Figure 1: Predicted values of total COD in permeate represented against the observed values for two different PLS models, one without using fluorescence data and the other with permeate EEMs compressed with 8 PC.

Using the PLS models it is also possible to infer about the contribution of each input parameter to determine the outputs, leading to a possible process optimisation.

Conclusions

Statistical approach using PLS proved to be able to model selected performance outputs for a MBR system. Moreover it was found that the integration of 2D-fluorescence matrices brings new insights about the biological system status, making possible the development of improved and more robust MBR models when the operating parameters and traditional analytical data are not robust enough to accurately predict the output variables. PLS modelling also showed that can be used as a powerful tool for a better understanding of the relationship between inputs and outputs, through the coefficient analysis of the models, which can lead to process optimisation.

New observations, acquired in intensive experimental tests performed at higher temperatures and decreased SRT, will be added to the PLS models. Input coefficients of PLS models will be further analysed aiming at establishing their contribution for each output prediction.

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CHALLENGE TESTING MEMBRANE MICROFILTERS AT A WASTEWATER FACILITY IN THE NEW YORK CITY WATERSHED

Joseph A. Habib, Denis Vial
Pall Water Processing, 25 Harbor Park Drive, Port Washington, NY 11050 USA
joseph_habib@pall.com, denis_vial@pall.com

Keywords: Microfiltration, Membrane, Tertiary Treatment, Upgrade, Watershed Protection

Introduction

The Hobart Wastewater Treatment Plant (WWTP) underwent a discharge permit upgrade in 2002 pursuant to New York City (NYC) Watershed Rules and Regulations. The upgrade work incorporated the addition of a tertiary treatment process, whereby secondary effluent from the extended air activated sludge process now undergoes rapid mix/flocculation, sand filtration, membrane filtration, and UV disinfection, before being discharged to the West Branch Delaware River.

Sand filtration in series with the membrane filtration system makes for a very reliable and robust process as is required per NYC specifications for upgraded WWTPs in the Watershed. The membrane system at Hobart was conservatively designed to treat the plant's rated capacity of 0.18 MGD (28.4 m³/hr) with the upstream media filters online. However, the capacity of the membrane system is generally understood to exceed that for which it is designed under the NYC specifications.

This study is proposed to proactively verify the membrane system's capability to handle design flow in the event that the sand filters need to be temporarily taken out of service due to maintenance, fouling, or failure. In this study, the sand filters were bypassed in a controlled manner and closely monitored for the duration of a simulated capacity flow event.

Objectives

1. Verify the MF system's capability to handle design flow or greater with the sand filters out of service.
2. Verify effluent quality and permit compliance using only the MF for filtration.
3. Provide plant Operations with the experience and confidence to successfully operate the membrane system through extreme conditions.
4. Produce actual full scale plant data to demonstrate to New York City Regulators that the 1997 technical specification document for membrane systems in the Watershed should be revisited.

Materials & Methods

The Hobart WWTP generally uses its full compliment of membranes to process normal flows, which is typically a fraction of the design flow of 0.18 MGD (28.4 m³/hr). The plant does however experience periodic high flow conditions where flow can exceed 0.2 MGD, particularly during periods of wet weather. Historical data shows high flow events at the Hobart WWTP typically lasting 2-3 days.

Historical data indicates average daily flows during May and June are approximately 0.062 MGD (9.8 m³/hr). Therefore, to achieve membrane flux rates at the design value; a number of membranes were taken out of service temporarily.

- 1) Preparation – Prior to bypassing the sand filters, the following should be performed.
 - a) Adjust membrane area for flux
 - b) Flow control
 - i) Buffering – due to normal fluctuations in flows over the three day test, a sufficient amount of feed was built up and stored in the plant's EQ tank and the sand filter's clearwell.
 - ii) The membrane plant was operated in a constant flow mode for flux control and to generate the most meaningful data. The clear well was used as a buffer to control inflow from the secondary clarifier while maintaining constant flow through the membrane plant.
 - c) Check/Restore Permeability
 - i) Ensure that membrane permeability is sufficient (i.e., low state of fouling and/or recent CIP) to handle the high flux and higher turbidity water it will process during the test
 - d) Integrity Test
 - i) Perform a standard pressure hold test on the membrane rack to ensure membrane integrity.
- 2) By Pass Sand Filter
 - a) Initiate Bypass
 - i) Position the necessary valves to bypass the sand filters while maintaining coagulation/flocculation.
- 3) Monitoring
 - a) The MF system operation will be monitored closely during bypass operation.
 - i) Online monitoring

- (1) TMP will be monitored closely to ensure that the membranes retain sufficient permeability to process the full hydraulic load.
 - (a) Operational options to ensure stable operation
 - (i) If required, an increase in the plant's backwash frequency can be implemented to control fouling.
 - (ii) If required, EFM can be initiated on a daily basis
 - (iii) If required, the full redundant MF rack can quickly be placed online should the fouling rate exceed operational control
 - (2) Turbidity will be monitored closely to ensure that effluent water quality is unaffected by the process and hydraulic changes.
- ii) Remote monitoring
 - (1) The plant may be monitored remotely via its built in modem connection during off-hours.
- 4) Sampling
 - a) A battery of tests will be conducted to ensure SPDES compliance throughout the test period.
 - i) SPDES parameters
 - (1) CBOD, TSS, P, N, Fe, UV, Hardness, Alk, Turbidity, Fecals
 - ii) Sample locations
 - (1) raw, secondary effluent, MF effluent
 - iii) Composite Sampling
 - (1) 2 sets of Composite samples will be taken by the plant and analyzed at Midstate Environmental Lab
 - iv) Grab Sampling
 - (1) 2 – 3 sets of Grab Samples will be taken and forwarded to a separate lab for comparison.
- 5) Restoration of Default operation
 - a) Place sand filters back online
 - b) Place redundant MF rack online
 - c) Take test rack offline to re-install membranes removed during preparation.
 - d) EFM or CIP if required
 - e) Resume normal operation.
- 6) Data Q/C
 - a) Process data from the MF system's SCADA system will be downloaded and analyzed to evaluate process related test performance.
 - b) Laboratory analyses performed by Hobart's default contracted lab will be supplemented by additional analyses at an alternate lab for verification and QC.

Results and Discussion

Over the course of three days, the membrane plant was operated without the benefit of sand filtration pre-treatment. During each of the three days, hydraulic flow was increased for several hours, exceeding the design capacity of the membrane system on two of these occasions as seen in Figure 1. Composite samples were taken at the plant influent, downstream of the secondary clarifiers, and downstream of the microfilters. The analytical results are presented in Figure 2.

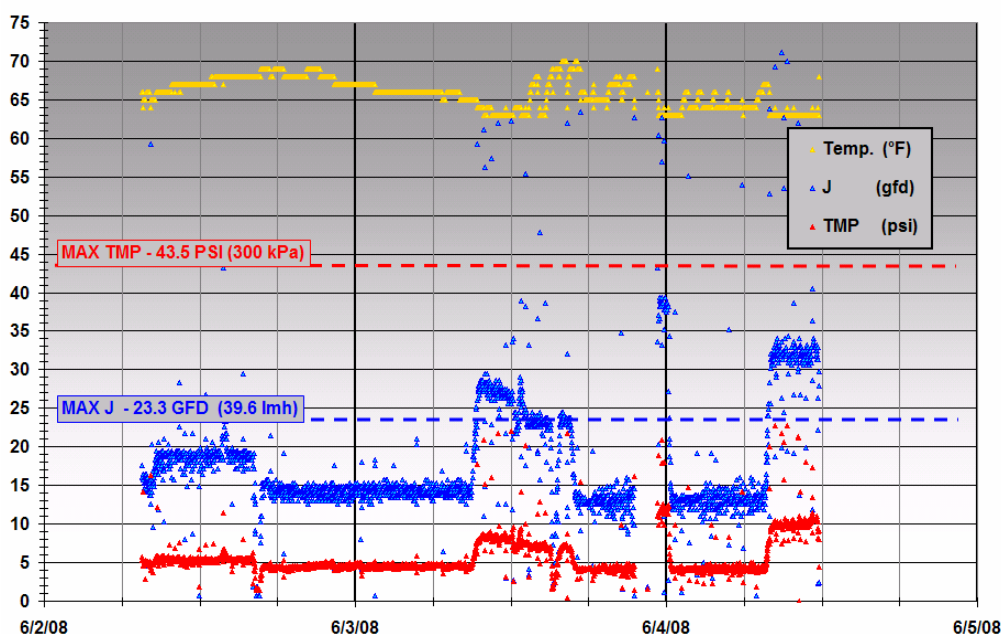


Figure 1: Bypass Study Online Data

		3-Jun			4-Jun		
		RAW	2ND EFF	MF FILTRATE	RAW	2ND EFF	MF FILTRATE
CBOD	mg/l	477	4	<1	146	<4	<4
TSS	mg/l	230	12	<3	117	10	<3
P AS P	mg/l	7.8	0.78	0.05	5.6	0.98	0.12
NH3 AS A	mg/l	42.6	<1	<1	27	<1	<1
FE	ug/l	1500	93	71	1100	84	68
UV ABS	per cm	1.3346	0.1602	0.1639	0.525	0.1506	0.1412
UV TRANS	%	4.6	69	69	30	71	72
HARDNESS CaCO3	mg/l	92	132	132	93	133	129
ALK CaCO3	mg/l	246	82	80	262	86	86
TURB	NTU	72.9	2.01	0.113	74.2	1.49	0.15
FECAL	mpn/100 ml	>4000	>400	<2	>4000	>4000	<20

Figure 2: Sampling Results

Conclusions

- The microfiltration system demonstrated its capability to handle flows in excess of design flow during simulated upset conditions.
- With the upstream sandfilters offline, microfiltration alone sufficiently produced effluent well within the plant's permitted discharge limits.
- As a result of this study, New York City Regulators are taking steps towards refining membrane system specifications to reflect changes and improvements in the technology.

OXYGEN TRANSFER IN MEMBRANE BIOREACTORS OPERATING AT HIGH SLUDGE RETENTION TIMES

Jochen Henkel*, Martin Wagner, Peter Cornel
Technische Universität Darmstadt, Institut WAR, Section Wastewater Technology, j.henkel@iwar.tu-darmstadt.de

keywords: oxygen transfer, α -factor, membrane bioreactor, greywater

Introduction

Water reuse is an inevitable element of an integrated sustainable water management. The reuse of adequately treated greywater might reduce the total urban water demand up to 50%!

Within the project "semicentralized supply and disposal systems for urban areas" two membrane bioreactor (MBR) pilot plants were built up, to study their performance for greywater treatment.

Objectives

The energy demand of MBR is considerably influenced by the α -factor, the ratio of the oxygen transfer coefficient in the sludge and in clean water ($\alpha k_L a_{20,MLSS} / k_L a_{20, \text{clean water}}$). Thus it was one objective of this project to study its dependency on different MLSS concentrations and the effect of high anionic surfactants concentrations in the influent.

Materials & Methods

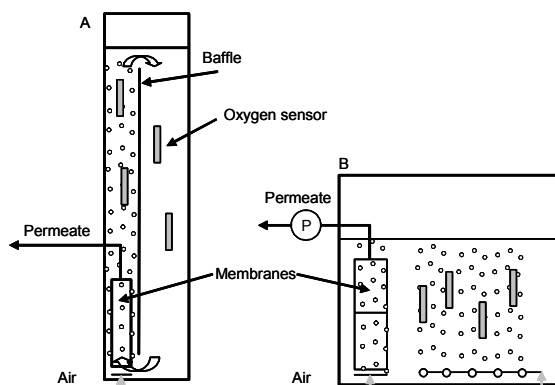


Figure 1: pilot plant setup

Aeration tests were performed according to the standard procedure described by the European Standard EN-12255-15 (2004). The desorption method was chosen as the appropriate method to determine the oxygen transfer coefficient. Three different air-flow-rates were chosen (maximum, middle, low) at the same MLSS concentration for every session. Clean water test were performed with drinking water before the beginning of the inoculation with activated sludge and at the end of the test period. The α -factor was calculated as the ratio $\alpha k_L a_{20,MLSS} / k_L a_{20, \text{clean water}}$. The air flow rate was measured with a thermal flow sensor TA10 (Hoentzsch GmbH, Waiblingen, Germany). Oxygen concentration was measured with 3 Evita Oxy 1100 sensors equipped with 0.4 and 0.2 μm membranes (Danfoss/Hach Lange GmbH, Düsseldorf, Germany) and an optical LANGE LDO sensor (Hach Lange GmbH, Düsseldorf,

Germany). The setup configuration as well as the aeration devices of the two pilot plants differed significantly (Figure 1). The mixed liquor suspended solids concentrations (MLSS) during the tests ranged from 5 to 18 g/L.

Results and discussion

With respect to the volumetric mass transfer coefficients at different MLSS concentrations (Figure 2 and Figure 3) the $k_L a$ value at a specific air flow rate decreased steadily as the MLSS concentration raised. A linear relation of $k_L a$ and air flow rate was noticed. A comparison of all results reveals that every reactor configuration and aeration system had its particular $k_L a$ characteristic.

After the $k_L a$ values were estimated, the α -factor was calculated by dividing the equation for a certain solid concentration through the equation obtained during clean water tests. This was done with the three specific air flow rates applied during the test. Finally the mean of these three values was calculated and plotted in Figure 4. The standard deviation for all calculated α -factors versus the three air flow rates was 2.25 % with a maximum standard deviation of 5 % for the coarse bubble aeration at a MLSS concentration of 19.5 g/L. It was interesting to find, that the differences between the α -factor at a given solid concentration were small, although the diffuser systems and the reactor configurations differed essentially. Consequently the huge differences of the α -factor at a given MLSS concentration obtained in activated sludge in this study and by other authors in Figure 4 left side can only be explained by the different sludge characteristics. Krampe (2001) investigated the α -factor of MBR-sludge from a laundry, a malt house and a paper mill. Cornel et al. (2003) studied two full scale wastewater MBR plants whereas Rosenberger (2003) measured 6 pilot scale and lab scale reactors located in Berlin. Finally Germain et al. (2007) tested ten biomass samples from both municipal and industrial pilot and full scale submerged MBR. One could assume that a comparison is not possible due to the different sludge origins and sludge characteristics or that the MLSS concentration is not the appropriate parameter for a correlation of α -factors.

However a considerable difference to other investigations was the low MLVSS concentration during the experiments in this study. Correlating the same α -factors with the MLVSS concentration available from the other authors in

Figure 4 (right side), a clear tendency can be found irrespective of the diverse sludge origins. Hence not the MLSS but the MLVSS concentration might be a more appropriate parameter to characterize the α -factor in activated sludge systems operated at high SRT and high MLSS concentration.

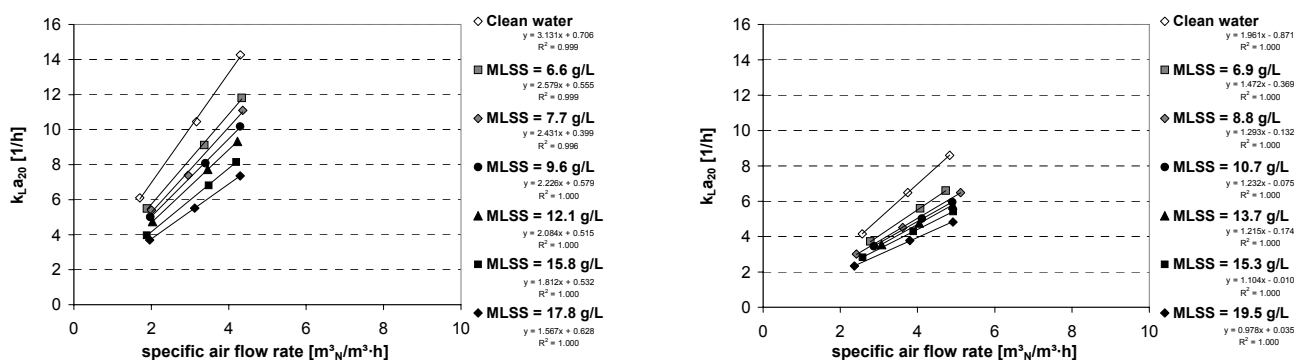


Figure 2: Mass transfer coefficient during fine bubble crossflow (left) and coarse bubble (right) aeration in reactor A

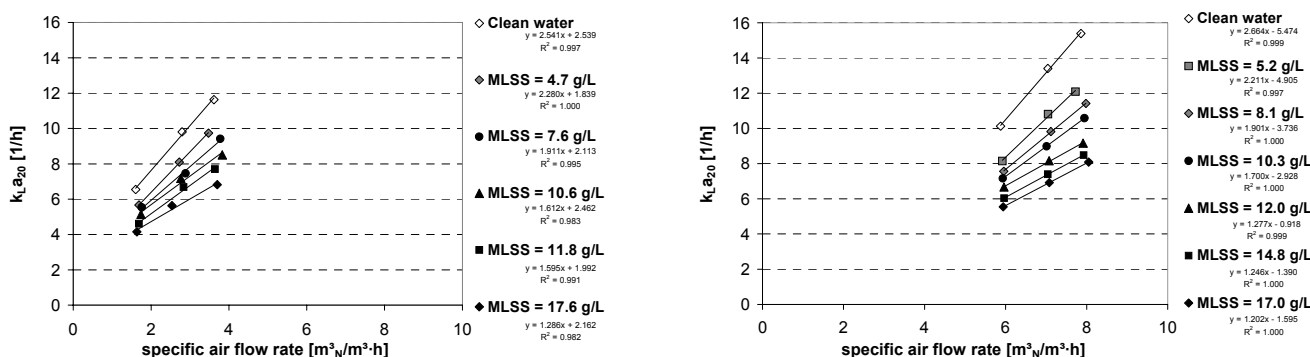


Figure 3: Mass transfer coefficient during fine bubble aeration only (left) and coarse bubble crossflow and fine bubble aeration (right) in reactor B

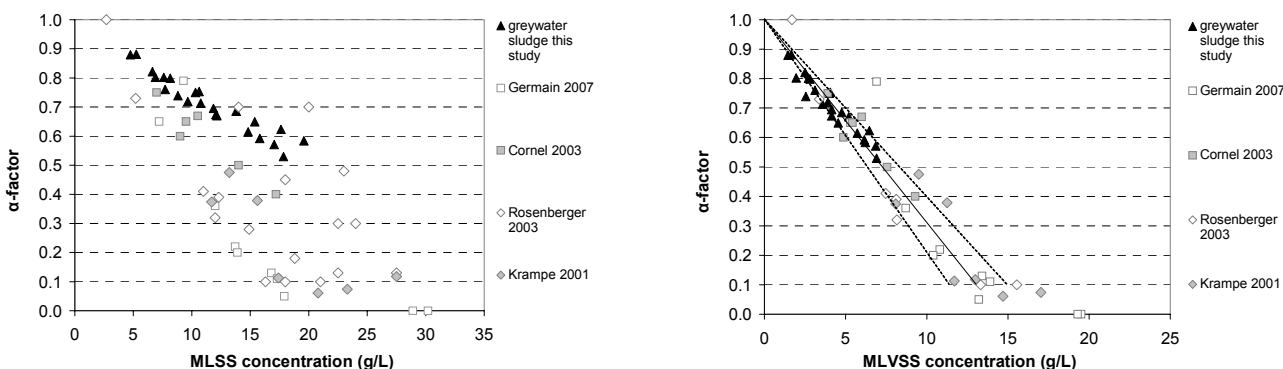


Figure 4: α -factor as function of the MLSS (left) and MLVSS (right) concentration in literature and in this study

Conclusions

Both reactors although very different in their setup configurations showed similar results concerning the decrease of the α -factor with increasing MLSS concentration. Consequently the design and the aeration devices had no significant impact on the α -factors.

The results reveal that at high SRT the α -factor is mainly influenced by the MLVSS concentration. A better approximation of the α -factor is now possible. However more data should be acquired to proof these observations.

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MEMBRANE BIOREACTORS – INFLUENCE OF DYNAMIC OPERATIONS

Hermann, S.*; Röttgers, N.*; Iversen, V.*; Drews, A.**; Lesjean, B.***; Kraume, M.*
 * TU Berlin, Chair of Chemical Engineering, ACK 7, Ackerstr. 71-76, 13355 Berlin, Germany
 Email: stephanie.hermann.1@tu-berlin.de
 ** University of Oxford, Dept. of Engineering Science, Parks Road, Oxford OX1 3PJ, UK
 *** Berlin Centre of Competence for Water, Ciceronstr. 24, 10709 Berlin, Germany

keywords: dynamic operations, rain water events, pilot plant studies

Introduction

Membrane fouling is still the major drawback of MBRs and thus one of the most discussed topics in MBR literature [1, 2]. Due to a reduced number of influencing parameters lab scale trials thereby find widespread application to investigate specific phenomena and processes. However, the published results of such investigations differ significantly and the transferability from lab to full scale is limited [3]. Fewer reports can be found concerning the influence of operational modes of pilot or full scale plants. Nevertheless, such studies are indispensable for the industrial application of MBR technology. Unsteady states like intermittent feeding or shifts in the oxygen supply have been identified as factors leading to a change in fouling propensity [4]. As membrane fouling causes a decreased permeability and therefore higher operational costs it should be estimated whether if and how the operational mode influences membrane performance and fouling, respectively.

Heavy rain falls or higher amounts of wastewater would require higher capacities and accordingly higher fluxes from time to time. This leads to dynamic operational modes and unsteady process parameters. The aim of the present study is to determine effects of dynamic operations due to heavy rain falls on membrane performance and nutrient removal.

Materials & Methods

Investigations concerning dynamic operations were realized in a pilot (figure 1) consisting of two 1m³ tanks with a working volume of approx. 0.8m³. The pilot is located in a 20' sea container on the grounds of a pumping station of Berliner Wasserbetriebe, thus drawing combined municipal wastewater from Berlin city centre as influent. After the settler used as a sand trap for removal of larger particles, the wastewater flows into a stirred anoxic tank.

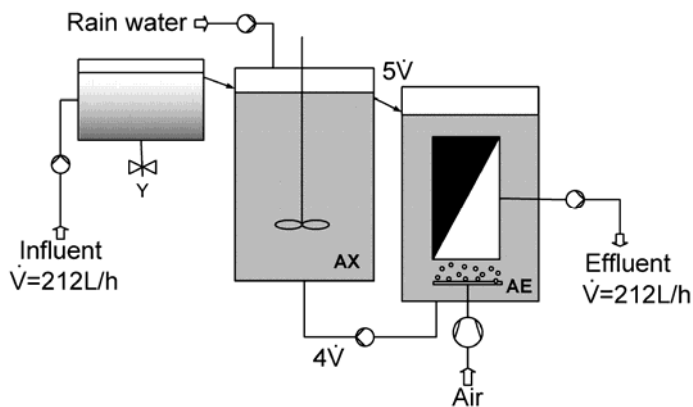


Figure 1: Flow sheet of the pilot

following tank is aerated and equipped with a 22m² membrane module (A3 Water Solutions, Germany, PVDF, nominal pore size 0.2µm). TMP, flux, T and pH in the membrane chamber are registered online.

To investigate the influence of dynamic operations, over a period of 3-4 weeks, on Mondays and Thursdays the flux was increased to 130% respectively 160% for 6 hours. Afterwards the flux was decreased to 90% respectively 80% for 18 hours to ensure a constant net flux over the investigated period of 24 hours. In order to determine the effect of rain water events, water was added according to the increased flux into the anoxic chamber, i.e. HRT decreased while organic loading remained constant.

To evaluate possible effects on the membrane performance, the TMP evolution was observed and compared to earlier investigated periods where the pilot was operated with constant parameters. Samples (influent, effluent, sludge) were taken at least twice a week (Mondays and Thursdays). Total COD and nitrogen removal, but also NH₄-N, NO₂-N, NO₃-N concentrations were determined to evaluate effects on the microbiologic activity. Additionally the sludge was characterized. Total suspended solids (TS), filterability (TTF) and dewaterability (CST) were measured.

Results and discussion

Earlier investigations where the pilot was operated with constant parameters, showed a characteristic exponential behaviour of the TMP evolution. The TMP only slowly increased in the first 20 to 40 days followed by a rapid steep increase [5]. Figure 2 shows this behaviour exemplarily for an operation period about one year before the investigations concerning dynamic operations. At that time, the TS of the sludge and the temperature were similar to the period where dynamic operations were investigated. During the periods when the pilot was operated with

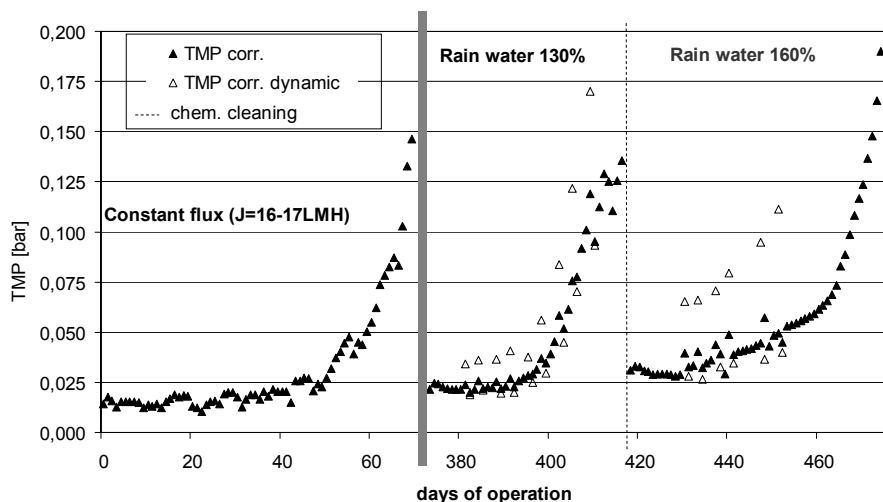


Figure 2: TMP evolution in the pilot plant

only occurs after 40 operation days thus the chemical cleaning is required later. In addition, sludge parameters (table 1) in this period were worsened compared to the contrary results. Nevertheless both evolutions in general show the exponential character with variations well-known from experience. The nutrient removal did not change in the periods when rain water events were investigated. Values for COD and total nitrogen were quite similar to values from earlier investigated periods (COD_{permeate} approx. 30 mg/L, N_{tot,permeate} approx. 10 mg/L). At the beginning of the period with fluxes increased to 160% nitrification seemed to be worsened. Ammonia (approx. 2-3 mg/L) was found in the effluent and nitrite (1 mg/L) in the sludge supernatant from the aerobic membrane chamber from time to time. Both compounds have not been found in permeate and sludge supernatant before. After two weeks of operation the values normalized and the effluent showed good quality. At that time the recirculation pump (from aerobic to anoxic chamber) failed from time to time which could lead to a changed nutrient removal. Additionally it should always be kept in mind that the influent is exposed to fluctuations which could also affect the process and explain the described effects.

Table 1: Sludge parameters

	TS [g/L]	CST [s]	TTF [s]
Reference	7.6 (±2.4)	43.9 (±16.0)	-
Rainwater 130%	7.1 (±1.2)	22.7 (±5.1)	25.8 (±6.4)
Rainwater 160%	8.6 (±1.3)	56.4 (±17.8)	44.8 (±14.5)

Conclusions

The TMP evolutions in general show the well-known exponential curves. No significant impacts of rain water events on the membrane performance could be determined. Although the sludge parameters were worse in the period where the flux was increased to 160%, a chemical cleaning was required later than in the period where the flux was increased to 130% implicating contrary results. Therefore sludge parameters seem not to influence membrane fouling. Nutrient removal was unchanged during the periods when rain water events were investigated. As operational failures and natural fluctuation of temperature and influent could influence the process the possibility to compare two following investigation periods is limited.

Acknowledgement

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IMPACT OF OPERATION CONDITIONS ON THE REMOVAL OF BULK ORGANICS AND BISPHENOL A IN A PILOT MBR

Herr, J.*, Kazner, C.*, Wintgens, T.* and Melin, T.*

* RWTH Aachen University - Aachener Verfahrenstechnik, Turmstr. 46, 52056 Aachen, Germany, jochen.herr@avt.rwth-aachen.de

keywords: MBR, micropollutant, operation conditions

Introduction

The occurrence of natural and synthetic organic compounds in surface waters has been extensively studied and as a result it has been confirmed that wastewater treatment plant (WWTP) discharges are a primary source of micropollutants in the water cycle (Petrovic, 2007). Advanced wastewater treatment processes like membrane bioreactor technology (MBR) or ultrafiltration are one option to satisfy increasing water quality requirements related to the reuse of domestic wastewater (Bixio and Wintgens, 2006). In recent years the application of MBRs became generally accepted and is considered as state-of-the-art-technology for municipal and industrial wastewater treatment.

Objectives

In this study the effect of different operation conditions on the membrane retention of bulk organic compounds as well as the trace organic compound bisphenol A was investigated. The results should show whether the fouling layer on a membrane is influencing the retention of organic compounds.

Materials & Methods

A pilot-scale MBR is operated at the municipal WWTP Aachen-Eilendorf in Germany. Primary effluent of the conventional activated sludge WWTP is used as inflow for the pilot plant. The set-up consists of a total biological reactor volume of 0.63 m³ divided into a pre-denitrification reactor (0.2 m³) followed by a nitrification reactor (0.2 m³), a buffering tank (0.1 m³) and the membrane tank (0.13 m³). It is possible to test three capillary hollow fibre modules simultaneously as three permeate extraction pumps allow a simultaneous operation with different operational conditions for each membrane module (PURON[®], Koch Membrane Systems GmbH, Germany). Each membrane bundle provides a total membrane area of 1.7 m².

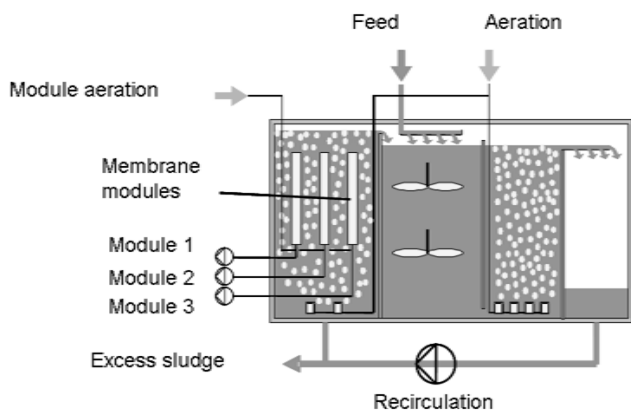


Figure 1: Setup of the pilot-scale MBR

Except for inevitable variations the general MBR performance was stable within the defined criteria: average SRT = 30.2 d, MLSS = 12.7 ± 4.8 g/L, F/M ratio = 0.111 kgCOD/(kgMLSS/d). Grab samples of the permeate from each membrane module were taken after 22, 70 and 142 h of continuous MBR operation. The activated sludge was sampled after 142 h. The sample was taken from the membrane tank. To compare membrane filtration performance of the three modules online data of the pilot MBR were used (Permeate flux J_p , transmembrane pressure difference TMP , effluent temperature T). For the characterisation of bulk organic compounds a size exclusion chromatography system was applied. The LC-OCD-UV-OND liquid chromatography system (DOC-LABOR Dr. Huber, Germany) is equipped with size exclusion column

HW55S (GROM Analytik + HPLC GmbH, Germany) and dissolved organic carbon and UV254 detectors. The LC unit separates organic compounds according to their molecular size and the separated compounds are detected by online detectors. Within this study the endocrine disrupting substance bisphenol A (BPA) was selected as industrial trace compound as it is ubiquitous in WWTP effluents. BPA concentrations in permeate, supernatant and raw wastewater are determined by an adapted LC/MS method according to Rodriguez-Mozaz et al. (2004).

The membrane modules were operated at a constant net flux of ca. 12.5 L/(m²·h) varying the gross flux or the instantaneous flux during the filtration cycle of each membrane module. Table 1 shows the applied operation conditions. As the net flux was kept constant by adjusting the filtration and backwash/relaxation durations accordingly, the productivity and the performance of the modules was comparable at every time step during the study.

Results and discussion

The applied operation conditions resulted in a significant difference of the fouling rates. The filtration performance is given in figure 2 as the evolution of the total resistances over time. The module with the highest gross flux (module 2) showed the highest fouling rate (1.2·10¹¹ 1/m/d) which was almost an order of magnitude higher compared to the

lowest fouling rate of module 3 ($2.4 \cdot 10^{10}$ 1/m/d). The fouling rate of module 1 ($7.2 \cdot 10^{10}$ 1/m/d) was between module 2 and 3. Backwash proved to be slightly more efficient than relaxation periods.

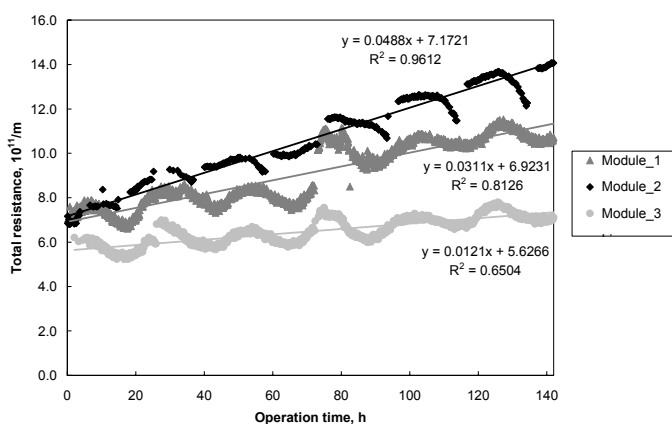


Figure 2: Total resistance (temperature corrected) and fouling rates during the study

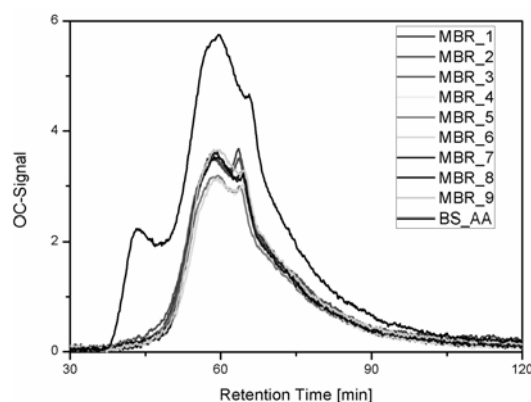


Figure 3: Comparison of TOC distribution in supernatant (BS_AA) and permeate (MBR_1 to MBR_9) detected by LC-OCD

The quality of the permeates are given in table 1. In general an excellent permeate quality was achieved irrespective of the applied permeate flux. For most of the quality parameters the deviations are negligible indicating biodegradation as the governing retention and removal mechanism being involved. Membrane retention rates from the third sampling (presumed steady conditions) indicate small differences in the removal of BPA depending on the module operation conditions. The highest removal was observed for module 3 which had the highest fouling. The removal rates are 56% for module 3 compared to 33% for module 1 and 44% for module 3 (data not shown here).

