# WORKSHOP

# Membrane technologies for alternative water resources

**5 March 2009**
**Thessaloniki**
**Greece**

**Organized in the framework of**

MBR-Network

Network of EU projects on Membrane Bioreactor technology

# Book of Abstracts

**Center for Research and Technology - Hellas (CERTH)**
**Chemical Process Engineering Research Institute (CPERI)**
Laboratory of Natural Resources and Renewable Energies Utilization (NRRE)

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# Preface

**Dear Workshop Participants,**

We are very pleased to host here in Thessaloniki this important Workshop entitled “Membrane technologies for alternative water resources”, jointly organized by CERTH and the European MBR-Network. The motivation for this Workshop stems from our belief that systematic efforts should be undertaken to cope with the seriously diminishing clean water resources that are also threatened by anthropogenic pollution. These problems are more acute in Southern European countries. Advanced membrane technologies offer cost effective solutions to these problems, allowing recycling of treated clean effluents and utilization of other degraded resources, thus protecting and enhancing potable water supplies.

The Workshop is focused on Membrane Bio-Reactors (MBR), a relatively new technology with significant technical and environmental advantages; however, other important membrane technology applications are also covered. Emphasis is placed on assessing the state of the technology, through presentations by experts from industry, R&D Institutions and other organizations. Therefore, it is hoped that the Workshop will yield significant benefits for participants, such as an improved awareness of the technical characteristics and applications of membrane technologies, as well as a convenient meeting ground facilitating communication and interaction with experts and others involved in the field. These targets are in full accord with CERTH’s key objective of strengthening collaboration with all organizations (at the national and international level), that are active in its areas of expertise such as water treatment by novel technologies, in order to promote the solution of problems facing society today.

We hope all participants will find their attendance to this Workshop truly rewarding.

**Prof. Anastasios J. Karabelas and Staff**
Laboratory of Natural Resources and Renewable Energies Utilization
Chemical Process Engineering Research Institute - CERTH

# Preface

**Dear Workshop Participants,**

On behalf of the MBR-Network, I am pleased to welcome you in this workshop co-organised with, and kindly hosted by, CERTH in Thessaloniki. MBR-Network is a coalition of four major European research projects, all entirely dedicated to further development of the MBR technology. The MBR technology is since many years a Best Available Technique for treatment of industrial wastewater, and has already become a very viable option to handle municipal wastewater. To facilitate the acceptance and application of this new technology throughout Europe, the MBR-Network projects focused largely on capacity building, training and dissemination activities.

Few months before completion of the MBR-Network projects, this workshop aims to translate key knowledge gathered during the projects to the water professionals of Greece and its region, but also to encourage the exchanges and discussions on the potential embedded in novel membrane technologies to face the dramatic challenges of water scarcity while providing alternative water resources such as water reuse or desalination. We are therefore very pleased to be able to propose a program including also presentations from other key European projects such Medina or Reclaim Water, and also to welcome industrial companies to present their technologies, products and references.

I wish you an excellent workshop with fruitful contacts and inspiring presentations and debates.

**Boris Lesjean**
Berlin Centre of Competence for Water
Coordinator of Amedeus, MBR-Network project

# Contents

## Session 1. Responding to clean water shortage: Water re-use

## Session 2. MBR systems: a mature or an emerging technology?

## Session 3. Membrane equipment and major applications

## Session 4. Membrane desalination

# Workshop Program

**09:00 Welcome - Opening addresses**

A. J. Karabelas, B. Lesjean

## 09:05-10:45 Session 1. Responding to clean water shortage: Water re-use

1. Water recycling in Europe and the Mediterranean: framework conditions and technologies for future development
   *T. Wintgens, University of Applied Sciences, Northwestern Switzerland*
2. Water Reuse: Challenges and opportunities for Greece
   *P. Gkikas, Hellenic Ministry of Environment, Physical Planning & Public Works, Greece*
3. Sustainable water re-use from the EYATH Waste Water Treatment Plant of Thessaloniki
   *A. Soupilas, K. Kotoulas, E. Kalafati, Thessaloniki Water Supply & Sewerage Co, EYATH S.A., Greece*
4. International case studies using membrane technology for Integrated Water Cycle Management
   *J. C. Schrotter, J. Leparc, S. Rapenne, Veolia Water, France*

## 10:45-11:00 Coffee break

## 11:00-12:40 Session 2. MBR systems: a mature or an emerging technology?

1. Introducing the MBR technology and the European market
   *B. Lesjean, Kompetenzzentrum Wasser, Berlin, Germany*
2. Economic aspects of large scale membrane bioreactors
   *C. Brepols, H. Schäfer, N. Engelhardt, Erftverband, Germany*
3. Containerized MBR for upgrading small WWTP
   *P. Hlavinek, D. Vilím, Univ. of Brno, Czech Republic*
4. Kubota Membrane Bio-Reactor technology - Overview and applications in Greece
   F. Varidakis, *Kubota Membrane Europe Ltd, London, United Kingdom*
   N. Papasarafianos, P. Chaldeos, D.G. Deriziotis, *Technor Engineering Ltd, Greece*

## 12:40-14:00 Lunch break

## 14:00-15:40 Session 3. Membrane equipment and major applications

1. First year of operation of the hybrid side stream MBR in Ootmarsum
   H. Futselaar, *Norit X-flow, The Netherlands*
2. Experiences of Veolia with the BIOSEP MBR technology
   *C. Natsis, VeoliaWater Solutions & Technologies, Central & Eastern Europe*

3. Integrated MBR-RO systems for water recycling based on selected case studies
   *C. Kullmann and K. Vossenkaul, KOCH Membrane Systems GmbH, Germany*

4. Reducing Environmental Impact and operating costs through membrane mechnologies
   *B. Renda, GE Water, Europe*

## 15:40-16:00 Coffee break

## 16:00-17:40 Session 4. Membrane desalination

1. Membrane desalination: present and future - A researcher's perspective
   *A. J. Karabelas, CERTH, Greece*

2. Innovative ultrafiltration pretreatment to seawater RO - Details on plant layout and cost advantages
   *R. Krüger, R. Winkler, M. Heijnen, Inge, Germany*

3. Exploring MBR technology as pre-treatment in reverse osmosis seawater desalination
   *G. Di Profio, E. Curcio, E. Drioli, Univ. Calabria, Italy*

4. MEDINA Project: "Seawater characterisation and membrane autopsies tools for better design and operation of SWRO plants"
   *S. Rapenne, Veolia Water, France*

## 17:40-18:20 Closure addresses

CENTRE FOR RESEARCH AND TECHNOLOGY - HELLAS (CERTH)
CHEMICAL PROCESS ENGINEERING RESEARCH INSTITUTE (CPERI)

# LABORATORY OF NATURAL RESOURCES & RENEWABLE ENERGIES UTILIZATION

**The Natural Resources and Renewable Energies Laboratory (NRRE)** has been one of the founding research teams of CPERI since its establishment in 1985. At **NRRE,** R&D is focused on **water treatment and pollution abatement, energy conservation, utilization of renewable energy and other natural resources, and effects of environmental pollution.**

***Technological targets and applications*** are as follows:

- ✓ Water management, conservation and quality improvement by advanced methods (membrane desalination, treatment of potable water, municipal and industrial effluent treatment and reclamation).
- ✓ Utilization of geothermal fluids and of solar energy
- ✓ Development of methods for mitigating fouling of heat exchangers and of other process equipment.
- ✓ Process improvement/intensification in multi-phase systems (packed beds, condensers/heat exchangers, agglomeration and breakage processes)
- ✓ Environmental pollution; measurement techniques, modelling, effects on human health

## RESEARCH DIRECTIONS

### I. Advanced membrane processes for water treatment & physical separations

- ✓ Fouling of MF, UF, NF, RO membranes
- ✓ Improvement of membrane modules/elements
- ✓ Design/optimization of integrated systems
- ✓ Advanced wastewater treatment

### II. Solids precipitation processes

- ✓Development of inorganic layers/films (crystalline or amorphous) on solid surfaces
- ✓ Mitigation of scaling and of particulate deposits
- ✓ Preparation of special nano- and micro-particles

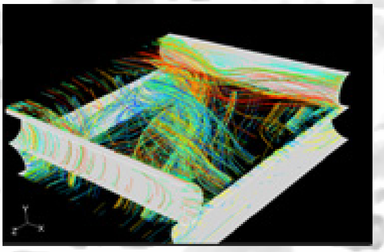
### III. Multi-phase flow processes

- ✓Gas/liquid flow in pipes and process equipment
- ✓ Dynamics of solid/liquid and liquid/liquid dispersions

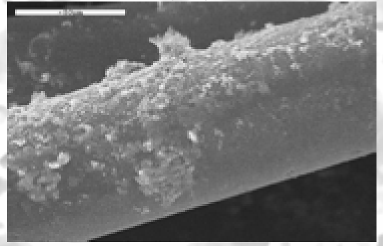
### IV. Environmental pollution

- ✓Methods to determine pollutants load
- ✓Assessment of impact on human health

**High-pressure membrane pilot unit (RO)**



**3D simulations of the flow field within spirally-wound membrane elements**



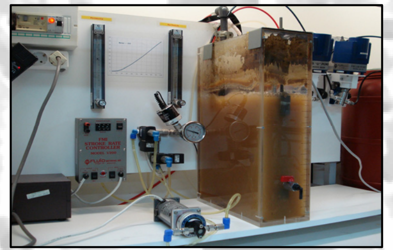
**SEM analyses of a fouled hollow fiber membrane**

**Medium pressure membrane pilot unit (LPRO/NF)**

## R&D PROJECTS IN ADVANCED MEMBRANE PROCESSES

- ✓***"Study of transport phenomena in desalination membrane elements"*** ,
  Ms C.P. Koutsou, Chem. Eng., PhD, Funding: MEDRC project no 03-AS-006
- ✓***"Study of UF membrane fouling by humic acids and polysaccharides",***
  Ms K. Katsoufidou, Chem. Eng. (PhD candidate), Funding: EC project AQUAREC
- ✓***"Colloidal fouling of RO membranes: Improvement of prediction techniques",***
  Mr D. Sioutopoulos, Chem. Eng. (PhD candidate), Funding: MEDRC (04-AS-002)
- ✓***"Retention of pesticides from drinking water sources by membrane processes",***
  Mr K. Plakas, Chem. Eng. (PhD candidate), Partial funding through EC projects
- ✓***"Study of Membrane BioReactors for wastewater treatment and reclamation",***
  Mr S.I. Patsios, Chem. Eng. (PhD candidate), Partial funding through EC projects
- ✓***"Reverse osmosis membrane post-treatment for improved performance",***
  Ms T. Mitrouli, Chem. Eng. M.S., Funding: Saudi Aramco, S. Arabia
- ✓***"Seawater pre-treatment for desalination: Assessment of novel filter media",***
  Ms T. Mitrouli, Chem. Eng., M.S., Funding: Maxit S.A., Norway

**Water analyses equipment**



**Laboratory MBR pilot unit**

**Chemical Process Engineering Research Institute**
**Laboratory of Natural Resources and Renewable Energies Utilization**
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*• Tel: **2310 498181, -182** • Fax: **498189** • e-mail: **karabaj@cperi.certh.gr***

# MBR-Network: The coalition of EU projects dedicated to the MBR technology

The European Commission has decided to promote the development of the MBR technology while funding four projects entirely dedicated to research, development, capacity building and technological transfer in regards to this promising wastewater treatment process. The four projects, namely AMEDEUS, EUROMBRA, MBR-TRAIN and PURATREAT are supported by three different financial instruments set up by the European Commission within the sixth Framework Program, and will be implemented in parallel from October 2005 up to December 2009.

Around 50 European and international companies and institutions are actively involved in these four projects and are joining their efforts and coordinate their actions within the cluster "MBR-Network". The four projects amount to a total budget of ca. 16 Million €, for which approx. 9 Million € will be financed by the European Commission. They represent the largest coordinated research initiative worldwide dedicated to MBR technology since the first developments of this treatment process in the early 90's.

Important technological breakthroughs, process improvement, knowledge and capacity transfer and building are expected, which will lead to better acceptance, competitiveness and broader implementation of the technology in both municipal and industrial fields. Detailed information on MBR-Network and the activities of the related projects is available at www.mbr-network.eu. The web-platform acts also as exchange point of the international MBR community and hosts many databases with search engines such as a list of companies (more than 50 entries to date) and other services such as a monthly literature scan (more than 1000 entries to date). About 1000 international specialists are registered to the website and can communicate via a public forum.

# Session 1

## Responding to clean water shortage:
## Water re-use

# Water recycling in Europe and the Mediterranean: framework conditions and technologies for future development

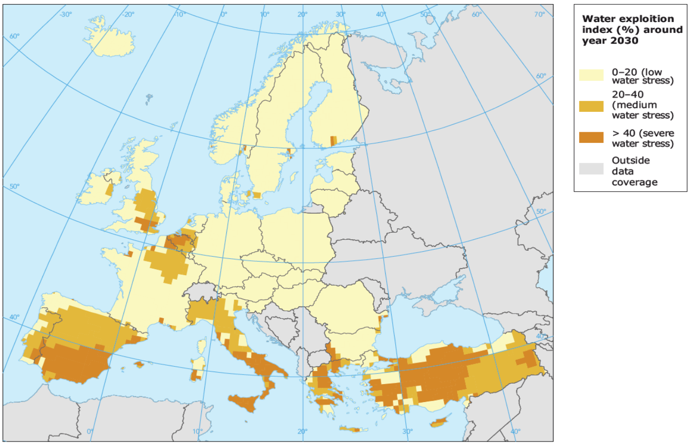
T. Wintgens[a], R. Hochstrat[a,b], C. Kazner[b], T. Melin[b]

[a] *Institute for Ecopreneurship, School of Life Sciences, University of Applied Sciences Northwestern Switzerland, Gründenstrasse 40, 4132 Muttenz, Switzerland*

[b] *Department of Chemical Engineering, RWTH Aachen University, Turmstrasse 46, 52056 Aachen, Germany*

## Introduction

Many countries and regions of the world are facing water scarcity and deterioration of groundwater quality caused by climate change and a continuous population growth especially in coastal areas. The acute or chronic water stress triggers the need for integrated water cycle management and the supplementation of the available freshwater resources. The utilization of alternative water sources such as seawater and brackish water desalination as well as water reclamation and reuse are mitigation options applied up to now (Bixio et al., 2006; Fritzmann et al., 2006). It is to note that this practice is encouraged because many Mediterranean countries as outlined in European Commission on the management of water scarcity and drought (European Commission, 2007). The water stress conditions in the Mediterranean region are expected to aggravate as a probable consequence of climate change impacts as depicted in Fig. 1 (EEA, 2007).



**Note:** The water exploitation index is the percentage of available water resource abstracted each year.

**Figure 1**. Water stress situation in Europe considering climate change impacts (EEA, 2007).

Many regions are prone to experience an increase in water stress, which can be expressed with the water exploitation index. The water exploitation index is a simple parameter expressing the ratio of water abstraction to renewable freshwater resources. Besides the quantitative aspects, water stress has also a water quality dimension. In course of the implementation of the Water Framework Directive (2000/60/EC) the status of water resources has been analysed and evaluated with regard to achieving a "good ecological status" by 2015. European Union Member states had to assess the quality of the water bodies according to Art. 5 of the Water Framework Directive.

The investigation in the Member States has revealed that quite a number of water bodies in the European Union are at risk of failing to meet the quality objectives by 2015, as set in the WFD. Between 30% and 75% of the groundwater bodies in UK, France, Spain, Malta and Cyprus are categorised "at risk", and an additional 15% to 50% were evaluated as being probably at risk (Fig. 2). The identification of types of pressures exerting a significant impact on water resources are either qualitative (e.g. diffuse or point pollution with nitrates and pesticides or seawater intrusion into coastal aquifers) or quantitative (e.g. over abstraction of groundwater). In the scope of River Basin Management plans the water authorities will have to address the identified pressures and set up a programme of measures. The utilisation of alternative water resources or options such as aquifer recharge can be part of these programs. In the European policy water saving, e.g. supported and enforced by economical measures, has a priority. While water reuse is a regarded as a possible water conservation measure seawater desalination is regarded as a last resort option (European Commission, 2007).

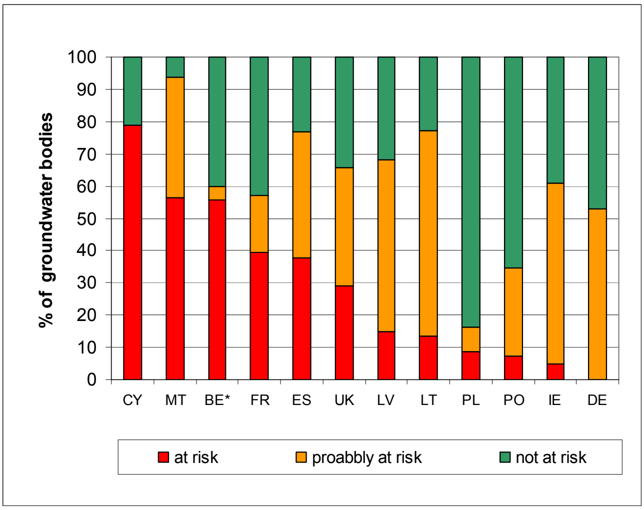


**Figure 2.** Status of groundwater in selected European countries (National reports on Art. 5 WFD accessed via CIRCA).

## Technologies for water stress mitigation - an overview on European research

In the 5th Framework Programme e.g. the MEDAWARE project (2003) and the AQUAREC project have studied concepts for reuse of reclaimed municipal wastewater (Wintgens et al., 2005). Utilising also AQUAREC results, a Euro-Mediterranean working group under the lead of Malta and the European Commission DG Environment has provided a reference report about the status of water reuse in Europe and the Southern Mediterranean countries (EU-MED, 2007).

A range of potential technological options for water stress mitigations have been studied in a number of ongoing or just completed European research projects funded under the 6th Framework Programme. Among those projects is RECLAIM WATER (www.reclaim-water.org) looking at water reclamation technologies for safe groundwater recharge (Fig. 3). The Gabardine project (www.gabardine-fp6.org*)* also investigates managed aquifer recharge using alternative water resources. Water desalination is specifically studied in the MEDINA (medina.unical.it) and MEDESOL project (www.psa.es/webeng/ projects/medesol).

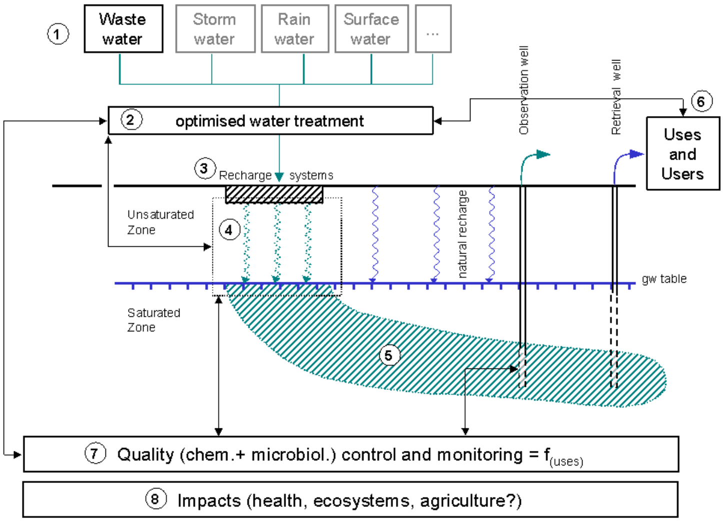


**Figure 3.** RECLAIM WATER concepts for managed aquifer recharge studies utilising alternative water sources.

The two integrated projects AQUASTRESS on integrated water stress mitigation options (www.aquastress.org) and TECHNEAU on technologies for safe drinking water supply have both considered alternative water sources and desalination as water management options to be applied particularly in the Mediterranean area.

The calls for proposals in the 7th Framework Programme (e.g. the joint NMP/ENV call in 2008 and the SICA call in 2009) give an indication about which type of topics are going to receive attention in future research with respect to water technologies. Membranes will continue to play a key role in the exploitation of alternative water resources and focus areas will be, e.g.:

- New membrane materials incorporating nanotechnologies such as carbon nanotubes,
- Functionalisation of membrane surfaces e.g. with nanoparticles or molecular imprints,
- More research on currently less employed desalination processes such as electrodialysis or membrane distillation,
- More robust and cost-effective membranes for bioreactors.

## References

CIRCA (2006) CIRCA - Communication & Information Resource Centre Administrator - http://forum.europa.eu.int/Public/irc/env/wfd/library.

Bixio, D., C. Thoeye, J. De Koning, D. Joksimovic, D. Savic, T. Wintgens, T. Melin (2006), Wastewater reuse in Europe, Desalination 187, 89-101.

European Environment Agency (2007), Climate change and water adaptation issues, Technical Report EEA 2/2007.

European Commission (2007), Addressing the challenge of water scarcity and droughts in the European Union, Communication From The Commission To The European Parliament and the Council. COM (2007) 414 final.

Fritzmann C., J. Löwenberg, T. Wintgens and T. Melin (2007), State-of-the-Art of Reverse Osmosis desalination, Desalination 216, 1-76.

MEDAWARE EU funded project (2003), Development of Tools and Guidelines for the Promotion of the Sustainable Urban Wastewater Treatment and Reuse in the Agricultural Production in the Mediterranean Countries –

http://www.uest.gr/medaware/reports/cyprus.doc

Mediterranean Wastewater Reuse Working Group (MED WWR WG): Mediterranean Wastewater Reuse Report. JOINT MEDITERRA-NEAN EUWI/WFD PROCESS, November 2007 - http://www.emwis.net/topics

Wintgens, T., R. Hochstrat, T. Melin, P. Jeffrey, M. Salgot (2005), Political and legislative framework conditions for wastewater reclamation and reuse in Europe, Proceedings 20th Annual Water Reuse Symposium, September 18-21, 2005, Denver, Colorado, USA.

# Water Reuse: Challenges and Opportunities for Greece

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[b] *General Secretariat of Public Works, Special Service of Public Works for Greater Athens Sewerage and Sewage Treatment, Hellenic Ministry for the Environment, Physical Planning and Public Works, Varvaki 12, Athens, 11474, Greece*

[c] *Department of Environmental Engineering, Technical University of Crete, Chania 73100, Greece, e-mail: petrosgikas@gmail.com*

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## Abstract

Water reuse has been practiced for centuries in Mediterranean Basin. Modern technology allows now for safe use of reclaimed water. Quality criteria for water reuse have been established by many national of local authorities all over the world, and particularly in water stressed regions. Little water reuse is currently practiced in Greece, due to the (until recently) lack of water reuse criteria, despite water deficiency, particularly in the insular regions of the Aegean. The recent water reuse criteria in Greece, for landscape irrigation, are expected to encourage water reuse and thus to drive towards to a more sustainable development model. However, quality criteria for agricultural water reuse should also be established soon. The present article describes the status of water reclamation and reuse in Greece and examines the potential for further applications.

**Keywords:** water reuse, water reclamation, irrigation, sustainable development

## Introduction

Greece, in total, has sufficient water resources, however, a number of factors are reducing substantially the availability of water and the potential for water exploitation. Thus, while the average precipitation height for Greece is about 881 mm/yr, it is distributed unevenly in space, with northeastern Greece receiving over 1700 mm/yr, while some islands of the Aegean receive less than 300 mm/yr [1]. Moreover, water precipitation is also unevenly distributed over time, thus, south Greece receives about 80 to 90 % of the total precipitation during winter, while north Greece does not receive more than 20% of the annual precipitation during summer [1]. It is not only water availability that is unevenly distributed over space and time, but also water demand. Thus heavily agricultural areas, such as Thessaly, and large urban areas, such as Athens and Thessaloniki, are strongly water stressed, importing water from far away; while touristy developed areas, such as the Aegean Islands have a high water demand during the summer season, and little water needs during winter. The water exploitation index (the mean annual total water abstraction divided by the mean annual total renewable freshwater resources) for Greece is lower that that of many northern European countries, however it tents to rise, as between 1990 and 2002, it climbed from approximately 10.5 to 12% (see Fig. 1). However, at approximately the same period, water abstraction for agricultural uses was reduced by 2.5%, which considered positive, as agriculture abstracts over 80% of the freshwater resources [2]. Significant progress has been made recently with respect to wastewater management, as more than 70% of the national population in Greece, is serviced by wastewater treatment plants [2].

The last is an advantage for the production of reclaimed water from wastewater. Wastewater reclamation and reuse has been practiced in Greece since the ancient times [3]. Today, limited water reuse is practiced in Greece. This not due to low acceptance by the public, neither due to the sufficiency of existing water resources, but primarily due to the lack of relative legislation.

## Legislation on Water Reuse

Universal EU criteria for water reuse do not exist. Also, reclaimed water does not considered in water balances, according to the WFD (Water Frame Directive) 2000/60/EC [4], despite the fact that it is a large fraction of total water recourses in some southern European countries. In the EU Directive 91/271/EC [5], concerning urban wastewater treatment, it is generally mentioned that “Treated wastewater shall be reused whenever appropriate”, however there is no further discussion about the appropriate cases for water reuse, neither quality criteria for recycled water. Thus, many European countries, or even local authorities, have established, or are considering establishing, their own quality criteria. WHO (World Health Organization) has recently issued new guidelines for safe water reuse [6]. The new WHO guidelines on water reuse do not propose quality values in terms of pathogens allowance per volume of reclaimed water, like the older WHO criteria [7], but they are placing the general frame for safe water reuse, which may be adapted to the peculiarities of each region.

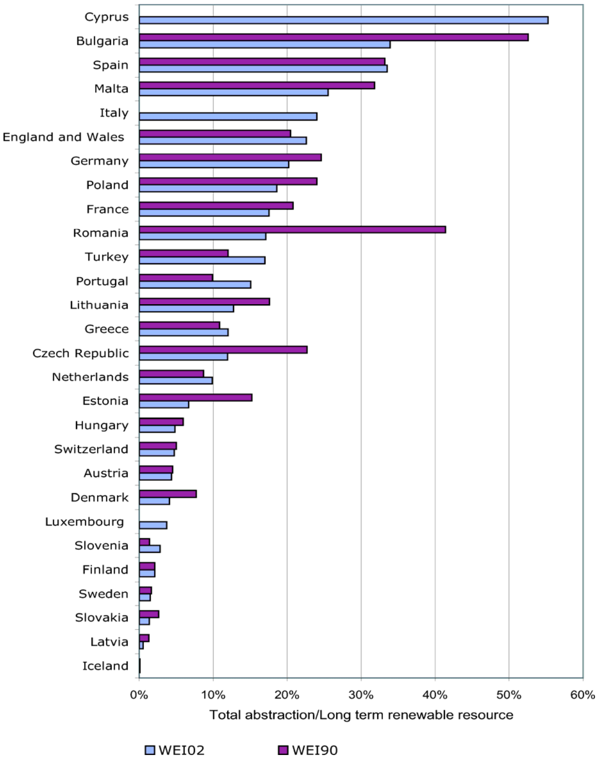

**Figure 1.** Water exploitation index (total water abstraction per year as percentage of long-term freshwater resources) in 1990 and 2002 (Adopted from [2]).

Until November 2008, the Greek legislation imposed that reclaimed water could only be used in fenced areas inaccessible to the public, regardless of the degree of treatment [8, 9]. Recent modification of the above legislation allows the usage of high quality reclaimed water only for landscape irrigation, in areas where the public has unrestricted access, and by any irrigation method, including spray irrigation [10]. It is expected that a number of municipalities will be benefited from the new legislation, however, hotels and golf courses are expected to take the initiative in using reclaimed water. The water reuse criteria for Greece are summarized in Table 1. However, the last legislation only deals with landscape irrigation, leaving out the use of reclaimed water for agricultural or other types of applications.

**Table 1.** Water reuse criteria for Greece for landscape irrigation, with unrestricted access to the public [10].

<table>
<tr><td>Total coliforms (TC)</td><td>Other parameters</td><td>Treatment should consist of at least</td></tr>
<tr><td>≤ 2/100 mL for 90% of the samples. Additionally, TC should not exceed 20/100 mL in more than one sample, for any continuous two months period of time.</td><td>$BOD_5 < 10$ mg/L<br>Suspended solids (SS) < 10 mg/L</td><td>Secondary biological treatment, plus coagulation, plus filtration, plus disinfection.<br>(a) The above processes should follow the order of appearance above.<br>(b) Filtration velocity should not exceed 8 $m^3/m^2/h$, during normal operation.</td></tr>
<tr><td colspan="3">Any form of irrigation is allowed, including spray irrigation.<br>For TC and SS: At least one sampling and analysis every 3 days.<br>For $BOD_5$: At least one sampling and analysis every 7 days.<br>Exemption: In small islands, without sufficient laboratory infrastructure, TC, $BOD_5$ and SS analysis should be performed at least once every 7 days.</td></tr>
</table>

## Water Reuse Projects in Greece

Water reuse is currently practiced extensively in may water deficient areas allover the world [11]. In Israel, it is estimated that over 25% of water used has been reclaimed from wastewater [12]. Extensive wastewater reclamation for agricultural and landscape purposes is practiced in California, Florida, Australia, middle east, and is south European and north African countries. Water reclamation and direct potable reuse is practiced since 1968 in Windhoek, the capital of Namibia [13, 14], while tap water in Singapore contains now 1% of reclaimed water, which has been scheduled to increase in the near future to 12% [15].

As mentioned above, limited water reuse projects are currently operating in Greece. The existing projects may be classified as agricultural or forestry/landscape irritations, while no industrial projects utilizing reclaimed water from municipal wastewater are known to the author.

### Agricultural irrigation

Agricultural applications of reclaimed water in Greece are limited due to the lack of quality criteria. Thus the existing applications are primarily experimental and are only applied in industrial crops cultivations. The greatest by far water reuse project has been accomplished in Thessaloniki (by the Thessaloniki Enterprise for Water and Sewerage), where the appropriately treated effluent from the wastewater treatment plant of Sindos is mixed with agricultural water from Axios river and used for the irrigation of cotton, rise, corn and alfalfa fields, at the municipality of Chalastra [16]. Approximately 160,000 m3 of treated water per day were used during July and August 2007, to irrigate 1,200 ha of industrial crops cultivations [17]. Reclaimed water is used in smaller scale to irrigate cotton fields in Levadia (approximately 3,500 m3/d), olive trees in Hersonissos, (approximately 4,500 m3/d), Amfisa (approximately 400 m3/d) and in Palecastro (280 m3/d) and in several other places [18].