Table 1: Applied operation conditions and permeate concentrations for organic compounds

Module	Net flux	Gross flux	Duration of filtration cycle	Duration of backwash or relaxation cycle	Back-wash flux	Total operation time (study)	Overall fouling rate	Permeate concentrations n = 3		
								COD	DOC	BPA
-	L/(m ² ·h)	L/(m ² ·h)	s	s	L/(m ² ·h)	h	1/m/d	mg/L	mg/L	mg/L
1	12.1	12.4	650	15	0	175	$7.2 \cdot 10^{10}$	15.53±1.16	6.03±0.40	0.05±0.012
2	12.7	38.2	30	60	0	175	$1.2 \cdot 10^{11}$	15.90±1.51	6.07±0.59	0.04±0.006
3	12.5	15.3	400	30	24.7	175	$2.4 \cdot 10^{10}$	15.87±1.62	6.03±0.57	0.05±0.000

The analysis of the LC-OCD measurements (figure 3) clearly indicates the partial retention of dissolved organic matter (DOM). The diagram shows no clear relation between the applied operation conditions and the retention of DOM. It can be distinguished between 3 groups of similar chromatograms for permeate which can be related to the 3 different samplings (1st sampling: MBR_1 to 3; 2nd sampling: MBR_4 to 6; 3rd sampling: MBR_7 to 9). The differences within these groups are marginal.

Conclusions

The comparison of TOC concentrations in activated sludge supernatant and permeate reveals a partial retention by the membranes of 68%. LC-OCD confirmed this partial retention and gave evidence of membrane retention of small sized organic compounds. The respective flux significantly affected the resulting fouling rate. The membrane retention of BPA varying at different fouling rates shows possible interactions with bulk organic matter.

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TOWARD A BIO-FOULING DESCRIPTION IN SIDESTREAM AN-MBR TREATING MUNICIPAL WASTEWATER: ADVANCED AUTOPSIES ON UF MODULES

Herrera-Robledo M., Calderon K., Morgan JM and Noyola A.

*Institute of Engineering, Universidad Nacional Autónoma de México (UNAM).

Apartado Postal 70-472; 04510, Ciudad Universitaria, Coyoacan, México, D.F., México. FAX (+52) 55- 5616-21-64.

MHerreraR@ii.unam.mx; noyola@pumas.ii.unam.mx

keywords: Bio-fouling, Biologically induced mineralisation, UASB, Ultra-filtration

Objectives

This document is part of a major Mexican research project aimed to characterize the fouling layer developed in a pilot-scale AnMBR in order to develop anti-fouling MBRs. The aim of the present paper was to identify the main components and micro-organisms (*Bacteria* and *Archae*) associated to cake layers developed during UF of anaerobic effluents and furthermore to describe their spatial distribution inside cake in order to get evidence for biologically induced mineralization process during cake layer development.

Materials & Methods

Membrane Autopsy: An AnMBR experimental arrangement (Figure 1), fed with UNAM's municipal wastewater, was an up-flow anaerobic sludge blanket (UASB) reactor (0.87m^3) coupled to ultra-filtration (UF) membrane modules (5.02m^2). Irreversibly fouled (2400 hours of operation) UF tubular membranes from *Koch Membranes* (Abcor®-ultra-cor® module: 10-hfm-251-uvp) that were periodically cleaned with HClO were used for this study. Samples of a fouled membrane after 5 days of operation (B) and a cleaned membrane (C) were compared. Initially single membranes (3m length) were removed from modules and cut every 15 cm; 4 cm^2 squares samples were collected and stored at 4°C for further determinations. Specific density and gravimetric determinations were performed in every sample point. **DNA isolation and Microbial Identification:** Samples of 11.28cm^2 (4 cm length) and 33.84 cm^2 (8 cm length) of B and C membranes respectively were used for DNA isolation. It operation was performed guided by *Fast ID method* (Genetic ID NA, USA). **Microbial ID:** Specific primers for 16S rDNA regions related to *Archae* (Parch 340F and 340R) and *Bacteria* (GC-338F and 518R) specimens were combined with standard end-point PCR techniques (30cycles: 94°C 45s, 55°C 55s and 72°C 60s) for bio-film DNA amplification. The Microbial ID strategy was completed after temperature gradient gel electrophoresis (8% w/v acrylamide gel, $2^\circ\text{C}/\text{h}$ from 55 to 65°C on Universal Mutation Detector, Biorad); Vec-T clone techniques (*pGEM®-T*, Promega, USA, 5 as insert/vector ratio); transformation on competent *E.coli*; differential selection; plasmid purification and capillary sequencing (*ABI PRISM 3000*). Sequence analysis was performed by using *Chromas (v1.45)* and sequence collection was obtained by BLAST on NCBI databases. Multiple alignment analysis was performed by using Clustal X and phylogenetic and molecular evolutionary analyses were conducted using MEGA version 4. **FISH:** After specific primer-probe design for *Pseudomonas* and other α - and γ - *Proteobacterium* several *In situ* fluorescence assays in anaerobic bio-films are being conducted nowadays by K. Calderon at University of Granada in Spain and will be further presented. **Scanning Electron Microscopy (SEM) and microanalysis:** Membrane samples were dehydrated at critical point and over them SEM-EDX were performed on Cambridge-Leica SEM (Sterescan 440, UK). Energy dispersion spectroscopy (EDX) were applied on regular surfaces of biofilm ($100 \times 100\text{ um}$), using a solid-state (Si/Li) detector (*PentaFET*, UK) and they were analyzed with ISIS Link software, version 1.04a.

Results and discussion

Fouling distribution was determined using gravimetric studies (dynamic TGA) for both membranes. Deposits were not homogeneously distributed along fouled membrane B, showing a wave pattern (valleys and crests). This fouling behavior may be related to the tulip model that describes bio-film development and detachment on membrane surfaces as a cyclic phenomenon (Wimpenny *et al.*, 2000). Cleaned membrane (C) showed a more uniform distribution of deposits. Organic matter (volatile solids) was the most important mass fraction in both samples (average 67% for B and 86% for C membranes). A characterization of the organic material on B samples revealed that it was formed by EPS: 37 % as CHO's and by protein and humic acids (60%).

Theoretical cake layer development for cross-flow UF of anaerobic effluent

a) Soluble EPS in anaerobic effluent, after adhering on a membrane surface, cover specific areas, producing micro-environmental conditions that enhance attached bacterial development following the phenomena described as minimal area surface (Saa and Teshke, 2006). *Proteobacterium* and *Pseudomonadae*, main bacterial species identified in the mature cake layers (see Table 1), have the skill to produce EPS at high rate (*Surface conditioning*).

b) There are zones in bio-polymers that concentrate electric charge. These zones may induce inorganic deposition by hetero-epitaxial mineralization according to fundamentals described by Stephen Mann, (2001). Inside tubular UF membrane unit, experimental conditions (relative high pressures, turbulence) biological mineralization may be induced by presence of EPS and low solubility inorganic cations in the effluent (*favorable hydrodynamics for cell-surface interactions*).

c) EPS that surrounds micro-colonies are basically proteins and carbohydrates from bacterial origin. Its structure and composition may be related with specific functions as pathogen island and other genetic transference, inter-cellular communication, micro-nutrient assimilation, etc. (Flemming *et al.*, 2001). Through Biologically Induced Mineralization between EPS and inorganic matter, an extra-cellular mineralized matrix may be built; micrograph in Figure 2 may support this statement (*Initially a reversible and irreversible microbial adhesion occur and after growth and micro-colony spread*).

TGGE	Microorganism ID (NCBI report)	E value
A	<i>Bosea sp.</i> (S145 16S rRNA gene, partial sequence)	1.00E-68
B	<i>Novosphingobium pentaromativorans</i> (US6-1 strain 16S rRNA gene, ps)	3.00E-74
C	Not reported sequence	NA
D	<i>Stenotrophomonas maltophilia</i> (isolate RI56 16S gene, ps)	7.00E-26
E	<i>Acinetobacter sp.</i> HPC1339 (16S rRNA gene, ps)	2.00E-84
F	Uncultured bacterium clone (WD9_aak08e03 16S rRNA gene, ps)	7.00E-73
G	<i>Sphingomonadaceae bacterium</i> (SIMO-586 16S rRNA)	3.00E-71
H	<i>Alpha proteobacterium</i> (partial 16S rRNA gene, clone JG35-k2-AG66)	5.00E-79
I	<i>Brevundimonas diminuta</i> (strain 764 16S rRNA gene, ps)	2.00E-66

Table 1: Main bacterial species associated to cake layer developed during 5-day anaerobic effluent ultra-filtration (up-dated at march 9th, 2008); Archae findings will be further presented.

d) Hybrid associations (organic-inorganic) enhance mechanical properties of the cake layer, making its detachment from membrane difficult. Recently Kim *et al.*, (2008) confirm that micro-organisms are active during ultra-filtration process and may generate *in situ* some EPS that would enhance inorganic precipitation. As a result, solid saturation in mineralized cake layer increases trans-membrane pressure (TMP) and a higher pressure on the layer. This gets to a point when the structure collapses forming a compacted material that may be accompanied by a sudden TMP rise. This mechanism is the basis for collapse-compression hypothesis in cake layers developed in AnMBR (C²H) recently proposed by Herrera-Robledo *et al.* (2008) (*Detachment between bio-film and membrane, just genetic vestiges from micro-colonies and BIM structures remain after cleaning operations*).

Conclusions

Deposits on fouled UF membranes were not homogeneously distributed along them, showing a wave pattern (valleys and crests). Organic matter was the main component in samples of fouling layers in both fouled (67%) and cleaned (86%) membranes. Biological evidence (genetic vestiges) of bacteria capable to produce EPS at high rate supports the hypothesis of the existence of epitaxial sites for development of crystals or amorphous precipitates by biologically induced mineralization.

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INFLUENCE OF SELECTED OPERATIONAL PARAMETERS ON (IR)REVERSIBLE FOULING IN MBR'S

Celine Huyskens ^{a,b}, Etienne Brauns ^b, Erwin Van Hoof ^b, Heleen De Wever ^b

^a UA (University of Antwerp), Groenenborgerlaan 171, 2020 Antwerp

^b VITO (Flemish Institute for Technological Research), Boeretang 200, 2400 Mol, celine.huyskens@vito. be

keywords: membrane bioreactor, reversible fouling, irreversible fouling, hydraulic retention time, sludge retention time

Introduction

Membrane fouling in membrane bioreactors (MBR's) is a very complex phenomenon. VITO (Flemish Institute for Technological Research) has developed an online fouling measurement method called the MBR-VFM (VITO Fouling Measurement) which allows to distinguish between the reversible and the irreversible fouling component of MBR mixed liquor.

Objectives

Many studies have been carried out to assess the influence of operational parameters on fouling. However, information about the reversibility of this fouling is often lacking. In this research, the MBR-VFM was used to investigate the influence of hydraulic retention time (HRT) and sludge retention time (SRT) on both reversible and irreversible fouling.

Materials & Methods



Figure 1: The MBR-VFM set-up: (left) fouling sensor, (right) measuring apparatus

The MBR-VFM aims to determine the reversible and irreversible fouling component of MBR mixed liquor through an online measurement. To obtain a representative build-up of reversible and irreversible fouling, the conditions during the measurement are similar to the ones in full-scale MBR's. In fact, the MBR-VFM can be considered as a mini submerged MBR consisting of a fouling sensor and a measuring apparatus (Figure 1). A tubular membrane is placed in the fouling sensor and permeate is extracted from the sensor during inside-out filtration driven by a vacuum pump. Filtration is carried out at low transmembrane pressure (TMP) and in crossflow mode, caused by the injection of air bubbles at the bottom of the membrane lumen.

The application of a cyclical measurement protocol consisting of filtration and relaxation steps enables to distinguish between reversible and irreversible fouling. To obtain a short-term measurement, hydraulic conditions (flux and crossflow) are such that the occurrence of either reversible or irreversible fouling is provoked.

All relevant filtration data are automatically stored and used to calculate the permeated volume versus the normalized (ir)reversible filtration resistances in MBR-VFM graphs. Recently, an image recognition program based on fuzzy set logic was developed to summarize the complex fouling behavior represented by these graphs in a reversible and an irreversible fouling value between 0% (no fouling) and 100% (very high fouling). The MBR-VFM set-up, measurement protocol and data processing are explained in more detail in [1].

In this study, the MBR-VFM was used to investigate the influence of HRT and SRT on both reversible and irreversible fouling. For this purpose, 2 identical laboratory-scale MBRs were operated in parallel at different HRT and SRT (Table 1). The installations had an active volume of 22.5L, were fed with municipal wastewater and contained flat sheet *Kubota* membranes. The filtration cycle consisted of 8 min filtration and 2 min relaxation. Filtration was carried out at a constant flux, fouling could thus be monitored by the increase of transmembrane pressure (TMP). In addition, MBR-VFM analyses were performed online at least twice a week.

Table 1: Values for SRT and HRT for MBR 1 and MBR 2

	MBR 1	MBR 2
SRT (d)	30	10
HRT (h)	18	9
Flux (L/hm ²)	15.6	15.6
Membrane surface area (m ²)	0.1	0.2

Results and discussion

Figure 2 shows the evolution of TMP in both reactors. The arrows indicate when a chemical cleaning with hypochlorite was carried out. In MBR 2, TMP increased much stronger and a chemical cleaning had to be carried out after only 10 days of filtration. Still TMP continued to rise quickly. To avoid frequent chemical cleanings, the flux in MBR 2 was lowered from 15.6 to 10.4 L/hm² on day 35. But even after this flux reduction, TMP increase in MBR 2 remained higher than in MBR 1 and chemical cleanings needed to be carried out more frequently.

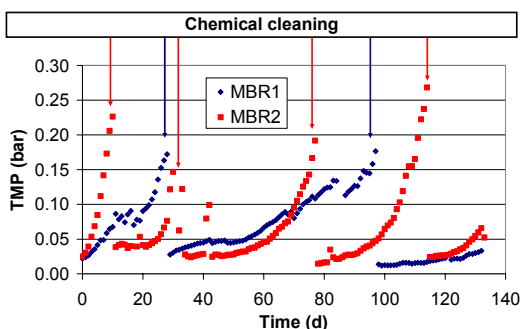


Figure 2: Evolution of TMP in lab-scale MBRs

that this difference was mainly due to fouling of the reversible type. This was confirmed by the fact that prolonged relaxation phases during stand-still of the reactors with continuous air scouring reduced the initial TMP upon restart.

A correlation was found between the reversible fouling values and the concentration of carbohydrates and total organic carbon (TOC) in the supernatant for both MBRs. Such a correlation could not be found for proteins (Figure 3). This is an indication that TOC and carbohydrates probably played a role in reversible fouling phenomena, while proteins had no significant contribution. Although a correlation could also be found between the irreversible fouling values and the TOC and carbohydrate concentration, the value of the correlation coefficients was much lower than for the reversible fouling. This is contradictory to literature results where these compounds have rather been associated with irreversible fouling phenomena [2]. However, some researchers (e.g. [3]) also found that the supernatant contributes to the formation of a reversible fouling layer.

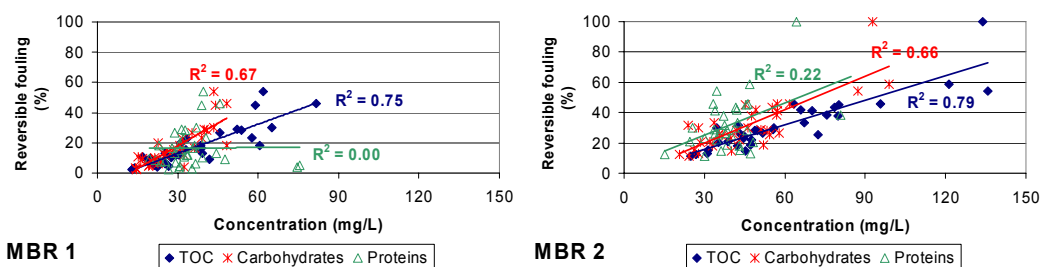


Figure 3: Correlation between supernatant compounds and reversible fouling values

Conclusions

Many studies have already been carried out to assess the influence of operational parameters on fouling in MBR's. However, information about the reversibility of this fouling is often lacking. In this study, a new fouling measurement method was used to assess the influence of HRT and SRT on the reversible as well as irreversible fouling component. Both the online filtration data and the MBR-VFM measurements indicated that shorter retention times lead to more severe fouling. In addition, the MBR-VFM could now demonstrate that this fouling was mainly of a reversible nature. Furthermore, a correlation was found between the reversible fouling propensity and the concentration of carbohydrates and TOC in the supernatant, indicating that these substances probably also played a role in the observed reversible fouling phenomena.

In the future the MBR-VFM will be used as an online sensor in an advanced control system enabling the deployment of reversible and irreversible fouling data for the control of physical and chemical cleaning actions. This would reduce operational costs associated with membrane fouling, thereby making MBRs more competitive in comparison to conventional wastewater treatment systems.

Acknowledgements

This work was performed in the frame of EU-project AMEDEUS (FP6 contract n° 018328). It was also funded by the University of Antwerp through a PhD fellowship. The authors would like to thank Rob Muyshondt, Louis Raats, Filip Vanhoof and Lynn Van Tilborg for their technical assistance.

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PILOT-SCALE DEMONSTRATION AND OPTIMIZATION OF SIDE-STREAM MBR USING CERAMIC MEMBRANE

Koichiro Kando*, Shigehiro Suzuki*, Hiroki Itokawa**, Hiromasa Inoki**, Hitoshi Nakazawa**

* Metawater Co., Ltd. 1 Maegata-cho, Handa, Aichi, Japan, kando-koichiro@metawater.co.jp / suzuki-shigehiro@metawater.co.jp

** Japan Sewage Works Agency, 5141 Shimosasame, Toda, Saitama, Japan, itokawah@jswa.go.jp / inoki@jswa.go.jp / nakazawa@jswa.go.jp

keywords: ceramic membrane, side-stream, membrane bioreactor (MBR)

Introduction

Considering the recent international trend of MBR technology toward larger-scale installation, Japan Sewage Works Agency (JS) has been conducting pilot-scale studies regarding demonstration and optimization of several MBR systems which have been developed/modified for mid- to large-scale municipal WWTPs. The poster describes one of them, a novel MBR system using a ceramic membrane module (Figure 1). The membrane has a physically stable body, highly resistant to various kinds of chemicals and durability. A side-stream (external) MBR system was developed with this ceramic membrane, which enables flexible configuration fit for various conditions of existing WWTPs. Long-term operating results of the pilot-scale plant, as well as optimization of system parameters and membrane cleaning criteria, are to be presented.

Objectives

The pilot-scale study has been performed in order to demonstrate and optimize the membrane and biological performances of the MBR system in the course of long-term operation treating domestic sewage. Reduction of specific energy consumption has been of great interest as well.

Materials & Methods

The pilot-plant, 100 m³/d of hydraulic capacity, was installed and operated at JS R&D center at Moka City in Japan (Figure 2). The system was designed for nitrogen removal with pre-denitrification configuration, where an external ceramic membrane system was incorporated. For the influent wastewater, primary effluent of the adjacent municipal WWTP was fed to the anoxic tank without any screening. Typical ranges of some biological parameters are summarized in Table 1. The membrane filtration was performed by a suction pump with constant flux mode (3.2 m/d). As a maintenance cleaning measure, a combination of three kinds of periodical backwash was tested (Figure 3). In the "ordinal backwash", the mixed liquor circulation is stopped and external pressurized water is injected from permeate side, removing sludge cakes from the membrane surface. Water used for washing is discharged from the inlet of the membrane module. The "pulse backwash" injects external pressurized water while keeping mixed liquor circulation active, thereby further removing sludge cakes from the membrane surface. In the "chemical enhanced backwash (CEB)", membrane module is filled with chemicals (NaClO; approx. 100~150mgCl/L) which is injected from permeate side, followed by the ordinary backwash to remove settled cloggings.

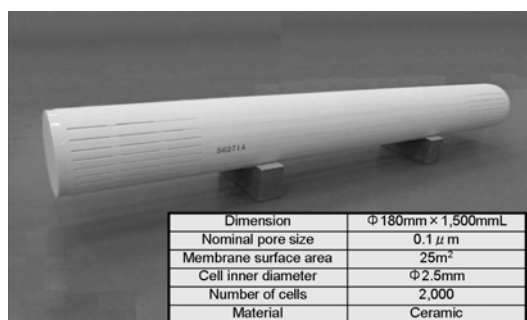


Figure 1: Ceramic membrane

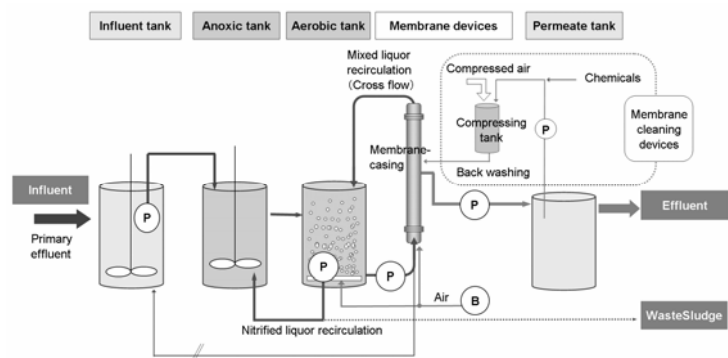


Figure 2: Experimental flow

Table 1: Experimental apparatus and condition

Bioreactor	Influent	Primary effluent of Moka WWTP
	System configuration	Pre-denitrification with internal recycle + external (side-stream) MBR (Ratio of nitrified liquor recirculation :200□)
	HRT	6 h
	SRT	35~90 d
	MLSS	6,800~9,900 mg/L
	BOD-SS loading	0.03~0.07 kg kg ⁻¹ d ⁻¹
	Diffuser	Ceramic high density diffuser
Membrane filtration method	Membrane	Ceramic membrane(full scale)(MF)
	Filtration method	Cross flow filtration method□ constant flow□

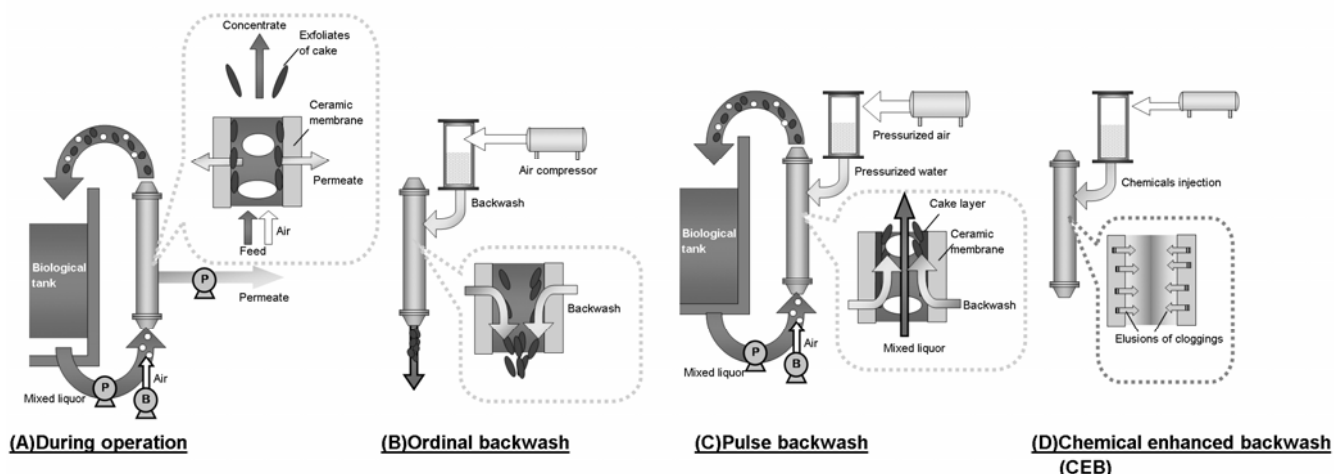


Figure 3: Methods for ceramic membrane washing

Results and discussion

(1) Membrane filtration performance

During the 5 months operation in high temperature season (water temperature: 20~33°C), TMP increased gradually but still under acceptable range (Figure 4), showing stable membrane performance under high flux condition (3.2 m/d on average) without any recovery cleaning. Finally, the elevated TMP value was fully recovered by chemical cleaning with NaClO (3,000 mgCl/L) and citric acid (1%). The filtration performance of coming winter season will be presented in the poster.

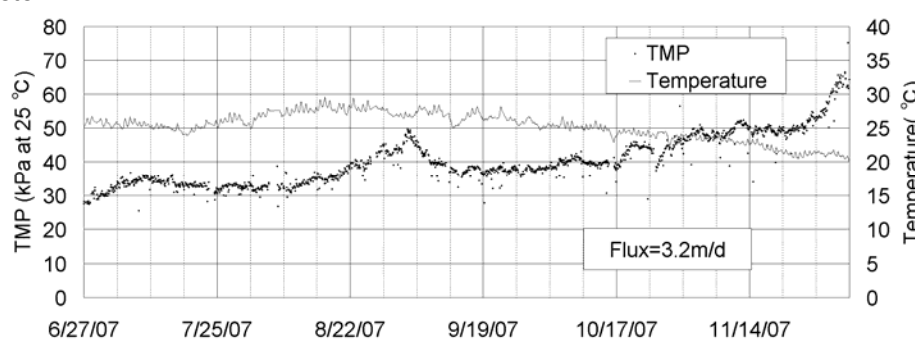


Figure 4: Variation of TMP and temperature

(2) Biological treatment performance

Range and average values of the influent and effluent (permeate) water qualities are shown in Table 2. Although the influent wastewater was rather "weak", the plant showed excellent biological treatment performance in terms of both carbon and nitrogen removal. Results of ongoing investigations, including phosphorus removal by simultaneous precipitation and comparative study with different biological configurations with EBPR, will be presented in the poster.

Table2: Water quality data (average)

	Influent	Effluent
SS	37.0~100.0	N.D. ~ 0.5
BOD	51.0~120.0	0.7 ~ 1.8
COD _{Mn}	31.1~ 63.2	3.8 ~ 7.2
T-N	21.4~ 43.3	6.2 ~11.9
NH ₄ -N	13.9~ 31.3	N.D. ~ 2.1

Unit: mg/L

Conclusions

- Pilot-scale external MBR system with ceramic membrane was successfully operated under high flux (approx. 3 m/d). By supplying primary effluent as the influent, pre-screening could be omitted. A combination of three on-line backwash methods successfully reduced the TMP increase to acceptable range.
- The membrane with elevated TMP was fully recovered to the initial performance by chemical recovery cleaning.
- With pre-denitrification configuration, the plant showed satisfactory performance in terms of both carbon and nitrogen removal. Incorporation of biological phosphorus removal is the ongoing matter of demonstration.

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Patent pending: EP06111646.3-2113 METHOD FOR CLEANING SEPARATION MEMBRANE
EP06111652.1-2113 METHOD FOR CLEANING SEPARATION MEMBRANE

RHEOLOGICAL PROPERTIES OF MEMBRANE BIOREACTOR SLUDGE : INFLUENCE OF TOTAL SUSPENDED SOLIDS AND SOLUBLE ORGANIC MATTER

KHONGNAKORN Watsa, VACHOUD Laurent, DELALONDE Michèle and WISNIEWSKI Christelle

UMR Génie des Procédés, Eau et Bioproduits (GPEB)
 Université de Montpellier 1
 Université Montpellier 1 - UFR Pharmacie
 15, Avenue Charles Flahault
 BP 14491

34093 Montpellier – Cedex 5

kwatsa@univ-montp2.fr, laurent.vachoud@univ-montp1.fr, michele.delalonde@univ1-montp2.fr, wisniewski@univ-montp2.fr

Keywords: Rheological properties, biological sludge, membrane bioreactor, solids concentration, soluble organic matter

Introduction

The ability of membrane bioreactor (MBR) system for retaining high biomass concentration allows operations in long sludge retention time (SRT) conditions, which is a good thing for minimizing the excess sludge production. However, the implementation of complete sludge retention MBR is still in question because of the sustainability of microbial behaviour, effect of soluble microbial products (SMP) on membrane fouling and also rheological properties of the sludge. The same questioning about the sludge behaviour can be done for unsteady-state conditions, due to a peak loading or a particular stress. Actually, whatever the disturbance may be, marked changes in activated sludge microorganisms communities and physico-chemical composition are shown to have an influence on rheological parameters [1, 2, 3, 4] and then on the efficiency of the mixing, the aeration but also on the sludge post-treatment (dewatering...) and management (transporting, storing, landfilling...).

Objectives

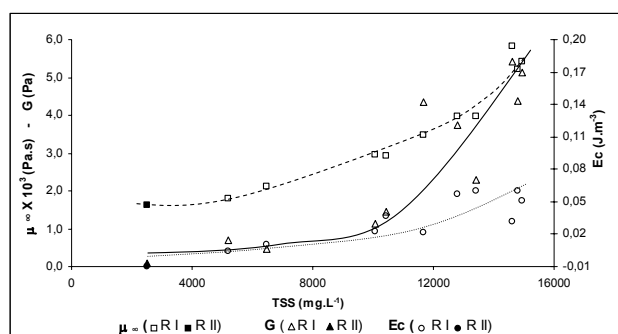
This study was conducted to investigate the rheological behaviour of sludge coming from a prolonged SRT MBR. The rheological characteristics of the sludge are quantified for various total suspended solids (TSS) and soluble organic contents (COD), parameters which are able to have a strong influence on the sMBR sludge properties.

Materials & Methods

Sludge is drawn from a 50 L submerged membrane bioreactor (sMBR) unit continuously feed with a synthetic complex influent. The filtration unit consists in 2 modules (each of 0.1 m²) of capillary polysulphone hollow fiber membranes (2 mm in external diameter, 0.08 µm in pore size). The behaviour of the biological system is studied for two running periods (RI and RII), characterized by different organic loads (VLR) and/or solid retention times (SRT).

Concerning the rheological characterisation, three parameters (G , E_c and μ_∞) are calculated: (i) G , named shear modulus, represents the rigidity of the sludge network, (ii) E_c is the energy of cohesion of the network sludge and (iii) μ_∞ is the limit viscosity of the sludge, measured for the highest stress values.

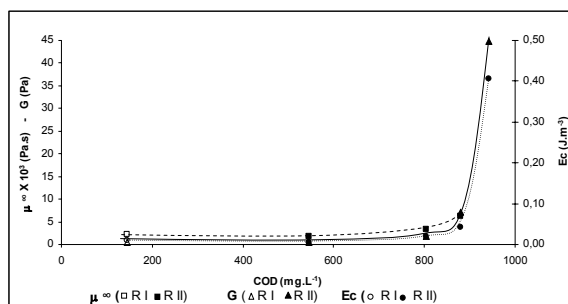
Results and discussion



The three parameters increase exponentially with increasing TSS content (figure 1). The shear modulus G represents the rigidity of the sludge network and characterizes the sludge response for the lowest stress values, for which the structure of the sludge and the interactions between the solids are not disrupted. When the TSS content increases, the interactions between the flocs, and so between the solids, are favoured, leading to a more rigid structure of the sludge network (G increases) and to an increase of the sludge cohesion. The evolution of the energy of cohesion with TSS content confirms these comments. The limit viscosity, μ_∞ , can not be related to the interactions between solids because it is

Figure 1: G , E_c and μ_∞ versus TSS concentration

determined for the highest stress values, for which the sludge can be assimilated to a continuous fluid with a Newtonian behaviour. This limit viscosity corresponds to an apparent viscosity of an equivalent liquid whose properties depends of the volume solid fraction. Consequently, it is not surprising that the limit viscosity increases with the TSS concentration.



G , E_c and μ_{∞} increase with a COD increase (figure 2). This increase of G and E_c could be related to the increase of soluble microbial products, expressed in soluble COD. These soluble microbial products are mainly made up of polysaccharides and proteins. They are likely to create linkages between the flocs, leading to a much more rigid structure of the sludge and then to an increase of the shear modulus and of the cohesion of the sludge network. The limit viscosity, μ_{∞} , increases with the COD concentration. This result reveals the importance of the composition of the liquid phase, and especially of soluble organic microbial products, on the sludge behaviour.

Figure 2: G , E_c and μ_{∞} versus COD concentration

According to the results obtained, it seems obvious that the influence of the organic soluble polymeric products is more important than the one of the solid fraction. The measured parameters are more affected by the increase of the COD concentration than by the one of the TSS concentration, with significantly different order of magnitude. Contrarily to the other rheological parameters, μ_{∞} varies in a same range for TSS or a COD variation.

Conclusions

The obtained results show clearly that operating conditions, susceptible to change total suspended solids (TSS) and soluble organic compounds (COD) concentrations, modify the rheological behaviour of the sludge. The key role of the soluble organic compounds is greatly underlined, and notably in comparison with the one of the TSS concentration. Specifically, the soluble organic content affects the parameters describing the solid behaviour of the sludge, i.e. the energetic stability of the initial network established between the flocs. For sludge little solicited, the soluble organic matter, essentially assimilated to polymeric microbial products, contribute greatly to the creation of a network increasing the rigidity of the sludge. When the stresses increase, the flow of the sludge is possible, the polymer network is disrupted. In this situation, the flow is fewer dependants to the presence of soluble organic compounds.

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SEPARATION PERFORMANCE OF POLYELECTROLYTE-MODIFIED ULTRAFILTRATION MEMBRANES

J. Kochan*, T. Wintgens**, J. E. Wong***, T. Melin*

*Aachener Verfahrenstechnik, Lehrstuhl für Chemische Verfahrenstechnik, RWTH Aachen, jozef.kochan@avt.rwth-aachen.de

**Fachhochschule Nordwestschweiz, Hochschule für Life Sciences, Institut für Ecopreneurship, Gründenstrasse 40, 4132 Muttenz, Switzerland

***Institute of Physical Chemistry, RWTH Aachen University, Landoltweg 2, 52056 Aachen, Germany

Keywords: polyelectrolyte, coating, ultrafiltration membrane

Introduction

Coating with polyelectrolytes is an alternative method to modify membranes. Due to the mild conditions, it is not damaging to the surface as compared to commonly applied modification methods. Over last years, many studies have been devoted to characterization of the deposited thin film originating from diverse poly-ion combinations or constructed under variable deposition conditions for different applications [1, 2]. However, only few trials have focused on polyelectrolyte-modified membranes for wastewater treatment [3].

Objectives

The aim of this paper is to investigate how the deposition of polyelectrolyte layers onto the membrane surface changes the sieving characteristics of membranes. Dextran solutions and sludge supernatant have been used for filtration and their permeation through the modified and unmodified membranes has been determined by total organic carbon retention and size exclusion chromatography. Moreover, the shift of molecular weight cut-off value has been studied.

Materials & Methods

The coating experiments were carried out with polyethersulfone ultrafiltration membranes. To determine the molecular weight cut-off (MWCO) a dextran solution (dextran dxtb2000 supplied by Polymer Standards Service; MW = 1 520 000 g/mol; was filtrated in cross-flow mode. During these tests, the cross-flow velocity was set to 0.1 m/s and the trans-membrane pressure to 0.2 bar. The chemical composition of the feed and the permeate solution was analysed by the size exclusion chromatography (SEC) carried out with a High Performance Liquid Chromatography system (Agilent Technologies, Series 1100; Software WINGPC Unity, Polymer Standards Service). The same method was also applied to characterize the molecular mass distribution of soluble compounds in the sludge supernatant and permeate.

The characteristics of polyelectrolytes employed (purchased from Sigma-Aldrich) in this study are summarized in figure 1. Solutions of the polyelectrolyte were prepared from 0.02 M (based on repeat units of the monomer) in water for PEI and in 0.5 M NaCl for PDADMAC and PSS respectively. PES membranes are negatively charged; therefore the first layer adsorbed is a poly-cation. PEI and PDADMAC were chosen as poly-cations due to their high surface charge density to promote anchoring of the first layer to the PES membrane. In this work, PES membranes have been modified with a single layer (PEI or PDADMAC respectively), two layers (PEI/PSS and PDADMAC/PSS) and three layers (PEI/PSS/PDADMAC and PDADMAC/PSS/PEI) of polyelectrolytes.

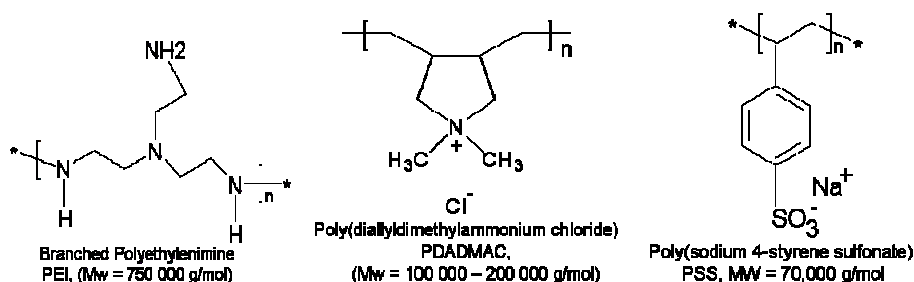


Figure 3: Polyelectrolytes used for modification

Briefly, the PES membrane is dipped into a polyelectrolyte solution for 3 hrs at room temperature (20 °C), washed three times with deionised water to remove any loosely bound polyelectrolyte before immersion in the next polyelectrolyte solution. This cycle is repeated until the desired number of layers is achieved. Coating experiments with different numbers of layers were performed with pieces obtained

from one single fibre in order to assure comparable starting conditions.

Results and discussion

Figure 2 shows that the used membrane has an open pore structure and therefore the MWCO value is not detectable with the used standard dextran solution. However, after the deposition of PEI the MWCO is shifted to $3.52 \times 10^6\text{ Da}$ and after the second deposited layer of PSS to $4.65 \times 10^5\text{ Da}$. It clearly proves that the deposited polyelectrolytes become a thin separation layer on the surface and control the sieving performance of membranes.

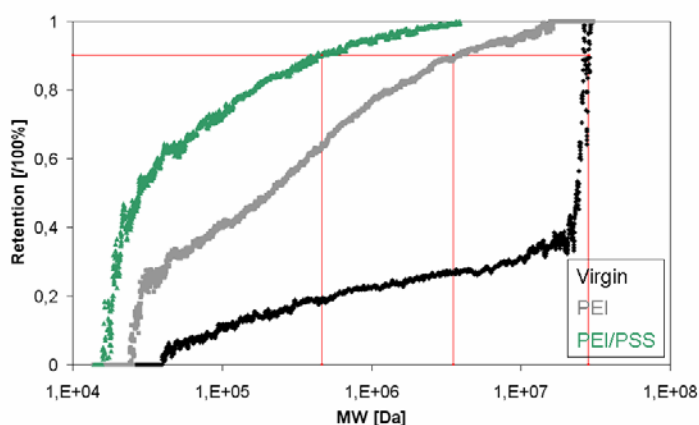


Figure 4: Dextran rejection (MWCO)

	TOC [mg/L]		TOC retention [%]
	Feed	Permeate	
Unmodified	11.3	9.5	15.9
PDADMAC	11.1	7.7	30.5
PEI	11.2	7.5	33.0
PEI/PSS	10.3	5.1	50.5
PDADMAC/PSS	10.2	5.9	42.2

Table 1: TOC rejection

Although dextran retention is likely the best approach for MWCO determination, it does not correspond to the envisaged applications. To evaluate the relevant separation performance of polyelectrolyte membranes, sludge supernatant from an aerobic MBR has been filtrated and characterized by TOC removal and SEC.

The TOC values of feed and discharged permeate for both unmodified and modified membranes are pointed out in table 1. As notable, already a single deposited layer is able to reject roughly 15% more TOC as compared to the unmodified one and a bi-layer system even 30 %.

The results of SEC complement our study on separation performance. As figure 3 shows, the unmodified membrane is able to remove only high molecular substances with elution time around 6.5 min. That rejected peak holds for the 15% of TOC removal by the virgin membrane. The PEI/PSS coated membrane is able to remove not only that peak but even smaller compounds coming through the detector after 6.8 min what hints to substances in the range 1 – 100 kDa. Looking at the circles in figure 3 a-b, one can see that the unmodified membrane has rejected all compounds of a molecular size of 6750 Da and the PEI/PSS coated one even of 3696 Da.

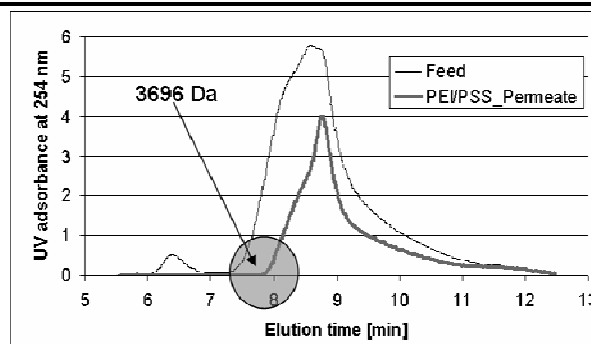
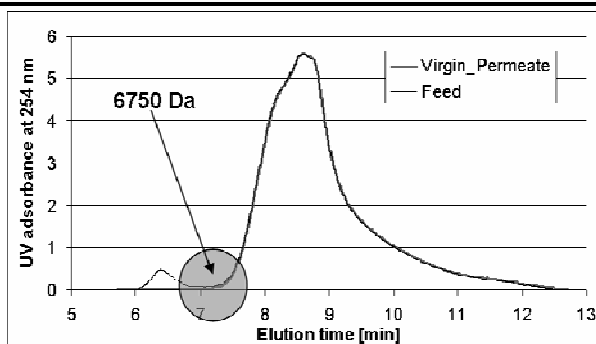


Figure 5: SEC of feed and permeate passed across unmodified (left) and PEI/PSS modified membrane (right)

Conclusions

In summary, the modified membranes feature a significant shift of MWCO even after one and two deposited layers what indicates a dense structure of the thin film. Adsorbed layers also induced an enhanced and sharper separation performance in sludge supernatant filtration characterized by TOC and SEC respectively.

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COMPARISON OF THE OPERATIONAL PROCESSES OF THREE DIFFERENT FULL-SCALE MEMBRANE BIOREACTORS

Pawel Krzeminski*, Elif Atasoy, Arjen van Nieuwenhuijzen, Jaap van der Graaf
* Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands
p.krzeminski@tudelft.nl

keywords: membrane bioreactors, MBR, municipal wastewater, filterability, operational parameters

Introduction

In face of increased waste water production efficient purification methods are needed. Membrane bioreactors (MBR) are among the most promising emerging technologies in the water treatment sector. However, despite their significant rise in popularity and applicability there are still a number of important knowledge and operational issues that need to be addressed.

The efficiency of different membrane bioreactor plants can vary strongly depending on type, design capacity, wastewater quality, cleaning strategies and effluent requirements. Moreover, the relationship between operational parameters and plant performance (permeability, fouling, cleaning) is not clear yet. Thus knowledge improvement on operational parameters and interaction between such parameters as well as the influence on plant performance is fundamental and essential for the future of MBR technology. An optimisation of MBR operation which also takes into account membrane types, materials and configuration, operational settings and economic aspects is also required.

Objectives

The main objective of this work is to investigate effects of operational parameters on MBR performance. The operational process performances of three full-scale membrane bioreactors in the Netherlands – Heenvliet, Ootmarsum and Varsseveld - will be compared in this study. Filterability and its relationship to plants operational parameters will be under investigation. These data will be worked out in a database to compare performance on full scale and to identify the correlations between those parameters. This should provide information on effects of different membrane bioreactors configurations and may give insight into operational issues and efficiency of the plants. In final this operational aspect comparisons should lead to the optimization of the costs, energy demand and chemical addition.

Materials & Methods

For the purpose of this research the Delft Filtration Characterisation method (DFCm), described in detail by Evenblij [1], will be used. This filtration unit was developed by Delft University of Technology specifically for filtration characterisation and membrane fouling research. The DFCm consists of a small-scale filtration unit (Figure 1) and is operated on the basis of a measuring protocol. The DFCm facilitates the measuring and characterization of different samples of activated sludge under the same conditions. The mobile construction of the installation permits measurements to be performed directly on the MBR site.

A measurement campaign consisting of filterability tests at each location will lead to the development of the MBR database [2]. In this study activated sludge from different compartments of the plants will be measured in order to compare filterability results and then correlate with the plants operational data. Furthermore analytical and statistical tools will be implemented for the comparison study in order to explain all the various relations and the importance of the specific operational parameters.

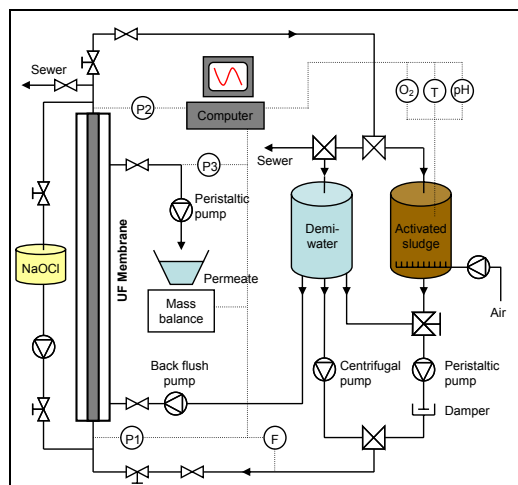


Figure 1: Delft Filtration Characterisation installation

Results and discussion

We will present experimental results obtained during filterability monitoring of the full-scale MBRs. Our work will discuss relation between operational parameters and filterability of activated sludge for the membrane bioreactors optimization studies based on case of three different full-scale Dutch MBRs.

Acknowledgments

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OPTIMISATION OF MBR OPERATION AND RELIABILITY USING FAILURE MODE ANALYSIS

Valentina Lazarova

Suez-Environment, 38 rue du prés. Wilson, 78230 Le Pecq, France, valentina.lazarova@suez-env.com

Keywords: Urban water reuse, ultrafiltration , operation costs, monetary and non-monetary benefits

Introduction

During the last twenty years, membrane bioreactor (MBR) technology rapidly evolved from a leading-edge technology to a viable cost competitive alternative of conventional biological treatment. Despite the strong interest of researchers in this technology and the significant operational experience, very few information exists on the causes of failure of BRM systems. It is worth noting that the main technical challenge is the control of membrane fouling. Nevertheless, the main causes for failure of full-scale MBRs for treatment of industrial or municipal wastewater were not well understood, documented and explained. In this context, the main objective of this study is to present and discuss the main causes of failure and membrane fouling of full-scale MBR systems with recommendations for optimisation of the reliability of operation .

Methodology

Four full scale municipal wastewater treatment plants with submerged membranes Zenon (ZeeWeed 500) located in France and Spain have been monitored to evaluate the treatment efficiency, reliability of operation, fouling control and the main reason for system failures. All studied municipal MBRs are located in sensitive areas (bathing zones, water reuse for aquaculture) and any incompliance of water quality can lead to a crisis situation with potential strong financial penalties. To help collecting the needed information, the MBR units were divided into typical functional elements and sub-elements. The technical performance was evaluated on the basis of reliability of operation, lifetime of equipment, ease of operation, odour control and potential of elimination of emerging pollutants. The analysis of the reliability of operation of MBR systems, in terms of observed failures or likelihood of failure and their potential impact, was assessed by several meetings with plant managers and operators on a formal and informal basis.

The reliability of operation was estimated using failure mode analysis in compliance with the main findings of the Failure Mode Effects and Criticality Analysis (FMECA) tool. It is based on the evaluation of the major consequences of failures, including environmental pollution, consent exceedance, volume compliance, odors, unsatisfactory sludge disposal, bathing beach failures, health and safety, reputation and adverse public perception, financial impacts (direct costs of repair, excess costs, loss of income) and contract failure. Each consequence includes several important impacts, which are rated by a relative score related to defined economic value. Failures modes are then prioritised as a function of their probability, severity and detectability. Based on this prioritisation and the associated technical-economic analysis of all potential failures of a given MBR, actions were recommended to prevent failure or to reduce the likelihood of failure occurring.

Results and Discussion

The analysis of the long term performances of the studied membrane facilities confirms the high reliability of operation of MBR technology compared to conventional biological treatment. For each MBR unit, a risk matrix for the selected functional elements was build depending on frequency and impact of failures (Table 1). The occurrence and the severity of failures are classified from very unlikely to frequent with ranks from 1 to 10. When the third factor of detectability is added to calculate the risk priority number (RPN), the ranking of failure modes evolves as shown by the Table 1.

Table 1. Example of risk matrix for the reliability of operation of a SMBR

Occurrence/ Severity	Very- unlikely	Remote	Occasional	Probable	Frequent
Very-high (health risk)	–	–	–	–	–
Critical	Damage-of- modules	Damage-of- membranes	Membrane- clogging	Fault-of-air- scouring	Micro-sieve- clogging (0,5- or-0,75-mm)
Major	Power- failure	Failure- of-PLC	Failure-of- membrane- auxiliary- equipment	Fault-of- blowers-&- diffusers-of- aeration- basins	Fin-screen- clogging (1-or-3-mm)
Moderate	–	Failure-of- SCADA-&-HMI	Fault-of- recirculation-of- mixed-liquor	Failure-of- sludge- treatment	Fault-of-PLC- link-(modems, etc.)
Minor	–	Failure-of- chemical- dosage- (polymer, FeCl ₃)	Fault-of-inlet- pumps	Failure-of- buffer-tank- equipment	Foaming

In all investigated facilities, the biggest RPN is calculated for the clogging of fine screens and the faults of PLC system, characterised by high frequency and not easy detection. Membrane fouling and damage remains a high risk with problems of easy detection.

Even if the occurrence of module or membrane damage is very unlikely, their potential impact is very high and critical for MBR performance and reliability.

The operation of activated sludge in terms of good aeration is another important factor with strong impact on membrane performance. In fact, any deterioration of activated sludge flocs with release of colloids and soluble microbial products due to fermentation, peaks of salinity or toxic shock loading, leads to loss of membrane permeability and membrane fouling. Compared to conventional activated sludge, poor characteristics of the mixed liquor does not significantly affect permeate quality in terms of compliance with discharge consents. This is the main reason way MBR systems are considered as more efficient and reliable. Nevertheless, it is important to stress that lifetime and permeability of membranes can be reduced, impeding thus the overall technical-economic performance.

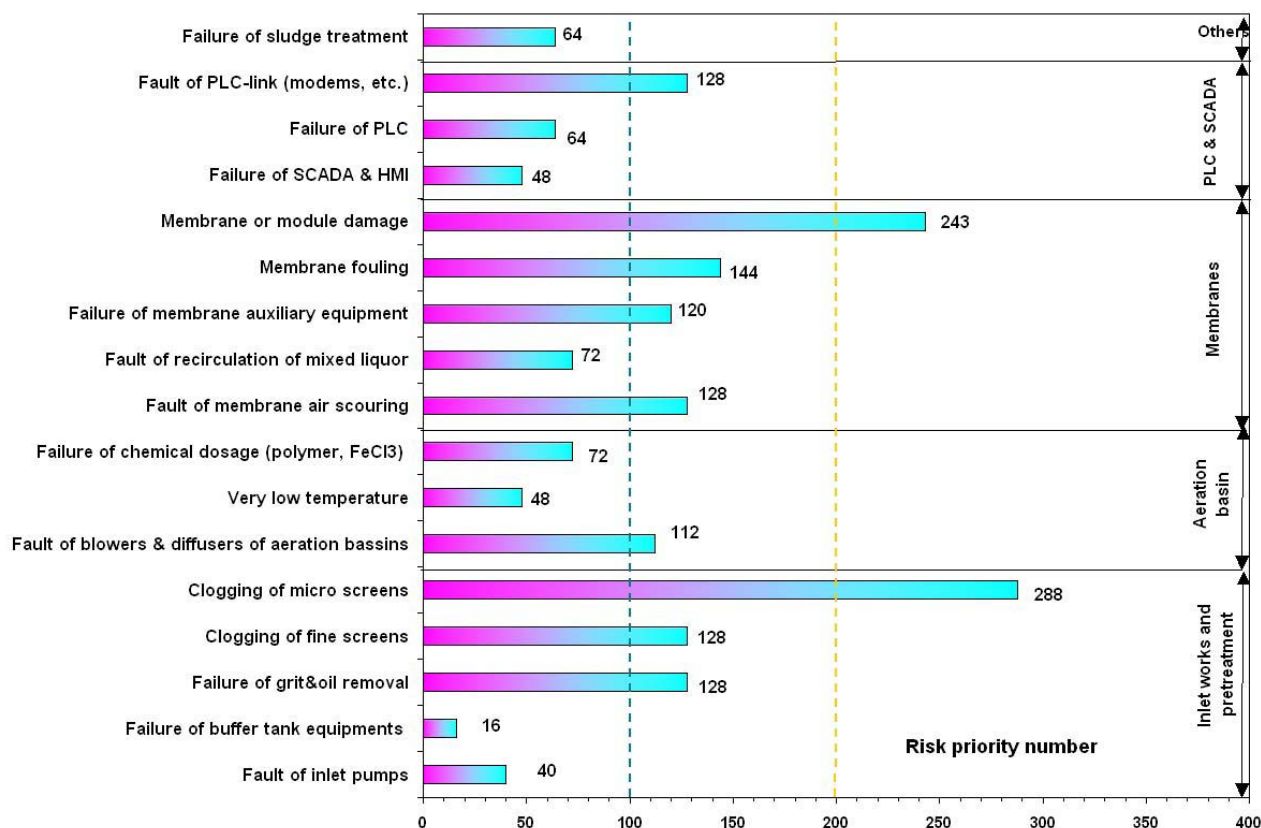


Figure 1. Comparison of risk priority numbers for the selected failure modes of two BRM

Conclusions

To better characterise the weak areas of SMBR operation and develop actions to prevent their occurrence, the failure mode analysis was used as a problem prevention tool. It was demonstrated that the major risk is undoubtedly membrane damage or fouling. Two types of equipment have been identified as the major cause for decrease of membrane performance – faulty pre-treatment, mainly fine screening and grease removal, and poor activated sludge properties induced by faulty aeration or shock salt and toxic loadings. PLC and SCADA systems appear as very reliable tools for operation of membrane systems. However, their functions have been often disturbed by some minor problems related to unreliable equipment such as communication links. The risk of failure of electromechanical equipment is recognised as low because its redundancy and remote control, enabling immediate detection of failures.

The application of FMECA to the four submerged MBR systems, constructed and operated by different companies, enabled to well describe failure conditions, found similar weak points, identify whether failures are reproducible or transient and estimate what combination of conditions and sequence of events could lead to failure. Finally a set of recommendations, including operational procedure and equipment replacement, were formulated to improve future design and operation.

MBR AERATION AND FOULING, DIFFERENTS LEVELS OF OBSERVATION

J. Lebegue, M. Heran, A. Grasmick
 UMR 016 Génie des Procédés, Eau et Bioproduits (GPEB), UM II
 34093 Montpellier – FRANCE

julie.lebegue@univ-montp2.fr, marc.heran@univ-montp2.fr, alain.grasmick@univ-montp2.fr

Keywords: Membrane bioreactors, Hollow fibre, Aeration, Membrane fouling

Introduction

For a given SMBR system, membrane fouling is linked to the more or less reversible accumulation of macromolecules and solids on the membrane surface and to the irreversible sorption of soluble molecules inside the pores. If the reversible accumulation can be minimized by filtering in subcritical conditions, it is important to investigate the aeration effect on the irreversible sorption of soluble molecules.

Objectives

This paper shows how the suspension characteristics and membrane aeration intensity are link together. First the influence of membrane air flow rate on fouling during long term experiment was analysed. Then, a specific cleaning protocol was introduced in order to analyse the different fraction of fouling on the hydraulic resistance due to (i) the sludge accumulation, (ii) the irreversible thin biofilm onto the membrane surface and (iii) the role of adsorbed compounds.

Materials & Methods

Experiments were carried on in the lab scale submerged membrane bioreactor SMBR equipped with two hollow fibre bundles in parallel as described Fig. 1. The MBR was continuously fed with a synthetic substrate. Whereas

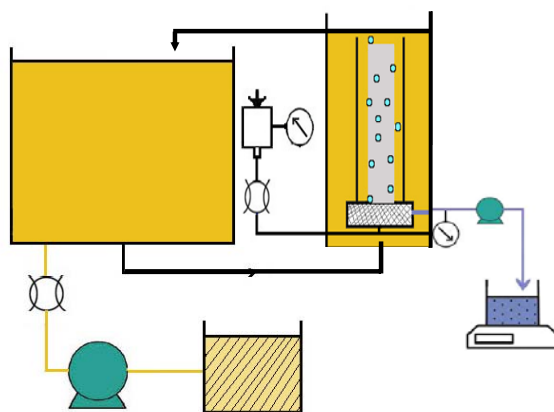


Figure 1 : Experimental set-up

different sludge concentration and permeate flux were tested to obtain different fouling rate (fig. 2) for the fouling slip up, the experiments were carried out again with a constant 20 LMH permeate flux with a range of variation of X_{SS} between 4-6 g/L. The filtration was then systematically stopped in both bundles as soon as TMP reached 0.3 Bar (R_T). Thus the resistance was calculated when the module was rinsed under tap water (until no sludge accumulation could be visually observed inside the bundle) : $R_T - R_S$, else each fibre was wiped to remove biofilm : $R_T - R_S - R_A$ (Fig. 3).

Results and discussion

a- Reversible fouling: Influence of membrane aeration on sludging control:

The results showed (Fig. 2) that membrane air flow rates appeared as a determining criterion to minimize sludging when filtering under intensive conditions. An air flow rate of 300 L/H allowed sustainable permeate fluxes operation, while an air flow rate of 100 L/H are only sufficient for low permeate flux (10 LMH). Under a specific amount of TSS which was dragged to the membrane due to the permeate flux ($70 \text{ gTSS} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$), the air flow rate has no effect on the fouling rate, later than, the influence of aeration must be introduced in the equation.

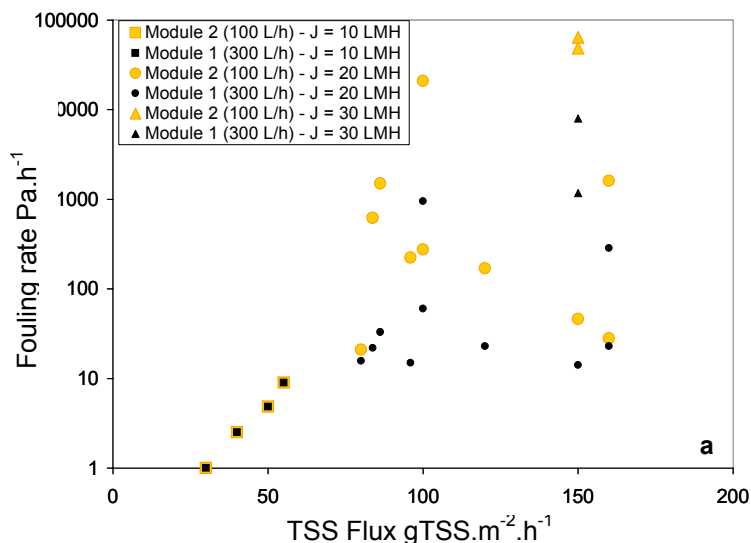


Figure 2 : Fouling rate versus TSS drag to the membrane due to the permeate flux

b- Zoom in on Fouling phenomena and Hydraulic resistances splitting up

The discontinuous line is marked for reference on each graphic at the value of 10^{12} m^{-1} . In the defined working conditions, the extent of sludging on the hydraulic resistance can be observed when operating with low membrane airflow rates. If sludging can be avoided by increasing aeration, the resistance due to biofilm and soluble adsorbed molecules are of the same order of magnitude. Nevertheless, membrane aeration also appears to have a positive effect on biofilm resistance. These results confirm the importance of good sludging control in the bundle. This is also largely dependant on the suspended solid concentration in the bulk

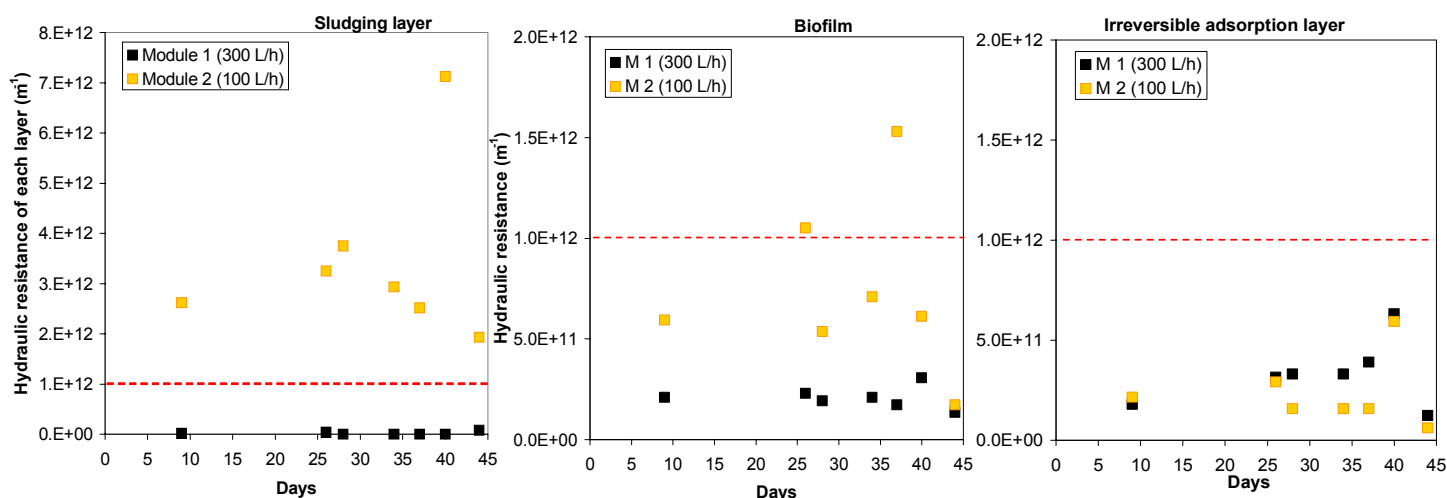


Figure 3 : Different levels of fouling observation : sludge accumulation, biofilm and adsorbed compounds

Conclusions

An appropriate aeration rate can avoid the resistance due to the sludge deposit. If the resistance due to biofilm and soluble adsorbed molecules are of the same order of magnitude, the aeration could also minimize hydraulic resistance due to the presence of biofilm. These observations provide important helpful information for the fouling modeling of SMBR. In fact, once the aeration is optimized, the effort must be concentrate on the biofilm evolution instead of modeling the sludge cake accumulation.

OPERATION OF DOMESTIC PILOT MBR WWTP

Zuzana Matulová*, Petr Hlavínek*, Tina Pikorová**, Miloslav Drtil***

* Institute of Municipal Water Management, Brno University of Technology, Faculty of Civil Engineering, Zizkova 17, 612 00 Brno, Czech Republic, e-mail: matulova.z@fce.vutbr.cz

** Department of Sanitary & Environmental Engineering, Slovak University of Technology, Radlinskeho 11, 813 68 Bratislava, Slovak Republic, e-mail: pikorova@yahoo.com

*** Department of Environmental Engineering, Institute of Chemical and Environmental Engineering, Faculty of Chemical and Food Technology, Slovak University of Technology, Radlinskeho 9, 812 37 Bratislava, Slovak Republic, e-mail: miloslav.drtil@stuba.sk

Keywords: domestic wastewater, household MBR WWTP, temperature influence, filamentous bacteria, sludge bulking.

Introduction

The aim of this research is to get a practical experience with operation of a household MBR plant under the real conditions with real domestic wastewater that differs from the municipal wastewater. Additionally, the main target is to optimise the MBR plant operation for a further full-scale application. For household MBR plant is typical that the system must cope with a long-time zero load or vice-versa with more concentrated wastewater in big amounts (i.e. on weekends).

Objectives

In this study the treatment plant is fed by real domestic wastewater. In contrast to most other experiments with small-scale WWTPs carried out in laboratories and facilities of large municipal WWTPs (polygons), which guarantee stable and flexible operation. However, the characteristics of wastewater and activated sludge in these studies usually differ from those that occur in real small-scale/single-household WWTPs. Obviously, the wastewater does not originate from a sewer system and several difficulties must therefore be overcome: for example, wastewater is not diluted with rainwater or with infiltrated underground water; the influent of wastewater and pollutant load varies significantly and uncontrollably. Furthermore, the influent may contain hair, toilet paper, and other particles (Abegglen, et. al., 2008), which are removed at the efficient mechanical pre-treatment facilities in a regular WWTP. One of the main goals of this research was to test the response of membrane and activated sludge to different conditions during real operation of the household MBR plant, such as a long period of zero influent/load, or vice versa the presence of a large amount of concentrated wastewater, extreme winter temperatures (below 5-6°C), high pH values, and the presence of domestic detergents.

Materials & Methods

Our single household MBR plant, shown on Figure 1, is located in a garden of a 4-member family house. All wastewater produced in the house flows into the plant (not equipped with any safety bypass or overflow). The household MBR plant consists of 3 tanks in series (each having a volume of 0.58 m³). The first 2 tanks are used as a preliminary treatment stage. These sedimentation tanks, where the majority of insoluble substances are removed by means of sedimentation, are also used to store the sludge. A submersible pipe prevents floating material overflow before the pre-treated wastewater flows into the biological reactor equipped with a PVDF micro-filtration membrane module, with a surface area 6.7 m², and the pore size is <0.1 µm. The effluent is stored in a tank and can overflow to the stormwater sewer or can be used for watering lawn and garden, cleaning floors and later after technical modification for toilet flushing and laundry. Hydraulic retention time in the whole MBR plant was 7.2 days (HRT

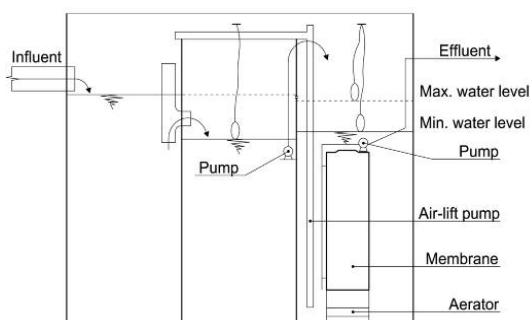


Figure 1: Scheme of the pilot-scale MBR plant

in pre-treatment and activation was 4.8 or 2.4 days, respectively). The mean volumetric load B_v was 0.35 kg of COD m⁻³ d⁻¹.

Results and discussion

The quality of raw wastewater and effluent

The samples were collected at least twice a week (an intensive research study at real conditions). The average water consumption in a 4-member family house was about 0.240 m³ d⁻¹, i.e. 60 L resident⁻¹ d⁻¹, (whereas Slovak legislation recommends 135 L resident⁻¹ d⁻¹ (in a range of -25% to +15%). The difference between the recommended and currently measured values is relatively large and is particularly attributed to the fact that a typical family (two working adults and two school-age children) only spends about one half of the day in their home. This is also influenced by changes in life style, the use of environment-friendly appliances. Similarly, the pollutant load is also affected. The levels of COD, BOD₅, and P_{total} varied in a range of 40-60% of the proposed values recommended by STN 75 6401 – Note: The value of N_{total} was nearly the same!

The levels of COD in the influent and in the supernatant varied significantly in all 3 phases. COD concentrations in the effluent was relatively stable showing a mean level of 53.4 mg/L in the monitored period. BOD₅ levels in the effluent varied in a range of 0.2 - 8 mg/L throughout the whole period, indicating the effectiveness of 99.5%. During the first two phases, primary sludge in sedimentation tanks showed minimum anaerobic decomposition (confirmed by the visual or sensorial inspection of a primary sludge sample taken from sedimentation tanks; respective sludge was brown, without the disintegration of larger particles and had a distinct odour – one should be very careful with the application of this kind of sludge on the soil). During third period were temperatures higher and anaerobic degradation partly started. Sludge was black and unfortunately started floating and foaming. Gradually decreased pH even more intensified anaerobic degradation (mainly hydrolysis)....