### Forestry/landscape irrigation

Maybe the greatest and most successful forestry/landscape irrigation is the one practiced by the Chalkis Enterprise for Water and Sewerage, at the Pasas Island (where the wastewater treatment plant of the town of Chalkis is located) and at the mainland coasts facing the island, where the reclaimed water is pumped by an undersea pipeline [19]. Figure 2 shows the island of Pasas before and after the implementation of the waster reuse project. Other minor forestry/landscape irrigation projects are operating in Karystos, Serifos, Samos, Ierissos, and in several other locations [18]. The common characteristic of all applications is that the irrigating land is fenced and inaccessible to the public.

A number of private landscape irrigation applications are operating in hotels, particularly in Crete and in the Aegean Islands. All the hotel gardens which are irrigated with reclaimed water should be theoretically inaccessible to the public, until the implementation of the new legislation [10].

## Opportunities for water reuse in Greece

The opportunities for the use of reclaimed water in Greece are practically unlimited, as almost nowhere water is abundant. The existing infrastructure in municipal wastewater treatment plants is a clear advantage, as the extra cost for additional treatment, in order to comply with the reclaimed water quality criteria, is relatively low [20]. Additional wastewater treatment infrastructure, for settlements with inhabitants between 2000 to 10,000 people is expected to be built in the coming years, after the implementation of the last phase of the European Directive for urban wastewater treatment [5]. Implementation of decentralized and satellite strategies in wastewater management are expected to benefit water reuse [21]. Moreover, the utilization of novel treatment technologies, like attached growth and membrane treatment systems, both of which demand minimal footprint for such installations are expected to make water reclamation more attractive, particularly for hotels, golf courses and tourist resorts. Low cost technologies, such as natural wastewater treatment systems and lagoons may be employed successfully by small settlements or municipalities, with difficulties to afford high capital costs.

**Figure 2.** The Pasas Island, where the wastewater treatment plant of the town of Chalkis is located, before (left) and after (right) irrigation with reclaimed water.

Greece should give priority in establishing water reuse criteria for other applications, apart from landscape irrigation (which now exist), particularly for agricultural applications. The most severely water deficient areas of Greece, particularly the Aegean Island and eastern Crete are expected to benefit from the use of reclaimed water for agriculture. Agricultural areas, like Thessaly and Macedonia are also expected to benefit. It is worth mentioning, that wastewater reuse is often practiced de facto in many lowland areas, as treated or untreated wastewater flows to rivers, which subsequently is used for agricultural irrigation.

The tourist industry, particularly in the Aegean Islands, where in many cases freshwater costs more than 7 € per m3 (the cost is subsided by the Ministry of Aegean and Insular Policy) [22], will benefit from the use of reclaimed water. Also the municipalities of the insular and other areas will be able to sustain more green areas by the use of reclaimed water. A prominent advantage for water reuse in touristy areas is the fact that water demand follows the same trend as wastewater production, thus minimizing the need for storage facilities, which are particularly costly [20].

The greater area of Athens is currently using about 800,000 m3 of high quality potable water per day, which after appropriate treatment is discharged into the Saronic Gulf. It is now time to consider the use of reclaimed water for landscape irrigation of greater Athens. A challenging opportunity for the use of reclaimed water comes from the creation of the Metropolitan Park of Athens, at the old airport of Athens in Hellinikon. It would be totally unsustainable to convey potable quality water from Evinos River to irrigate a great park in Athens, when available technology for water reclamation exists, and abundant flow of wastewater is available next to the park. Additionally, if a part of the available land will be given for residential buildings, then reclaimed water can be also used for toilet flushing, with the installation of the appropriate infrastructure during the erection of the buildings [23]. It should be noted that there will be no need for onsite treatment of biosolids, as they can be conveyed to the wastewater treatment plant in Psyttalia through the existing collection mains [21]. It is worth mentioning that the Special Service of Public Works for Greater Athens Sewerage and Sewage Treatment, in collaboration with the Central Water Agency are currently elaborating a plan to examine water reuse opportunities in Attica.

It should be noted that reclaimed water may be used for the recharge of overexploited aquifers and for the prevention of seawater intrusion in coastal areas. Successful large scale experimentations on the restoration of the aquifer have been carried out at the Valley of Antemoundas in Thessaloniki, which may be used as guideline for other applications [24].

Finally, it should be underlined that, it is important to educate the public about the benefits of reclaimed water, and about safe handling. It is of paramount importance to build reliable water reclamation plants, in order to gain public acceptance. Any investment in water reclamation infrastructure will be without practical meaning, if the public lose its confidence in the safety of reclaimed water.

## Conclusions

Modern technology allows now safe water reclamation and reuse. As a result many national and local authorities all over the world have established quality criteria for the use of reclaimed water. Now, little water reuse is practiced in Greece, mainly for industrial agricultural applications and for hotel gardens, only in fenced areas. Recently, new legislation has set quality criteria for water reuse in Greece, only for landscape irrigation. Practically water reuse opportunities in Greece are unlimited, after the establishment of quality criteria in all potential water demanding activities. Severely water stressed regions, like Attica, the Aegean Islands and eastern Crete are expected to be the first to benefit from the use of reclaimed water. Finally, it is important to educate the people in the safe use of reclaimed water, in order gain public acceptance.

## References

1. Hellenic Ministry for the Environment Physical Planning and Public Works, [National Program for the Management and Protection of Water Resources]. A. Andreadakis and D. Koutsogiannis, Department of Civil Engineering, N.T.U.A., 2008. Athens, (*In Greek*).
2. European Environmental Agency, The European Environment - State and Outlook 2005.

Office for Official Publications of the European Communities, 2005.

3. Angelakis, A.N. and S.V. Spyridakis, The Status of Water Resources in Minoan Times-A Preliminary Study. Diachronic Climatic Impacts on Water Resources with Emphasis on Mediterranean Region, ed. A.N. Angelakis and A. Issar. 1996, Spriner-Verlag: Heidelberg, Germany, 161-191.
4. European Communities, Framework for Community Action in the Field of Water Policy. The Official Journal of the European Communities L 327/1, 2000. 2000/60/EC.
5. European Commission, Council Directive 91/271/EEC Concerning Urban Waste-Water Treatment. Official Journal of the European Parliament L135/40-30 May, 1991.
6. World Health Organization, Guidelines for the Safe Use of Wastewater, Excreta and Graywater. 3rd ed. 2006, France: United Nations Environment Program.
7. World Health Organization, Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture: Report of a WHO Scientific Group, in WHO Technical Report Series, WHO, Editor. 1989: Geneva, Switzerland.
8. Hellenic Ministry for Social Services, [Sanitary Decree on the Disposal of Sewage and Industrial Wastewaters]. General Secretariat of Sanitation, 1965. E1beta 221/22.1.1965(Article 8), Athens, Greece (*In Greek*).
9. Hellenic Ministry for Sanitation, [Irrigation of Hotel Terraces with Treated Sewage]. 1983. Circular A5/2050/64/21.12.83 (*In Greek*).
10. Hellenic Ministries of Interior for Health and Social Solidarism and or the Environment, Physical Planning and Public Works, Modification of case "gamma", Paragraph 1, Article 8, of the E1 "beta"/221/1965 Sanitary Decree. Journal of the Hellenic Government, 2008. Common Decision, FEK 2089/9.10.2008 (*In Greek*).
11. Gikas, P. and G. Tchobanoglous. The Importance of Water Reuse in Sustainable Water Resources Management: State of the Art through the Presentation of Selected Case Studies. in 2nd International Conference on Small and Decentralised Water and Wastewater Treatment Plants. 2008. Skiathos, Greece.
12. Arlosoroff, S., Wastewater Management, Treatment, and Reuse in Israel, in Wastewater Reuse-Risk Assessment, Decision-Making and Environmental Security, M.K. Zaidi, Editor. 2007, NATO Public Diplomacy Division, Springer: The Netherlands, 55-64.
13. Harrhoff, J. and B. Van der Merwe, Twenty-five Years of Wastewater Reclamation in Windhoek, Namibia. Water Science and Technology, 1996. 33(10-11), 25-35.
14. du Pisani, ed. Direct Reclamation of Potable Water at Windhoek's Goreangab Reclamation Plant. Integrated Concepts in Water Recycling, ed. S.J. Khan, A.I. Schafer, and M.H. Muston. 2005, University of Wollongong: NSW, Ausralia. 193-202.
15. Singapore Public Utilities Board, Singapore Water Reclamation Study-Expert Panel Review and Findings. 2002, Singapore.
16. Soupilas, A., F. Papastergiou, and C. Pantelidou. [Reuse of Treated Domestic Water in Greece. Is it Possible?]. in HELOCO 2005. 2005. Athens, Greece (*In Greece*).
17. Anonymous, [The Pilot Study of the Municipal Enterprise of Thessaloniki for Water and Sewerage]. http://www.hydromedia.gr/content.asp?contentid=125, 2008.
18. Tsagarakis, K.P., Tsoumanis, P.Carzoulakis, K.Angelakis, A.N., Water Resources Status Including Wastewater Treatment and Reuse in Greece-Related Problems and Prospectives. International Water Resources Association, Water International, 2001. 26(2): p. 252-258.
19. Kanaris, S., et al. Advanced Wastewater Treatment for Reuse at the Wastewater Treatment Plant of Chalkis. in Proceedings of the International Workshop on Implementation and Operation of Municipal Wastewater Treatment Reuse Plants. 2004. Thessaloniki, Greece.
20. Gikas, P. and G. Tchobanoglous, Sustainable Use of Water in the Aegean Islands. Journal of Environmental Management, 2009.doi:10.1016/j.jenvman.2009.01.020 (*In Press*).
21. Gikas, P. and G. Tchobanoglous, The Role of Satellite and Decentralized Strategies in

Water Resources Management. Journal of Environmental Management, 2009. 90: p. 144-152.
22. Hellenic Ministry of Aegean, Water Supply of Anhydrous Islands. www.ypai.gr, 2007.
23. Zavoda, M. The Solaire, a High-Rise Residential Reuse Case Study. in Proceedings, 20th Annual WateReuse Symposium. 2005. Alexandria, VA: WateReuse Association.
24. Fikos, H., et al. [Integrated Management of Water Resources of the Anthemoundas Basin]. in HELECO 2005. 2005. Athens, Greece, (*In Greek*).

# Water recycling in Europe and the Mediterranean: framework conditions and technologies for future development

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The increasing demand for water in the region of Thessaloniki has motivated the implementation of intensive water management measures to achieve an efficient utilization of the limited available water supplies.

Thessaloniki is the second largest city in Greece with a population of almost 1.100.000. Thessaloniki’s Water Supplier and Sewerage Co (EYATH S.A.) is the household water supplier for the city and the surrounding municipalities. The daily water supply of the fresh water amounts to almost 250.000m$^3$ and comes from groundwater abstraction and also from surface water from the Aliakmon river that goes for treatment to the city’s Water Treatment Plant. Water demand for the summer months increases substantially and in addition future consumption is expected to increase due to the natural development of the city and the surrounding area. Therefore there will be a need for additional water sources to meet the expected increase in demand. Thus, in an effort to be prepared for that demand, EYATH S.A. is putting special emphasis on new technology.

EYATH S.A. is also responsible for the collection, treatment, and disposal of the city’s waste water. On a daily basis, 180.000 m$^3$ of the domestic and industrial waste-water are treated in the 3 Wastewater Treatment Plants that belong to the company. The w/w undergoes advanced treatment and disinfection and the effluents produced are disposed of analytical results into the recipient, which is the Thermaic Gulf. Monitoring and analytical results show that the quality of the above effluents comply with the terms and conditions set by the Urban Waste Water Treatment Directive (UWWTD) 91/271 EEC.

Based on this fact, recycling of the treated effluent for further use was promoted through a series of research programs, activities and efforts. In general, EYATH’s main goal is to “move towards an Integrated Water resources managnent strategy” that will also be helpful in the area of infrastructure that is a dominant source of concern for the Water companies. More specifically :

- Effluents from Thessaloniki‘s W/W Treatment Plant (EELTH) are used for irrigation in agriculture. Last summer, 11 million m$^3$ of treated effluents were sent to be used for irrigation purposes.
- 180.000 m$^3$ of the treated effluents are disposed of the Thermaic Gulf on a daily basis from the EELTH. Therefore, in an attempt to investigate the feasibility of using aquifers as the primary facility for large scale storage of this alternative water source, we have become involved in two Research projects where the technique of Artificial Recharge (AR) was investigated.
    1. 14 partners from 9 European Countries are involved in the first project that is called GABARDINE with the title “Groundwater Artificial Recharge based on alternative sources of water” that was financed by 6th Framework Programme for Research. This project is due to end this year.
    2. The second project with the title “Artificial Recharge in the Industrial Area of Thessaloniki using treated effluents from the Thessaloniki w/w treatment

plant" included a) the design- purchase & operation of membrane – microfiltration & Reverse osmosis unit and b) the design-purchase and operation of the system of artificial recharge. The program (EPPER), was co-funded by the European Union and the Greek Ministry of Environment.

- Apart from the above actions, that have to do with waste water as a valuable source, special emphasis is given on minimizing water losses in the water distribution system which amount to 26%.
- Finally, consumers are being informed by means of brochures and leaflets and through the mass media on how to avoid unnecessary water consumption on a daily basis.

In this presentation a brief description will also be made of the processing units of Thessaloniki's wastewater treatment plant (EELTH) and on the membrane and microfiltration pilot (reverse osmosis) plant belonging to EYATH which was used within the framework of the Research programs for the Artificial Recharge (AR) of the treated effluents of the EELTH. This pilot plant will be operated as a demonstration plant for EYATH's future needs and also for training purposes.

# International case studies using membrane technology for Integrated Water Cycle Management

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The WHO estimates that investment of 180 billion US dollars each year is required if drinking water purification and waste water treatment are to meet worldwide demand. These figures refer solely to increase in capacity and do not include the renovation or modernization activities that will be needed over the coming years, to adapt sewage works to the latest technologies. The volume of business that will create is considerable and is set to increase sharply on a global level in the years ahead.

Waste water is water that has become contaminated through use. It includes household sewage, municipal waste water, industrial effluent, collected rainwater and water that flows off paved surfaces.

The number of people who have no access to adequate waste water treatment currently stands at 2.9 billion, 80% of whom live in the developing and newly industrialized countries of Asia.

As global population increases the water pumped for potable supplies from river, lakes and aquifers is increasingly polluted with wastewater. Unplanned or unintentional indirect reuse in developing countries is largely responsible for approximately 4 billion cases of diarrhea daily resulting in 2.2 million deaths a year mainly of children under 5 years of age [WHO 1999].

It is widely recognized that recharging surface and groundwater resources directly or indirectly with appropriately treated wastewater (reclaimed water) ensures the sustainability of the environment with no risk to public health.