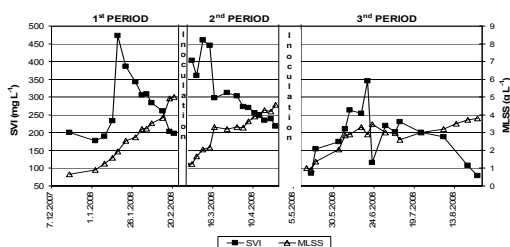


Figure 2: Progress of SVI and MLSS concentration during whole experiment

Quality of activated sludge and its parameters

In the activated tank were also observed sludge sedimentation properties. Sedimentation was verified in each period that means with three inoculums. In Figure 2 is shown the evaluation of sludge volume index (SVI) and mixed liquor suspended solids (MLSS). In the first two periods, *Microthrix Parvicella* was identified as a dominant filamentous microorganism – its abundance ranked 5 on a 6-degree scale according to Jenkins 1993. At such a massive sludge bulking, the membrane showed another advantage as compared to conventional activated sludge process with a secondary clarifier - the membrane, as a physical barrier,

prevented the leak of biomass from the biological system. The sedimentation and separation of such bulking sludge would not be possible in a secondary clarifier (particularly at a fitful hydraulic loads typical of a household WWTP) and the sludge would be washed out from the system....

Flux and membrane fouling

In Phase 1, the filtration step started without the regulation of flux and trans-membrane pressure (TMP). The initial flux was 45 LMH and the system remained without any interventions. It was assumed that most household WWTP owners and users are not and will not be wastewater treatment experts and will not pay any attention to flux or pressure regulation. The flux after approx. 3 months dropped from 45 to 10 LMH (this decrease occurred after a flow of 21.6 m³, i.e. 3.2 m³/m² of filtered water through the membrane). In Phase 2, for the possibility of flux regulation we installed a throttle at the effluent conduit. During the first 3 days of this phase, the initial flux was set to a value of 13 LMH. For the remaining 3 months, the flux was set to 20 LMH. After this period of time, a rapid decrease below 6 LMH was observed. In phase 3, the membrane module was operated at a low flux of 10 LMH.

Conclusions

The single-household MBR plant ran continuously for twelve months, in order to investigate the overall process performance and more specially the sludge and membrane behaviour to specific conditions like extreme temperature, high pH, long time zero load, etc. From this experiment the following conclusions could be drawn:

- Average influent quality: COD 867 mg L⁻¹, BOD 607 mg L⁻¹, P_{total} 17.8 mg L⁻¹, N_{total} 204 mg L⁻¹; NH₄-N 152 mg L⁻¹.
- Effluent quality COD 53 mg L⁻¹, BOD₅ 2.3 mg L⁻¹ fulfilled legislative demands for household WWTPs without problems. Despite of sufficient sludge age, the requirement for complete nitrification in the HWWTP may be risky, particularly because of low temperatures and substrate inhibition of nitrification.
- High pH and low temperature may markedly slow down anaerobic stabilization of primary sludge in settle tanks.
- Sludge separation by settling in a clarifier would be impossible because of massive sludge bulking, only installed membrane module guaranteed the perfect effluent quality.
- Low temperature, bulking sludge, high pH (coupled with precipitation PO₄-P), request for minimum service work - difficult flux regulation in conditions of a household WWTPs, a non-solid permeate pump (with references!) are the factors which may endanger function of membrane process in conditions of household WWTP.
- When the lower filtration flux is used it is necessary to pay attention to retention volume...

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MBR: SEARCHING FOR OPTIMUM FOULING CONTROL STRATEGIES

E. Meabe*, L. Sancho*

* CEIT (Section of Environmental Engineering) and TECNUN. Paseo Manuel de Lardizabal, 15. 20018 San Sebastián (Spain)

E-mail: emeabe@ceit.es, lsancho@ceit.es

Keywords: Membrane Bioreactor (MBR), Fouling, Backwash optimization

Introduction

Membrane fouling is one of the most serious concerns affecting MBR performance. Backwashing operational parameters notably affect the hydraulic efficiency of the system and membrane area requirements. However, due to complex mechanisms involved in filtration processes, MBR systems are operated in practice with fixed filtration sequences, generally proposed by membrane suppliers. Several investigations have studied the effect of backwash frequency and its duration on submerged membranes fouling rates. However, most of these studies have been developed with unreal membrane modules or are based on short-term tests. Furthermore, it is important to analyze backwash efficiency changes occurred when fouling increases, as different sequences could be imposed depending on recent history of the membrane.

Objectives

In the present study the influence of various backwashing parameters on fouling rate has firstly been studied. The main objective was to determine which operating variables (frequency, duration and flux of backwash) are the most influential. Furthermore, permeability profiles during suction phase have been analyzed to evaluate fouling characteristics for different membrane states.

Materials & Methods

The study was developed in a pilot plant fed with urban wastewater. The MBR system consisted in a 160 L biological reactor which contained a hollow fibre membrane module (0.4 μm). This module had real scale dimensions with less filtration area (3.22 m^2) in order to reproduce as nearly as possible real application hydrodynamics. Particle deposition was minimized through coarse bubble aeration, with a SAD_m of 0.9 $\text{Nm}^3/\text{m}^2\cdot\text{h}$. MLSS concentration was maintained around 12 g/L.

The system was operated in suction/backwash cycles, whose frequency and duration were changed. Part of extracted permeate was stored in the cleaning tank and NaOCl was added to get a 2ppm concentration in backwash stream. After each experimental phase a chemical cleaning was carried out. All process variables (P, flows, DO, T) were continuously monitored. The MBR was operated in constant flux mode and filtration performance was evaluated in terms of permeability, K . Permeability estimation was based on Darcy's law and dependence of viscosity on temperature was corrected:

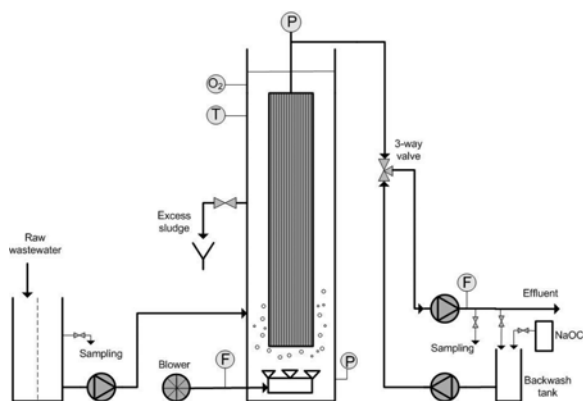


Figure 1: Schematic diagram of membrane bioreactor system

$$K^{20^\circ\text{C}} = \frac{1}{\mu^{20^\circ\text{C}} \cdot R} = \frac{J^{20^\circ\text{C}}}{PTM} = \frac{J^T \cdot e^{-0.0239(T-20)}}{PTM}$$

Results and discussion

Long-term permeability evolution

The influence of flux, frequency and duration of backwash was investigated in different experimental phases shown in Table 1. In these phases the system was operated in conditions which allowed a net permeate production of 60 L/h, requiring slightly higher instantaneous flux (J_{inst}) when net flux ratio (%J) was lower.

Table 1: Experimental runs filtration performance

RUN	t_P (min)	t_{BW} (min)	J_{BW}	$J_{inst}^{20^\circ\text{C}}$ ($\text{L}/\text{h}\cdot\text{m}^2$)	%J*	$-dK^{20^\circ\text{C}}/dt$ ($\text{L}/\text{h}\cdot\text{m}^2\cdot\text{bar}\cdot\text{d}$)
1	30	2	2J	24	82.3	5.6
2	30	1	2J	22	90.3	7.5
3	30	1	3J	23	87.5	7.4
4	15	1	2J	24	82.3	3.3

* $\%J = J_{net}/J_{inst} \times 100 = (J_P t_P - J_{BW} t_{BW}) / [(t_P + t_{BW}) J_P] \times 100$

Observed permeability profiles were similar in all cases: an initial "pore-blocking" period during which permeability declined sharply regardless filtration sequence, followed by a steady decreasing period (cake filtration). Long-term fouling rates were evaluated as the slope of permeability (average value for each cycle) vs. operation time, without considering initial portion of the curve. Suction time was observed to have the largest effect on loss of permeability: decreasing the frequency of backwashing from 30 to 15 min with the same backwash time allowed fouling rate to decrease 56% (Run 2-4). Furthermore, increasing backwash time from 1 to 2 min implied a reduction of 34% in fouling rate (Runs 1-2). On the other hand, no improvement was achieved when increasing backwash flux (Runs 2-3) and very similar permeability profiles were obtained. Finally, although working with the same net flux ratio, better results were found

when operating with 15/1 cycles instead of 30/2 (Runs 1-4). This fact involves that backwash frequency has more influence than backwash duration in controlling fouling rate, which could be due to the fact that cake layer formation depends on filtered volume. Permeability profiles for different suction times (Runs 2-4) are shown in Figure 2. Initial rapid permeability decline is similar in both cases but from fourth day onwards fouling rate changes significantly. Furthermore, it has been observed that when the system is operated with more favourable conditions (smaller flux or 15/1 sequence) permeability remains nearly constant after lineal decrease. The so-called permanent regime implies that steady fouling level has been attained enabling longer operation time until chemical cleaning is needed. In conclusion, the aim is to work in such conditions which enable to reach the permanent regime with an adequate TMP.

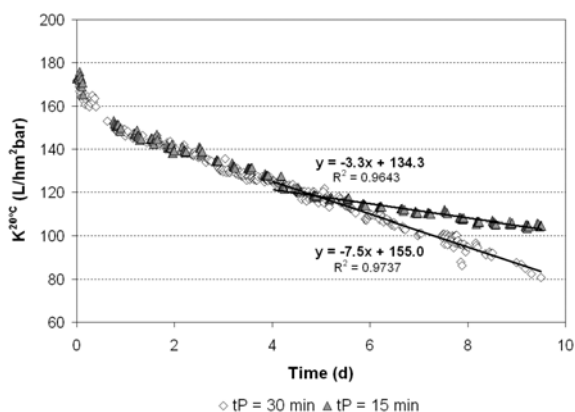


Figure 2: Permeability profiles for different suction time. $t_{BW} = 1$ min

In-cycle permeability evolution

As membrane got more fouled, permeability profiles during suction time were found to be different. Whereas first cycles after chemical cleaning are characterized by significant permeability decline and considerable permeability recovery with backwash, when fouling evolves permeability profiles are flatter and backwash is less effective (Figure 3). This fact implies that fouling mechanisms change: when membrane is clean (low TMP), apart from pore blocking reversible fouling occurs and backwash effectively removes accumulated particles. However, when TMP increases, fouling becomes more irreversible probably due to the more compact and stable cake layer. It was also observed that higher permeate flux leads to less reversible fouling (Figure 4): for equal total filtered volume not only permeability is lower, but also backwash is not as effective in recovering permeability.

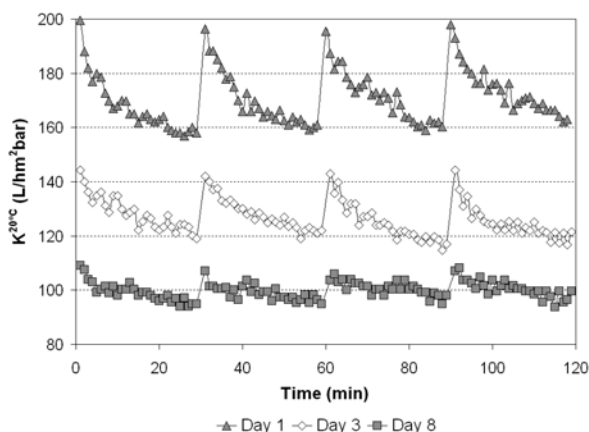


Figure 3: In-cycle permeability profiles for different membrane fouling levels (30min/2min 4 filtration cycles). $J^{20°C} = 22 \text{ L/hm}^2$.

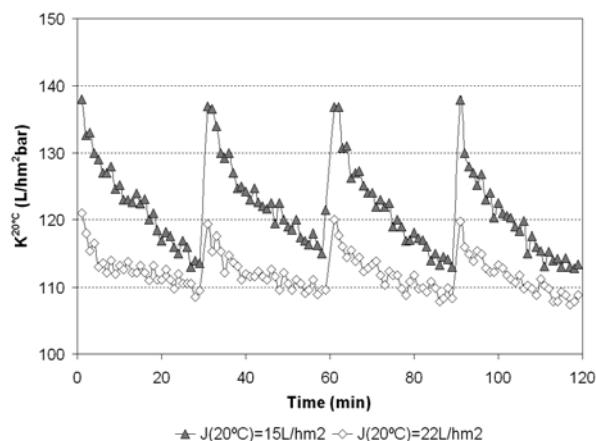


Figure 4: In-cycle permeability profiles with different permeate flux when $V_{\text{filtered}} = 12 \text{ m}^3$ (30min/2min 4 filtration cycles).

According to these findings, changeable backwash conditions can be proposed. Once stable permeability is reached and considering that at high TMP irreversible fouling is predominant, longer suction times could be imposed without deteriorating filtration performance.

Conclusions

- Backwash frequency was found to be the most influential parameter on fouling rate. In studied conditions and working with the same net flux, it is preferable to operate the system with more frequent backwash at the expense of reducing backwash duration.
- First cycles of operation are characterized by rapid permeability decline and high backwash efficiency, contrary to advanced stages where irreversible fouling occurs, generating flatter profiles and less backwash efficiency.
- For equal total filtered volume, higher fluxes generate more irreversible fouling.
- Long-term operation with optimized filtration sequences allows to reach a stable permeability region, characterized by flat permeability profiles and where irreversible fouling is predominant. In such conditions different filtration sequences with longer suction time or even relaxation could be imposed providing that flat profiles are maintained. Thus, filtration is carried out in optimum conditions and hydraulic efficiency of the system increases.

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DECISION SUPPORT SYSTEM FOR MBR FOULING CONTROL

Hector Monclus, Giuliana Ferrero, Jan Sipma, Joaquim Comas and Ignasi Rodriguez-Roda
 Laboratory of Chemical and Environmental Engineering (LEQUIA). Science and Technologic Park of University of Girona.
 c/ Pic de Peguera, 15. E17003. Girona. Catalonia Spain.

{hector, giuliana, jsipma, quim, ignasi}@lequia.udg.cat; Tel: +34972183249

keywords: decision support system, fouling, MBR, permeability, TMP

Introduction

Controlling membrane fouling is one of the key issues in MBR operation, as this will result in decreased operational costs and a longer lifetime of the employed membranes. Due to the complex mechanisms of fouling it is not possible yet to establish clear relationships between a measurable parameter and the extent of fouling. However, the existing theoretical and empirical knowledge of potential causes and effects of fouling can be used to construct a knowledge base (KB), which enables to compare influent characteristics and operational conditions to theoretical and empirical information. The KB is usually integrated within a Decision Support System (DSS), multi-level knowledge-based computer systems that not only reduce decision-making time, but also improve the consistency and quality of the decisions [1].

Objective

The main objective is to design, develop and implement a DSS to control remotely and supervise in real-time the integrated operation of a membrane bioreactor pilot plant for wastewater treatment [2] and reuse. The first task has been to search for correlations between slope values of permeability and different stages of fouling as early and preventive warning signal.

Materials & Methods

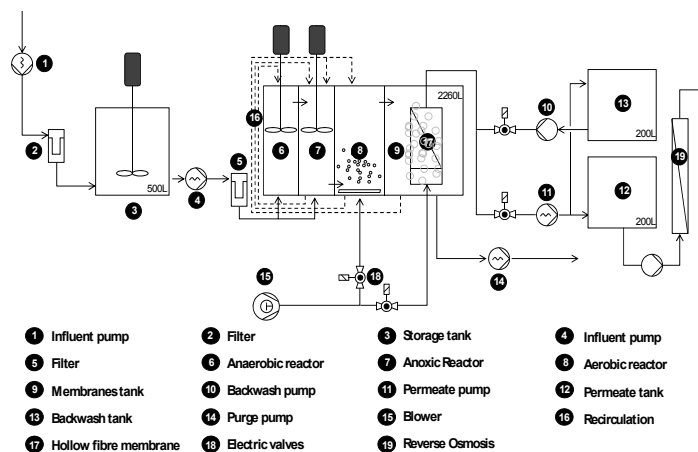


Figure 1. Scheme of the MBR pilot plant showing the different compartments, flow directions and main instruments and equipment.

The experimental facility where the DSS will be implemented consists of two pilot plants for biological nutrient removal and tertiary treatment for wastewater reclamation. Both pilot plants comprise a pre-screening system, a bioreactor with UCT configuration (anaerobic, anoxic and aerobic tanks) for nutrient removal followed by a compartment with submerged membranes. The main differences between the two plants are the treated volume and the membrane configuration: the first, situated in Castell D'Aro WWTP (Catalonia, NE of Spain) (figure 1), treats 4 m³/d with Microza hollow fibre membranes (Asahi Kasei Chemicals Corporation; 12,5 m² total filtration area; 0,1 μm pore size); the second is located in El Vendrell WWTP (Catalonia, NE of Spain) and treats 24 m³/d with KUBOTA flat sheet

membranes (40 m² total filtration area, 0,4 μm pore size). Finally, a reverse osmosis unit treats the membrane bioreactor permeate from Castell d'Aro pilot plant producing water of good quality for water reuse.

The pilot plants are fully equipped and automated with online sensors (conductivity, pH, ORP, ammonium, dissolved oxygen, suspended solids, temperature and scum detector), pressure transducers (for transmembrane pressure -TMP- and permeability calculation), flow meters and level transmitters, and the use of a PLC and SCADA system that acquires digital and analogical data and controls all the automatic control loops of the plant, mainly the control of aeration, permeate and backwashing fluxes, hydraulic retention time, sludge retention time or mixed liquor suspended solids (biomass) concentration and recycles.

Table 1: Characteristics of the pilot plant for biological nutrient removal and tertiary treatment		
	Castell d'Aro Pilot Plant	El Vendrell Pilot Plant
Total volume	2.26 m ³	14,7 m ³
% Reactors volume anaer/anox/aer/membranes	14/14/23/49	17/17/42/24
Membrane configuration	Hollow fiber	Flat sheet
	Microza (Asahi Kasei Chemical Corporation)	Kubota Zenon 1st year 2nd year
Total area	12,5 m ²	40 m ²
Pore size	0.1 μm	0.4 μm
Max net flux	24 l/m ² ·h	36 l/m ² ·h
Permeate/back pulse cycle	9 min permeate/1 min back pulse	9 min permeate/1 min relaxation

Results and discussion

Existing theoretical and empirical knowledge [3] of potential causes and effects of fouling has been used to build a knowledge base for monitoring (Figure 2), early detection and control of membrane fouling [4]. Significant changes in TMP (or permeability) are used to infer operational problems due to fouling.

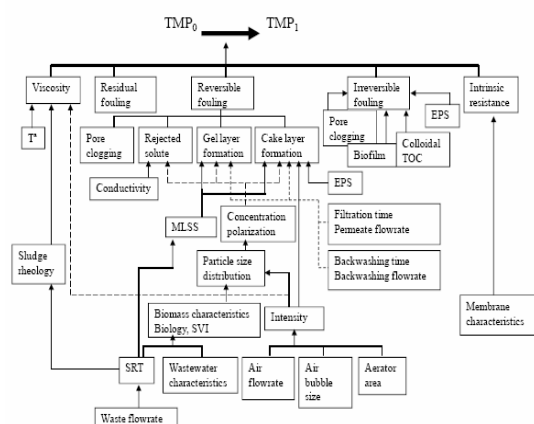


Figure 2: Theoretical and empirical knowledge base for fouling operational problems.

After the first chemical cleaning the slope increased from -2,25 to +29,89; after approximately 12 hours the permeability got stabilized (slope +8,92) and subsequently started to decrease, as it is shown from the negative slope values (Figure 4). After the second chemical cleaning a smaller increase is shown (from -1,15 to +14,37).

Phase 3 and phase 4 appear to have similar slope values of respectively (-1,25) and (-1,24) (Figure 3), the phase 3 was about 30 days but the second was 40 days. This fact must be considered for treatment and interpretation of data.

The analysis of permeability and its slope during long periods (Figure 3) or, yet specifically, during one day (Figure 4), is important to detect the necessity of chemical cleanings. However, when the slope is very negative and the permeability is very high the membrane can be considered affected by irreversible fouling (see day 0 to day 10, Figure 3).

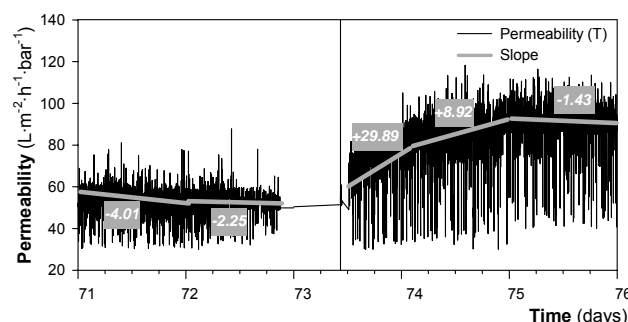


Figure 4: Permeability signals (corrected for temperature) and its slopes during two periods of chemical cleanings.

Conclusions

It's possible to identify an on-line signal that allows to automatically detecting membrane performance, to counteract potential membrane fouling with control preventive actions (e.g. increasing backwash flow rate, proceeding with a chemical cleaning, increasing aeration of the membranes and reducing treated flux) and to identify the results of control actions.

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Permeability has been daily recorded on line and the daily average values were obtained applying data filtering within a significant range (average $\pm 40\%$). Permeability trends, such as slope values have been calculated through the entire investigational period with the daily average values. Weekly, daily and single permeate/back pulse cycle trends and other specific time frames trends were obtained using the filtered raw signals. Figure 3 shows the evolution of the daily average permeability during the experimental period; values are automatically gathered every 10 seconds. Operation flux has been progressively increased and two chemical cleanings (days 73 and 112, Figure 3 and 4) were performed, reestablishing almost initial operational conditions in the first case and slightly increasing the permeability in the second.

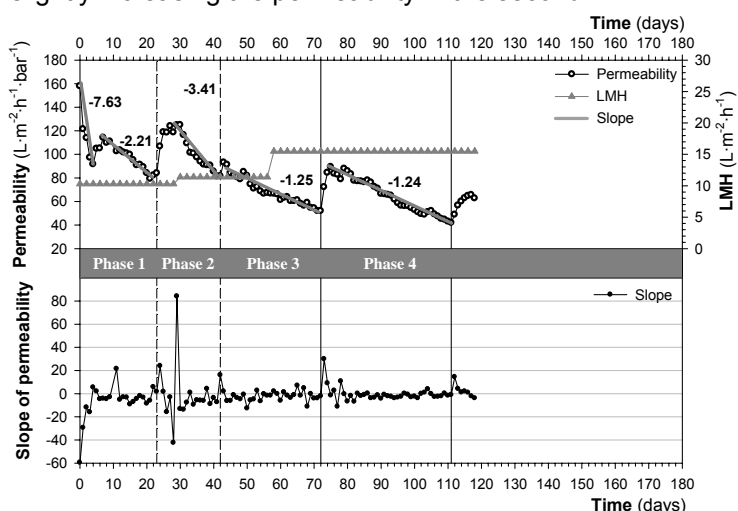
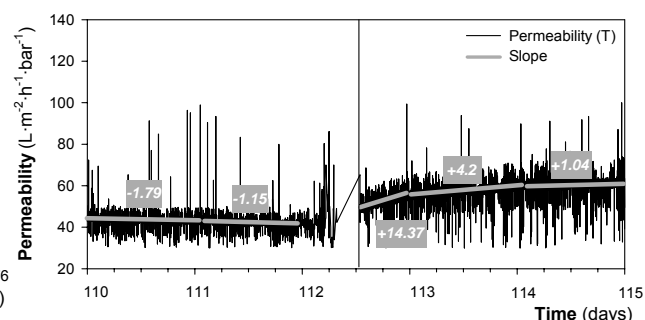


Figure 3: Permeability (corr temp.), LMH and the slopes of the different phases. Vertical broken line (backwash with double backwash flux, days 23 and 42). Black line (chemical cleaning days 73 and 112).



SEASONAL EFFECT: IMPACT ON MBR SLUDGE FILTERABILITY DEPENDING ON MEMBRANE CONFIGURATIONS

Adrien Moreau*, Maria Lousada Ferreira*, Arjen van Nieuwenhuijzen*, Jaap van der Graaf*

*TUD, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2600 GA Delft,

a.a.moreau@tudelft.nl

keywords: DFCm, MBR sludge filterability, membrane configuration, seasonal effects

Introduction

Membrane Bioreactors (MBR) were intensively investigated in the past few years by many research groups. However there is still few data available concerning large scale plants and especially their performance fluctuations depending on temperature or season (winter/summer). During this study twelve large-scale MBRs (four full-scale MBR plants are presented in this abstract) were investigated during two different stages, once in winter and once in summer.

Objectives

Due to low temperature and changes in viscosity, MBR sludge filterability drastically decreases during winter time. The aim of this study was to quantify impacts of seasonal changes on sludge filterability variations in large-scale MBRs depending on membrane configurations.

Materials & Methods

Delft University of Technology has developed a small scale Filtration Characterisation Installation combined with a measuring protocol to investigate sludge filterability or sludge reversible fouling potential. The DFCm (see figure 1) is a short term experiment described in detail by Evenblij et al., . A single side stream ultrafiltration membrane tube (X-flow, diameter = 8mm, nominal pore size = 0.03 μ m) forms the basic filtration system of the unit. Peristaltic pumps are used for the sludge recirculation with a cross-flow velocity of 1m/s. The permeate is extracted at a constant flux. Sludge samples collected from different MBRs can then be filtrated under identical operational circumstances. In this way differences in filterability can be related exclusively to MBR sludge properties of the sample. The main step of the measuring protocol is the sludge filtration step. During the filtration step several parameters (TMP, resistance, flux, temperature, pH) are monitored and stored in a computer file using the software application Testpoint. The main output of an experiment is the course of the resistance during filtration. In this graph the filtration resistance is plotted against the permeate production per membrane surface. The starting- or membrane resistance is similar for all experiments and is left out of consideration when analyzing the results. As a result of fouling of the membrane during filtration the filtration resistance will increase. The slope of the curve gives an indication of the sludge filterability; a steep curve corresponds with a poor filterability. To make a comparison between different curves each curve can be represented as the value ΔR_{20} : this value represents the increase of the resistance after a permeate production of 20 L/m².

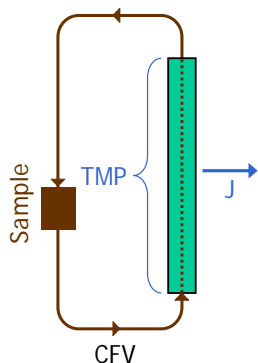


Figure 1: Schematic overview of the DFCm Unit.

each curve can be represented as the value ΔR_{20} : this value represents the increase of the resistance after a permeate production of 20 L/m².

Results and discussion

Seasonal variation results coming from four full scale MBRs are presented as example in Figure 2. Two hollow fibre (HF) membrane configurations and two flat sheet (FS) configurations are represented.

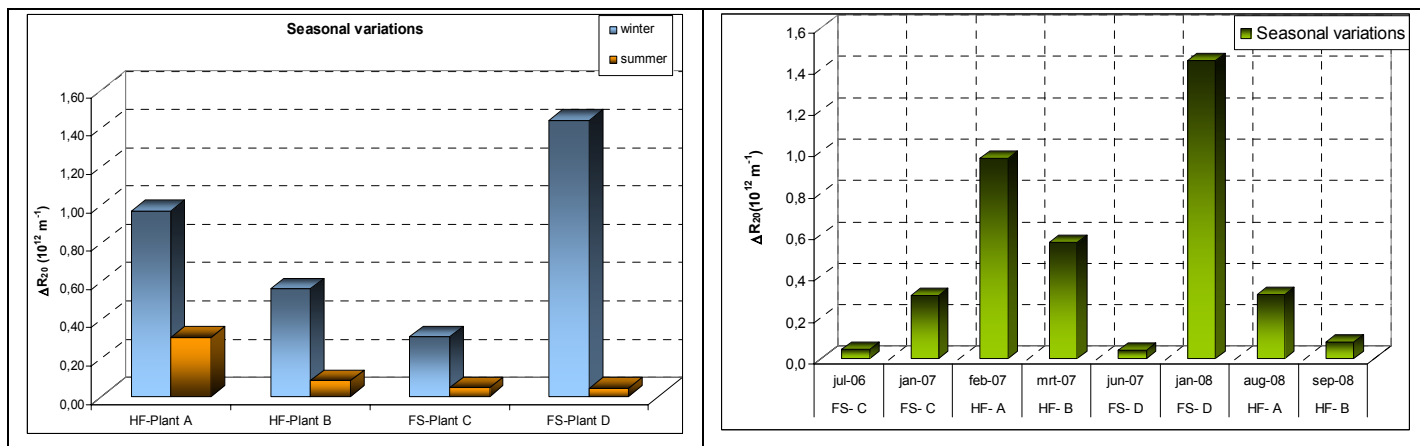


Figure 2: sludge filterability (average) comparison winter/summer (a) sludge filterability evolution along the years (b). A general trend can be underlined. Compare to winter time MBR sludge filterability improved drastically during summer period. The average value of ΔR_{20} decreased from 0,95 to 0,31 10^{12} m^{-1} (68 % improvement) for the hollow fibre configuration A and from 1,44 to 0,04 10^{12} m^{-1} (97 % improvement) for the flat sheet configuration D (two extreme cases). An improvement of the sludge filterability of 85% was generally observed.

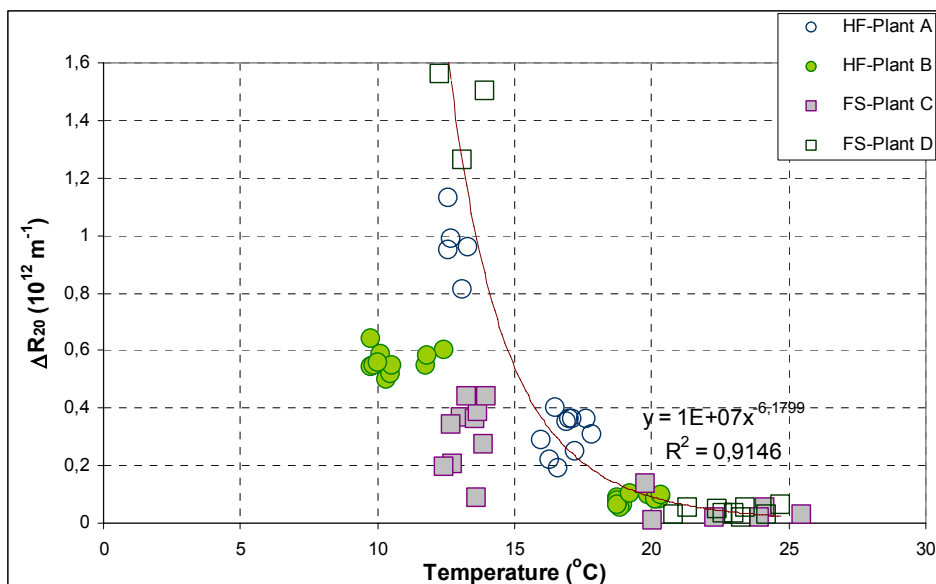


Figure 3: MBR sludge filterability depending on temperature.

A strong correlation was found between sludge filterability and temperature (Figure 3, $R^2=0,91$). However, Temperature changes does not explained large fluctuations in sludge quality observed around 13°C between MBR plants A, B, D. Sludge filterability data were compared with general data of each MBR plants (Table 1) in order to explain those differences. However no correlations were found between sludge quality variations and standard data (TSS, SRT), hydrodynamics (aeration) or SMP (Soluble Microbial Products-results not shown in this abstract).

Table 2: General data concerning MBR plants A to D

Plant	FS- C	FS- C	HF- A	HF- B	FS- D	FS- D	HF- A	HF- B
Date	jul-06	jan-07	feb-07	mrt-07	jun-07	jan-08	aug-08	sep-08
ΔR_{20} (10^{12} m^{-1})	0,05	0,31	0,97	0,56	0,04	1,44	0,31	0,08
st deviation	4,8%	11,6%	11,4%	3,7%	1,4%	15,9%	7,0%	1,5%
TSS (g/L)	12,7	11,2	10,2	9,3	15,7	16,2	12,7	10,5
SRT (d)	20	20	21	24	25	25	21	24
Pore size (μm)	0,08	0,08	0,04	0,04	0,2	0,2	0,04	0,04
SADm (m^3/m^2)	0,44	0,44	0,375		0,33	0,33	0,375	
SADp	21	18	16		20	17	12	

Conclusions

Sludge filterability variations due to seasonal fluctuations were quantified for four full-scale plants, two hollow fibre and two flat sheet configurations. A strong improvement in filterability was underlined from winter to summer period. Temperature seems to be the major factor explaining the 85% average improvement in full scale MBR plants. However, temperature effect was not sufficient to explain all differences in sludge filterability, especially at low temperature. No correlations were found between sludge quality variations and standard data (TSS, SRT), hydrodynamics (aeration) or SMP to account for sludge filterability scattering. Information regarding cake and floc structures or viscosity might be valuable to get a better understanding of tracked filterability behaviours under low temperature conditions.

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Acknowledgements

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REVERSIBLE FOULING QUANTIFICATIONS: ANY LINKS WITH FULL-SCALE PLANT PERMEABILITY?

Adrien Moreau*, Pawel Krzeminski*, Arjen van Nieuwenhuijzen*, Jaap van der Graaf*

*TUD, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2600 GA Delft,
a.a.moreau@tudelft.nl

keywords: DFCm, MBR sludge filterability, reversible fouling, permeability.

Introduction

Membrane Bioreactors (MBR) is one of the most promising technologies from this last decade. However its wide-spread application is strongly limited by membrane fouling. Due to practical limitations, most of studies on fouling are focusing on reversible fouling (short term fouling) whereas irreversible or long term fouling remains poorly investigated. Therefore only little valuable information is available in literature about this key issue in full scale plant applications. During this study, ten large scale MBR plants were investigated in term of reversible fouling. Data concerning membrane performance of each plant were collected in order to investigate the relevancy of reversible fouling measurement campaign.

Objectives

The aim of this study was to figure out under which specific conditions MBR reversible fouling investigations might be useful to predict membrane performances of large scale plants.

Materials & Methods

Delft University of Technology has developed a small scale Filtration Characterisation Installation combined with a measuring protocol to investigate sludge filterability or sludge reversible fouling potential. The DFCm (see figure 1) is a short term experiment described in detail by Evenblij *et al.*, . A single side stream ultrafiltration membrane tube (X-flow, diameter = 8mm, nominal pore size = 0.03 μ m) forms the basic filtration system of the unit. Peristaltic pumps are used for the sludge recirculation with a cross-flow velocity of 1m/s. The permeate is extracted at a constant flux. Sludge samples collected from different MBRs can then be filtrated under identical operational circumstances. In this way differences in filterability can be related exclusively to MBR sludge properties of the sample. The main step of the measuring protocol is the sludge filtration step. During the filtration step several parameters (TMP, resistance, flux, temperature, pH) are monitored and stored in a computer file using the software application Testpoint. The main output of an experiment is the course of the resistance during filtration. In this graph the filtration resistance is plotted against the permeate production per membrane surface. The starting- or membrane resistance is similar for all experiments and is left out of consideration when analyzing the results. As a result of fouling of the membrane during filtration the filtration resistance will increase. The slope of the curve gives an indication of the sludge filterability; a steep curve corresponds with a poor filterability. To make a comparison between different curves

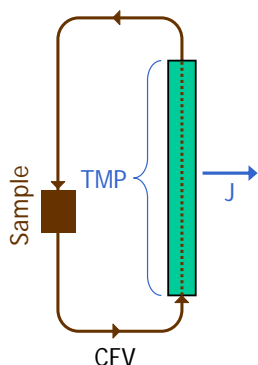


Figure 1: Schematic overview of the DFCm Unit

each curve can be represented as the value ΔR_{20} : this value represents the increase of the resistance after a permeate production of 20 L/m².

Results and discussion

The sludge filterability (reversible fouling potential) of five full-scale plants against the full-scale permeability data are plotted in Figure 2. Three hollow fibre (plants A, B and C), a side-stream multi-tube (plant D) and a flat sheet (plant E) membrane configurations are represented. Different behaviours can be observed:

- The submerged hollow fibre plant A shows quite a good correlation between reversible fouling measurements and plant permeability data. When the sludge filterability got worse (ΔR_{20} value increased from 0,25 to 2,8 10^{12} m^{-1}), a permeability drop was also noticeable (from 200 to 47 L/m² h Bar).
- The plant B, C and D shows roughly a stable permeability for stable values of sludge filterability (reversible fouling potential). The sludge filterability data scattering is due different sample collection points (different membrane tanks) whereas collected permeability data are average values. Because the range of investigated filterability data is narrow, it is difficult to draw reliable conclusions about possible correlations. Some more investigations will be practised during winter period to get a wider range of MBR sludge filterability data.
- The flat sheet plant E shows a complete different behaviour. Sludge filterability data does not matched with collected permeability data.

The observed difference between plant A and plant E might be explained by the different used cleaning protocol. The plant A is a hollow fibre membrane configuration MBR with a weekly based chemical cleaning schedule

whereas the plant E is a flat sheet membrane configuration MBR with a yearly based chemical cleaning schedule. Due to its high time-frequency cleaning, Sludge filterability measurements could be linked with permeability data, as reversible fouling remains the major contributor to fouling in a weekly basis. However, in the case of low time-frequency cleaning, reversible fouling does not remain the main contribution to total membrane fouling. Under these conditions reversible fouling measurements are not relevant anymore to describe full-scale plant membrane performance (or duration between the last cleaning and the measurement campaign has to be taken in account).

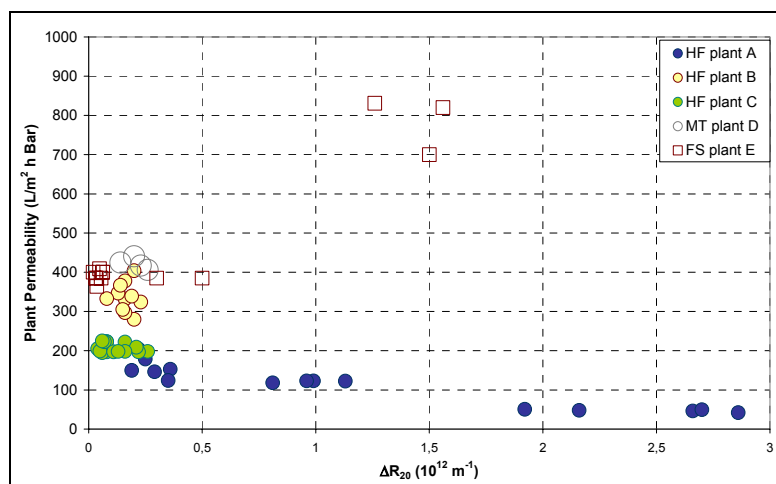


Figure 2: Sludge filterability versus full scale plant permeability data depending on their configurations

The sludge filterability (reversible fouling potential) of five pilot-scale plants against pilot permeability data are plotted in Figure 3. Two hollow fibre (plants D and E) and three flat sheet (plant A, B and C) membrane configurations are represented. No correlations were observed between reversible fouling measurements and pilot plant permeability data (except a slight link for the flat sheet pilot A). It might be due to difficulties to maintain stable conditions in a pilot scale plant. However dynamical sludge filterability fluctuations (between specific experiments in the same pilot plant) were successfully correlated with pilot permeability data (Results are not presented in this abstract).

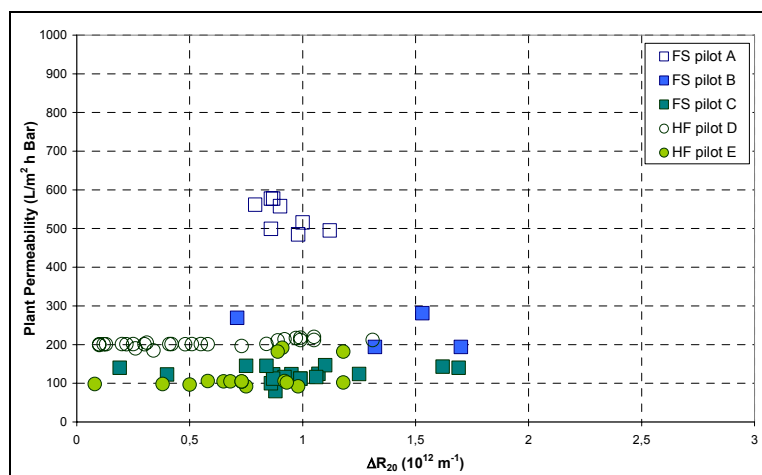


Figure 3: Sludge filterability versus pilot plant permeability data depending on their configurations

Conclusions

The sludge filterability (reversible fouling potential) of ten large-scale plants was confronted with MBR plant permeability data. Reversible fouling measurements seem to be significant to assess membrane performance under specific conditions:

- Reversible fouling measurements seems more relevant in full-scale plants rather than in pilot scale plants,
- Reliable correlations between reversible fouling measurements and MBR membrane performance assessments were observed under regular chemical cleaning (weekly basis) or clean membranes conditions.

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Acknowledgements

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AIRLIFT MBR AT MUNICIPAL WWTP TERNEUZEN Pilot research supports full scale implementation

M.A. Pot*, J. van Agtmaal*, P.A. de Boks*, A.M.J. Veraart**, H. Schonewille***

*Evides Industriewater, P.O.Box 4472, 3006 AL Rotterdam, The Netherlands (m.pot@evides.nl)

**Waterschap Zeeuws-Vlaanderen, P.O.Box 88, 4530 AB Terneuzen, The Netherlands (averaart@wszv.nl)

***NORIT Membrane Technology, P.O.Box 731, 7500 AS Enschede, The Netherlands (h.schonewille@noritmt.nl)

Keywords: airlift, MBR, municipal, WWTP, full scale, biofouling potential

Introduction

Waterschap Zeeuws-Vlaanderen owns and operates the entire public water infrastructure in the region Zeeuws-Vlaanderen (1200 km²), including 7 WWTP's. The municipal WWTP Terneuzen (50,000 Pollution Equivalents) was built in 1990 and underwent several extensions over the years to meet stricter regulations. Evides NV is active in potable water and industrial water. Evides Industriewater implemented 10 water treatment plants according to the DBFO concept (Design Build Finance Operate). Evides is the Dutch largest provider of industrial water and is active internationally (Europe and Asia). Evides owns and operates the "DECO plant" to supply various water qualities to the chemical plants of Dow Benelux at Terneuzen (van Agtmaal *et al*, 2007). Since the beginning of the year 2007 a volume of 5000 m³ per day of effluent of the Terneuzen WWTP is reused at DECO plant to service Dow Benelux. This is the first time that a combination of industrial and municipal wastewater is being reused on a large scale in the industry in the Netherlands.

Objectives

Investments in the Terneuzen WWTP for improvement of the effluent quality are foreseen in the near future. Furthermore, the volume of reuse of effluent has to be doubled before 2010. Therefore the Terneuzen WWTP will



Figure 1: Future site of the Airlift MBR at Terneuzen

be upgraded & integrated with an MBR system in the year 2009. The MBR system will have a nominal hydraulic capacity of 400 m³/hr and a maximal hydraulic capacity of 620 m³/h. The permeate water from the MBR is free of particles and will not be discharged to the environment, but fed to an RO membrane unit at DECO plant for further polishing and reuse as boiler feed water. To increase the hydraulic load of the MBR the effluent of the conventional effluent of the existing WWTP is fed to the MBR. The feasibility of direct UF treatment of the conventional effluent will be evaluated as an alternative.

Currently a NORIT MBR Airlift pilot system is operated and generating process data to service the engineering for the full scale MBR plant. Objectives for the pilot scale research are

determining the feasibility of different effluent suppletion schemes and the maximum and operational membrane flux through the MBR. Also the biofouling potential of both the MBR permeate and the conventional effluent has to be determined experimentally under different MBR operating conditions.

Materials & Methods

Both the full scale and the pilot installation are supplied are based on the Airlift MBR by NORIT Membrane Technology (Enschede, The Netherlands). It is a side-stream system that has had its first full scale application treating the sewage of the town of Ootmarsum, The Netherlands (Futselaar *et al*, 2007). The fully automatic pilot installation has a nominal capacity of 3 m³/h (at 50 l/mh). Iron(III)chloride is added to the MBR to lower the phosphate concentration in the permeate. For determining the biofouling potential of the MBR permeate and conventional effluent the membrane fouling simulator or MFS is used (Vrouwenvelder *et al*, 2006).

Results and discussion

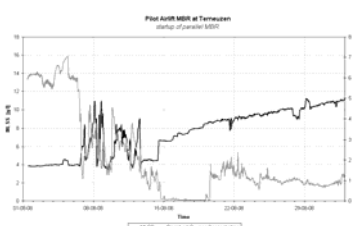


Figure 3: Startup of parallel MBR pilot

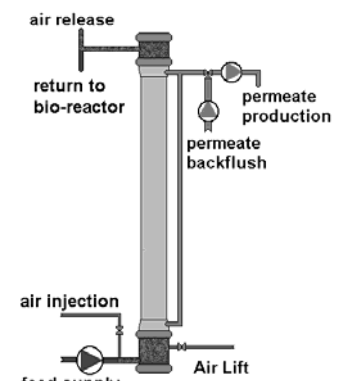


Figure 2: NORIT Airlift MBR

Initially the pilot Airlift MBR at Terneuzen was operated as a hybrid MBR, treating the activated sludge from the conventional WWTP. Recently the operating philosophy was changed to parallel MBR, comparable to the full scale design for the WWTP Terneuzen. Wastewater is taken directly following the primary settler and pumped into the Airlift MBR bioreactor. The

desired sludge concentration MLSS is 10 kg MLSS / m³. The desired BOD load is 0,05 kg BOD / (kg MLSS · day). The nitrogen load is 16 g N / (kg MLSS · day). Figure 3 shows the startup of the pilot MBR at those conditions. It is expected that more results of the pilot will be available during the presentation at the Final MBR-Network Workshop in Berlin (March 2009).

Conclusions

The WWTP Terneuzen (The Netherlands) will be upgraded & integrated with an MBR system in the year 2009. The permeate from this 620 m³/hr Airlift MBR will be exclusively used as RO feed water to provide a local chemical industry of demineralised water. A pilot Airlift MBR system is used to determine operation parameters for the design of the full scale installation.

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EFFECTS OF BIOFILM FORMATION ON OXYGEN TRANSFER MEMBRANES IN MEMBRANE MICRO-AERATED ANAEROBIC DIGESTERS

P.G. Rathnasiri*, Deshai Botheju**, Rune Bakke**

*Department of Chemical & Process Engineering, University of Moratuwa, Sri Lanka, Email: ratnasiri@cheng.mrt.ac.lk

**Telemark University College, Faculty of Technology, Porsgrunn, Norway, Emails: Deshai.Botheju@hit.no : Rune.Bakke@hit.no

Keywords: Biofilm, Membranes, Anaerobic digestion, Microaeration, Mass transfer

Introduction

Application of partial aeration in anaerobic digestion (AD) can improve treatment efficiency via; 1] reduced initial activation time period (Nguyen et al., 2006), 2], suppression of sulphate reducing bacteria (Tang et al., 2004 and Zhou et al., 2007), 3] and enhancing degradation of resilient components like lignocelluloses (Juanga, 2005) and resins (Durán et al., 2008). It has been found that the improved COD degradation by micro aeration in anaerobic reactors can be attributed to enhance hydrolysis (Hasegawa et al., 2000; Johansen and Bakke, 2006). Micro aeration implies oxygen supply of less than 10-15 % of total organic (measured as chemical oxygen demand; COD) loading rate of the anaerobic reactor. Supply of small amounts of oxygen to anaerobic digestion is an example where accuracy is important to enhance COD removal while avoiding decreased CH₄ production. Published micro aeration studies are based on traditional aeration techniques, supplying air as bubbles directly to the bulk liquid phase, causing air to also reach head space and dilute the produced biogas, making it less suitable for combustion (Durán et al., 2008). This is not desirable, so it is necessary to develop alternative aeration strategies for improved control to enhance biomass mineralization and methane production. Supplying oxygen by circulating aerated water inside a membrane loop placed in the reactor bulk liquid is proposed as a new strategy for micro aeration. An application of this approach is investigated here to study biofilm effects on mass transfer, required for precise aeration control.

Objectives

The main objective of this study is to introduce the new conceptual design of the Membrane Microaerated Anaerobic Digester (MMAD) and test it experimentally to access the expected effect of enhanced mineralization compared to a strictly anaerobic case, while maintaining high biogas quality for energy recovery purposes.

Methods & Theory

This study investigates effects of biofilm formation on membrane oxygen mass transfer during continuous micro aeration of an intermittently fed anaerobic reactor called membrane micro-aerated anaerobic digester (MMAD) and shown in Figure 1. Clean silicone membrane loops were inserted in the bulk liquid phase of MMAD and used for continuous micro aeration of the reactor by circulating oxygen saturated water in the membrane lumen. It was observed that biofilm develops naturally on the bulk liquid side of the membrane and is well established in 3 weeks.

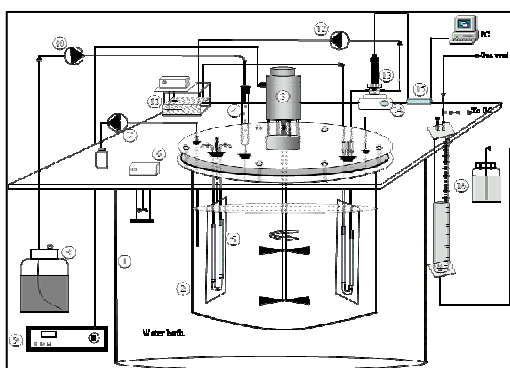


Figure 1. Schematic view of the MMAD

1.Outer water jacket, 2. Glass reactor vessel, 3.Motor with variable speed drive, 4.Medium supply with inlet back growth preventer, 5.Membrane module, 6. Thermostat, 7.Mixed liquor removal pump, 8.Biological medium, 9.Mixing control unit 10.Medium supply pump, 11.Distilled water at 35 °C, 12.Recirculation pump, 13.Oxygen probe in flow through cell, 14.Magnetic stirrer, 15.Oxygen meter, 16.Eudiometer)

Oxygen mass transfer rate J_i (mg/d/m²) is given by:

$$J_i = \frac{(C_{i,in}^b - C_{i,out}^b)}{R_{tot}} = K_{OM} (C_{i,in}^b - C_{i,out}^b) \quad (1)$$

$$1/K_{OM} = 1/k_{i,in} + 1/k_{i,out} + L/D_{i,m} S_{i,m} \quad (2)$$

$$R_{in} = 1/k_{i,in} \quad (3)$$

$$R_{out} = 1/k_{i,out} \quad (4)$$

$$R_m = L/D_{i,m} S_{i,m} \quad (5)$$

According to the conventional bio fouling argument, and/or is reduced hence reducing KOM due to biomass growth on the membrane, causing a decrease in diffusion coefficient $D_{i,m}$ and in flux J_i . The oxygen utilization rate inside the biofilm is accounted for to explain the opposite observations made here and, to some extent, by others (Casey et al., 2000; Osa et al., 1997).

Results and discussion

The oxygen transfer rate (OTR) is 5-10 times higher with a mature

biofilm (>30d) compared to the clean membrane case. Oxygen was transferred to head space and diluted the produced biogas prior to biofilm development while no oxygen was detected in the biogas after the biofilm was established.

OTR is highest just after feeding MMAD and gradually decreasing to a stable “no-feed” level after about 20 hours. This significant OTR increase following reactor feeding shows that OTR is a function of the oxygen utilization rate (OUR) in the biofilm, which again is influenced by the organic loading rate (OLR).

The formation of an active biofilm leads to decreased $C_{i,outb}$, increasing the driving force of transport, $C_{i,inb} - C_{i,outb}$. This effect override the biofouling effect (reduced KOM) when the biofilm is mature enough, and lead to a strongly increased mass transfer through the membrane. No oxygen was detected in the biogas after the mature biofilm was established implying that membrane biofilm prevent O₂ transfer to the biogas by efficient local consumption, implying that the MMAD principle is suitable for enhanced mineralization in biogas production processes.

Conclusions

The overall conclusion is that the MMAD principle is suitable for enhanced mineralization in biogas production processes and that membrane biofilm enhance OTR and simultaneously prevent O₂ transfer to the head space thus maintaining the quality of generated biogas.

Nomenclature

$C_{i,in}^b$	bulk liquid phase concentration of oxygen inside membrane tube (mg/l)
$C_{i,out}^b$	bulk liquid phase concentration of oxygen outside membrane tube (mg/l)
$D_{i,m}$	diffusivity coefficient of oxygen in membrane material (m ² /s)
J_i	Oxygen transfer rate (mg/m ² .d)
K_{OM}	overall mass transfer coefficient (m/d)
$k_{i,in}$	inside liquid phase mass transfer coefficient (m/d)
$k_{i,out}$	outside liquid phase mass transfer coefficient (m/d)
L	membrane thickness (m)
$R_{i,in}, R_m, R_{i,out}$	Inside resistance, membrane resistance, outside resistance respectively (d/m)
$S_{i,m}$	equilibrium partition coefficient of oxygen in membrane –liquid interface

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HYDRODYNAMIC CFD SIMULATION OF A TWO-PHASE FLOW IN AN ULTRAFILTRATION MEMBRANE TUBE FOR A SIDE-STREAM MEMBRANE BIOREACTOR

N. Rios*, I. Nopens* and P. A. Vanrolleghem*,**

* BIOMATH – Department of Applied Mathematics, Biometrics and Process Control. Coupure Links 653, B-9000, Ghent, Belgium

** modelEAU, Département de génie civil, Université Laval, Pavillon Pouliot, Québec, G1K 7P4, QC, Canada

keywords: Computational fluid dynamics, Fouling, Side-stream membrane bioreactor, Two-phase flow, hydrodynamics

Introduction

(Bearing in mind the more stringent effluent quality standards imposed by the EU Water Framework Directive (EU-WFD), treatment efficiencies need to be improved. These improvements can be achieved both in terms of biological removal efficiency as well as in the sludge-water separation step. The latter can be achieved by Membrane Bioreactors (MBR), which have proven to be a good alternative to achieve high effluent quality. However, a common problem encountered with MBR systems is fouling of the membrane resulting in frequent cleaning and replacement (Judd, 2006), making it a less appealing alternative in terms of cost-effectiveness. This has been the limiting factor in the full-scale application of these systems.

In search for better control of fouling, literature has focused on the determination of the fouling constituents. Also, it has been shown that the hydrodynamics near the membrane surface play an important role. To reduce the fouling on the membrane often air is introduced (Cui et al., 2003) in the sludge flow to create a gas-liquid two-phase cross-flow. This is done for the following reasons: 1) Increase the permeate flux; 2) Improve membrane rejection characteristics (reduction of fouling) due to the early transition from laminar to turbulent flow, 3) Increase the surface shear stress to remove foulants that are already attached and 4) increase the mass transfer between the cake layer and the bulk region. However, the governing mechanisms are not yet completely understood, which results in a trial and error approach to use hydrodynamic control of fouling.

Objectives

To study the fouling behaviour in MBR systems, a lab-scale side-stream MBR has been set up for data collection. It uses a tubular ultrafiltration membrane X-FLOW (Norit, The Netherlands). A hydraulic model of the system is needed to better understand the mechanisms and allowing to better control the fouling phenomenon. The latter can be done using Computational Fluid Dynamics (CFD), which has proven to be a powerful tool for improving design and operation of wastewater treatment systems.

Materials & Methods

In order to develop a hydrodynamic model of a two-phase (sludge-air) flow, it is important to consider five characteristics of the flow: 1) in- and outgoing flow rates, which are related to the amount of sludge and air that is pumped into the membrane and the permeate flux that is crossing the membrane surface; 2) Physical properties of both phases, in particular the viscosity of the sludge, which exhibits a non-Newtonian behaviour (Rios et al., 2007); 3) The flow pattern, which depends on the inclination of the pipe (e.g. vertical). It was found that the MBR under study is operated in the slug flow region (Taylor bubbles); 4) the holdup of each phase. Since the gas flows at a higher velocity than the liquid, the volumetric fraction of the liquid (known as holdup) near the outlet is higher than at the inlet of the tube. 5) Pressure drop along the tube which depends on the energy losses through the tube, shear stresses and the holdup. The pressure drop is also function of the diameter and length of the tube and the velocity of the fluids as well as the viscosity. A two-phase (sludge-air) flow model was implemented in Fluent® 6.3 (Ansys, USA) using the volume of fluid (VOF) model which is a multi-fluid approach. This implies that each phase has a set of equations that needs to be solved and the phases are linked together by their respective volume fractions. In this model the dispersed phase (air) is treated as a continuous medium, analogous to the fluid phase (sludge).

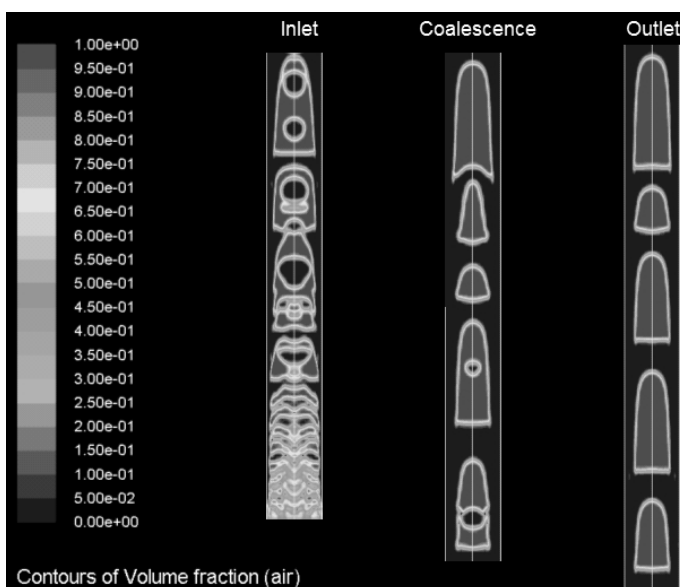


Figure 1: Contours of the volume fraction of air for a velocity of 0.5 m s⁻¹ for sludge and air

5) Pressure drop along the tube which depends on the energy losses through the tube, shear stresses and the holdup. The pressure drop is also function of the diameter and length of the tube and the velocity of the fluids as well as the viscosity. A two-phase (sludge-air) flow model was implemented in Fluent® 6.3 (Ansys, USA) using the volume of fluid (VOF) model which is a multi-fluid approach. This implies that each phase has a set of equations that needs to be solved and the phases are linked together by their respective volume fractions. In this model the dispersed phase (air) is treated as a continuous medium, analogous to the fluid phase (sludge).

Results and discussion

Preliminary simulations were performed using constant physical properties both for air and sludge.

Fig. 1 shows the contours of the volume of air for the inlet, the middle (coalescence of bubbles) and outlet of the membrane in the case of 0.5 m s^{-1} of air. Near the inlet (approximately 5 cm of length) it can be observed that there is a mixture of air and sludge because both phases are entering together with the same volumetric fraction as was mentioned previously (same velocity). Near the outlet one can observe that the bubbles have the specific Taylor bubble shape (bullet shape) with a round nose and a cylindrical body. Also, it is possible to observe that the bubbles have different sizes. This is due to the fact that bubbles accelerate and coalesce with a preceding bubble. This phenomenon occurs because the wake generates acceleration of the next bubble. If the wake would be larger (i.e. with more space between consecutive bubbles) this acceleration could be avoided and all bubbles would move with a constant ascension velocity and have a similar size (Kawaji et al 1997). The shear stress oscillates due to the continuous passing of bubbles through the tubular membrane. In addition, based on the fluctuation of the shear stress, it is possible to assume that at a certain location of the membrane, a variety of shear stresses occurs at a certain frequency. In order to interpret this in a better way a histogram, which shows the frequency of the occurrence of a certain shear stress at any place of the membrane (Fig. 2), can be used. The histograms show two things: 1) the range of shear stresses distribution (SSD) that the membrane surface and, hence, the sludge attached to it is exposed to and 2) the frequency of this exposure.

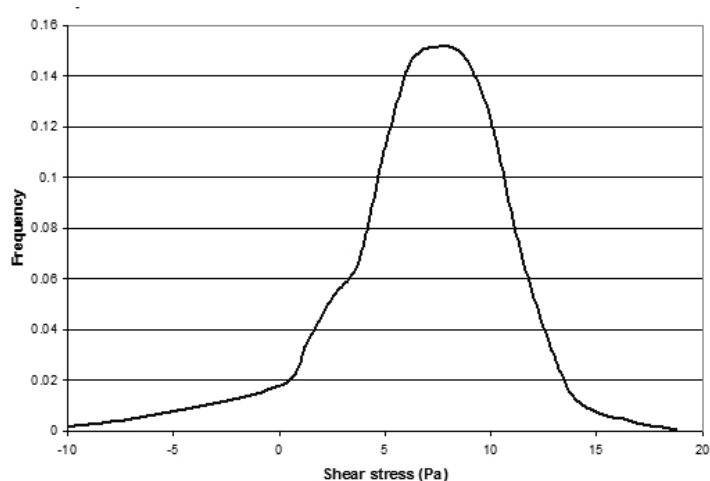


Figure 2: Histogram of the shear stress for sludge-air with a velocity of $0.5-0.5 \text{ m s}^{-1}$

The shear stress oscillates due to the continuous passing of bubbles through the tubular membrane. In addition, based on the fluctuation of the shear stress, it is possible to assume that at a certain location of the membrane, a variety of shear stresses occurs at a certain frequency. In order to interpret this in a better way a histogram, which shows the frequency of the occurrence of a certain shear stress at any place of the membrane (Fig. 2), can be used. The histograms show two things: 1) the range of shear stresses distribution (SSD) that the membrane surface and, hence, the sludge attached to it is exposed to and 2) the frequency of this exposure.

Conclusions

The hydrodynamic model was implemented in Fluent and used to determine the optimal gas requirements (flow rate) and, hence, the power consumption of the pump (sludge) and the compressor (air) in terms of pressure drop across the membrane tube. The effectiveness was evaluated through relating these inputs with apparent shear stresses near the membrane surface. The latter can be expressed as shear stress distributions (SSD). A range of gas-air flow rate mixtures were investigated and resulted in different SSDs. These can be related to the dynamics of the transmembrane pressure (TMP) which was measured in the lab-scale MBR

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MASS TRANSFER COEFFICIENT DETERMINATION OF A TWO-PHASE FLOW FOR AN UF MEMBRANE IN A SIDE-STREAM MBR

N. Rios*, I. Nopens* and P. A. Vanrolleghem*,**

* BIOMATH – Department of Applied Mathematics, Biometrics and Process Control. Coupure Links 653, B-9000, Ghent, Belgium

** modelEAU, Département de génie civil, Université Laval, Pavillon Pouliot, Québec, G1K 7P4, QC, Canada

keywords: : Two-phase flow, mass transfer, heat transfer, MBR, hydrodynamics

Introduction

This work focuses on a side-stream membrane bioreactor (sMBR) for wastewater treatment and it uses a tubular ultrafiltration membrane (X-FLOW, Norit, The Netherlands). A common problem encountered with MBR systems is the fouling of the membrane resulting in a need for frequent cleaning and replacement (Judd, 2006). The hydrodynamics near the membrane surface play an important role. It has been shown that the hydrodynamics near the membrane surface play an as important role. To reduce the fouling on the membrane air is often introduced in the sludge flow to create a gas-liquid two-phase cross-flow (Cui et al., 2003). This is to increase the permeate flux, to improve membrane rejection characteristics (reduction of fouling) due to the early transition from laminar to turbulent flow, to increase the surface shear stress to remove foulants that are already attached and to increase the mass transfer between the cake layer and the bulk region. However, the governing mechanisms are not yet completely understood, which results in a trial and error approach to use hydrodynamic control of fouling.

Objectives

The work presented here focuses on a better understanding of the mass transfer coefficient near the membrane surface.

Materials & Methods

Due to the complexity involved in mass transfer measurements for two-phase flows, there are some studies that focus on developing correlations between heat and mass transfer. This is possible because of the analogies between heat and mass transfer models in dimensionless form which are based on the transport of momentum, mass, heat and energy, and more specifically in the Lewis number (Le), which is a dimensionless number defined as the ratio of thermal to mass diffusivity (Shirazi et al, 2004):

$$\frac{Sh}{Nu} = \frac{Sc}{Pr} = Le$$

where Nu and Pr are the Nusselt and the Prandtl numbers respectively. They are defined in Table 1.

Table 1. Dimensionless heat and mass transfer numbers

Heat transfer	$Nu = \frac{hd}{k_{cond}}$	$Pr = \frac{\mu}{\rho \alpha_t}$	$\alpha = \frac{k_c}{\rho C_p}$
Mass Transfer	$Sh = \frac{kd}{D}$	$Sc = \frac{\mu}{\rho D}$	

In Table 1, h is the convection coefficient, k_c the thermal conductivity, μ the viscosity, ρ the density, C_p the specific heat and α_t the thermal diffusion coefficient. These kinds of analogies are commonly used in cases where it is easier to obtain heat transfer data rather than mass transfer data. To obtain an equation for the mass transfer coefficient in a two-phase flow it is necessary to use a heat transfer correlation (Kim et al., 2000) for two-phase flow in vertical pipes. Equation (18) can be easily solved for the mass transfer coefficient using Table 1:

$$k = \frac{\alpha_t}{d} Nu = \frac{k_c}{\rho C_p d} Nu = \frac{h}{\rho C_p} \quad (19)$$

Where h can be obtained from a heat transfer correlation which was developed for a wide range of fluid combinations and different flow patterns was developed by Kim (2000).

Results and discussion

To validate this heat-and-mass transfer analogy, the results of Zheng and Che (2006) were used. The authors performed different experiments at different gas-liquid (water-nitrogen) flow rates and obtained different values of mass transfer coefficients.

Table 2. Comparison of the mass transfer coefficient between Table 5 and 6

		Zheng and Che (2006)	Heat correlation
U_{SL} $m s^{-1}$	U_{SG} $m s^{-1}$	k $\cdot 10^{-4} m s^{-1}$	k $\cdot 10^{-4} m s^{-1}$
0.344	0.45	11.8	5.9
0.651	0.45	5.7	7.1
0.344	0.15	6.6	3.1
0.651	0.15	4.3	4.4

* where U_{SL} and U_{SG} are the superficial liquid and gas velocities.

From Table 2, it is possible to observe that the results of the heat-and-mass transfer correlation are under and over predicted compared to the experimental data. When the superficial velocity of the liquid is high ($0.651 m s^{-1}$) and the gas velocity is lower ($0.15 m s^{-1}$) the prediction of the analogy is quite good. That can be due to the fact that the slug and liquid length are similar. As for the other cases, when the velocities change there is no evident trend. A possible reason could be that this analogy does not take into account some factors, such as the length of the Taylor bubble and the liquid slug. Also, it is important to consider that in a vertical tube, the Taylor bubbles will coalesce when they are moving upward. Therefore, the mass transfer coefficient will be affected, because at the inlet the Taylor bubbles are small, but at the end of the tube they will be longer and will yield a higher contribution in the mass transfer coefficient. However, the order of magnitude of the analogy is consistent with the experimental data and could be a good approximation to a certain extent.

Conclusions

To determine the mass transfer coefficient experimentally is an arduous task and requires a lot of time and experimental work. Besides, it can only be done for solutions where the mass diffusion coefficient and the chemical reaction is well known. Therefore, to apply it in an activated sludge, which is a heterogeneous mixture causes difficulties. To overcome this, a heat transfer correlation, which is well studied in the literature is suggested, to determine the mass transfer coefficient using the Sherwood number. A validation with literature was made and proved that this type of analogy is valid to a certain extent. Over and under predicted behaviour is observed but a similar order of magnitude was found which is promising for future research. Also, it is important to notice that this type of analogy does not take into account certain zones in the slug flow pattern, such as the film zone (where the bubble is passing) and the wake which affects the final result in the mass transfer coefficient.

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EFFECT OF HIGH SLUDGE AGES ON THE SLUDGE CHARACTERISTICS IN MEMBRANE BIOREACTORS

J. Schaller, A. Drews, M. Kraume

Technische Universität Berlin, Chair of Chemical Engineering, ACK 7, Ackerstr. 71-76, 13355 Berlin, Germany, Email: Jana.Schaller@tu-berlin.de

Keywords: viscosity, dewaterability, SRT

Introduction

Aerobic biological wastewater treatment produces a significant amount of excess sludge, which is expected to rise due to the increasing number of wastewater treatment plants and more stringent effluent criteria. In this context, the reduction of excess sludge production is an interesting alternative to conventional excess sludge treatment and disposal. However, the objective of sludge reduction must be achieved without detriment to the overall efficiency of the process (quality of treated water and quality of residual sludge) (Ginestet, 2007).