The applications of direct treated wastewater reuse include:

- Irrigation water (agriculture, landscape, sport and recreation).
- Water for manufacturing and construction industry (cooling and process water).
- Dual water supply systems for urban non-potable use (toilet flushing and garden use).
- Fire fighting, street washing, dust suppression and snowmaking.
- Water for restoration and recreation of existing or creating new aquatic ecosystems.
- Recreational water bodies (including land redevelopment).
- Aquifer recharge through injection wells for saline intrusion control.
- Fish ponds.

The applications of indirect treated wastewater reuse include:

- Increasing water availability for potable water production.
- Increasing storage and water availability for industry.
- Aquifer recharge for saline intrusion control and delayed abstraction to increase water resources in quantity and quality.

The UN Agenda 21 clearly states that water is a finite and critical resource that needs an integrated resource management approach and that water reuse should be promoted. While direct potable reuse is still a distant possibility and may never be implemented except under extreme conditions, indirect potable reuse such as groundwater recharge with advanced wastewater treatment technologies is a viable option. Multiple uses of water via reclamation and reuse have become an essential element of future water resources development in integrated water resources management; thus, opportunities and challenges will continue well into the 21st century.

A proactive risk management approach depends on technologies and solutions to reliably protect public health and the environment. Membrane processes are considered as the best available technology for this purpose. Membrane processes include natural and artificial processes to ensure that the appropriate water qualities are achieved throughout the dynamic water cycle.

Perhaps the main reasons for the growth in this market could be summarized as:

- The ability of membranes to reliably produce the quality of water specified
- Water shortage due to climate change, population growth
- Water quality and environmental legislation
- Cryptosporidium outbreaks leading to the development of very large ultrafiltration and microfiltration systems (average 35 % annual growth in installed capacity) that are being used reliably to protect reverse osmosis systems on reuse projects
- Developments of higher efficiency reverse osmosis technologies with lower energy and capital costs. (RO & NF average annual installed capacity growth of 11%.
- Recognition that indirect potable water reuse has been normal practice in most large cities and along populated river basins for centuries.
- Recognition that reclaimed water is normally drought proof and water pumped over long distances is very expensive and not sustainable.
- Recognition that recycled water can replace potable water for applications where drinking water quality is not required e.g. toilet flushing, irrigation of garden, sports fields, urban landscapes and street washing.
- Recognition by manufacturing industry that “potable substitution” with reclaimed water reduces their costs, protects the environment and makes the potable water previously used for process applications available for the community.

The move toward membrane technology is happening right now in Australia (the global leader in water reuse with 25 years of experience) where most of reuse as well as desalination projects include membrane processes. A good example is the Western Corridor Recycled Water Project in Australia that will deliver world class technologies using sustainable principles. The project has the capacity to supply up to 232 megalitres per day of purified recycled water. The purified recycled water is wastewater that has been treated to a very high standard with micro-filtration membrane, reverse osmosis membrane and advanced oxidation technology. This drinking-quality water is then injected into another water supply source such as a dam, where natural processes provide an additional environmental and time buffer. Finally, the blended water is subjected to the usual treatment process which currently applies to dam water at the existing water treatment plant before distribution to consumers. At all stages of this process, the water is subjected to water quality monitoring and testing. In Queensland, purified recycled water will be subject to a new regulatory regime to ensure that it meets health and safety requirements.

# Session 2

## MBR systems:
## a mature or an emerging technology?

# Introducing the MBR technology and the European market

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## Abstract

With a steady market growth in Europe greater than 10% per annum since about a decade, the technology of membrane separation of activated sludge, commonly referred to as “membrane bioreactor” (MBR), is considered as a key technology for future wastewater treatment and reuse schemes. Compared to conventional treatment technologies, MBR systems enable complete disinfection of the treated water, and may lead to superior elimination of substances in a reduced footprint. The commercialisation of the submerged MBR systems in the late 90’s precipitated rapid and extensive market penetration. The size of installations has grown from few thousand to almost hundred of thousands population equivalent in only a few years, from the first municipal full-scale demonstration plant in Porlock WWTP (UK, commissioned in 1998, 3,800 p.e.), up to the largest MBR plant in Europe to date of Nordkanal, Germany, commissioned in 2004 to serve a population of 80,000 p.e. Today, about 1000 units of representative size are in operation in Europe and Middle-East, and several thousands of “household units” (4 to 50 p.e.) are installed. The technology is now ripe to be applied in Greece and other neighbouring countries: it has become economically viable for municipal wastewater treatment in cases when advanced treatment is required such as unrestricted wastewater treatment or for the upgrade or retrofit of existing infrastructure.

## Introduction on MBR technology and short history

The technology of membrane separation of activated sludge, commonly referred to as “membrane bioreactor” (MBR), is the combination of activated sludge treatment together with a separation of the biological sludge by micro- or ultra-filtration membranes with pore size of typically 10 nm to 0.5µm to produce the particle-free effluent. The latter step replaces the final clarifiers used in conventional activated sludge treatment which achieve solid separation by gravity only. The physical barrier imposed by the membrane system provides complete disinfection of the treated effluent. It also enables operation at higher sludge concentrations (typically up to 20 g/L instead of max. 6 g/L with conventional systems), and therefore permits to reduce the required footprint and/or sludge production. However, for municipal applications, the MBR technology is usually related to a higher total life cost, due to the high energy cost. In addition, the perceived risk related to the fouling and the replacement costs of the membrane remains an important limiting factor to its broad application.

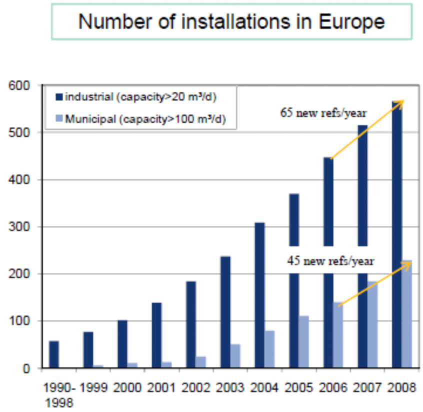
After initial development started in the late 60s, the MBR technology for wastewater treatment experienced rapid development from the early 1990’s onwards. The first systems commercialised in the 70’s and 80’s were based on what have come to be known as sidestream configurations, i.e. the membrane separation step was employed in an external sludge recirculation loop, mainly with in-to-out flow through organic or ceramic tubular membranes. Due to the high energy demand, these technologies targeted only small and niche market applications such as treatment of ship-board sewage, landfill leachate or industrial effluents.

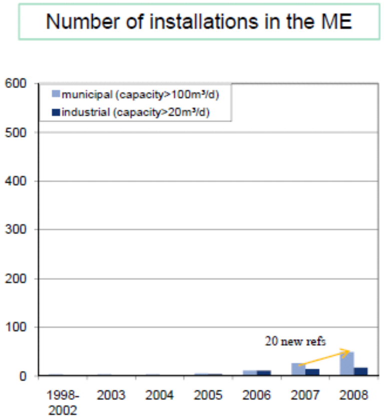
In the early 90’s, the Japanese Government launched an ambitious 6-year R&D project which led to a major technological and industrial breakthrough of the MBR process: the conception of submerged membrane modules, working with low negative pressure (out-to-in permeate suction) and membrane aeration to reduce fouling. This paved the way towards a significant reduction of capital and operation costs, due to the reduction and simplification of equipment and the abandonment of the energy demanding sludge recirculation loop. Nowadays, two types of technologies of submerged membrane modules are predominant on the MBR market. Both feature out-to-in permeate filtration and comprise the flat-sheet (or plate & frame) membrane module and the hollow fibre membrane module.

The commercialisation of the submerged MBR system precipitated rapid and extensive market penetration. The first pilot-scale European submerged MBR plant for municipal wastewater was built in 1996 (in Kingston Seymour, UK), soon followed by the construction of the full-scale Porlock WWTP (UK, commissioned in 1998, 3,800 p.e.), Büchel and Rödingen WWTPs (Germany, 1999, resp. 1,000 and 3,000 p.e.), and Perthes-en-Gâtinais WWTP (France, 1999, 4,500 p.e.). A few years later only, in 2004, the still largest MBR plant in Europe was commissioned to serve a population of 80,000 p.e. (in Kaarst, Germany). The size of installations has thus grown from few thousand to hundreds of thousands population equivalent in only a few years.

## Current Market in Europe

A recent market survey indicated that by the end of 2008, close to 1000 major MBR units (i.e. with a capacity greater than 100 m3/d and 20 m3/d for respectively applications with municipal and industrial wastewater) were in operation in Europe and in Middle-East. This was split between about 550 industrial references in Europe (+ 65 new units per year), about 250 municipal references in Europe (+ 45 new units per year) and about 50 references in Middle-East, essentially for municipal applications and with a growth of about 20 new units per year. In addition, several thousands of “household units” (4 to 50 p.e.) were installed throughout the continent in decentralised sanitation schemes. On the other side of the size scale, 37 large units were commissioned with a capacity greater than 5 MLD, demonstrating the maturity of the technology, the larger units being installed or planned in the Middle-East. To be noted that 1/3 of the municipal applications concern projects of upgrading or retrofitting existing plants.


Number of installations in Europe


Number of installations in the ME

Although the municipal sector represents 2/3 of the current revenue share due to the larger size of works, the MBR technology is better established in the industrial sector, where it is accepted as proven and competitive Best Available Technology, than in the municipal segment, where its economical competitiveness remains tangible on marginal applications only with very specific frame conditions such as advanced treatment required (bathing water or water reuse), few space available for plant construction, or plant retrofitting / upgrade projects.

## The MBR-Network

The European Commission (EC) has wished to consolidate this technological expertise and to accelerate the development and application pace of the MBR technology in Europe. The EC has therefore decided to support and finance within the sixth Framework Program four projects entirely devoted to research, development, capacity building and technological transfer in regards to this promising wastewater treatment process. These four projects, namely AMEDEUS, EUROMBRA, MBR-TRAIN and PURATREAT are implemented in parallel from October 2005 up to December 2009.

Close to 50 European and international companies and institutions are actively involved in these four projects and will join their efforts and coordinate their actions within the cluster “MBR-Network”. These projects amount to a total budget of ca. €15 million, for which ca. €9 million will be financed by the European Commission, and represent the largest coordinated research initiative on this topic worldwide. Research work mainly conducted by the group of around 30 leading universities and research centres in the MBR field is therefore focusing on strategies to reduce the aeration demand, to control the fouling mechanisms of the membrane systems and to optimise the membrane chemical cleaning regimes.

The projects is also fostering the development and optimisation of competitive MBR filtration systems “made in Europe”. Four membrane and module producers (Puron, A3 water solution, Polymem and Inge) aim to develop prioritary products based on innovative and distinct concepts of low-cost and high-performance MBR filtration systems. The resulting added competition should further reduce the investment costs related to the technology and accelerate its application.

## Conclusion

The MBR technology is now a mature technology for the European market and should be considered among the toolbox of Best Available Technologies available for wastewater management schemes, as demonstrated by the amount of plants in operation in several countries. Despite the drawback of the relatively high operation cost, essentially due to high energy requirement and the cost of membrane replacement, the technology can be an economical option in cases requiring advanced treatment (bathing water, unrestricted water reuse) or retrofitting of existing infrastructure for wastewater treatment. It is therefore anticipated to see in the coming years a broader application of the technology in Southern countries such as Greece.

The MBR-Network is expected to achieve significant technological breakthroughs for the MBR technology, while improving the current process engineering and operation practices. It will improve the competitiveness of the MBR European market and render common this high-tech process for municipal wastewater treatment.

Novel and alternative MBR filtration systems have recently appeared in the market and we can expect that the most innovative products will raise commercial interest in the coming years.

## References

Bixio D., De Wilde W., Nenov V., Eliades P., Lesjean B., Thoeye C., Potential of innovative Dual CAS-MBR configurations in two very diverse market situations: Bulgaria and Cyprus. Water Practice and Technology, Vol. 3, issue 2, 2008.

Lesjean B. and Huisjes E.H., Survey of European MBR market, trends and perspectives. Desalination 231 (2008) 71–81.

Lesjean B., Ferre V., Vonghia E., Mosslang H. Market and design considerations of the 37 larger MBR plants in Europe. MDIW2008, 20-24 October 2008, Toulouse, France.

# Economic Aspects of Large Scale Membrane Bioreactors

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## 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 and especially MBR Technology. Since 1999 the Erftverband has commissioned three full scale membrane bioreactor plants (see table 1).

**Table 1.** Main technical data of the Erftverband’s MBRs

| | **Rödingen, 3,000 PE.** | **Glessen, 9,000 PE** | **Nordkanal, 80,000 PE** |
|---|---|---|---|
| **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,<br>separate filtration | 10,200 $m^2$ hollow fibre modules,<br>separate filtration | 84,480 $m^2$ hollow fibre modules,<br>integrated filtration |
| **Effluent requirements** | COD < 30 mg/L<br>$NH_4$-N < 4 mg/L<br>$P_{tot}$ < 1.5 mg/L | COD < 30 mg/L<br>$NH_4$-N < 1.5 mg/L<br>$P_{tot}$ < 0.6 mg/L | COD < 90 mg/L<br>$NH_4$-N < 10 mg/L<br>$P_{tot}$ < 1.5 mg/L |

## Investment cost

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. On average the investment cost can be comparably lower than for conventional activated sludge (CAS) plants with additional treatment steps. Figure 1 shows the specific investment cost of 26 plants that have been built during the last 15 years.

## Operational Cost

The MBRs energy consumption is often higher than for CAS plants. However other main cost factors like personnel and sludge disposal are similar to conventional technologies. Figure 2 shows the energy demand of the Erftverband’s WWTPs in 2007 including the MBRs.

## Membrane reinvestment

The lifetime and reinvestment of the membrane filters is important to the life-cycle-cost. De Wilde has projected a possible lifetime of 13 years. The experience at the Rödingen MBR has shown that eight years of membrane lifetime are achievable even under sub optimal conditions. As an example the discounted present value of a MBR for 10,000 PE was calculated and compared to a CAS with additional treatment that achieves a similar effluent quality. The CAS therefore features a sand-filtration and a UV disinfection. The model calculation shows that the break even point for the two options is at a membrane lifetime of seven years.