Nowadays the interest in high SRT is sparked as an option for sludge minimisation, but a detailed study is required for the optimisation of the overall costs. At long SRT, biomass concentration tends to increase which along with a change in population and physiological state can influence biomass characteristics. Sludge physical properties play an important role in overall economics of membrane bioreactors due to their influence on filtration and their effects on handling excess sludge. Higher solids concentrations may impact on sludge rheology, which may affect hydrodynamic conditions in the MBR, transport phenomena and energy requirements for mixing and aeration thus, changing operating costs. Also, sludge disposal costs depend on physical properties like dewaterability, which may change at high SRT. Although some trends of some properties have already been reported in the literature (Germain et al., 2007; Khongnakorn et al., 2007), still a larger database is needed for substantial information of the impact of high SRT on sludge characteristics in membrane bioreactors. There is a lack of data especially for downstream aspects like dewaterability, but also correlations for mass transfer and rheological behaviour show some deviation and uncertainty, possibly due to the impact of other parameters like HRT, loading rate etc.

The aim of this study is to investigate sludge properties (viscosity, dewaterability, filterability, oxygen transfer) in two membrane bioreactors operated at a various sludge ages to obtain a defined sludge characteristics database to be used in an overall cost optimisation model.

Materials & Methods

Two submerged MBRs for C- and N-removal equipped with an anoxic and an aerobic tank and an internal recirculation of 400 % were used to study the sludge characteristics at different operating conditions (see Table 1). They are of different size (10L and 40 L, respectively) and equipped with different membrane modules (plate and frame and hollow fibre, respectively) and are fed with a complex synthetic wastewater representing a municipal wastewater with a targeted total COD of 600 mg/L.

Table 1: operational parameters of the investigated MBRs

	Period 1		Period 2		Period 3		Period 4	
	06.06.07-15.09.07		16.09.07-24.03.08		30.04.08-31.07.08		01.08.08-31.12.08	
	MBR I	MBR II	MBR I	MBR II	MBR I	MBR II	MBR I	MBR II
Volume [L]	10	40	10	40	10	40	10	40
Solid Retention Time [h]	140	140	140	140	140	140	15	75
Hydraulic Retention Time [h]	10	10	10	10	5	10	10	10
Sludge loading [kg COD/(kgTS d)]	0.126	0.084	0.088	0.054	0.108	0.083	0.219	0.100

Sludge samples were taken once a week from the aeration tank of both plants and were analysed immediately for total and volatile suspended solids (TS, VSS) concentration, dewaterability (CST), filterability (TTF), rheology and oxygen transfer coefficient (k_{La}). The influent synthetic wastewater and the permeate were sampled once a week and analysed for total COD, total N, NH_4-N , NO_2-N , NO_3-N concentration.

Results and discussion

Both bench-scale MBRs showed good results in terms of COD elimination efficiency, which was mostly above 95%. The TN elimination efficiency in MBR II is mainly between 80-85%, whereas in MBR I the TN elimination varied between 70-85% due to stronger fluctuations in oxygen concentration.

Activated sludge is known to be a non-Newtonian fluid. The apparent viscosity μ_{∞} as a function of TS concentration is shown in Figure 1, where μ_{∞} is the viscosity at a very high shear rate, where μ is nearly constant, in this case at a

shear rate of 2300 s^{-1} . Furthermore apparent viscosity is strongly dependent on temperature; therefore all results were corrected to a temperature of 20°C .

With increasing biomass concentration apparent viscosity increases, while the viscosity for a given MLSS concentration is slightly different in both plants.

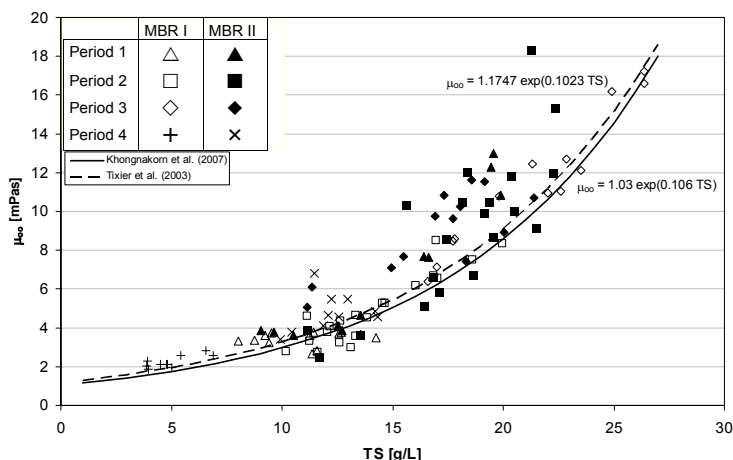


Figure 1. Apparent viscosity μ_{∞} versus total solids concentration

This might be due to fluctuations in the influent COD concentrations, which results in differently loaded wastewater. In comparison to literature correlations the obtained apparent viscosities are up to two times higher, especially for higher TS concentrations between 15 and 20 g/L. In agreement with literature also an exponential relationship is found for the investigated MBRs. Especially the correlation including both MBRs (MBR I and MBR II) is quite similar to the correlations found by Khongnakorn et al (2007) and Tixier et al. (2003), just the prefactor is a bit higher with 1.22 compared to 1.17 and 1.03, respectively. Therefore, the viscosity of an activated sludge is not only a function of TS but

also a function of other sludge characteristics which have to be identified and operating conditions, specific

power input and thus plant size.

Figure 2 shows the CST for both plants as a function of TS concentration. The absolute value of CST differs by up to a factor of 5 for both sludges at the same TS concentration. It is shown that below a critical TS concentration of approx. 15 g/L, the biomass concentration has nearly no influence on the dewaterability. Above 15 g/L a dramatic increase in CST can be observed. Therefore higher TS values will result in a strongly lower sludge dewaterability potential. In comparison to literature (Khongnakorn et al., 2007) the obtained CST values in this study are very high, thus indicating a poor dewaterability for both sludges. Therefore the potential to dewater these sludges is low and sludge treatment cost would increase dramatically. Additionally, mass transfer efficiency decreases with increasing TS, thus increasing aeration requirements.

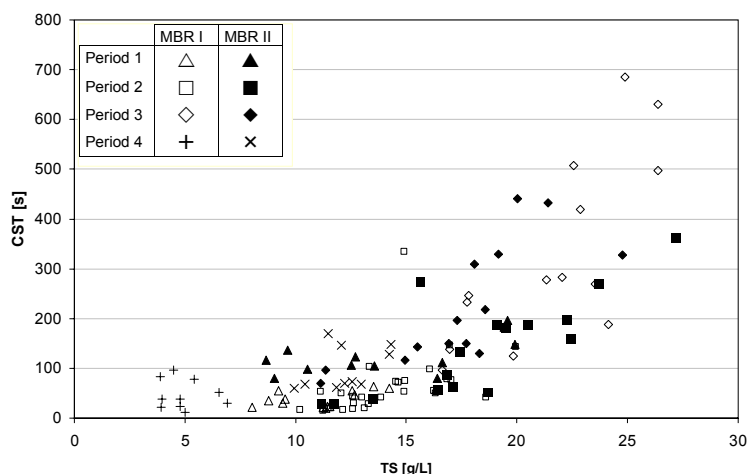


Figure 2 Capillary suction time versus total solids concentration

Conclusions

Sludge characteristics at various sludge ages were investigated and correlations between them were established and compared with literature to establish a more substantial sludge characteristics database than what is available currently. It was shown that the viscosity of an activated sludge is not only a function of TS concentration but also a function of other parameters which have to be identified and operating conditions. The CST seems to be nearly unaffected below a biomass concentration of 15 g/L and then abruptly increases dramatically resulting in a dramatic decrease of sludge dewaterability. Both properties show a wide range of uncertainty, which will be implemented in modelling overall plant and sludge handling costs.

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MICROBIAL POPULATION STRUCTURE OF PILOT- AND FULL-SCALE MEMBRANE BIOREACTORS

A.F. Silva¹, G. Carvalho^{1,2}, M. Lousada-Ferreira³, A. van Nieuwenhuijzen³, G. Guglielmi⁴, J.G. Crespo², M.A.M. Reis², M.T.B. Crespo¹

¹IBET/ITQB, UNL, 2781-901 Oeiras, Portugal, filipasilva@itqb.unl.pt, gildacarvalho@dq.fct.unl.pt and tcrespo@itqb.unl.pt

²REQUIMTE/CQFB, Chemistry Department, FCT, UNL, 2829-516 Caparica, Portugal, jgc@dq.fct.unl.pt and amr@dq.fct.unl.pt

³TUD, Fac Civil Engn, Sect Sanitary Engn, Witteveen Bos Consulting Engn., NL-7400 AE Deventer, Netherlands, M.LousadaFerreira@tudelft.nl and a.vnieuwenuhuijzen@witteveenbos.nl

⁴UNITN, Department of Civil and Environmental Engineering, Via Mesiano, 77, 38050 Trento, Italy, giuseppe.guglielmi@ing.unitn.it

keywords: MBR, microbial population, activated sludge, polyphosphate accumulating organisms, FISH

Introduction

Membrane bioreactors (MBR) have growing importance in wastewater treatment due to their small footprint and high quality effluent. The introduction of membranes in activated sludge systems has a structural impact on plant design and operation, which probably affects the bacterial community profile and its metabolic activity. Some important aspects that might influence microbial selection in MBRs are the higher sludge retention time and sludge concentration normally operated in these systems; lower oxygen transfer rate due to higher biomass concentration; the selectivity of the membrane as a physical barrier able to retain macromolecules in the membrane tank.

The bacteria responsible for biological nutrient removal are some of the microorganisms whose presence is crucial for municipal wastewater treatment. Previous studies concerning biological nutrient removal in MBRs were mainly focused on the nitrifying populations^{1,2}. It is generally acknowledged that the long sludge ages normally operated in MBRs support slow growing organisms such as nitrifiers, which has been confirmed by molecular examination of the nitrifying microbial population in MBR. Nevertheless, the presence of polyphosphate accumulating organisms (PAOs) in MBRs has seldom been investigated by microbial analysis, despite the demonstration of the effectiveness of MBRs for enhanced biological phosphorus removal (EBPR)³. Ahmed et al (2008)⁴ studied the microbial population composition of an anoxic/anaerobic-aerobic MBR with carbonaceous, nitrogen and phosphorus removal and found a high number of *Accumulibacter*, a major PAO. This is, to the best of our knowledge, the only study reporting microbial analysis of PAOs in MBRs.

Objectives

This work aimed at evaluating the microbial community structure of several pilot- and full-scale MBRs, with special focus of the phosphorus removing-related populations.

Materials & Methods

Fluorescence *in situ* hybridisation (FISH) analysis was carried out using oligonucleotide probes targeting *Accumulibacter* (PAO462; PAO651; PAO846); PAO's major competitors, the glycogen accumulating organisms (GAOs): *Compectibacter* (GAOQ431; GAOQ989; GB_G2), *Defluviococcus vanus* cluster 1 (TFO_DF618; TFO_DF218) and cluster 2 (DEF1020_H;DEF988_H); and all *Bacteria* (EUB338; EUB338_II; EUB338_III). Semi-quantification results were obtained through image evaluation by an experienced operator.

Results and discussion

Samples were collected and fixed for FISH analysis at the membrane tank of four full-scale MBR plants ranging from 9,700 to 80,000 person equivalents (Monheim - Germany, Henvliet - The Netherlands, Schilde - Belgium and Nordkanal - Germany) and four pilot MBR plants (Margaretenhohe - Germany, EAWAG - Switzerland, NTNU - Norway and Lavis - Italy). Two of these plants had flat sheet type of membranes and all others had hollow fibres. Most of the analysed plants had submerged membranes in a tank separated from the biology tank, which was comprised of an anoxic and an aerobic zone. Only Margaretenhohe and Henvliet contained also an anaerobic compartment for phosphorus removal.

FISH semi-quantification analysis showed a relatively high abundance of PAOs in all analysed plants, except for one (Figures 1), with levels that were often similar to those observed in the MBR plants that contained a dedicated anaerobic compartment. Some of the analysed plants also exhibited a substantial number of GAOs, possibly due to lower levels of phosphorus in the feed (such as the case of Lavis which had chemical phosphorus precipitation pre-treatment) or to other GAO-favouring conditions⁵. These values will be confirmed by quantification based on image analysis of a statistically significant number of photographs acquired with confocal laser scanning microscopy.

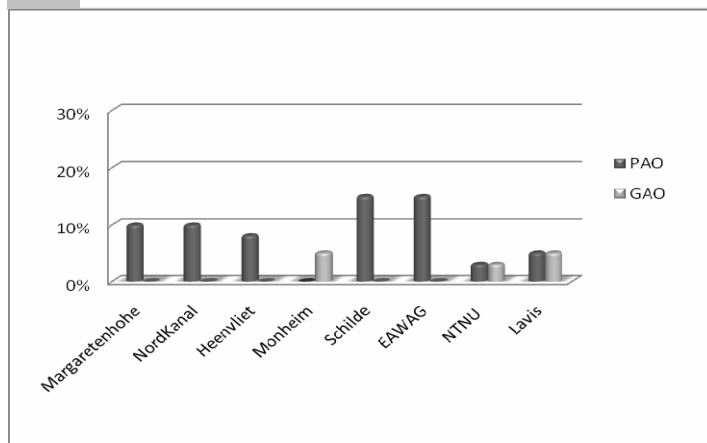


Figure 1: FISH semi-quantification results of PAOs and GAOs

The fact that PAOs tend to grow in MBRs even when these were not designed for EBPR could be related to the high floc compactness and density of external polymeric substances (EPS), which were observed in most examined samples. This could be possibly due to fact that MBRs tend to contain anaerobic micro-niches in higher proportion than conventional activated sludge (CAS), which give PAOs and GAOs the competitive conditions to thrive. Indeed, the membrane acts as a physical barrier that seems to enhance the concentration of EPS in the tank and promote sludge compactation in the cake layer, which added to the higher biomass concentration that might enhance the creation of anaerobic zones within the flocs.

Conclusions

These results suggest that MBRs, along with the known advantages in relation to CAS, can also support the growth of phosphorus removing bacteria even without an anaerobic compartment. These data will be compared to samples collected from a CAS plant run in parallel (i.e. identical wastewater composition) with one of the studied plants, in order to further investigate this hypothesis.

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PERFORMANCE EVALUATION OF SUBMERGED MEMBRANE BIOREACTOR PILOT UNITS FOR REFINERY WASTEWATER TREATMENT

A.P.R. Tôrres¹, V.M.J. Santiago² and C.B. Piacsek³

¹ PETROBRAS / CENPES - aptores@petrobras.com.br

² PETROBRAS / CENPES - [vaniamjs@petrobras.com.br](mailto:vaniemjs@petrobras.com.br)

³ COPPE / UFRJ - cristiano@peq.coppe.ufrj.br

keywords: membrane bioreactor (MBR), wastewater, refinery, water reuse

Introduction

The industrial wastewater reuse has as the main goal to preserve the hydric resource through to minimizing the impact to the aquatic ecosystems, which can be obtained by reducing the wastewater generation and the pure water consume. The water demand in an crude oil refinery is approximately 0,7m³water/m³ processed oil, being the cooling tower system responsible for 60% of this consume. The wastewater treatment unit of the company has the primary and secondary steps of the treatment that guarantees to comply with the legal requirement to discharge at the hydric receptor's bodies. However, to make possible the industrial effluent reuse, additional steps must be implemented to give an acceptable quality for cooling tower system or steam generation. The MBR effluent can be sent directly to the reuse as the process water or to the tertiary treatment steps to improve its quality to feed the cooling system or to steam generation.

Objectives

In order to demonstrate the technical viability of this technology, three pilot units with different configurations were evaluated by monitoring the main membrane and biological parameters. All pilot units evaluated have the submerged bioreactor configuration with microfiltration polymeric membrane. Two of them have the membrane unit as flat sheet, while the last one has hollow fiber membranes. The units had the hydraulic capacity of 0.5 to 2.0 m³/h and the installed membrane area of approximately 60 to 70 m², permitting to work with a permeate flux of 10 to 25 L/m².h.

Materials & Methods

This study was developed with submerged membrane bioreactor (SMBR). In the pilot units with flat sheet configuration (Kubota and Seghers Keppel), the membrane module was submerged in aeration tank (biological tank), while the pilot unit with hollow fiber configuration (Zenon), the membranes were located in an external tank (membrane tank). Several analyzers, as example pH, dissolved oxygen, suspended solids, level, pressure and flow were used to process control, by the activation of chemical pumps (acids, caustics), actuation in blower, alteration of permeate pump flow, and also to analytical monitoring in order to maintain the optimal conditions for biological and membrane process. The cleaning procedures (operation, maintenance and recovery), recommended by the membrane suppliers and technology, were adopted and the checked and the efficiency was examined by flux curves. These procedures has the objective of minimize the fouling effect as well as to prolong the lifetime of the membranes.

Results and discussion

The MBR feasibility in the wastewater treatment was demonstrated by operating the pilot units at the refinery of Betim (REGAP/MG). The efficiency of this process was estimated by organic (97%) and ammoniacal nitrogen (96%) removal. The quality of the treated effluent, the evaluation of suspended solids and turbidity removal (98%), allows considering the MBR an appropriate technology for pre-treatment for water desalination steps or preparation of water of high quality for industrial reuse.

Conclusions

This study allowed the determination of the effluent quality and the estimation of the biological and membrane process parameters and the knowledge about the process has been permitted the introduction of this technology in the company, making possible the implement in PETROBRAS of new industrial units.

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ASAHI KASEI MBR PILOT RESEARCH AT THE UTRECHT WWTP

A.G.N. van Bentem*, A.C. Kubota**, N. Nijman* and T.B. Hashimoto**

* DHV B.V., Laan 1914 no 35, 3818 EX Amersfoort, The Netherlands (E-mail: andre.vanbentem@dhv.com)

** Asahi Kasei Chemicals Corporation, 1-105 Kanda Jinbocho Chiyoda-ku, Tokyo 100-8101, Japan (E-mail: kubota.ac@om.asahi-kasei.co.jp)

keywords: MBR pilot research, Membrane fouling and cleaning, Minimizing energy consumption, MBR operation

Introduction

On behalf of the Japanese membrane company Asahi Kasei Chemicals Corporation, DHV executes a MBR pilot research project at the Utrecht wwtp in the Netherlands. At the Utrecht wwtp, the Waterboard Stichtse Rijnlanden and DHV offer membrane suppliers the opportunity to test and optimize their membranes by independent experts. Asahi Kasei is the first company that takes this opportunity. Asahi Kasei is supplier of the Microza hollow fibre membranes. DHV will investigate and optimize the operating window of the membrane module during a research period of 1.5 year (from January 2008 – June 2009).

Objectives

The research program focuses on the membrane performance and development. The following research goals can be distinguished:

- Optimization of the process settings for the Asahi membranes;
- Definition of the operation window for the Asahi membranes;
- Demonstration of the membrane performance under Dutch conditions;
- Recommendations for future developments.

Materials & Methods

The pilot plant (see figure 1) consists of a pre-treatment (1 mm screen), an anoxic tank, an aeration tank and a membrane tank with two separated submerged membrane cassettes. Each cassette contains 4 membrane modules of 25 m² surface area each. The total membrane surface area is 200 m².

The main characteristics of the Microza membrane module are:

- | | | |
|-------------------------|---------------------------|----------------|
| ○ Membrane type | Submerged / Hollow fibre; | |
| ○ Membrane material | PVDF | |
| ○ Nominal pore size | 0.1 | µm |
| ○ Membrane surface area | 25 | m ² |
| ○ Module diameter | 15 | cm |
| ○ Module length | 2.0 | m |

Results and discussion

The research has started in January 2008 with the current membrane type of Asahi Kasei. After two months the new membrane type (with a higher porosity) was installed in the pilot. Several tests have been executed to determine the membrane performance at start up. Since then, the pilot has been operating stable at a net flux of 20 l/(m².h) on both racks or alternating the individual racks.

At the moment of writing this document, a start will be made with testing the membranes at higher fluxes for longer times, up to a net flux of 33 l/(m².h). Both long-term test will later be executed at winter temperatures. Next to that, additional tests with different process cycle settings and process conditions will be tested, to define the optimal settings for the Microza MBR-modules. The existing membrane cleaning procedures will be evaluated and optimised, to improve the membrane performance and to save chemicals.

Conclusions

The Microza MBR operates at relatively high constant fluxes at stable TMP's. The required aeration capacity is low compared to other membrane systems (varying between 0.20 – 0.28 Nm³/(m².h)). The cleaning procedures can be improved and adapted to Dutch circumstances.



Figure 1: The Microza MBR pilot plant at Utrecht wwtp



Figure 2: The Microza membrane modules

In the first phase of the research program, the pilot plant has already shown the potential of the Microza MBR system. The research program will continue until mid 2009. The remaining research period will be used to further optimize the process settings and the cleaning procedures and to investigate the limits of the system.

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FOULING BEHAVIOUR OF MODEL SOLUTIONS AND SLUDGE FRACTIONS IN MEMBRANE BIOREACTORS

P.F.H. van den Brink*, G.O.J. Smith**, A. Zwijnenburg*, M.C.M. van Loosdrecht***

* Wetsus, paula.vandenbrink@wetsus.nl

**Norit Process Technology

***TU Delft, Environmental Biotechnology

Keywords: membrane fouling, model solutions, sludge fractions, humic acids, alginate

Introduction

MBR systems ensure increased effluent quality while a smaller footprint is needed. The most expensive part of an MBR system is the membrane unit, which is susceptible to fouling. Membrane fouling results in higher operating costs and the need for larger membrane areas [LeClech, et al. 2006]. If fouling could be predicted for different MBR systems, preventive measures could be taken and, thereby, operating and investment costs would decrease.

Objectives

In this project, a fundamental approach is taken to elucidate the membrane fouling mechanisms, which can be scaling by inorganics, adsorption, pore blocking, pore narrowing, biofilm formation and cake & gel layer formation (see Figure 1). By combining modelling and controlled experiments, mechanisms can be uncoupled and dominant mechanisms can be identified.

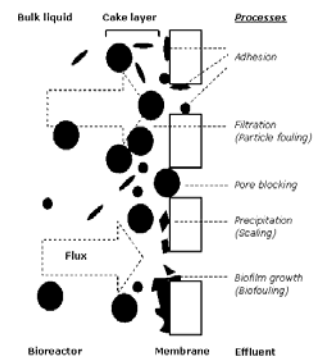


Figure 1: Fouling mechanisms



Figure 2: Experimental set-up

Materials & Methods

Membrane fouling is investigated by setting up a mathematical model that includes the before-mentioned mechanisms. The modelling is done with finite element methods in the COMSOL software and a representative membrane geometry is used. In order to validate the model, data from literature are used, if available. In addition, controlled experiments are performed with test cells (see Figure 2) [Vrouwenvelder, et al. 2006], in which the focus is on one of the mechanisms. Adsorption kinetics is studied with reflectometry.

The filtration experiments are performed according to the flux step method developed by van der Marel et al. [2008], in which the flux is gradually increased and relaxation is applied in between the increasing flux steps. From the resistance data, fouling rates (dR/dt , calculated according to Darcy's law) and reversibility values were obtained. Scanning electron microscopy is used to visualise the fouling layer. Fouling mechanisms are studied separately, but also interactions between foulants are subject of investigation. This is done by working with model solutions, and sludge fractions from two different systems: a pilot scale MBR and a full scale MBR (Varsseveld, the Netherlands). Several analyses are performed in addition to the filtrations in order to identify foulants and monitor their retention: chemical oxygen demand (COD), total organic carbon (TOC), viscosity, protein concentration (according to Bradford method), polysaccharide concentration (according to Dubois method). Recently, another technique was applied to characterise the sludge fractions: Liquid Chromatography – Organic Carbon Detection (LC-OCD).

Results and discussion

Several filtrations were performed with model solutions and sludge fractions. Fouling rates of paper filtrates (filtered through 12-25 μ m filter) of the two systems (pilot and Varsseveld) were compared to fouling rates of model solutions, containing respectively 10 ppm alginate + 1 mM Ca^{2+} (10 mM total ionic strength, base case) and 20 ppm alginate + 2 mM Ca^{2+} (10 mM total ionic strength, high Ca+alg). Alginate is used here as a model compound for polysaccharides, which were reported in literature to be major foulants. Results are shown in Figure 3. The graph shows generally increasing fouling rates at increasing flux values, which can be explained by the higher convective flux of fouling material to the membrane surface. The trends shown in this graph are rather different though. Fouling rates for the base case are rather low and almost constant with increasing flux. For the two paper filtrates, the

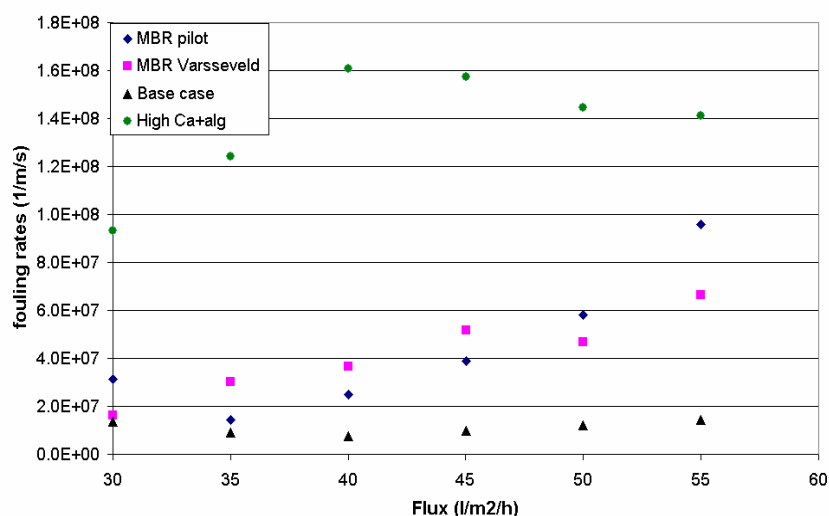


Figure 3: Fouling rates model solutions and sludge fractions

fouling rates are similar, but two different trends with the increasing flux values can be observed: linear for the full scale and more exponential for the pilot system. This indicates that the critical flux is lower for the paper filtrate of the pilot system than for the paper filtrate of the full scale MBR. The experiment with high calcium and alginate concentrations shows very high fouling rates. Although paper filtrates have a low polysaccharide concentration (approx. 2 mg/l) compared to the model solutions, higher fouling rates were obtained as compared to the base case. This indicated that other foulants might contribute to the overall fouling behaviour of these sludge fractions as well. LC-OCD analysis revealed the composition of the sludge fractions. Apart from biopolymers, other possible

foulants were humic substances, and their breakdown products. Future work will be focussed on including other kind of compounds (proteins, humic acids) and studying their combined fouling behaviour.

Conclusions and outlook

From these experiments, it can be concluded that membrane fouling in membrane bioreactors can not be assigned to one major foulant, although this is often done in literature. Several foulants are interacting and thereby causing the membrane to foul.

To elucidate membrane fouling further, the combined fouling behaviour of several fouling compounds will be studied further. A detailed analysis on the deposition layer on the membrane will be performed. LC-OCD analysis helps to distinguish between the different organic molecules that are present in sludge fractions, and reflectometry will be applied to study the adsorption behaviour of these compounds onto the membrane surface. These experimental data will be used in the mathematical model, which is under development.

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MEMBRANE PROPERTIES INFLUENCING FOULING IN MBR

Perry van der Marel^{a,b,*}, Arie Zwijnenburg^b, Antoine Kemperman^a, Matthias Wessling^a, Hardy Temmink^{b,c}, and Walter van der Meer^{a,b}

^aMembrane Technology Group, IMPACT Institute of Mechanics, Processes and Control Twente, Faculty of Science and Technology, University of Twente, P.O. Box 217, NL-7500AE Enschede, The Netherlands

^bWetsus, Centre for Sustainable Water Technology, P.O. Box 113, NL-8900 CC Leeuwarden, The Netherlands

^cDepartment of Environmental Technology, Wageningen University, P.O. Box 8129, NL-6700 EV Wageningen, The Netherlands

* Corresponding author. Tel.: +31 58 2846200; Fax: +31 58 2846202.

Email: perry.vandermarel@wetsus.nl

Keywords: Improved flux-step method, critical flux, fouling reversibility, MBR.

Introduction

Membrane bioreactors (MBR) gain more and more attention over the past years for the treatment of municipal and industrial wastewater. But despite several advantages above conventional systems – such as a better effluent quality and smaller footprint – membrane fouling still hampers full-scale applications, in particular for municipal wastewater.

Objectives

Membrane fouling is influenced by operational conditions, feed properties, and membrane properties. The main objective of this study was to identify the best membrane properties for MBR. In a parallel study feed properties were optimized [1]. A combination of these strategies results in much larger fluxes.

Materials & Methods

A matrix of membranes varying in membrane material, pore size, pore morphology, and hydrophobicity were used in this study. In this overview, the performance of seven different membranes is discussed.

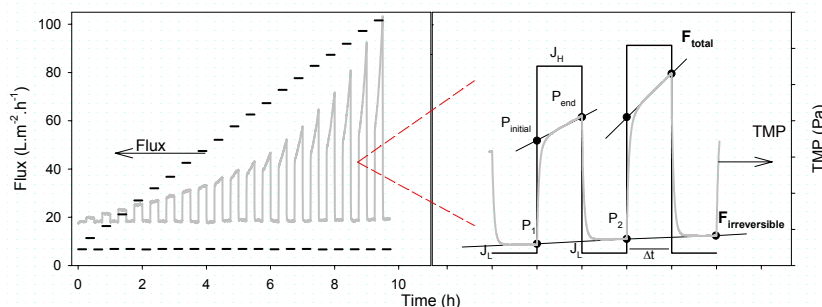


Figure 1: Improved flux-step method (IFSM)

Hydrophilic polyvinylidene fluoride (PVDF) membranes with pore sizes in the range of 0.02 μm (P1), 0.05 μm (P2), 0.1 μm (P3), and 0.2 μm (P4) were prepared. Hydrophilic membrane P3 was made hydrophobic (H). For comparison two commercial hydrophilic flat sheet membranes (A and B) were used. The membranes were investigated for fouling with the improved flux-step method [2] (IFSM, Figure 1). The IFSM not only reveals the total fouling rate (F_{total})

associated with a critical flux (J_c), but also the irreversible fouling rate ($F_{\text{irreversible}}$) associated with a critical flux for irreversibility (J_{ci}). After each filtration step at J_H , a low reference flux (J_L) was applied which can be regarded as a form of relaxation. All fouling is irreversible if J_{ci} equals J_c , while fouling is partially reversible when J_{ci} exceeds J_c .

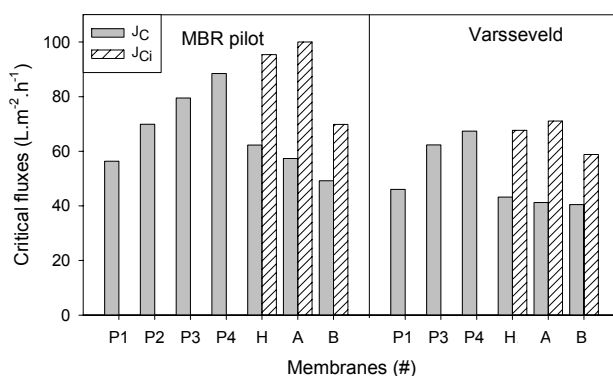


Figure 2: Critical flux (J_c) and critical flux for irreversibility (J_{ci}) for various membranes

Two feed sources were used in the IFSM; activated sludge from a MBR pilot fed with municipal waste water, and activated sludge from a full-scale MBR (Varsseveld, the Netherlands). Long term experiments were performed with the sludge from the MBR pilot to verify the results obtained from the short term IFSM.

Results and discussion

Figure 2 shows that membrane P4 had the best membrane properties out of the seven membranes examined.

P4 shows the largest J_c and reveals a very low irreversible fouling tendency (high J_{ci}). J_c increased with an increase in pore size from P1 to P4. J_{ci} was much larger than J_c for the PVDF membranes. Values for J_{ci} were above the maximum flux that was applied

(100 L.m⁻².h⁻¹) demonstrating that all fouling was completely reversible.

J_C was lower for membrane H than for P3 at equal membrane properties other than the hydrophobicity. The fouling was only partially reversible for H showing that a hydrophobic membrane is less suitable in a MBR. Compared to e.g. P3 and P4, the J_C for the two commercial membranes was lower, while the fouling appeared to be partially irreversible. The commercial membranes were hydrophilic but revealed a similar fouling behaviour as for H in terms of irreversible fouling. Other differences in membrane properties between P3/P4 and the commercial membranes (membrane material, pore morphology, pore size, and surface porosity) caused this behaviour.

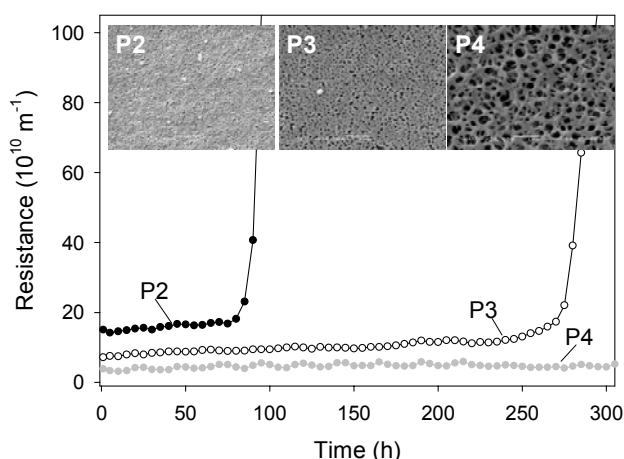


Figure 3: constant flux filtration at 50 L.m⁻².h⁻¹ with three home made PVDF membranes

below the applied flux resulting in severe fouling conditions with concentrations at the membrane surface higher than the critical gel-concentration [4].



Figure 4: gel-layer on P1 (left) and P3 (right)

Membrane fouling was more severe for the activated sludge from the MBR in Varsseveld resulting in lower J_C 's for all membranes. However, the course of the fouling behaviour of the various membranes was similar to the course with sludge from the pilot MBR.

Membranes P2, P3, and P4 were used in a long term experiment with constant flux filtration at 50 L.m⁻².h⁻¹ (below the J_C of these membranes) with the sludge from the MBR pilot (Figure 3). A two stage fouling process was found for P2 and P3, with a gradual increase followed by a steep increase. The time period of the first stage is defined as the sustainable time [3]. Its length increased with increasing pore size of the membranes.

In contrast to P4, the membranes P2 and P3 were covered with a gel-layer at the end of the experiment (Figure 4). The gel-layer was thicker for P2. It was hypothesized that the gradual fouling in stage 1 was caused by pore blocking / narrowing and local gel-formation. These phenomena gradually decreased J_C

Conclusions

For two completely different activated sludge mixtures the P4 membrane revealed the best membrane properties out of seven membranes examined.

P4 showed the largest J_C and J_{Ci} .

J_C increased with increasing membrane pore size.

Fouling was not completely absent during long term constant flux filtration below J_C . The sustainable time increased with increasing pore size.

The most dominant fouling mechanism during long term filtration runs appeared gel-layer formation.

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COMBINATION OF FLUX ENHANCERS FOR MBR

Jörn Villwock*, Vera Iversen*, Anja Drews*, Boris Lesjean**, Matthias Kraume*

*Chair of Chemical Engineering, Technische Universität Berlin,
 Straße des 17. Juni 136, MA 5-7, 10623 Berlin, Germany, sekretariat.vt@tu-berlin.de
 ** Berlin Centre of Competence for Water, Cicerost. 24, 10709 Berlin, Germany
 E-mail: joern.villwock@gmx.de

keywords: flocculation, flux enhancing chemicals, SMP, MBR, dewaterability

Introduction

One significant limitation in the broader application of membrane bioreactor systems is the so called membrane fouling which reduces filtration performance resulting in higher operation costs. Soluble and colloidal materials like soluble microbial products (SMP) and extracellular polymeric substances (EPS) are considered to be major foulants in MBR [1]. Several studies have shown that the addition of flux enhancing chemicals like metal salts, natural and synthetic polymers and powdered activated carbon (PAC) can cause a reduction in the foulant concentration and/or increase the sludge filterability [2] [3].

Objectives

As different additives act in different ways (e.g. by adsorption, enlargement of flocs, reductions of solutes and colloids in the supernatant...) a combination of different flux enhancing chemicals might be interesting. This study aims towards getting the optimum result by combining the different working mechanisms of the different additives. Therefore, the effects of the combination of flux enhancing chemicals of different dosages on SMP concentration and sludge filterability were investigated.

Materials & Methods

Activated sludge samples were obtained from a pilot-scale MBR aerobically treating domestic wastewater in the city of Berlin. The tested substances included a metal salt (Merck, ferric chloride), a cationic polymer (Nalco, MPE50) and a powdered activated carbon (Norit, SuperSA). These chemicals were combined with each other in various dosages as shown in table 1. The respective optimum concentration was determined in previous shaking flask tests for single additives [2].

Table 1: combinations of additives and dosage (optimum dosage according to [2])

sample no.	1	2	3	4	5	6	7	8	9
additive (s) (dosage)	reference sludge	A1 (od)	A2 (od)	A1 (od) + A2 (od)	A1 (od) + A2 (0.5)	A1 (0.5) + A2 (od)	A1 (0.5) + A2 (0.5)	A1 (1.2) + A2 (od)	A1 (od) + A2 (1.2)

(A1: additive 1, A2: additive 2, od: optimum dosage, 0.5: 50% of optimum dosage, 1.2: 120% of optimum dosage)

Shaking flask tests were conducted for each combination to determine the extent of SMP removals and the effect on sludge dewaterability. Raw or additive-dosed sludge samples (250 mL) were mixed in 500 mL flasks in a reciprocating shaker for 1 h, at 20°C temperature and a frequency of 100 min⁻¹. Afterwards, sludge samples were filtered prior to SMP analysis. Concentrations of protein and polysaccharide fractions of SMP were determined in the supernatant based on the methods reported by [4] and [5], respectively. The dewaterability of the different sludge samples was evaluated measuring the capillary suction time (CST).

Results and discussion

Fig. 1 shows the results of the SMP analysis for the combination of ferric chloride and activated carbon. While ferric chloride does not alter the SMP concentration significantly, the activated carbon causes a noticeable decrease in SMP removal of nearly 90% of the protein concentration and 45% of the polysaccharide concentration. As can be seen, the activated carbon is almost exclusively effective on SMP removal; the combination of both substances does not cause an improvement.

Fig. 2 shows the results for the combination of ferric chloride and cationic polymer. As can be seen, the SMP removal caused by ferric chloride is comparable to that one from Fig. 1. SMP removal achieved by the cationic polymer is about 70% of the protein concentration and 45% of the polysaccharide concentration.

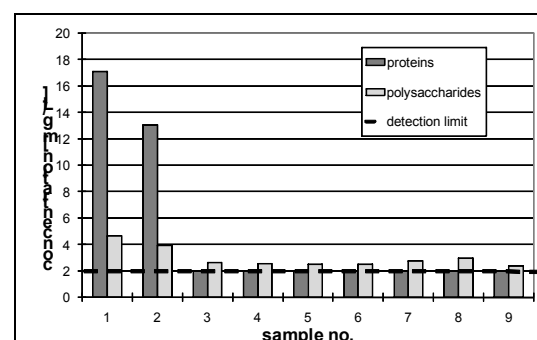


Figure 1: SMP concentration for the combination ferric chloride (A1) and activated carbon (A2)

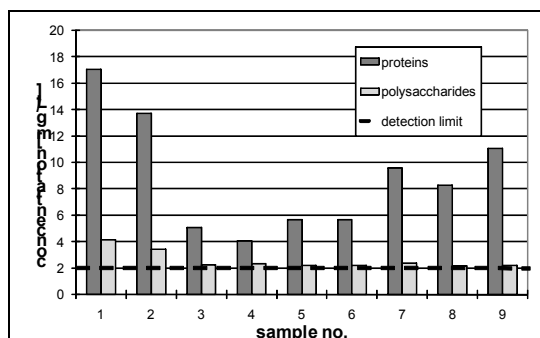


Figure 2: SMP concentration for the combination ferric chloride (A1) and cationic polymer (A2)

As can be seen, all SMP concentrations are below detection limit of 2 mg/L (dashed line) for sample no. 5 to 9. Just as in Fig. 1, the activated carbon affects a higher decrease in protein concentration than the cationic polymer alone. But only the combination with the cationic polymer increases the removal of polysaccharides up to 55%.

It must be said that the used sludge showed relatively low SMP concentrations. Therefore, further tests will be conducted with a different sludge with higher SMP concentrations.

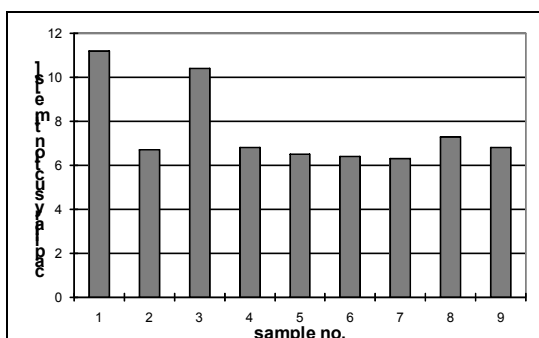


Figure 4: Dewaterability for the combination cationic polymer (A1) and activated carbon (A2)

The combination of both additives at optimum dosage shows the best efficiency on SMP removal. An over- or underdose of one of the additives results in reduced SMP removal, see sample no. 5 to 9.

The results of the SMP analysis for the combination of cationic polymer and activated carbon are shown in Fig. 3. The combination of these additives results in SMP removals of about 90% of protein concentration and 55% of polysaccharide concentration for the considered dosages.

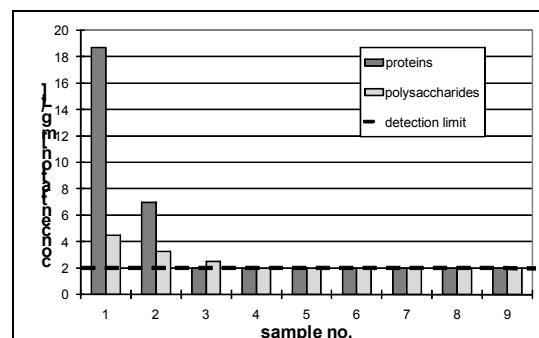


Figure 3: SMP concentration for the combination cationic polymer (A1) and activated carbon (A2)

Fig. 4 shows the results of the dewaterability measurements for the combination of cationic polymer and activated carbon. In comparison to the other additives the cationic polymer is most efficient in increasing the dewaterability. In contrary, the addition of activated carbon and/or ferric chloride has only a slight impact.

Conclusions

Three different additives and their combinations were tested on their effects on SMP removal and sludge dewaterability. While the activated carbon is most efficient on SMP removal with up to 90% of protein concentration and 45% of polysaccharide concentration, the cationic polymer is most suitable to increase the dewaterability, in this case up to 40%. Therefore, the combination of these two additives can be stated the best to use.

Acknowledgement

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EVALUATION OF MIXING EFFICIENCY & NUTRIENT REMOVAL IN MEMBRANE BIOREACTORS VIA CFD MODELLING WITH EXPERIMENTAL VALIDATION

Yuan Wang, Matthew Brannock, Greg Leslie*

UNESCO Centre for Membrane Science & Technology, University of New South Wales, Sydney 2052, Australia

* Corresponding author, contact details: Tel: +61-2-9385 6092; Fax: +61-2-9385 5966

Email: yuanw@student.unsw.edu.au; matthew.brannock@worleyparsons.com; g.leslie@unsw.edu.au

Keywords: MBR, Mixing, CFD, RTD

Introduction

The major disadvantage of current membrane bioreactor (MBR) design tools such as BioWin® [1] is that the mixing characteristics are assumed to conform with either complete mixing (CSTR) for aeration tanks, or plug flow (PFR) for some anoxic channels. Empirical techniques are then used for sizing reactor or position mixers to achieve complete mixing [2, 3]. This often leads to an overestimate of the actual mixing energy for large installations, and hence the inaccurate estimation of biological nutrient removal.

Objectives

The purpose of this research is to develop a model using computational fluid dynamics (CFD) to account for how membrane configurations (i.e. hollow fibre vs. flat sheet) affect hydrodynamics at a set level of nutrient removal and subsequently allowing optimisation of the overall MBR performance.

Materials & Methods

The MBR vessel features can affect flow regimes which can be expressed by residence time distributions (RTDs). CFD modelling formulates and solves the fundamental mass and momentum balance equations using numerical

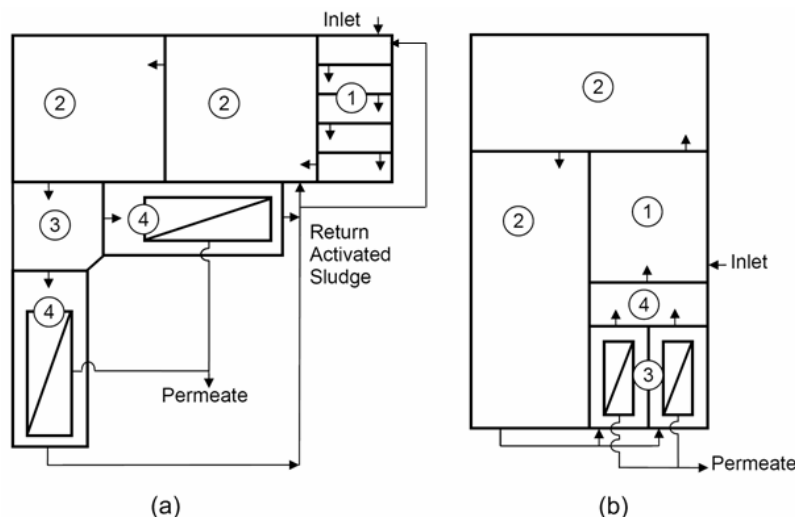


Figure 1 Overview of the full-scale MBRs' process setup; (a): FS MBR – 1. Bioselector, 2. Swing aerobic/anoxic zones, 3. Aerobic zone, 4. Membrane filtration vessel; (b): HF MBR – 1. Anoxic zone, 2. Aerobic zones, 3. Membrane

techniques and can be used for the prediction of RTDs of full-scale MBR plants. Two Australian full size MBRs were selected for RTD assessment, one having hollow fibre (HF) membranes and the other having flat sheet (FS) membranes (Figure 1).

To describe flow of the liquid and gas components of the multiphase flow, the Euler-Euler model was implemented [4]. The continuous phase was the water/sludge mixture and the dispersed phase was air. The assumptions made for the dispersed phase were: i) the bubbles are spherical; ii) the bubbles have constant diameter; iii) no collisions, coalescence or break-up of bubbles. The Morsi-Alexander drag force coefficient for the bubbles was used along with the mixture $k-\epsilon$ turbulence

model. The free surface was considered to be symmetry plane for the liquid phase and an outlet for the dispersed phase (i.e. degassing effects). The liquid phase fluid properties were that of water and for the gas phase were that of air. A simplification here was that the liquid phase viscosity is that of water which is valid for the majority of shear rates/stress experienced in the system. The CFD model implemented here only includes the liquid-gas phases, as the positive buoyancy forces from rising bubbles is much greater than the negative buoyancy forces from settling sludge [5]. The mean bubbles size used was 5 mm as calculated from the correlation by Akita and Yoshida [6]. The liquid outlet for the membrane module was assumed to be a negative source term for mass. Species transport equations with bioreactions were incorporated from Activated Sludge Model No. 1 (ASM1) [7]. Mass transfer of oxygen from the gaseous phase into the liquid phase was incorporated using the model proposed by Higbie [8] which is based on the slip velocity and diameter of the bubbles. The developed MBR CFD model was compared against field measured RTDs for hydrodynamics and against the COST Simulation Benchmark [1] for the biological nutrient removal component of the model.

Results and discussion

RTDs were generated at both sites with high reproducibility and tracer recovery (>96%) and were successfully reproduced by the CFD model (Figure 2). The FS MBR has a Peclet number of 0.29 and number of completely

mixed tanks in series of 1.10, while the HF MBR has a Peclet number of 0.68 and 1.24 of completely mixed tanks in series, which showed that the two MBRs were both close to completely mixed conditions. However, it was found that FS MBR required 20% more mixing energy than the HF MBR to achieve the completely mixed conditions (Table 1). The energy consumption of an MBR is usually characterised using specific energy consumption, which is the total energy consumed per m³ of permeate. The specific energy consumption of FS MBR and HF MBR was 1.23 and 0.98 kWh/m³ respectively. Among these, higher mixer power input of the FS MBR is resulting from its larger reactor volume. The aeration energy required for the bioreactor of the FS MBR was 3.3 kW, significantly lower than that of the HF MBR due to its simultaneous nitrification-denitrification design. However, the energy usage due to the aeration of flat sheet membranes is more than twice of the hollow fibre membranes.

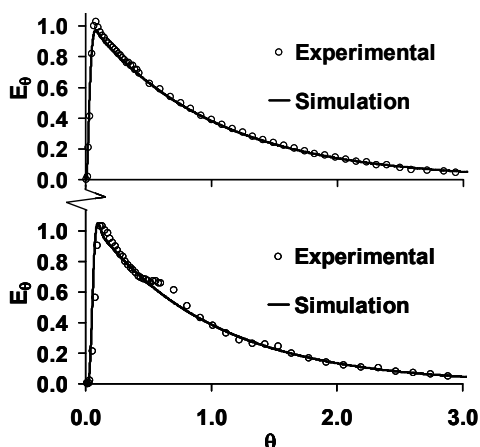


Figure 2: Experimental & CFD Modelled RTDs, Top: Hollow Fibre MBR; Bottom: Flat Sheet MBR

(anoxic and aerobic) were compared (Table 2). The differences between the benchmark & CFD simulation outlet concentrations for the anoxic tank were minimal (i.e. <1%). For the aerobic tank the largest difference was ~10%. Further work needs to be undertaken to correct this discrepancy.

Power Sink	FS MBR	HF MBR
Mixer	7.1 kW	2.2 kW
Bioreactor Aeration	3.3 kW	8.5 kW
Membrane Aeration	29.5 kW	13.8 kW
Recirculation Pump	16.0 kW	18.5 kW
Total	55.8 kW	42.9 kW
Specific Energy Consumption	1.23 kWh/m³	0.98 kWh/m³

Table 1 Comparison of energy usage of two MBRs

Pollutant Species	Units	Anoxic Tank 2		Aerobic Tank 3	
		B'mark	CFD	B'mark	CFD
<i>S_S</i>	g/m ³	1.46	1.47	1.15	1.30
<i>X_S</i>	g/m ³	76.4	77.1	64.9	68.0
<i>X_{B,H}</i>	g/m ³	2553	2554	2557	2557
<i>X_{B,A}</i>	g/m ³	148	148	149	148
<i>S_{NO}</i>	g/m ³	3.66	3.69	6.54	5.70
<i>S_{NH}</i>	g/m ³	8.34	8.34	5.55	6.24

Table 2: Comparison of selected parameters between COST Simulation Benchmark & the MBR CFD Model

Conclusions

A CFD model was developed to assess the implications of membrane configurations on MBRs' hydrodynamics and mixing efficiency and was successfully validated using field measured RTD data of full size MBR plants. Hollow fibre membrane module was found to be more energy efficient than the flat sheet membrane module. The biological reaction component of the CFD model was also successfully benchmarked against the COST ASM1 Benchmark. The development of this model improves the MBR design with the view of achieving the optimum mixing at lowest possible energy inputs at a set level of nutrient removal.

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WASTEWATER UPGRADING TECHNOLOGIES: A PRELIMINARY COMPARISON USING ANALYTICAL HIERARCHICAL PROCESS (AHP) ANALYSIS

Fei Yang*, Amos Bick**, Gedion Oron***

*J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midraset Ben-Gurion, 84990, Israel
(PhD student, Email: feiyang@bgu.ac.il)

**Dept. Industrial Engineering and Management, Jerusalem College of Technology, Jerusalem, Israel

** Dept. Chemical Engineering/ Environmental section, Shenkar College of Engineering and Design, Ramat-Gan, Israel.
(Corresponding author, Email: amosbick@gmail.com)

***J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midraset Ben-Gurion, 84990, Israel

***Dept. Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer Sheva, Israel.

***The Environmental Engineering Program, Ben-Gurion University of the Negev, Beer Sheva, Israel.
(Email: gidi@bgu.ac.il)

Keywords: Analytical Hierarchical Process; Effluent Polishing; Wastewater Treatment

Introduction

Effluent treatment has attracted a great deal of attention during the past decade. However, reuse of effluent is associated with health and environmental risks. Adequate selection and adaptation of the treatment phases can minimize these hazards and engineering, economical and environmental aspects should be linked in order to make optimal treatment and effluent reuse (Salgot, 2008).

Objectives

This current paper presents the treatment process coupled with management modeling [Analytical Hierarchical Process (AHP)] analysis (Saaty, 2005). The principal new results of this paper include: (i) A practical experience with the use of AHP for effluent treatment identification, and; (ii) A discussion concerning the use of AHP for the purpose of optimal effluent treatment process selection

Materials & Methods

The research includes seven alternatives: (i) stabilization ponds, (ii) Constructed Wetlands, (iii) Primary Treatment plus Sand Filters, (iv) Activated Sludge, (v) Activated Sludge & Plastic Carriers, (vi) MBR, and; (vii) MBR & Reverse Osmosis.

The general criteria for technology selection comprise: (i) Reliability: production of an acceptable effluent under unusual conditions of feed variations, (ii) Typical, efficiency and performance of the technology (iii) Technical skill, scientific support and managerial expertise, (iv) Space requirements, and; (v) O&M and capital cost.

A short version conceptual database of technologies and performance based on research experiments and literature review is introduced in Table 1.

Table 1. Technologies and parameters selection

Technology	Reliability	BOD Removal	Salinity Removal	O&M Skill	Space Required	O&M Cost	Capital Cost
Stabilization Ponds	Low	Medium	Low	Very Simple	High	Low	Medium
Constructed Wetlands	Medium	Medium	Low	Simple	High	Very Low	Medium
Activated Sludge	High	High	Low	Medium	Medium to Low	High	Very High
Activated Sludge & Sand Filters	High	Very High	Low	Medium	Medium	Very High	Very High
Activated Sludge & Carriers	High	Very High	Low	Medium	Medium to Low	High	Very High
MBR	Very High	Very High	Low	High	Very Low	Very High	High
MBR & RO	Extremely High	Extremely High	High	Extremely High	Low	Extremely High	Very High

Results and discussion

The result (Table 2) formalizes and renders systematically the preferred selection. According to Table 2 and based on scientific and engineering researches (Lesjean and Leiknes, 2006; Oron *et al.*, 2008) it can be stated that the best alternative is the MBR process.

Table 2. AHP final preferences concerning effluent treatment process selection

Treatment (Alternative)	Preference (Combined Normalized Scale)	Ranking Priority (P_i)
Stabilization Ponds (SP)	0.184	3
Constructed Wetlands (CW)	0.190	2
Activated Sludge (AS)	0.097	6
Activated Sludge & Sand Filters (AS&SF)	0.070	7
Activated Sludge & Carriers (AS&C)	0.108	5
MBR	0.195	1
MBR&RO	0.156	4

An important phase in most multi-attribute models is to focus on a series of sensitivity analyses in order to establish a sense of robustness of the recommendations. Sensitivity tests (Table 3) encounter most critical dimensions for which the smallest percentage modification will cause a change in the ranking of the alternative.

Table 3. Summary of the sensitivity analysis for effluent treatment selection (AHP model)

Quality Criteria (Priority vector)	Optimal Selection (Range)	
Reliability (0.062)	MBR(0.0-0.20)	MBR+RO(0.20-1.0)
BOD Removal (0.038)	MBR(0.0-0.20)	MBR+RO(0.20-1.0)
Salinity Removal(0.025)	MBR(0.0-0.09)	MBR+RO(0.09-1.0)
O&M Skill (0.166)	MBR(0.0-0.18)	SP(0.38-1.0)
	CW(0.18-0.28)	
Space Required (0.277)	CW(0.00-0.27)	MBR(0.27-1.0)
O&M Cost (0.101)	MBR(0.0-0.12)	MBR(0.12-1.0)
Capital Cost (0.331)	MBR(0.0-0.35)	CW(0.35-1.0)

The most effective parameter is the one for which the minimal percentage change will cause a variation in current ranking of the alternative (Triantaphyllou and Sanchez, 1997). According to Table 3 there are four effective parameters: O&M Skill, Space Required, O&M Cost and Capital cost.

Conclusions

The work demonstrates that the proposed AHP methodologies can be useful in the field of adequate wastewater treatment process selection. The work presents the variability effects of process variables and shows how AHP technique points out the importance of four criteria: O&M Skill, Space Required, O&M Cost and Capital cost. These characteristics are of direct scientific and engineering concern and provide useful explanations for analysis of wastewater treatment performance and selection. Management strategies should be site specific accounting for social, cultural, environmental and economic conditions in the target area - technology selection should be accomplished by conducting a comprehensive site evaluation process.

In the future, upgrading of existing wastewater treatment plants (wwtps) will become a challenging task (Brepols *et al.*, 2008). Since MBR technology has been realized as an alternative for wwtp upgrading (Yang *et al.*, 2006), new research fields for upgrading MBR technologies must be considered (Leiknes and Ødegaard, 2007) and training programs by the academy for municipality employees must be redesigned for the proper operation and maintenance of equipment and facilities.

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STANDARDIZATION OF MEMBRANE BIO-REACTOR WORKING GROUPS USING PARTIAL ORDER SCALOGRAM ANALYSIS (POSA)

Fei Yang*, Gedion Oron**, Amos Bick***

*J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midraset Ben-Gurion, 84990, Israel (PhD student, Email: feiyang@bgu.ac.il)

**J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midraset Ben-Gurion, 84990, Israel

**Dept. Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer Sheva, Israel.

**The Environmental Engineering Program, Ben-Gurion University of the Negev, Beer Sheva, Israel. (Email: gidi@bgu.ac.il)

***Dept. Industrial Engineering and Management, Jerusalem College of Technology, Jerusalem, Israel

*** Dept. Chemical Engineering/ Environmental section, Shenkar College of Engineering and Design, Ramat-Gan, Israel. (Corresponding author, Email: amosbick@gmail.com)

Keywords: MBR Standardization; Multi dimension Scaling; Partial Order Scalogram Analysis

Introduction

The European Water Commission decided to promote the development of the MBR technology in order to establish and standardize the wastewater industry (Lesjean and Leiknes, 2006; Lesjean and Huisjes, 2008; De Wilde *et al.*, 2008).

Objectives

The standardization procedure is based on skilled working groups, which were established by traditional points of views of researchers and managers. There is a need to reconsider the working group formation process, since MBR technology simultaneously tests many facets of scientific, engineering and economic aspects and requires a multidimensional coding that is not easily handled by traditional methods of analysis. One approach to examine the data analysis that will simultaneously examine degrees and interactions with respect to some underlying competitive scale is partial order analysis (Shye, 1985).

The purpose of this study is to analyze the research papers that were introduced at the last MBR Conference (at Harrogate England, May 2007): (i) to explore the different aspects of MBR that were introduced (and to define working groups), (ii) to understand the different structural patterns of connection induced by each relation between the specified working groups, and; (iii) to choose the 'logical' standard working groups.

Materials & Methods

Based on a review of all related articles concerning MBR issues (157 presentations) at the Harrogate conference, the original database was initially recorded. For the purpose of this study, a working database of 14 variables, based on the research subjects, were found (Project scoping and economics, module design, operation and fouling, Process configuration, Feed water characterization & monitoring, Cleaning and preservation, Concentrate / sludge handling, case studies, Presentation and dissemination of results, Overall and scientific coordination, Tests and analytical methods, Optimization, Kinetics of processes, and Pretreatment). Each article was scored in a dichotomous format as either absents (1) or presents (2) the specific variable. Coding the 157 cases formed the research data matrix that contains 63 different profiles (Table 1). [For example profile (11211112111111) describes an article that deals with operation and fouling of a specific case study]. In order to examine the behavior across all profiles of interaction, the data were subjected to a Partial Order Scalogram Analysis (POSAC software; Shye, 1985).

Results and discussion

Using POSAC, variable independence can be defined by mapping the original database: each of the profiles appear as a point in space and is defined by x and y base coordinates. From the fourteen variables, 'Project scoping and economics' indicates a good partition (Fig 1). This variable is an effective item and defines a clear structure. 'MBR operation and fouling' (Fig 2) indicated in this research is also "a good" structure that can be partitioned to create a distinctive zone. Concerning MBR, fouling is a critical issue (Haberkamp *et al.*, 2008) and according to Table 1, ID number 43 (fouling and case studies) has the maximum frequency (31 articles).

The fact that some of the profiles reside in different regions may depend on the data-gathering method, differences between the samples or a mixture of the two. There is also the real possibility that some articles may have different subjective meanings for different analysis. Any of these explanations may cause the discrepancies found. According to the POSA theory, the other twelve variables do not define a clear structure and should be considered as ineffective items due to their ambiguity and vagueness.

Conclusions

This paper makes important contributions by attaining a greater understanding of the nature and structure of MBR technology in order to support standardization needs. By using Partial Order Analysis (POSA), two main 'logical' stand-alone standard working groups were found dealing with: (i) cost and economics, and, (ii) Operation and fouling. These groups are clearly defined and can suggest procedures and directions for standardization of the MBR

process. All the other groups (module design, Process configuration, Feed water characterization & monitoring, Cleaning and preservation, Concentrate/sludge handling, case studies, Presentation and dissemination of results, Overall and scientific coordination, Tests and analytical methods, Optimization, kinetics and Pretreatment) are dependent groups and must co-operate in order to take a broad view of the issues that are responsible for.

Table 1. 63 different profiles (refer to working groups) that were exposed at the Harrogate Conference

ID	Profile	Freq- uency	ID	Profile	Freq- uency	ID	Profile	Freq- uency
2	21211112211111	1	24	11211111112112	2	46	11111121112111	1
3	12212112111111	1	25	22121111111111	1	47	11121112111111	2
4	11211112112211	2	26	12111112112111	1	48	21111111211111	3
5	21111112221111	1	27	21111112211111	7	49	11212111111111	1
6	12221112111111	1	28	21121111211111	1	50	11211111111112	1
7	11211112111221	1	29	21211112111111	3	51	12211111111111	1
8	11221112211111	1	30	11212112111111	2	52	11211111112111	2
9	11211112112112	1	31	11112112112111	1	53	11211211111111	2
10	22111112111111	1	32	21221111111111	1	54	12111111111211	1
11	11221112111111	3	33	11211212111111	2	55	12111111112111	1
12	11211112111211	8	34	11111212112111	1	56	11211111121111	1
13	11111112211112	1	35	21111111111112	1	57	21111111112111	1
14	11221111111211	1	36	21121111111111	1	58	11211111111111	2
15	11121112112111	1	37	21111112111111	6	59	11111111112111	2
16	11211112211111	1	38	11211111111211	6	60	11121111111111	2
17	11211112112111	8	39	11112112111111	1	61	11111111211111	2
18	11211112111112	7	40	11111212111111	1	62	11111112111111	2
19	11211122111111	1	41	11111221111111	2	63	11111111112111	1
20	12211112111111	3	42	11111112111112	3	64	21111111111111	1
21	21111112111211	1	43	11211112111111	31	65	11111111111111	0
22	112111121111121	2	44	21111111211111	5	1	22222222222222	0
23	11111112112112	1	45	11111111121211	1			

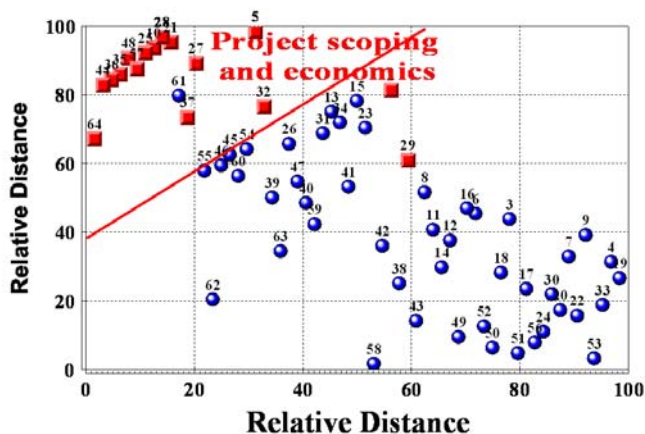


Figure 1: POSA results for project scoping and economics

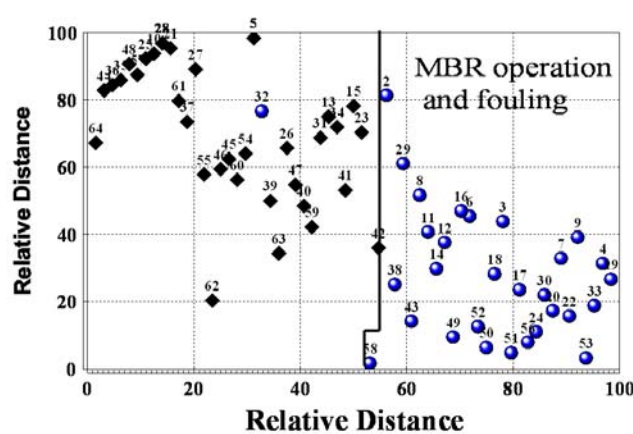


Figure 2: POSA results concerning operation and fouling

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THE EFFECT OF BIOFILM CARRIERS FILLING RATIO AND MIXING REGIME ON BIOMASS DISTRIBUTION, FOULING RATE, AND PROCESS EFFICIENCY IN A HYBRID GROWTH MEMBRANE BIOREACTOR (HG-MBR)

Fei Yang*, Ying Wang*, Jack Gilron**, Asher Brenner**, Gedion Oron**, Amos Bick***

*J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midrashet Ben-Gurion, 84990, Israel
(PhD student, Email: feiyang@bgu.ac.il)

**J. Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Midrashet Ben-Gurion, 84990, Israel.
(Email: jgilron@bgu.ac.il)

**Dept. Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer Sheva, Israel. (Email: gidi@bgu.ac.il)

**The Environmental Engineering Program, Ben-Gurion University of the Negev, Beer Sheva, Israel. (Email: brenner@bgu.ac.il)

***Dept. Industrial Engineering and Management, Jerusalem College of Technology, Jerusalem, Israel

***Dept. Chemical Engineering/ Environmental section, Shenkar College of Engineering and Design, Ramat-Gan, Israel.
(Corresponding author, Email: amosbick@gmail.com)

Keywords: Attached growth carrier; Draft tube; Hybrid growth; Fouling; Membrane bioreactor

Introduction

In membrane bioreactors (MBRs), improving ambient conditions and biomass properties is a practical alternative method to minimize membrane fouling and increase process efficiency (Drews *et al.*, 2007). A possible and promising approach for reaching such purposes is the use of hybrid growth MBR (HG-MBR) which combines the suspended- and attached- growth processes (Lee *et al.*, 2006; Sombatsompop *et al.*, 2006; Yang *et al.*, 2006; Leiknes and Ødegaard, 2007; Huang *et al.*, 2008; Ivanovic and Leiknes, 2008).

Objectives

In airlift MBRs, the enhanced flow velocity can offer a better driving force for carrier recirculation in the reactor, which lies behind the design of an Airlift HG-MBR (AHG-MBR) studied here. The idea of a Fixed HG-MBR (FGH-MBR) system is to keep the carriers as a fixed bed outside the draft tube, and try to get an anaerobic zone in the bottom for denitrification by adjusting the aeration rate. The HG-MBR without a draft tube can use a high ratio of filling carriers driven by a proper aeration diffuser. Therefore the objective of the present work is mainly focusing on the evaluation of three different configurations of HG-MBR systems for removal efficiencies and filtration performances during treating combined chicken manure wastewater, as a comparison with an airlift MBR, along with the optimal system configuration selection.