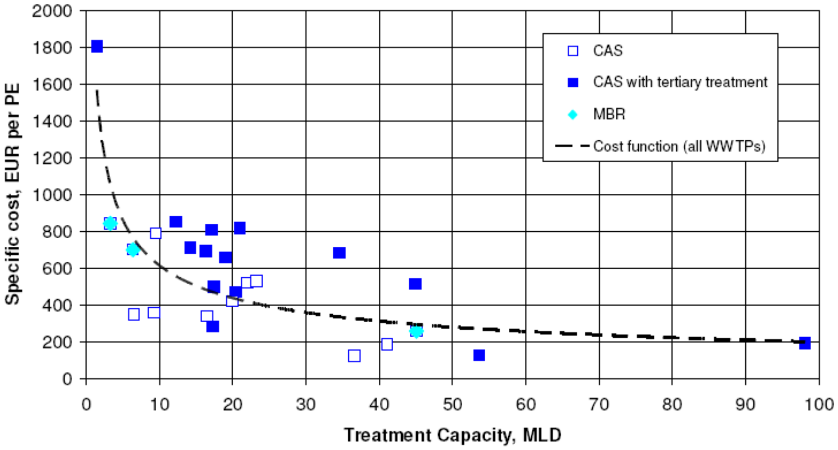

**Figure 1.** Specific investment cost for municipal WWTPs in the Erftverband association area.

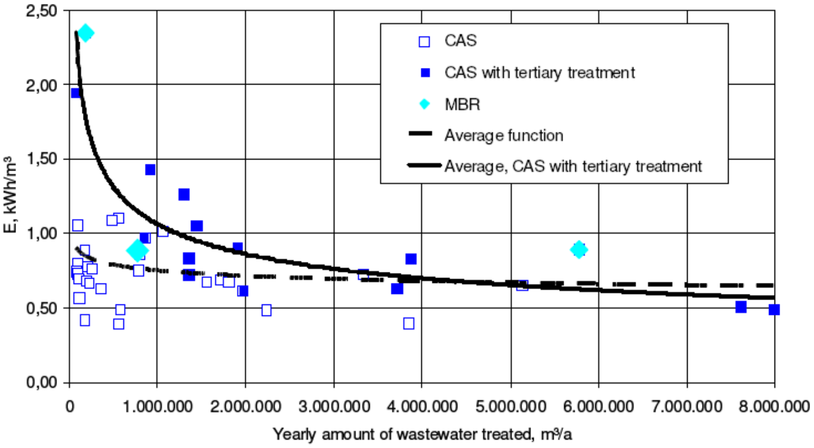

**Figure 2.** Specific energy demand per cubic metre wastewater treated.

## Conclusion

Under comparable conditions the investment cost for MBR plants are competitive against conventional activated sludge plants for municipal wastewater treatment. Even the MBRs disadvantage in energy cost may become negligible when the conventional technology has to be upgraded by tertiary treatment and disinfection in order to achieve the same effluent quality.

## References

[1] De Wilde, W.; Thoeye, C.; De Gueldre, G.: Membrane life expectancy assessment after 3 years of MBR operation at WWTP Schilde, 4th International Water Association Conference on Membranes for Water and Wastewater Treatment, 15-17 May 2007, Harrogate, 2007.

# Containerized MBR for upgrading small WWTP

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## Abstract

This paper presents technical information, which is used for detailed design and operation of containerized turn-key MBR plant of company Envi-pur, ltd. in the frame and support of EU project AMEDEUS. The paper is divided into the next parts: overview of existing containerized MBR’s, wastewater pre-treatment, buffer tank, bioreactor, physical and chemical cleaning of the membranes.

**Keywords:** MBR, membrane, containerized, wastewater

## Containerised MBR plants

MBR plants can be completely constructed at the factory and shipped as containerized modular plants or factory components can be installed in tanks (concrete or steel) constructed on-site. Containerized 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. The plant equipment includes:

- Pre-treatment
- Buffer tank
- Denitrification tank (anoxic tank)
- Bioreactor basin (aerobic tank)
- Permeate and recycle pumps
- Mixers
- Cleaning system
- Aeration system
- Controls (floats, LDO)
- Control panel
- System for operation and remote access

We’ve found more less 16 applications during the exploration of the containerized 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 standardized and are developed for certain application (Xanten - extension of the existing WWTP, Kunduz - German Forces, Afganistan, Weßling – wastewater from textile industry).

The next important producer of containerized 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 containerized 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 containerized 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 containerized membrane bioreactor is Suido Kiko Middle East. They produce containerized MBR plants fitted into 20’ and 40’ ISO containers.

### Envi-pur containerized MBR plants

One of important aspects for containerized plants is kind of used container. In concept of containerized 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-fiber modules recommend mesh size 1-2 mm.

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

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

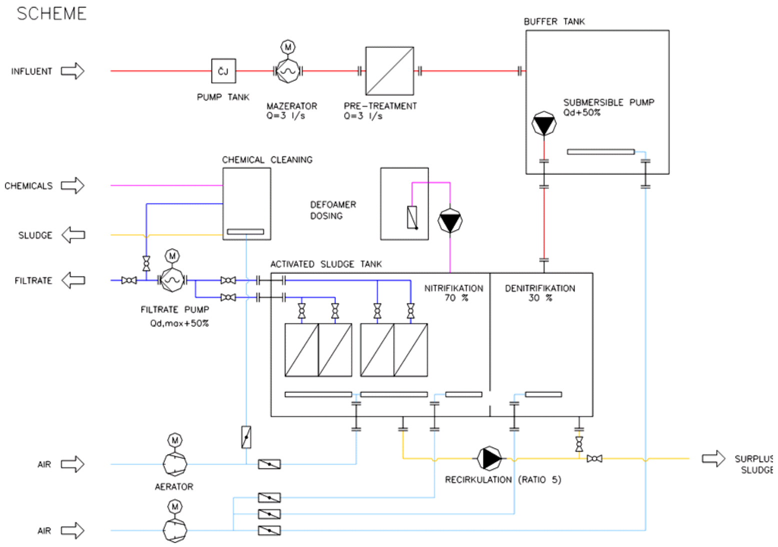
### Buffer tank

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 Qhourly (design flow).

### Bioreactor

The membrane bioreactor works as a classic activated sludge process with a different activated sludge removal. The sludge is removed on membrane modules instead of secondary settling. 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.

The figure bellow shows flow sheet diagram of containerized MBR plant. The diagram starts with influent which flows to pump tank from sewerage system. The wastewater is then pumped to pre-treatment facility using macerator (for containers with 500 PE) or the wastewater is pumped directly to buffer tank.



The buffer tank is aerated with coarse bubble aeration system as a protection of anaerobic condition in the tank. The wastewater is pumped to denitrification tank by submersible pump subsequently. Denitrification tank is linked to nitrification tank by the gap at the bottom of the tank. Activated sludge is then circulated from nitrification tank to denitrification tank by recirculation pump with recirculation ration equal to five. The recirculation pump is also used for pumping of surplus sludge.

There are minimum two membrane modules in activated sludge tank for parallel operation. Membrane modules have to be aerated in the reason of fouling protection. More about membrane modules is in the chapter 7.2. Activated sludge tank is aerated with fine bubbles aeration system. This aeration system is separated from the membrane aeration system and includes aeration of buffer tank, nitrification and denitrification tank.

The membrane permeate is pumped by permeate pumps. Part of permeate is stored in permeate storage tank (CIP tank on Fig. 3) 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 containerized 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.

## Chemical and physical cleaning

Chemical cleaning is carried out with mineral or organic acids, caustic soda or, more usually in MBRs, sodium hypochlorite, and can be performed either in situ ("cleaning in place" or CIP) or ex situ. Alternatively, a low concentration of chemical cleaning agent can be added to the back flush water to produce a "chemically enhanced back flush" (CEB).

Physical cleaning is less tedious than chemical cleaning on a number of bases. It is generally a more rapid process than chemical cleaning, lasting no more than 2 min. It demands no chemicals and produces no chemical waste, and also is less likely to incur membrane degradation. On the other hand, it is also less effective than chemical cleaning. Physical cleaning removes gross solids attached to the membrane surface, whereas chemical cleaning removes more tenacious material.

## Conclusion

Containerized 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.

## References

S. Judd (2006), The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment, Elsevier, ISBN 1-85-617481-6.

W. Yang, N. Cicek, J. Ilg (2006), "State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America", Journal of Membrane Science 270, 201–211.

S. Lyko, T. Wintgens, D. Al-Halbouni, S. Baumgarten, D. Tacke, K. Drensla, A. Janot, W. Dott, J. Pinnekamp, T. Melin (2007), Long-term monitoring of a full-scale municipal membrane bioreactor - Characterisation of foulants and operational performance, Journal of Membrane Science 317, 78-87.

S. Vigneswaren, W.S. Guo, P. Smith, H.H. Ngo (2007), Submerged membrane adsorption hybrid system (SMAHS): process control and optimization of operating parameters, Desalination 202, 392–399.

A3-Water systems - http://www.3a-gmbh.de

Kruger-Wabag - http://www.krueger-wabag.de

Mobile sewage treatment plants for desert construction sites - http://ww.pennnet.com

COPA MBR Technology - http://www.glv.com

Siemens - http://www.water.siemens.com

Seapoint - http://www.seapointinc.com/products/container.html

Eflo - http://www.eflo.com/html/eflo-mbr.html

Suido - http://www.suikime.com/MBR-CU.html

# Kubota Membrane Bioreactor technology - Overview and Applications in Greece

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## 1. INTRODUCTION TO KUBOTA CORP. AND THE GLOBAL MBR MARKET

### 1.1. Kubota Corp. History and Structure and European Business Model

Kubota Corporation was founded in Osaka, Japan in 1890 and currently employs around 24,000 staff in its home and overseas operations and subsidiary companies. The company consists of the Farm and Industrial Machinery Consolidated Division and the Water, Environment and Infrastructure Consolidated Division. The R&D, manufacturing and distribution of Kubota membrane technology products is handled by the Membrane Solutions Department of the WE&I Division.

The Membrane Solutions Department has been active in the European Membrane Bioreactor (MBR) market since 2001 through Kubota Membrane Europe Limited (KME), a wholly-owned subsidiary located in London, United Kingdom. KME operates through a vast network of Partner Companies (engineering firms or EPC contractors) situated across Europe and licensed to distribute its submerged membrane products and provide consultancy, process design and other services to the End Users.

The dominant position of Kubota membrane technology today is owed to more than 20 years of experience at the forefront of submerged MBR technology development and to the dedicated network of Kubota Partner Companies.

As MBR market leader, Kubota currently has the largest number of MBR installations of any membrane manufacturer, with a total of 2,948 installations globally (July 2008). More specifically, there are currently a total of 331 Kubota MBR plants in the Europe, Middle East and Africa (EMEA) region installed in 24 countries.

### 1.2. The Global MBR Market Today and into the Future

According to various industry analyses, the global MBR market is growing at double-digit rates, with an ever expanding range of applications from municipal/domestic to industrial, shipboard, offshore and others. The main factors for this expansion are:

(1) Implementation of more stringent environmental legislation and the requirement to comply with effluent discharge standards such as set by the Urban Wastewater Treatment and Bathing Water directives and Integrated Pollution Prevention and Control scheme; and

(2) Increasing stress on freshwater resources and an industry shift to more sustainable planning which relies on Best Available Technologies (BAT), water reuse and recycling. This is especially true for the water-scarce SE Europe and Middle East.

According to a report by the Business Communications Company, the global MBR market is rising at an average annual growth rate (AAGR) of 10.9% and is expected to approach USD363 million in 2010 (see Table 1). This steadily rising trend has been accompanied by an overall reduction in Kubota MBR process costs, as seen in Fig. 1.

**Table 1:** Global MBR market size in the period 1990-2010 (projected) (BCC, 2005)

| | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| **MBR market (USD, million)** | 5 | 15 | 105 | 220 | 363 |

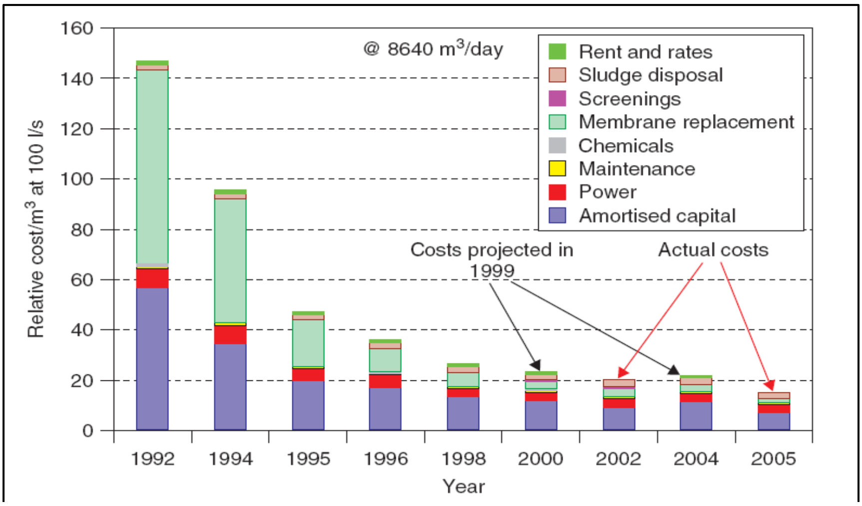


**Figure 1:** Kubota MBR process costs versus time (Kennedy and Churchouse, 2005.

## 2. KUBOTA FS MEMBRANE TECHNOLOGY: FEATURES & ADVANTAGES

### 2.1. Technical Description of the Kubota Submerged Membrane Unit

The Kubota Submerged Membrane Unit (SMU) consists of two main components: the membrane case and the diffuser case (both manufactured in 316 or 304 Stainless Steel and offered with the option of pickling).

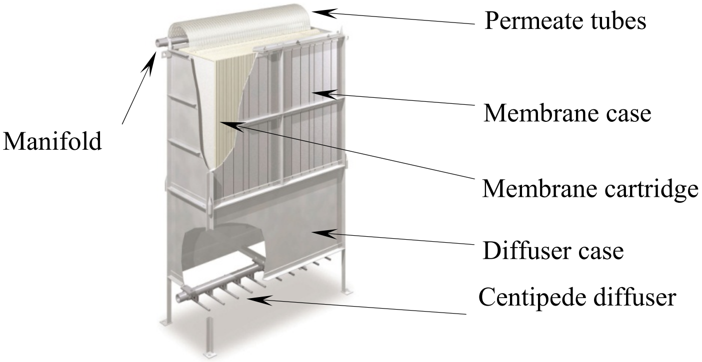
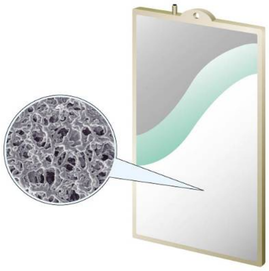


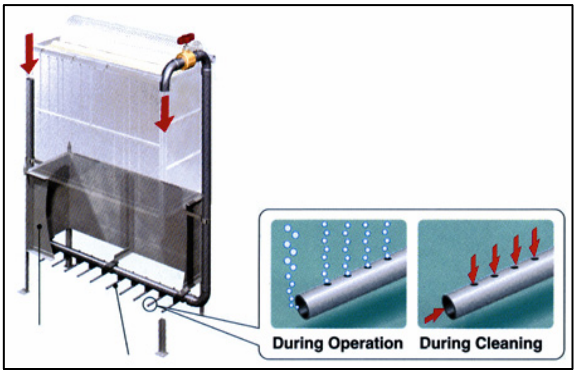
**Figure 2:** Kubota SMU schematic showing all component parts (Kubota Corporation).



The Kubota Type 510 cartridge contains two Flat Sheet (FS) membrane sheets (total surface area: 0.8 m$^2$) ultrasonically welded to each side of an ABS plate and separated by an inert felt spacer. The cartridge measures 1 m x 0.5 m and is 6 mm thick. The membrane sheet is made of chlorinated Polyethylene (PE) and is supported by a very strong non-woven substrate. The nominal pore size is 0.4 μm (Microfiltration range: 0.1-1 μm). However, due to the formation of the dynamic layer of protein and cellular material on the surface, the effective pore size in operation falls in the Ultrafiltration range (0.01-0.1 μm), sufficient to eliminate most bacteria, viruses and colloidal matter and provide full disinfection in accordance with the requirements of the EU Bathing Water Directive and other relevant regulations. Finally, cartridges are securely fitted to the membrane case at a separation of 7 mm. This largely prevents clogging of the membrane surface from sludge and debris.