Materials & Methods

Four different configurations of MBR/HG-MBRs were used in the experiments: 1) A-MBR with 295 mm draft tube without carriers; 2) AHG-MBR with carriers (20% filling ratio) and 295 mm draft tube; 3) FHG-MBR with carriers (50% filling ratio) and 235 mm draft tube with two meshes around the bottom and top of a draft tube; 4) HG-MBR with carriers (50% filling ratio) without a draft tube. A hollow fiber UF membrane module of ZW-10 (Zenon Inc, Canada) was submerged in the reactor which has a 190 L (working volume) drum-tank (80 cm height and 55 cm diameter). The ZW-10 was surrounded by an 8 mm mesh to protect it from damage by the moving carriers. Carriers supplied by AqWise (AqWise Ltd.) served as the biofilm support. The carriers are made from high-density polyethylene with a diameter and height of 13 mm and a specific surface area of 600 m²/m³. The carriers' circulation was driven by the Zenon air diffuser sitting at the bottom of the membrane module for the A-, AHG- and FHG-MBRs, and an additional fine air diffuser was installed in the bottom of the ZW-10 module for the HG-MBR in order to drive the carriers flowing smoothly. The systems were operated under constant-flux mode with a mode of 5 minutes filtration, 15 second backwash. All experiments were conducted for treating artificial wastewater made from domestic wastewater and chicken manure under ambient desert conditions.

Results and discussion

The COD loading rates and removal rates are shown in Figure 1 in relative to total biomass (MLVSS+biofilm biomass), while the NH₄-N loading and removal rates are shown in Figure 2. The effluent CODs from the A-MBR, AHG-MBR and FHG-MBR are still high for unrestricted reuse, while the HG-MBR gave a sufficient COD removal. Poor nitrification activities were observed in the A-MBR, AHG-MBR and FHG-MBR, while the HG-MBR gave an almost completed nitrification conversion. These are probably due to high loading rate and/or insufficient DO concentrations in the A-MBR and AHG-MBR and too short running time for the nitrifiers growing in the FHG-MBR.

The average biomass concentrations of the four MBRs are shown in Fig. 3. The MLVSS concentration in the A-MBR increased from 2,520 to 5,520 mg/L. In the AHG-MBR, the biomass was mainly MLVSS (95.3% of total biomass) and only 4.7% is contributed from the carriers. In the FHG-MBR, the biofilm biomass was dominant (67.6%), only 130 to 334 mg/L of MLSS in the internal tube due to filtering by the fixed carrier layer. In the HG-MBR, 68% of total biomass was the MLVSS while the biofilm remained in 32%. The competition for food between suspended- and attached- biomass retarded the rate of increase in MLSS concentration, and consequently diminished the fouling phenomena.

Figure 4 shows the variations of trans-membrane pressure (TMP) over time for the four MBRs. An extremely sharp increase of TMP occurred in 3.5 days in the FHG-MBR, probably due to the low MLSS concentration in the internal tube resulting in an elimination of the secondary dynamic membrane formation on the membrane surface (Lee *et al.*, 2001). The TMP in the A-MBR and AHG-MBR reach to 0.55 bars (the limited upper value) in 17.7 and 23 days, respectively, while the HG-MBR was still below 0.42 bars after 38.6 days of running. It could be concluded that a good balance between the MLSS and biofilm biomass inhibited the fast increase of the suspended biomass.

Conclusions

The HG-MBR is the optimal solution concerning the four selected configurations and is an alternative strategy to reduce the effect of membrane fouling by high biomass concentrations in general MBRs. Sustainable process operation with the HG-MBR without a draft tube have been achieved under the present conditions with efficient organic removal efficiency and nitrification efficiency. Future research includes: (I) adjusting the carriers filling ratio and operation conditions for reaching a lower fouling rate and a better balance between MLSS and biofilm by in HG-MBR systems, and; (II) improving the air diffuser for driving the plastic carrier's recirculation at higher carriers filling ratio.

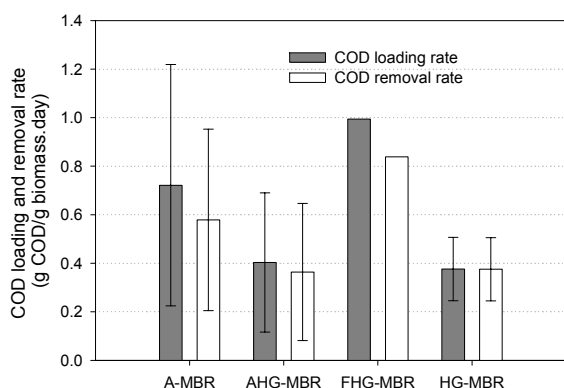


Figure 1: Average COD loading and removal rates.

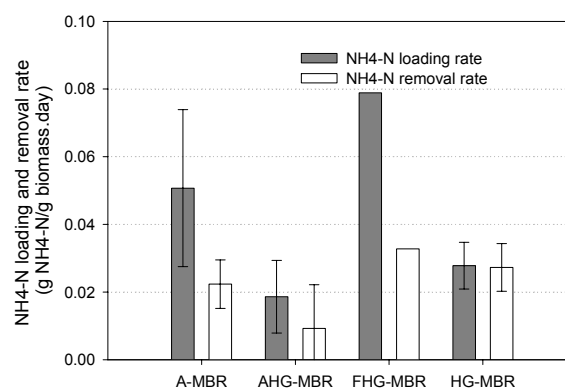


Figure 2: Average NH4-N loading and removal rates in the four MBRs.

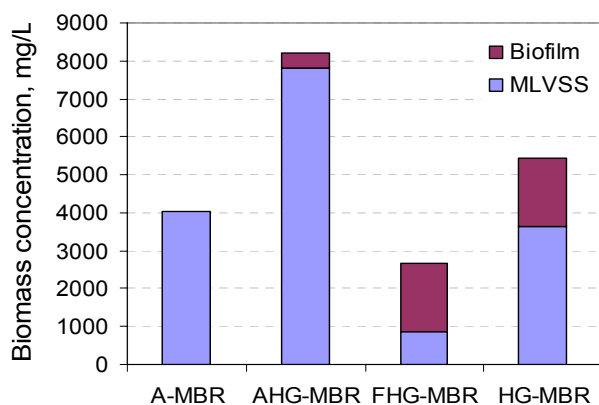


Figure 3: The biomass fractions in the four MBRs.

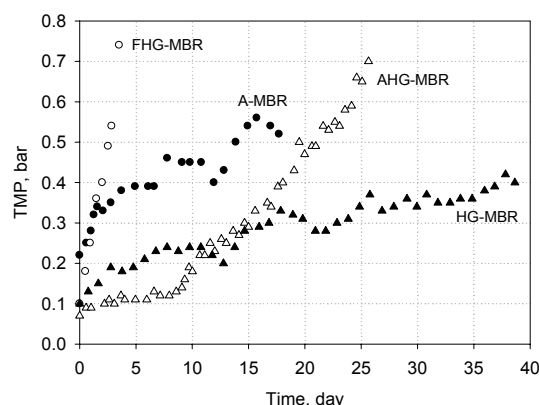


Figure 4: Variations of TMP over time of the four MBRs.

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ENHANCED CLEANING PROCESS FOR MBR

Barbara Zimmermann*, Stefan Krause*, Barbara Siembida** und Peter Cornel**

* Microdyn-Nadir GmbH, Rheingastr. 190-196, 65203 Wiesbaden, Germany (E-mail: ba.zimmermann@microdyn-nadir.de)

** Technische Universität Darmstadt, Petersenstr. 13, 64287 Darmstadt, Germany

Keywords: MBR, Granulate, Fouling Control, Polymeric Flat Sheet Membrane

Introduction

In membrane bioreactor (MBR) processes the separation of the biologically activated sludge and the treated wastewater is achieved by a membrane filtration process. Due to the superior effluent quality and the small footprint in comparison to the conventional sedimentation processes, MBRs have become an established wastewater treatment process during the last decades. However, MBR-processes face different problems concerning membrane fouling and braiding of the module. In submerged MBR-systems an air induced crossflow ensures the continuous control of the fouling layer on the membranes. Depending on the module type further strategies of fouling control are regular backwashing of the membranes with permeate or chemically enhanced cleaning processes. Current process optimisations and new module constructions aim to a reduction of costs and chemicals.

Objectives

The objective of this study was to develop a continuous, physically enhanced cleaning process in order to reduce the amount of cleaning-chemicals and their by-products and to reduce maintenance costs. The investigations were performed using Bio-Cell[®] modules, which provide polymeric flat sheet membranes combined with back-wash ability. The cleaning process was enhanced by polypropylene (PP) granulate, which were added into the filtration tank. By circulation through the module and moving with the crossflow along the membranes the granules are used to reduce the fouling layer on the membrane surface by continuous physical abrasion. Higher fluxes and less chemically enhanced cleaning are expected.

Materials & Methods

The new submerged membrane module (Bio-Cel[®]), developed by Microdyn-Nadir, combines the advantages of both mostly used submerged systems, flat sheet and hollow fibre modules. The core part of this module construction is the frameless membrane sheets. The mechanically strong PES membrane (Nadir[®] UP150) is laminated onto drainage layer. The lamination is strong enough to withstand backwash-pressure and, at the same time, the flow-resistance inside the membrane sheet is low, which ensures efficient back-washing of the membrane. The installation of the 2 mm thin membrane sheets with enough distance between the sheets allows the movement of the granules and a high packing density is achieved.

The granules were selected by taking into account different requirements. The diameter must be smaller than the distance between the membrane sheets of 8 mm. To ensure a continuous circulation of the granules in the filtration tank the density is very important, so that no sedimentation or no floating takes place. To maintain membrane integrity and avoid damages the granules should be ball shaped without sharp edges. And they should be biologically inactive. The chosen PP-granulate (PPTV20) have a density of 1,05 kg/dm³ and an average particle diameter of about 2,5 mm.

Two Bio-Cel[®] modules (10 m²) are set into separate filtration tanks of a laboratory plant, which consists of a de-nitrification tank (0.8 m³), nitrification tank (1.2 m³) and two filtration tanks in parallel (each 0.3 m³). One filtration tank (#1) serves as reference line and is operated without granules. Into the second tank (#2) 4 kg/m³ PP-granules are added. To keep the granules inside the filtration tank it was equipped with a screen for granulate rejection.

The activated sludge was fed with artificial waste water. During operation the effluent quality (turbidity, COD concentration), operation conditions (mixed liquor suspended solids (MLSS) content, temperature, pH-value) and the membrane conditions (flux, trans-membrane pressure (TMP), permeability) were recorded. To monitor the amount of granulate circulating in the filtration tank a granulate index (GI) was measured regularly. The particles were collected downstream in a collection vessel (d = 7 cm) ca. 50 cm below water level for 1 min.

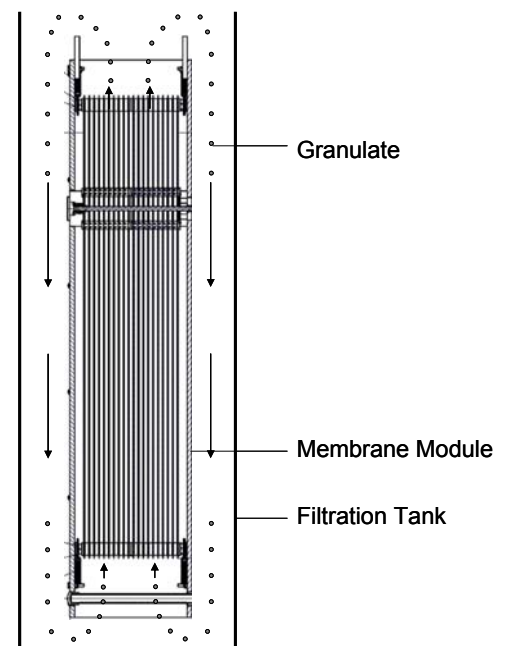


Figure 1: Schematic circulation of the granulates inside the filtration tank

Results and discussion

The laboratory plant with a line #1 as reference line and line #2 with the addition of PP-granulate was in operation since almost one year. The MLSS during the test period was about 10 g/L inside the aeration tank. With long sludge retention times (> 50 days) the average COD removal was about 94 % (effluent COD concentration about 20 mg/L). To control the integrity of the membrane sheets the turbidity of the effluent was measured online; it showed constant levels < 0,2 FNU. During the whole period of operation the granulate index stayed between 15 – 30 g/min. Both modules were back-washed regularly with permeate and module #1 had in-situ cleanings in intervals of 1-3 weeks.

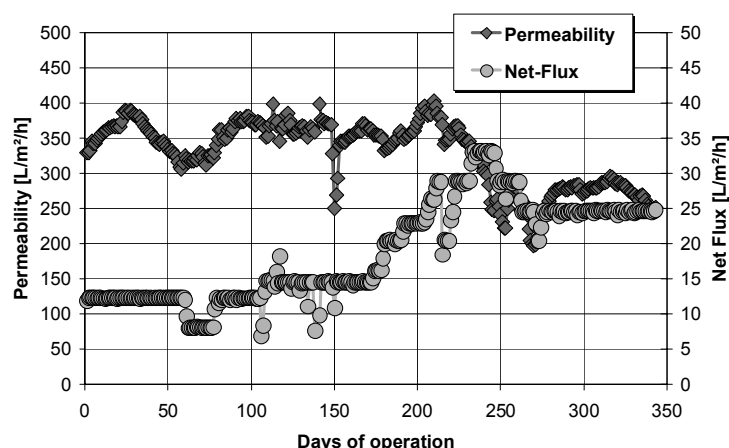


Figure 2: Permeability and Flux of the line holding PP-Granulates

The daily average of permeability and net flux of the granulate line (#2) are depicted in figure 2. Line #2 was operated with a net flux of 8-15 L/(m²h) for 170 days and showed a stable permeability of about 350 L/(m²hbar) during this time. In the second part of the experiment the net flux was raised stepwise (to 33 L/(m²h)). When the net flux exceeded 30 L/(m²h) the permeability started to decrease. But with a reduction of the flux to 25 L/(m²h) the permeability became constant again at a level ~25 % below the initial permeability.

The effluent control showed no quality impact concerning turbidity and COD. This can be taken as indicator that no severe damage is caused by the granules on the membrane surface.

Figure 3 shows the permeability of both lines during the period of operation with identical operation conditions. To compare the two lines the permeability is shown as percentage of the initial permeability of each module. After 70 days of operation the reference line (#1) has already lost 50 % of its initial permeability, which can only be maintained with regular in-situ cleanings (backwash with 1000 ppm NaOCl). After 120 days of operation a small amount of granules (1 kg/m³) was added to the line #1 which resulted immediately into a permeability increase of > 100 %. As soon as the granulate was removed from the reference line the permeability started to decline. Increasing the flux to > 15 L/(m²h) immediately led to a breakdown of the permeability to 50 %.

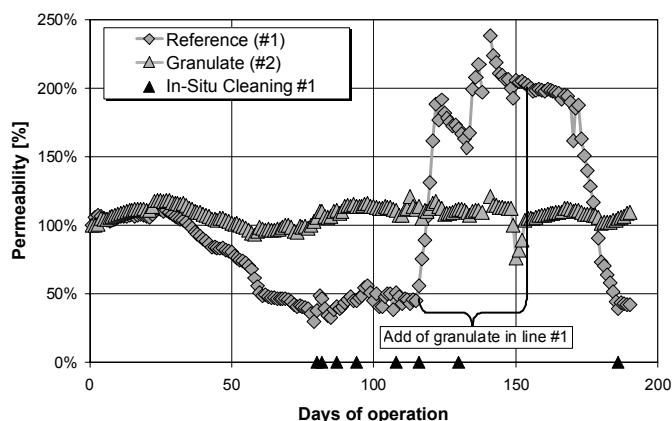


Figure 3: Comparison of both lines during the period with identical operation conditions

Conclusions

The pilot tests show that, enhanced by PP-granules, a continuous fouling control without chemicals is possible for MBR-processes. During the operation time of almost one year no chemical cleaning was necessary. Higher net fluxes up to 25 L/(m²h) can be achieved and peak flows up to 30 L/(m²h) are possible. Taking into account that the effluent quality is not fading this physical cleaning process is a promising alternative to future MBR processes. Further questions are how the lifetime of the membrane is effected by the abrasion of the granules.

DEVELOPMENT OF A METHOD FOR ON-LINE MEASUREMENT OF CARBOHYDRATES IN MEMBRANE BIORECTOR SYSTEMS

Sebastian Aust*, Renata Mehrez*, Mathias Ernst**, Martin Jekel*

* Chair of Water Quality Control, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: sebastian.aust@tu-berlin.de, renata.mehrez@tu-berlin.de; martin.jekel@tu-berlin.de)

** Centre for Water in Urban Areas, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: mathias.ernst@tu-berlin.de)

Keywords: carbohydrates, fouling, MBR, sequential injection analysis (SIA)

Introduction

Membrane fouling is an important issue in MBR operation as it negatively affects membrane performances and causes increased operational costs. Soluble microbial products (SMP) and extracellular polymeric substances (EPS) contained in activated sludge are supposed to have a high impact on the rate of fouling (Rosenberger et al.). So far determination of SMP and EPS levels has been realised by manual photometric analysis of carbohydrates and proteins; the most important constituents of SMP and EPS. The development of an on-line sensor, which detects carbohydrates and proteins concentration continuously in activated sludge, has been carried out and described (Mehrez et al. 2008, Mehrez et al. 2007). An automatic analysis procedure shall benefit precision of measurements and furthermore should allow the monitoring of the variation of SMP in the MBR for better understanding and prediction of fouling phenomena.

Objectives

This poster focuses on the development of the method to measure continuously the concentration of carbohydrates in MBRs. The retrieved data can be used to adapt MBR operation in order to delay respectively encounter membrane fouling, e.g. by aeration control or by the dosing of reagents that minimise concentration of fouling causing substances in the sludge.

Materials & Methods

The determination of carbohydrate concentrations is realised according to the DUBOIS method (Dubois et al.) where simple sugars, oligosaccharides, polysaccharides, and their derivatives give a yellow colour when treated with phenol and concentrated sulphuric acid. Absorption of the stained sample is measured at 490 nm.

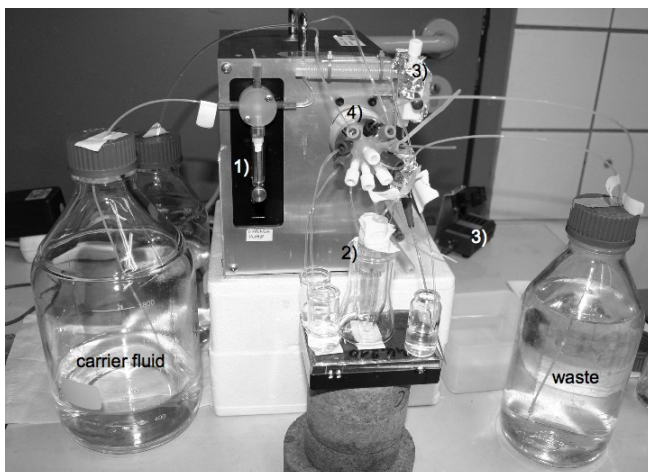


Figure 1: SIA setup

In this study a sequential injection analysis (SIA) device from the company FIALab Instruments, USA (MicroSIA) is used. The device can be manually operated via a computer based software interface, but also programmed for automatic operation. The SIA device can be seen in Figure 1 and consists of 1) a syringe pump with which carrier fluid respectively reagents can be aspirated and discharged; 2) a reaction chamber in which sample and reagents are mixed; 3) a flow cell unit with which absorption can be measured and 4) a multiposition valve with which various pathways to reagents, reaction chamber, flowcell and other ports are selected.

The sample is aspirated by the syringe pump and discharged into the reaction chamber. Subsequently phenol is added. Air is aspirated and injected into the reaction chamber in order to cause mixing of sample and reagent. Sulphuric acid is aspirated and discharged into the reaction chamber at high flow rate for immediate mixing. Again air is injected to support the mixing. The stained complex is led through the flow cell and absorption is measured at 490 nm. Absorption data is saved onto hard disk via computer software.

In order to optimise the analytical method, adjustments have been made to the composition of carrier fluid, volumes and flow rates of reagents respectively air, reagent contact times, settings of the photometric unit, setup of the reaction chamber. Manually set up stained batches were measured with SIA to obtain information on maximum measurable absorption which then could be compared with absorption rates of the automatic procedure.

Results and discussion

The SIA device itself was modified by using a self-constructed reaction chamber which is indispensable for a complete reaction of the reagents. The tubing diameter in between syringe pump and multiposition valve was enlarged in order to cope with high flow rates, especially applied for dosage of concentrated sulphuric acid. Many sets of data have been created and used to optimise the automatic programme course and to find optimum settings. Figure 2 shows retrieved data of manually and automatically measured absorption of glucose standard in a concentration range between 5 and 100 mg/L. The steepness of the calibration curves represents the sensitivity of each method, which is higher for automatic method (optical pathway 2 cm for automatic, 1 cm for manual method). The coefficient of determination R^2 is higher for automatic procedure due to better repeatability. Limit of detection (DL) as well as limit of quantification (QL) is lower for automatic compared to manual method.

Conclusions

An automatic procedure for the measurement of carbohydrates has been successfully developed and optimised with SIA technique. The method shows higher sensitivity and better repeatability which both can be attributed to automatic mode of measurement. Currently the SIA analyser is installed with an appropriate sample pre-treatment device at a pilot-scale MBR plant (Berlin Mitte) and monitors carbohydrate concentrations in the sludge. With the retrieved large data set the impact of carbohydrates on membrane fouling in MBR shall be verified.

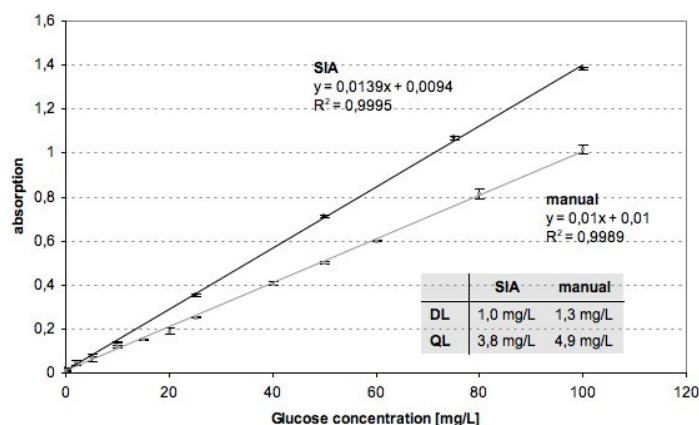


Figure 2: Correlation of absorption and glucose concentration

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DEVELOPMENT OF A SAMPLE PRE-TREATMENT DEVICE FOR ON-LINE ANALYSIS OF PROTEINS AND CARBOHYDRATES IN MEMBRANE BIOREACTOR SYSTEMS

Renata Mehrez *, Mathias Ernst ** and Martin Jekel *

* Chair of Water Quality Control, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: renata.mehrez@tu-berlin.de; martin.jekel@tu-berlin.de)

** Centre for Water in Urban Areas, Technische Universität Berlin, Straße des 17. Juni 135, Sekr. KF 4, D-10623 Berlin, Germany
(E-mail: mathias.ernst@tu-berlin.de)

Keywords: EPS, MBR, proteins, polysaccharides

Introduction

Soluble and colloidal substances like soluble microbial products (SMP) (also described as extra cellular polymeric substances - EPS) are considered to be the major foulants in membrane bioreactor systems (Rosenberger et al 2006). The concentration of SMP (or EPS) present in the supernatant of activated sludge is usually determined by measuring its most important constituents: polysaccharides and proteins.

Objectives

The objective of the present work was to develop an on-line sensor which detects carbohydrates and proteins concentration continuously in activated sludge for monitoring of the variation of these substances and for better understanding of fouling phenomena (Mehrez et al. 2008, Mehrez et al. 2007a). The presented poster focuses on the development of one component of this sensor – a sample pre-treatment device for continuous sampling of activated sludge. The filtrate of the filter is applied in subsequent photometric analysis. The main purpose was to develop a device that runs continuously and fully automatically and that assure the separation of high particle loaded sludge from the supernatant, without retaining the colloidal and soluble substances.

Materials & Methods

The developed sample pre-treatment device consists of stainless steel filter with a nominal pore size of 1 μm and surface of about 50 cm^2 . The filter is submerged in the activated sludge; the sludge is filtrated continuously with a flux between 10 and 17 $\text{Lm}^{-2}\text{h}^{-1}$. In order to prevent the filter clogging the filtration (10 min) is intermitted by the relaxation interval (2 min); the peristaltic pump stops and the valve opens allowing the air to come into the tube system. The pump and the valve are controlled by a clock-pulse generator. Furthermore the sludge turbulence and the air souring in the membrane reactor prolong the filtration time until the cleaning of the filter is necessary. The filter is cleaned with 1 % sodium hypochlorite for at least two hours followed by the treatment with 10 % concentrated sulphuric acid for at least two hours. The filtrated supernatant is pumped to the small sample vessel equipped with an overflow, which discharge the surplus filtrate. Subsequently the SIA analyser aspirates the necessary sample volume from the sample vessel and measures the concentration of carbohydrates or proteins in the supernatant.

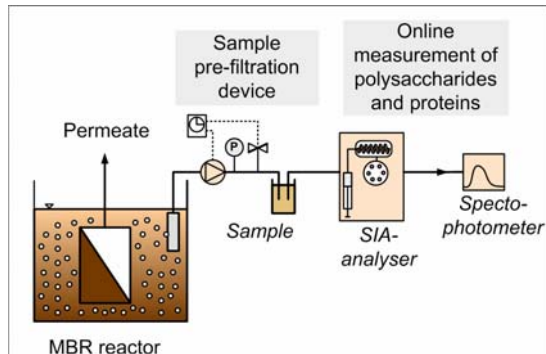


Figure 1: Scheme of the sensor for on-line measurement of SMP compounds.

Results and discussion

Separation characteristics Characterisation of separation properties of used stainless steel filter with regard to parameters like turbidity, DOC, concentration of polysaccharides and proteins were one of the objectives of different preliminary experiments in the lab. The results were detailed described in Mehrez et al. (2007b).

The stainless steel filter let pass in the supernatant contained carbohydrates and proteins and retains suspended solids and bacterial flocs in very effective way. Produced filtrate is not particle-free (similar to the paper filtration used as a reference), however the turbidity is very low and smaller than 2 NTU. Separation characteristics of stainless steel filter with regard to the concentration of polysaccharides and proteins are comparable to that of the paper filter (Whatmann, Schleicher and Schuell filter - 589/1 black ribbon, 125mm) used for the manual sample preparation (figure 2). Figure 2 shows obtained concentration of proteins and polysaccharides measured on different days in the filtrate produced by the developed pre-filtration device during continuous filtration. As reference manual filtrated sample was measured at the same time. Separation properties of stainless steel filter remain the same over the time; this guarantee representative sample pre-treatment during the whole filter run-time for subsequent measurement of proteins and polysaccharides.

Determination of critical flux and the filter run-time In order to find a sustainable flux for the filtration with stainless steel filter and to guarantee the longest filter run-time, critical flux were determined with different sludges and on different days. The procedure has been carried out according to Le Clech et al. (2003). The results have shown that the critical flux depends strongly on the sludge properties. The obtained values vary strongly - critical flux were found in the range between 10.6 and 18.4 Lm⁻²h⁻¹. As the surface of the filter is not completely smooth, particle or colloid deposition can take place, depending on sticky properties of the sludge. For continuous and sustainable analysis of carbohydrates and proteins the filter is therefore operated with a flux of ~10 Lm⁻²h⁻¹. Within these operation conditions the filter run-time is usually 10 to 14 days until the filter clogged and cleaning will be necessary.

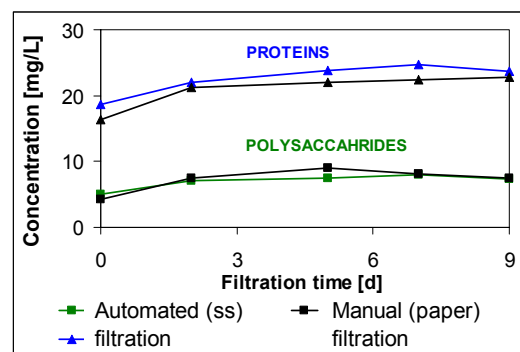


Figure 2. Obtained concentration of polysaccharides and proteins in sludge samples filtrated by pre-filtration device (automated) and paper filter as reference (manual filtration).

Conclusions

The developed sample pre-filtration device for continuous analysis runs stable; the quality of the produced filtrate is comparable with the manual paper filtration during the filtration time. Low filtration rate, relaxation and specific aeration of the filter are effective means to remove the cake layer and to prevent filter clogging. The used agents for the filter cleaning - sodium chlorite and sulphuric acid was sufficient to remove the deposited particles on the stainless steel filter surface and in the pores and to reuse the filter. The results obtained in this study show that the pre-treatment device is suitable to be applied in a continuous EPS sensor in the MBR pilot plant.

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Authors Index

Al-Beirut 75	Ciabatti 113
Alnaizy 85	Cicek 3
Amy 21	Cioni 113
Andreottola 27, 117	Comas 149
Aryal 19, 87	Colombel 81
Atasoy 139	Cornel 123, 185
Avesani	Corvini 97
Ávila-Arias 81	Crespo J.G. 17, 117, 165
Ballesteros Martín 99	Crespo M.T.B. 17, 165
Bakke 157	Cuevas-Rodríguez 89
Ben Aim 101	De Boks 155
Berg 53	De Gueldre 41, 69, 77
Bernal-Martínez 89	De la Londe 135
Bick 179, 181, 183	De la Torre 15
Bino 75	De Wever 43, 61, 131
Binz 91	De Wilde 41, 69, 77
Bixio 41, 77	Delgado-Luna 89
Boehler 59	Deurinck 77
Boland 91	Di Fabio 107
Bolzonella 107	Drews 9, 15, 29, 103, 109, 125, 163, 175
Bosq 51	Drtil 145
Botheju 157	Elslander 43
Bouju 91, 93	Engelhardt 79
Braimah 21	Ernst 9, 29
Brannock 47, 177	Espenan 51
Brauns 43, 131	Etxebarria 111
Brenner 183	Fane 5
Brepols 61, 73, 79	Fatarella 33, 113
Brüss 33, 55	Fatone 107
Buckley	Fauveau 115
Buetehorn 49	Fenu 21, 35
Buttiglieri 91	Ferreira 151
Bwapwa	Ferrero 149
Cabassud 25	Frechen 71
Calderon 129	Foxon
Carvalho 17, 117, 165	Galinha 17, 117
Casas López 99	García Sánchez 99
Cecchi 107	Geilvoet 11
Chang, C.J 101	Gilron 183
Chang, C.Y 101	Gnirss 63
Chang, J.S 101	Grasmick 19, 23, 31, 143
Charlery 103, 109	Grelier 37
Chiarani 27, 117	Grélot 31, 55
Chung 105	Guglielmi 27, 35, 73, 117, 165

Guigui 25
Habib 119
Hartley 91
Hashimoto 169
Heijnen 53
Heo 105
Henkel 123
Heran 23, 143
Hermann 29, 125
Herr 127
Herrera-Robledo 129
Hlavínek 57, 145
Hlustik 57
Hommes 97
Hunze 45
Huisjes 81
Huyskens 43, 131
Inoki 133
Itokawa 133
Iturbe 111
Ivanovic 67
Iversen 9, 15, 29, 33, 125, 175
Jekel 9, 29
Jimenez 35, 37
Joss 59
Judd 73
Kandasamy 19, 87
Kando 133
Kazner 127
Kemperman 173
Kennedy 21
Khirani 25
Khongnakorn 135
Kim 7
Kochan 49, 137
Koh 49
Kraume 9, 29, 33, 63, 103, 109, 125, 163, 175
Krause 185
Kreckel 55
Kroh 103, 109
Krzeminski 11, 139, 153
Kubik 57
Kubota 169
Lazarova 141
Lebegue 23, 143
Lee, C.H 7
Lee, E.S 105
Lee, J.H 105
Leiknes 67
Lens 43
Lesjean 15, 29, 33, 35, 61, 63, 69, 81, 125, 175
Leslie 47, 177
Lombardi 33
Lorain 51
Lousada-Ferreira 11, 165
Lüdicke 63
Machinal 31
Maes 71
Malato Rodríguez 99
Malpei 91
Matulová 145
Meabe 147
Mehrez 9, 29
Melin 49, 127, 137
Monclus 149
Moons 41
Moreau 11, 151, 153
Morgan 129
Mulder 21, 65, 73
Nakazawa 133
Nijman 169
Nopens 35, 159, 161
Noyola 129
Oliveira 17, 117
Oron 179, 181, 183
Paulussen 33
Pfaff
Phattaranawik 67
Piacsek 167
Pikorová 145
Pillay
Pollet 25
Portugal 17, 117
Pot 155
Rathnasiri 157
Reis 17, 117, 165
Richard 69
Rios 159, 161
Rodriguez-Roda 149
Roeder 53
Roels 35
Röttgers 125

Saalbach 45
Sánchez Pérez 99
Sancho 147
Santiago 167
Sarin 85
Saroj 35
Saux 51
Schäfer 79
Schaller 163
Schmidt
Schonewille 155
Schouppe 1
Siegrist 59
Siembida 185
Silva 165
Sipma 149
Smith 171
Spérandio 25, 35
Stueber 15, 63
Suzuki 133
Tazi-Pain 31, 37, 55, 69
Temmink 173
Teychene 25
Thoeye 41, 77
Tilche 1
Tôrres 167
Urkiaga 111
Vachoud 135
Van Agtmaal 155
Van Bentem 169
Van den Brink 171
Van der Graaf 11, 139, 151, 153
Van der Mareel 173
Van der Meera 173
Van Hoof 43, 131
Van Loosdrecht 171
Van Nieuwenhuijzen 11, 139, 151, 153, 165
Vanhoof 43
Vanrolleghem 159, 161
Venturini degli Esposti 113
Veraart 155
Verrecht 73
Vial 119
Vigneswaran 19, 87, 101
Vilim 57
Villwock 175
Vogg 53
Volmering 49
Vossenkaul 49
Wade 75
Wagner 123
Wang 47, 177, 183
Wessling 173
Winkler 53
Wintgens 49, 97, 127, 137
Wisniewski 135
Wong 137
Yamamoto 83
Yang 3, 179, 181, 183
Yeon 7
Yvenat
Zimmermann 185
Zwickenpflug 59
Zwijnenburg 171

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Results of fundamental and applied research as well as technological breakthroughs were unveiled by the project partners and international delegates in about 100 oral and poster presentations. This book of proceedings contains the extended abstracts of these contributions.

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