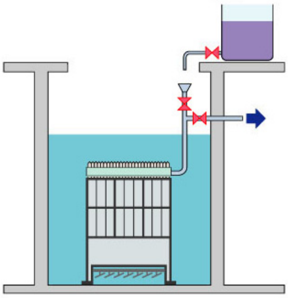
PU tubes collect permeate from a single point at the top of each cartridge, which then flows into the common manifold. As each tube can be disconnected individually, single cartridges can be removed for maintenance without having to remove the entire module. This gives a fully modular and versatile system.

*Simple and Reliable Membrane Air Scouring*



The Kubota Centipede$^{TM}$ Diffuser is housed in the diffuser case at the base of the module. The diffuser case ensures that air bubbles do not escape without first passing over all the membrane cartridges in cross-flow at a 90° angle. The diffuser comprises a central pipe branching out to 20 smaller pipes with 4mm holes drilled on the upper part. The main purpose of the coarse bubble aeration is to provide physical fouling control by cross-flow of air over the membrane surface (*‘membrane scouring’*) and to promote good mixing and circulation of mixed liquor in the membrane tank.

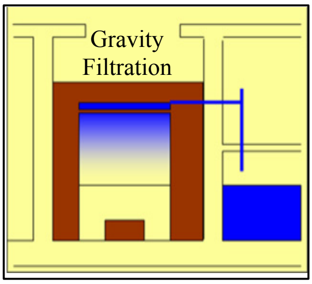
In addition to these two functions, some biomass oxygenation is also accomplished. Diffuser cleaning occurs by opening a valve connected via a manifold to both ends of the main pipe. The resulting suction draws sludge into the diffuser, thus removing any internal clogging. The air and sludge mixture is discharged back to the membrane tank and this cycle is carried out every 12 to 24 hours with the permeate valve turned off (no filtration). Finally, the air requirement is based 10 to 15L/ minute/cartridge.



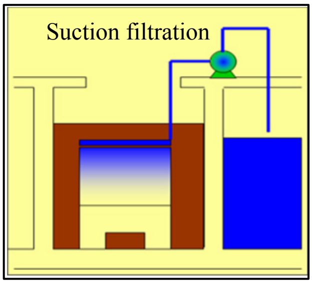
*CIP Membrane Chemical Cleaning*

Another major advantage of the Kubota system is the ability to carry out in-situ chemical cleaning of the cartridges, termed CIP (Clean-In-Place). There is no need for removing the membrane module(s) from the tank or for filling the entire volume of the tank with expensive chemical solution. This process is required only every 6 months for municipal applications and involves pouring 3L of dilute (0.5% w/w) NaOCl solution by gravity into each cartridge, through a separate chemical injection port for every module. Once filled, the cartridges are left to soak in the chemical solution for a few hours. Following this, there is recovery of the permeability up to the initial flux. Oxalic acid is used in the case of fouling caused by inorganic matter. Citric acid and Hydrochloric acid may also be used when the fouling is Ca-related.

*Gravity Operation with no Requirement for Suction Pumping*



Gravity Filtration Mode. In this mode, a small (minimum 500mm) hydrostatic head above the membrane module is sufficient to drive the filtration process. The main advantage is a reduction in capital and operating costs (no pumps or expensive constant-flow valves required). Plant maintenance is also easier, and permeate quality and flow rate can be checked separately in each module. The disadvantage is that plant operability will in this case depend on the hydraulic profile as well as the degree of membrane fouling.



Suction Filtration Mode. This mode involves the use of suction pumps on the outlet (permeate) side and is suitable in retrofitting applications or when the hydrostatic head is insufficient to drive filtration. In addition to running continuously, the pumps can also be operated only during start-up to give a ‘siphon’ effect. The following diagram illustrates a typical configuration for a Kubota MBR plant with suction filtration, including the chemical cleaning pipework.

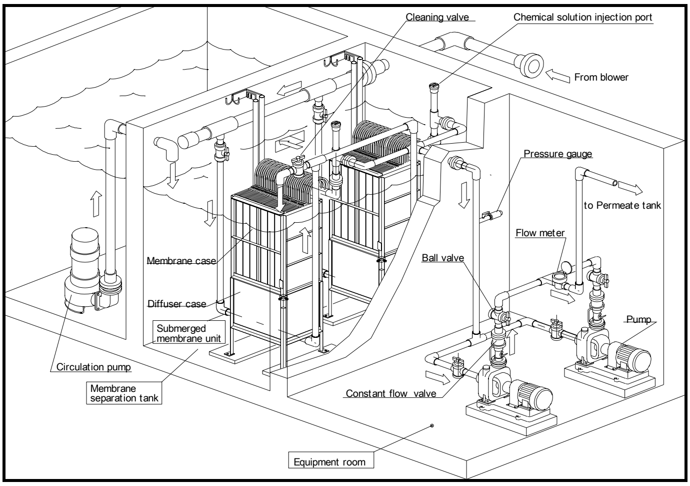


**Figure 3:** Typical Kubota MBR configuration in suction mode (Kubota Corporation).

*Simple installation and maintenance*

Kubota membrane modules are simple to install and maintain using the extra parts shown below. These include a Hand Hook for removing individual cartridges and a Guiderail and Lifting Tool for easy removal of the SMU from the membrane tank without causing any damage or having to drain the tank from mixed liquor.

*Pre-Treatment requirements (upstream of the MBR plant)*

Adequate pre-treatment is of fundamental importance in the operation of MBR plants. The presence of solid debris, hair and fibres inside the membrane tanks must be avoided at all times as this can result in membrane damage and reduced performance. To this end, a 3mm 2-directional (‘*perforated’*) or 1mm 1-directional (‘bar’) fine screen must be specified. A properly designed, installed and maintained fine screening stage is the minimum pre-treatment requirement. In addition, removal of FOG (Fats, Oils and Grease) and grit or sand may also be specified by the plant designer, depending on the nature of the raw wastewater.

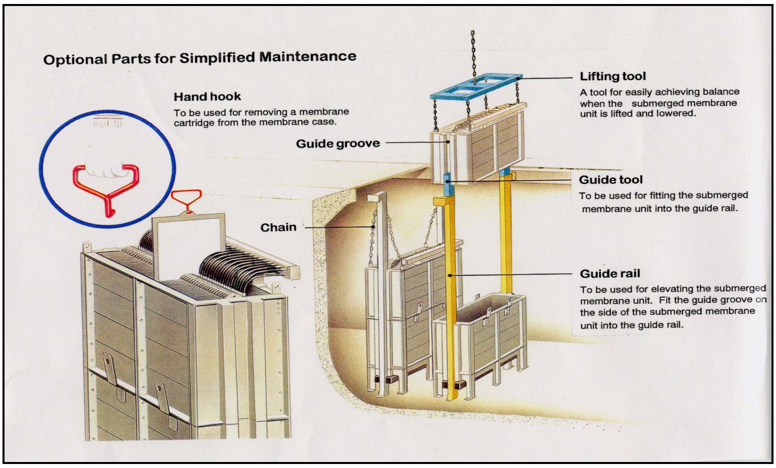


**Figure 4:** Optional parts for maintenance of Kubota SMU (Kubota Corporation).

## 2.2. Treatment Performance with use of Kubota Membrane Technology

Kubota MBR plants can meet the following requirements and specifications:

- World Health Organisation (WHO) standards for Unlimited Irrigation
- UN International Maritime Organisation (IMO) bacteriological limits
- Certification based on California State Water Recycling Criteria (‘Title 22’)
- 2006 Bathing Water Directive of the European Union (2006/7/EC)
- Fully disinfected effluent (4-log virus reduction & 6-log bacteria reduction)
- Certification by Japanese Construction Ministry to the following standards.

**Table 2:** MBR treatment standards specified by Japanese Ministry of Construction.

| Wastewater Parameter | Influent (mg/l) | Effluent (mg/l) | Reduction rate (%) |
|---|---|---|---|
| **BOD** | 200 | 5 | 97,5 |
| **COD** | 100 | 10 | 90,0 |
| **TSS** | 250 | 5 | 98,0 |
| **T-N** | 50 | 10 | 80,0 |
| **T-P** | 5 | 1 | 80,0 |

## 3. KUBOTA MBR PLANT CASE STUDIES

### 3.1. Porlock WwTP (United Kingdom)

The Porlock municipal wastewater treatment plant in SW United Kingdom is owned and operated by Wessex Water and is the oldest continuously operating submerged MBR plant in Europe, having recently celebrated its 10th anniversary. The plant has no primary settlement or grit removal and screening is to 3mm prior to entering the 4 membrane tanks, with a total membrane area of 2,880 $m^2$ and treatment capacity of 1,907 $m^3/d$ (3,880 PE). There are no suction pumps and filtration is totally driven by maintaining a head above the membrane modules of 0.1 bar (maximum). Moreover, there is no site operator and the plant is fully monitored via telemetry.

Membrane chemical cleaning takes place on average every 8 months and requires 6 hours off-line time per tank using NaOCl solution. MLSS concentration ranges from 8,000 to 27,000 mg/l, and on occasion exceeds 30,000 mg/l. A long sludge age (30-90 d) and low F:M ratio (0.02-0.07 kgBOD/kg MLVSS) result in low sludge production of 0.35-0.50 kgDS/kgBOD. The fall in average permeability since 1998 represents a mere 1% increase in TMP (Trans Membrane Pressure) over the entire period.

**Plate 1:** The Porlock MBR wastewater treatment plant in the United Kingdom.

After 10 years of continuous operation, effluent quality remains very high (Table 1). As this is a coastal site with proximity to a bathing beach, there was a requirement for compliance with the EU Bathing Water Directive and production of fully disinfected effluent. This has been achieved, with an average reduction in *F. Coliforms* exceeding 5.8 log over the entire period. Moreover, SDI (Sludge Density Index) tests carried out in February 2007 on permeate from the plant showed an average SDI of 1.50, which is well within the guidelines for use as Reverse Osmosis feed for re-use applications.

**Table 3:** Average Porlock influent/effluent quality data over the period 1998-2007 (Churchouse *et al.*, 2007).

| Wastewater Parameter | Samples | Influent | Effluent | Detection limit |
|---|---|---|---|---|
| **BOD (mg/l)** | 360 | 226 | <5 | 6 |
| **COD (mg/l)** | 200 | 424 | 22 | 10 |
| ***F. Coliforms* (pcu/100 ml)** | 200 | $12.8 \times 10^5$ | <21 | 10 |
| ***F+ Coliphage* (pcu/l)** | 80 | $1.54 \times 10^6$ | <26 | 10 |

Full membrane access (tank draining and removal of the membrane modules) has only been carried out once in Year 9. Following this, all membrane panels were checked and damaged ones replaced. Despite long-term exposure to sand and grit, macroscopic abrasion on membranes was remarkably slight and no microscopic effect was detected.

To-date, a total of 230 panels have been replaced out of the 3,600 installed, giving a failure rate of less than 6.4% over 10 years of operation. The majority of the failures were from potentially preventable causes: 127 panels had holes from debris and grit; 55 had internal sludge/contamination inside (probably due to smaller holes); 25 were damaged in handling; 14 had torn or split seals; and 9 were removed in error (cleanable staining). Such low failure rates are representative of the expected lifetime of Kubota membranes and a major strengths over competing membrane systems. Finally, if the Porlock plant was designed today it would probably have a nutrients (N & P) consent, the Kubota membrane modules would be configured in double decks, thus saving energy related to membrane air scouring. Finally, the membrane casings would be built in corrosion- and abrasion-resistant stainless steel.

### 3.2. Milos WwTP (Milos Island, Greece)

The design, construction and operation (for 2 years) of the wastewater treatment plant on Milos Island was awarded to Mesogeios S.A. (main project contractor) in March 2008, having been specified as an MBR process. Technor Engineering Ltd. - the exclusive representative in Greece for Kubota membrane technology - was chosen by Mesogeios S.A. to supply the required Kubota membrane modules and preliminary MBR process design. The project was wholly financed by S & B Industrial Minerals S.A., with the objective of delivering the only sewage treatment plant on the island, handling municipal as well as septic tank wastewater.

**Plate 2:** View of the plant main structure, including fine screening/grit removal, de-nitrification tank and membrane tanks, during commissioning (Kubota Corporation).

The plant is designed to operate completely in gravity filtration mode (no suction pumping required) with an average design flow of 420 $m^3/d$ (2,100 PE). The process comprises a balancing tank for the incoming municipal and septic tank wastewater, a compact pre-treatment unit for fine screening (to 3mm) and grit collection/removal, de-nitrification tank, 2 MBR tanks including pre-aeration using fine bubble disc diffusers, a permeate collection and post-chlorination tank, chemical addition for Phosphorous removal and a sludge treatment stage (thickening and dewatering).

Each of the 2 pre-aeration/membrane tanks has dimensions of 6.5m L X 2.8m W X 3.5m H and contains 4 X Kubota ES125 membrane modules, giving a total combined membrane surface area of 800 $m^2$ for both tanks. Following the first stage of this project there is an option for implementing a second stage for doubling the treatment capacity of the plant via installation of a second, identical line (another 2 tanks).

**Table 4:** Milos WwTP influent/effluent quality based on plant design specifications (Technor Engineering Ltd.).

| Wastewater Parameter | Influent | Effluent |
|---|---|---|
| **BOD (mg/l)** | 460 | <10 |
| **TSS (mg/l)** | 440 | <20 |
| **T-N (mg/l)** | 100 | <10 |

This project is very important since this is the first full-scale municipal MBR plant in Greece. All civil and M&E works have been completed - including installation of the membrane modules and successful clean water commissioning tests - and the plant will become fully operational before Summer 2009 with connection of the inlet to the island’s sewerage network. There is also a plan for permeate reuse for crop irrigation.

### 3.3. Regency Casino (Athens, Greece)

In April 2008, Enviplants S.A. - a contractor specialising in wastewater treatment - took on the design and construction of a Kubota MBR plant for the Regency Casino in the Mont Parnes area outside Athens. The plant was designed to operate in suction filtration mode, treating an average design flow of 150 $m^3$/d (600 PE). The treated wastewater is municipal and comes from casino facilities such as a restaurant, hotel, etc. Fig. 5 shows a block diagram of the process. The entire plant is compact (with the possibility of being removed and re-installed in a different location depending on the client’s needs) and based on pre-fabricated cylindrical plastic tanks. The membrane tank has dimensions of 3.8m D X 3.2m H and contains 2 X Kubota ES150 membrane modules, giving a total combined membrane surface area of 240 $m^2$.

**Table 5:** RC WwTP influent/effluent quality based on plant design specifications (Technor Engineering Ltd.).

| Wastewater Parameter | Influent | Effluent |
|---|---|---|
| **BOD (mg/l)** | 335 | <10 |
| **TSS (mg/l)** | 412 | <10 |
| **T-N (mg/l)** | 40 | <12 |

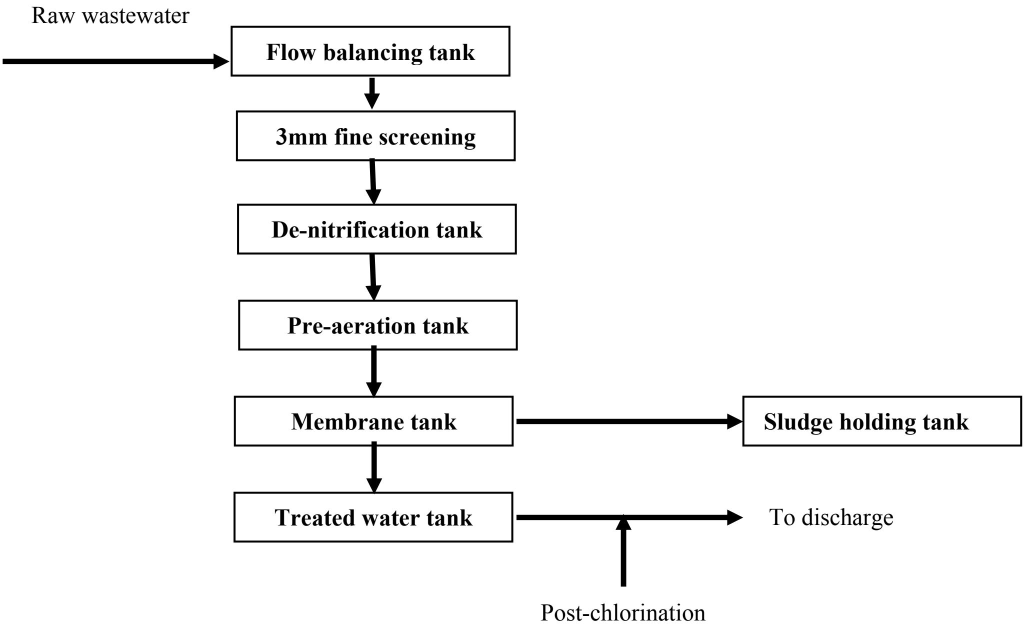


**Figure 5:** Process block diagram of the Casino Regency Kubota MBR plant.

## 4. Conclusions

- The global MBR market has been steadily growing at double-digit rates since the 1990s, making it the fastest-growing sector within advanced wastewater treatment. The main drivers for this have been more stringent environmental legislation and water scarcity
- Submerged MBR processes based on Kubota flat sheet technology has been in constant development for over 20 years and represent the *'State of the Art'* in wastewater treatment.
- Kubota MBR plants have been installed for municipal/domestic and industrial applications across the world and are especially attractive for plant retrofits and expansions, nutrient removal, water reuse/recycling and RO pre-treatment. Kubota is the leading Flat Sheet membrane manufacturer, with 2,948 plants worldwide ranging in capacity from 5 to 78,000m³/d.
- Kubota MBR plant design and operation have evolved considerably since the first full-scale municipal European MBR plant (Porlock WwTP in the United Kingdom) became operational in February 1998. Today's plants, such as those at Milos Island (first full-scale municipal MBR plant in Greece) and Casino Regency (Athens) illustrate these developments, with lower capital/operating costs, the ability to operate without suction pumps and a core design philosophy based around compact and integrated solutions.
- With all the many developments that have shaped the MBR industry over the past 10 years, there are still many challenges today such as optimising energy consumption and understanding the complex nature of membrane fouling.

## 5. References

Kennedy, S. and Churchouse, S.J. (2005): *Progress in Membrane Bioreactors: New Advances.* Proceedings of Water and Wastewater Europe Conference. Milan, Italy. June 2005.

Churchouse, S.J., Warren, S. and Floyd, M. (2007): *Feedback from the Porlock MBR plant in its 10th year of operation:- An analysis of the flux, effluent quality and membrane lifetime data to-date.* Proceedings of Aachen Water & Membrane Conference. Aachen, Germany. October 2007.

*'Membrane Bioreactors in the Changing World Water Market'* published in 2005 by The Business Communications Company, Inc., USA. (www.bccresearch.com).

# Session 3

## Membrane equipment and major applications

# First year of operation of the hybrid side stream MBR in Ootmarsum

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## Abstract

In recent years, Norit has developed and proven a totally new concept for treating domestic industrial waste water. The concept applies the side-stream AirLift principle using the robust and reliable side-stream cross-flow concept while incorporating advantages of the low energy consuming submerged systems. Based on this ‘outside the box thinking’ a new membrane bioreactor (MBR) concept was developed offering the solution, which is fully beneficial to the potentials of ultrafiltration (UF) membranes. The biological box can be designed and operated optimally, while the UF installation can be handled as a separate unit, performing clean, safe and efficient while producing bacteria and almost virus-free water for recycling or an ecological discharge. The Ootmarsum waste water treatment plant (located in the eastern part of The Netherlands) was commissioned successfully in October 2007 being the first large scale system using the Airlift MBR concept. The paper will discuss the background, design and the current performance of the Ootmarsum plant.

**Keywords:** membrane bioreactor; municipal waste water; side-stream; air lift; ultrafiltration

## Introduction

The Ootmarsum wastewater treatment plant (WWTP) is owned by the water authority Regge & Dinkel (WRD) and is situated in the municipality of Dinkelland (eastern part of the Netherlands). The WWTP discharges the treated wastewater into a water system with considerable ecological potential. In the restructuring plan the urban water chain/cycle has been integrated into an ecological water management approach. In order to fulfil the effluent requirements it was decided to modernise the WWTP which was built in 1974 originally. Intensive design studies were carried out resulting in the choice for a so-called hybrid system.

The hybrid system combines a conventional system followed by a sand filter with a MBR. The MBR has a limited hydraulic capacity. The idea is that a relatively large part of the dry weather flow (DWF) will be treated with the membranes. During periods of rain weather flow (RWF) the excess rainwater will be channelled via the intermediate buffer to the conventional active sludge system and the final settling tank. In this way, the surface area of the membranes can be considerably reduced in comparison with a complete MBR plant, and the membranes can be used at their optimum. With a hybrid MBR, the costs can be reduced relative to those of a complete MBR plant, without making many concessions in terms of effluent quality.

## Airlift concept

The first (industrial) MBR-systems were based on the cross-flow mode due to the relatively high solids content. The advantage is a better control of the cake layer build-up resulting in a more constant flux; drawbacks are a more complex system and the higher energy costs. The application of the MBR for municipal wastewater was not attractive due to the large flow with relatively low solid contents to be treated. This technique, however, became more attractive for larger flows with the introduction of systems where the refreshing of the feed along the membrane is not realized anymore by hydraulics but by pneumatics (aeration). The energy cost can be reduced significantly if the membranes are cleaned by means of air scouring and not anymore by cross-flowing of the feed solution. Moreover, permeation is forced not longer anymore by over-pressure, but by under-pressure (suction).

Current developments are in the direction of the subdivision of the total MBR system in (at least) two main parts being the tanks for the biological processes, and the tanks for installing the membranes. The original advantage of creating a very compact system by installing the membranes in (a part) of the aerobic section is not valid anymore caused by the call for more flexible systems.

The AirLift MBR-system consists of a bioreactor with an external loop with membranes outside of the bioreactor vessel (or basin). This side-stream way of sludge filtration enables almost all the possibilities to optimise individually the bioreactor and the membrane system, such as a large flexibility in coping with changes in hydraulic capacity and optimal distributions of flow over the different sections in the bioreactor. The distinguished process parts make the membrane inspection and replacement very easily without removing complete cassettes with membranes out of the bioreactor. In industrial applications this way of applying membranes in separation of water from sludge has lead to very compact units with highly efficient transition of the waste. The introduction of air-driven sludge circulation instead of hydraulic circulation has reduced the energy consumption to below 0.25 kWh/$m^3$ which is nowadays fully compatible with the submerged systems.

## Process description

The principle of the AirLift MBR is based on the same basics as used for the cross-flow principle, however, the turbulence within the tubular shaped membranes is achieved by sparging air into the vertically mounted membranes.

As is shown in Figure 1, the recycling flow propelled from the activated sludge tank at a velocity ranging from 0.3 – 0.5 m/s is enhanced in turbulence by adding air underneath the module with an additional 0.3 – 0.5 m/s. The permeate output can be controlled by a simple control valve for adapting the ‘gravitational flow’ or by a dedicated pump. A regular back pulse is executed to maintain the membranes performing at a steady state.

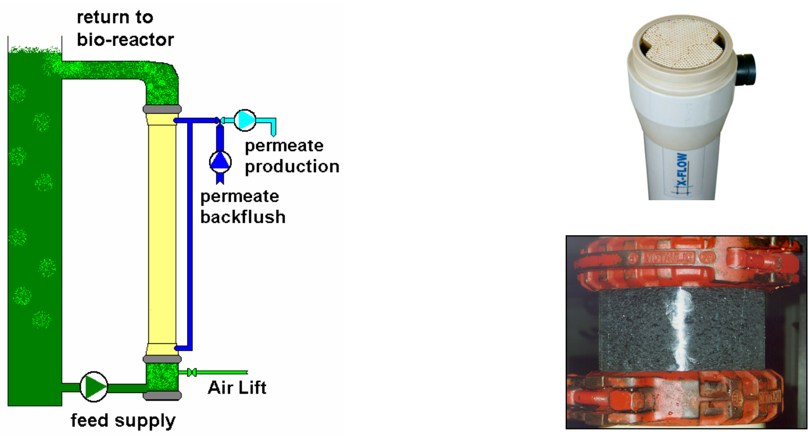

**Figure 1**. Basic principle of the Norit AirLift MBR with 8” X-Flow COMPACT membrane module and continuous aeration.

*Add on unit*

The biological reactor can be designed fully at its own optimal situation, while the optimisation can be carried out without any interference with the ‘clarifying’ step, which is the other part of the total system. The UF unit can be designed at its best performing configuration, also optimized for its specific task. This also allows the application of the UF unit as a ‘clamp on’ unit to existing reactors to get it upgraded to a MBR.

*Small footprint*

The optimal process conditions in the UF can be dedicated fully to flux optimisation. Being a tubular membrane system, energy can be directed to improve the flux, making the use of energy very efficient. In a submerged system a higher flux can be obtained by applying more air around the fibres or between the plates directed to the fouling specifically. Due to a badly defined hydrodynamical flow regime this additional energy input is not transferred efficiently into a higher flux. A tubular MBR system operates at a higher flux than the submerged systems reducing the required membrane area and the foot print.

*Energy consumption*

One of the strong points of a submerged system is the low power consumption. With the recent development of the AirLift system, this item is not a discriminating topic anymore. The low propeller based hydraulic circulation of the biomass causes hardly any pressure drop across the membranes, while the efficient use of air sparging enlarges the cross-flow motion along the membrane surface controlling the fouling efficiently. Currently, the energy consumption is comparable to the submerged systems being in the range of 0.18 – 0.25 kWh/m$^3$.

*Cleanability and automation*

Staying successfully in membrane business means knowing how to keep membranes clean in a technically easy and operator friendly way. All the methods to keep submerged membranes clean, such as removing membrane cassettes from the bioreactor or disconnecting membrane tanks for emptying them, followed by water spray brushing, are not very operator friendly.

A more efficient and easier method is obtained by placing the membranes outside the bioreactor allowing for many options to improve both the biological process as the membrane filtration. The separate placement of the membranes from the biomass enables a normal ‘cleaning in place’ situation by isolating the membranes easily from the bioreactor and performing the cleaning in a simple and automated way. No need for hoisting, spraying, pulling on dirty membranes.

*Influence of UF (cleaning) on the biology*

The total content of the membrane part of a side-stream system is significantly lower than of a submerged system resulting in two major advantages.

Due to the small content at the feed side of the tubular membranes a very small volume of sludge is present outside the bioreactor hardly influencing the biological degradation process. Only a small fraction of the sludge content is aerated additionally.

Secondly, the low volume hold up (both at the feed as at the permeate side) will limit the chemical usage, keeping cost and chemical usage low. The cleaning solution will reach the membrane surface quickly and efficiently, keeping time limited for the cleaning sequence. Meanwhile the biology will not be affected at all. Typically once a month or every two months a maintenance cleaning is executed, which frequency depends on the applied flux level.

*Reliable membranes*

Tubular membranes used for side stream applications are not new at all, but have a proven track record of over 25 years of operation, including the first generation – cross-flow –

membrane bioreactors. The Norit X-Flow tubular membranes used for the AirLift MBR application are real ultrafiltration, rigidly enforced, backflushable membranes which are already used in pressurized systems up to 10 bar treating surface water and backwash water of sand filters. In the AirLift MBR process the transmembrane pressure is limited to far less than 1 bar (typically lower than 0.3 bar), assuring a long life time. The track record of these tubular membranes in several demonstration AirLift MBR plants is an actual life time over 7 years of performance without any reduction in permeability.

**Figure 2.** Full-scale side-stream Airlift MBR system for municipal waste water treatment.

*Maintenance*

All the maintenance activities can be carried out under normal working conditions, as the membrane modules can stay in their normal position. No activities on top of the aerated zone of the bioreactor with all its aerosols or labour intensive removal of membrane cassettes have to take place. The maintenance can be organised just in the low flow hours by the easy disconnection of a stack from the system, keeping all the equipment in its place.

## Results

In October 2007 the first full scale MBR system using the AirLift system was commissioned successfully having a maximum hydraulic capacity of 150 m3/h. Figure 3 shows some typical performance results, while the system is running at a flux level of 55-60 l.(m$^2$.h).

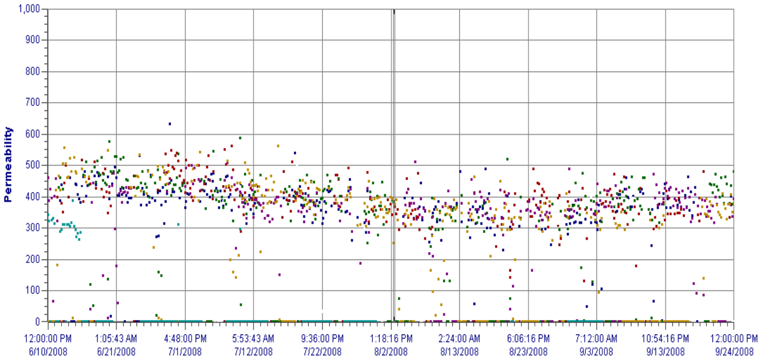

**Figure 3.** Typical performance of the Ootmarsum hybrid MBR: permeability versus time.

## Conclusion

The introduction of the AirLift, side-stream MBR system offers a technically proven and an economically flexible alternative for the submerged systems. Currently, several AirLift systems are under construction (varying in capacity between 10 and 1,000 m3/hr), while the first installations are running successfully.

# Experiences of Veolia with the BIOSEP™ MBR technology

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## Introduction

Increasing restrictions on the construction of wastewater treatment plants such as limited surface area available in modern urban settings and the necessity of revamping existing installations with minimum disruption are rendering the MBR technology the future trend in wastewater treatment. New directives require a treated effluent quality suitable for recycling and reuse and at the same time investors and industrial operators are increasingly interested in waste water recycling in order to reduce their dependence and their water costs.

Veolia Water, world leader in the provision of water and wastewater services, and its subsidiary Veolia Water Solutions & Technologies have acquired an extensive experience in the Design & Build of MBR plants as well as in the sales of standardised MBR solutions since their first MBR plant was commissioned in France in 1996. Two decades later, the Veolia group, with over 30 references on the municipal market and over 55 references on the industrial market has a broad feedback and return of experience both in design and construction and in operation of MBR plants.

The proprietary Veolia MBR technology is called BIOSEP™ (NEOSEP™ in USA, Japan, New Zealand and Australia) and owing to its modular design can operate with hollow-fibre, flat-sheet, or tubular membranes. BIOSEP™ plants use commercial membranes available on the market by recognised manufacturers. Consequently Veolia has developed a broad experience with various types of membranes. In order to assess and evaluate the performance of different membranes from different manufacturers, to choose the optimal membrane solution on a case by case basis according to each project’s particularities and to optimise the design and conception of its MBR systems, Veolia has developed its own in-house membrane expertise R&D team.

## ARAMIS

Anjou Recherche, Veolia Water Research & Development center which is located in Maisons Laffitte (France, West Paris area), has developed a unique membrane expertise service with two dedicated teams and high tech analytic equipment. These two teams are ARAMIS and SATA (Technical Assistance & Analysis Department). ARAMIS is made up of experts from different fields such as microbiology, water science, membrane processes and chemical engineering. Its overall objectives are to evaluate membrane performance, rejection rates, hydraulic and mechanical properties and to define optimal operating conditions to prevent membrane fouling, reduce energy consumption and water losses.

ARAMIS team is performing frequent ‘autopsies’ on the membranes of the MBR plants operated by Veolia in order to further extend its membrane cleaning expertise. The main research parameters of an ‘autopsy’ are the identification of species responsible for fouling using advanced specific tools for mineral, organic types and biological characterisation and the optimal cleaning sequence identification achieved by bench scale experimentation of product efficiency.

Further to the lab, bench or pilot scale research and development, Veolia is gathering a database of operational parameters of all MBR plants it operates. On every Veolia operated

MBR plant, flow, pressure and permeate turbidity are fully monitored as well as the feeding system to the membrane and all ancillaries. On the one hand this means that all Veolia MBR systems are always under control and on the other hand that an extensive central database of operational parameters of all the plants in operation is continuously updated comprising a valuable pool of experience for future projects.

## BIOSEP™ PACK

Through continuous R&D and benchmarking and drawing on several years of experience in using the BIOSEP™ process in the aerobic treatment of industrial and municipal effluent Veolia Water Solutions & Technologies is now offering a new membrane filtration system, the BIOSEP™ Pack. This new system is based on standardised filtration units - the core of the BIOSEP™ process. The standard BIOSEP™ Pack range comprises 10 models ranging from 500 to 5000 $m^2$ of membranes suitable for applications ranging from 4 to 60 $m^3/h$. The system is particularly suitable when stringent requirements are requested as for example very low SS and BOD treated effluent, disinfection or reuse of water.

The standard BIOSEP™ Pack filtration units have been designed in such a way as to provide the following advantages:

- Quality control of an industrialised product
- Fully automated operation
- Optimal modularity and adaptability
- Compact design
- Reduced cost by minimising design study time
- Rapid installation and commissioning
- Quick response to high load variations
- Units that can be dismantled and relocated
- Very easy to upgrade with low revamping cost

The standard BIOSEP™ Pack filtration plants are skid mounted compact units made up of two main fully packaged elements: the filtration membranes and the washing skid with the programmable logic controller. To meet the requirements for the installation of additional tanks in existing treatment plants the BIOSEP™ Pack is delivered along with a filtration tank and fixed to an external loop from the aeration tank. Alternatively the membranes can be immersed directly into the aeration tank. Membranes are hollow fibres made from polyethersulfone (PES), a material which is resistant to chlorine. The cut off of the membranes is around 0.1 μm. The lower ends of the fibres are fixed in a single header and the upper ends of the fibres are individually sealed. An air nozzle is integrated into the center of each module. The extraction of the permeate and the backwashing are therefore carried out at the bottom of the fibre. A soundproofed air blower and an automatic valve distribute the air at the bottom of the cases in order to agitate the membranes in sequence. This air renews the mixed liquor next to them. An anti-scumming detection sensor is provided which automatically controls the injection of antiscumming reagents. BIOSEP™ Pack filtration units operate on a volumic load between 2 to 3 $kgCOD/m^3$ / day (on the aeration tank) and an MLSS of 8 to 12gSS/l.

# Integration of MBR with RO for Water Reuse

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## Abstract

Currently, treated municipal wastewater is typically discharged to the environment in most parts of the world. It is, however, a potential water resource from which high quality water for reuse can be produced. Reuse applications include both non-potable applications such as irrigation and production of industrial process water, and indirect potable reuse including aquifer recharge. For many reuse applications, effluent from conventional wastewater treatment plants is frequently further treated by reverse osmosis (RO) to reduce the total dissolved solids in the effluent for water reuse applications.

There are some major challenges for RO systems operating on biologically treated wastewater. One challenge is plugging of the brine spacer due to high levels of suspended solids in the feed. Many RO systems today use ultrafiltration (UF) as pretreatment to remove suspended solids. The UF system does an excellent job of providing water with low suspended solids as to feed RO. However, the UF system requires additional space and does not effectively reduce the amount of dissolved solids such as organics that are fed to an RO system. The UF system can also be susceptible to upsets from a conventional wastewater treatment plant.

Instead of separating the biological treatment process and the ultrafiltration step, the latest wastewater treatment plants combine both processes in a membrane bioreactor (MBR). The membranes are integrated right into the aeration tank of the biological process. Advantages of this process are that a clarifier is no longer needed, and the effluent quality is considerably better, which improves RO performance. Additionally, the MBR process reduces footprint significantly compared to the combination of wastewater treatment followed by membrane filtration.

This paper discusses the challenges of using RO membranes for water reuse and the benefits of using MBR in comparison to UF as pretreatment for RO. The paper highlights examples of MBR systems providing RO pretreatment today. This paper also reviews cost factors for different pretreatment alternatives technology, and discusses factors that should be considered when deciding the optimum treatment train for a water reuse plant.

**Keywords:** Membrane bioreactor, Reverse Osmosis, pretreatment, MBR, RO, submerged membrane

## Introduction

Currently, biologically-treated municipal and industrial wastewater is typically discharged to the environment in most parts of the world. It is, however, a potential water resource from which high quality water for reuse can be produced. For example, at the City of Scottsdale, Arizona, Water Campus a 14 MGD (million gallons per day) water reuse plant has been in operation since 1999, and other even larger plants have recently been built around the world. Reuse applications include both non-potable applications such as irrigation and production of industrial process water, and indirect potable reuse including aquifer recharge. For many reuse applications, effluent from conventional wastewater treatment plants is frequently further treated by reverse osmosis (RO) to reduce the total dissolved solids in the effluent for water reuse applications.

## Challenges of RO Systems for Water Reuse

There are some major challenges for RO systems operating on biologically treated wastewater. One challenge is plugging of the brine spacer due to high levels of suspended solids in the feed. RO membranes used for most water reuse applications today are typically spiral-wound elements, where membrane leaf units are rolled around a central permeate tube. Feed water flows into a brine spacer, typically made of vexar-type netting with a thickness of between 28 and 31 thousandths of an inch. If there is a high level of suspended solids in the feed water, the brine spacer can become plugged.

A second challenge is organic fouling, since many biologically treated wastewaters contain high levels of organics. The organics in the feed water are rejected by the RO membrane and are progressively concentrated as the water flows across the membranes. Towards the outlet of the RO system, the concentration of organics can lead to excessive fouling of the membrane.

A third challenge is biofouling. Biofouling requires both the presence of microorganisms and a food source. The organics in wastewater make an excellent food source for microorganisms. In addition, some treated wastewaters have high levels of bacteria present and so biogrowth occurs quickly in the RO system. Even when the RO feed water is disinfected, an RO system is not sterile and so biogrowth can still occur, albeit at a slower pace. In the past, RO systems treating wastewater used cellulose-acetate (CA) membranes, since these membranes can withstand some free chlorine. Feeding water with a chlorine residual minimized biogrowth. However, since CA membranes have limited pH stability and operate at high pressures, the trend today is to use thin film composite (TFC™) membranes. These membranes are not chlorine-tolerant and so strategies other than chlorine addition to avoid biofouling must be used when treating wastewater. These strategies may include use of an alternate disinfectant such as chloramine, or the minimization of organics and microorganisms in the feed by providing more extensive pretreatment.

Another issue with RO systems operating on some wastewaters is calcium phosphate scaling. Since municipal effluent can be relatively high in phosphate, RO systems operating at high water recoveries sometimes suffer from calcium phosphate scaling. This can be handled by operating at lower water recovery, utilizing acid or antiscalant to minimize scaling, or modifying the operating conditions of the wastewater treatment plant (WWTP) to reduce the amount of phosphate in the RO feed.

Issues such as plugging, fouling and scaling lead to operation of the RO system at higher feed pressures with increased power consumption, increased chemical costs for cleaning and shorter membrane life. Hence, to minimize overall water reuse system lifecycle costs, the pretreatment steps before the RO should be chosen carefully.

## RO Pretreatment

There are many different pretreatment schemes and operational strategies. The optimal pretreatment scheme varies depending on many factors including cost of power, cost of chemicals, cost of labor, cost of land, wastewater source and the existing wastewater treatment system (if any).

### *Conventional Pretreatment*

A typical "conventional pretreatment" scheme for effluent prior to RO might be primary treatment, biological treatment and solids-liquid separation such as secondary clarification. The crucial part of the process is the solids-liquid separation. With a conventional sedimentation process, there is often insufficient removal of bacteria and suspended solids. Tertiary treatment, such as sand filtration, may be used to improve the solids-liquid separation to provide higher quality water to feed an RO system. A coagulant such as ferric chloride may be used in combination with the sand filtration to enhance solids and organics removal. Typical secondary effluent is approximately 20 ppm TSS (total suspended solids) and 20 ppm BOD (biological oxygen demand) and is relatively high in organics. Sand filtration will reduce these levels to a range where RO systems can be operated. However, upsets in the secondary clarifier can lead to effluent with higher levels of TSS and BOD causing problems for the RO, such as plugging of the brine spacer with suspended solids and fouling due to organics. Power consumption for RO systems with this type of pretreatment tends to be high, and membrane life is often quite short.

More extensive pretreatment schemes that have been more successful in protecting the RO membranes have included lime-softening to reduce solids and organics. However, this is an expensive choice in terms of operating costs and is not totally successful in preventing fouling of TFC RO memberanes.

*Ultrafiltration as RO Pretreatment*

Many water reuse systems today use ultrafiltration (UF) as pretreatment to RO to remove suspended solids. Most of these systems use hollow fiber membranes. UF membranes do an excellent job of providing water with low suspended solids to feed an RO. The typical feedwater to UF membranes in a water reuse scheme is either secondary or tertiary effluent. Since the UF system is an extra treatment step, it requires additional footprint, and the operating costs incurred are in addition to the operating costs for the conventional WWTP. Also, UF does not effectively reduce the amount of dissolved solids such as organics or phosphates that are fed to an RO system. Hence, UF will not prevent organic fouling or calcium phosphate scaling in the RO system. The UF system can also be susceptible to upsets from a conventional WWTP. The UF system protects the RO system from the upsets, but these upsets can increase the operating costs for the UF system.

*Membrane Bioreactor as RO Pretreatment*

A further development over ultrafiltration is a membrane bioreactor (MBR). Instead of separating the biological treatment process and the ultrafiltration step, the latest wastewater treatment plants combine both processes in a membrane bioreactor (MBR). In an MBR, the ultrafiltration membrane modules are submerged in the activated sludge to combine the biological step and the solid-liquid separation into a single process. Since the membrane acts as a barrier, this improves the effluent quality. Also, the membrane barrier eliminates the secondary clarifier and allows the activated sludge to be more concentrated. This reduces the volume requirement for biological tanks, thus saving space and money. Overall, the MBR process reduces footprint significantly compared to the combination of wastewater treatment followed by sand filtration or ultrafiltration. The footprint savings due to the wastewater treatment plant alone can be as much as 50%, and there are additional footprint savings since the additional tertiary filtration steps are eliminated.

*Example of MBR Technology*

There are many different configurations of MBR technology. One example that optimizes both membrane and module design is the PURON™ submerged hollow fiber UF module from the authors' company. The patented module is designed to avoid the clogging and sludging that is an issue with some MBR module designs offered today. The module features hollow fiber membranes with a pore size of approximately 0.05 micron. The lower ends of the membrane fibers are fixed in a header while the upper ends are individually sealed and are free to move laterally as shown in Figure 1. All solids and particulates remain on the outside of the fibers while permeate is sucked out of the inside of the fibers by means of a vacuum.

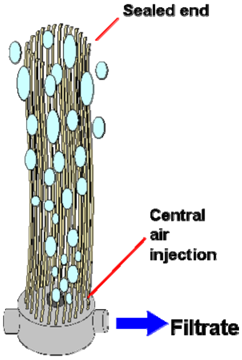

**Figure 1.** Membrane bundle

The fibers are arranged in bundles and are submerged vertically into the activated sludge. To maintain the filtration rate of the membrane modules, air scouring is carried out at regular intervals. An air nozzle is integrated into the center of the bundles to apply the air for scouring purposes. The central arrangement of the air nozzles inside the membrane bundles reduces the energy consumption, since the air is injected at the place where the risk of sludging is highest. The module design ensures that even hairs and fibrous compounds will be removed reliably from the system, so that a coarse prescreen can be used, thus improving capital and operating costs.

A special feature of these membranes is their enormous mechanical strength. This mechanical strength is provided by a braid inside the membrane material.

The individual fiber bundles are connected in rows. Several of the rows are mounted into a frame made of stainless steel to form a module as shown in Figure 2. The free moving fibers combined with central aeration ensure stable filtration during plant operation, long membrane life, and low operating costs by reducing the need for energy, cleaning and maintenance.

**Figure 2.** UF Module for MBR

## Benefits of MBR for RO Treatment

There are a number of benefits of using MBR in comparison to UF as pretreatment for RO. First of all, the MBR process improves quality of effluent in terms of BOD and COD over conventional wastewater treatment followed by UF.

For example, Table 1 shows data of influent at effluent quality from a demonstration MBR plant at the Honoliuli Wastewater Treatment Plant, HI. BOD levels are consistently around 2 mg/l, which is much better than the 10-20 ppm typically achieved by a conventional WWTP. COD and TOC levels are also low. In addition, the treated effluent achieved 0.00 PFU/100 ml of coliphage in the effluent, from a feed with 5.2 – 6 x 105 PFU/100 ml.

**Table 1.** MBR water quality – Honoliuli Wastewater Treatment Plant, HI

| **BOD (mg/l)** | | **COD (mg/l)** | | **TOC (mg/l)** | | **TN (mg/l)** | | **Oil&Grease (mg/l)** | |
|---|---|---|---|---|---|---|---|---|---|
| Inf. | Eff. | Inf. | Eff. | Inf. | Eff. | Inf. | Eff. | Inf. | Eff. |
| 253 | 1.42 | 533 | 20.2 | 55.3 | 7.3 | 38.0 | 7.6 | | |
| 253 | 1.62 | 578 | 16.7 | 89.4 | 6.4 | 36.0 | 8.2 | | |
| 298 | 1.77 | 687 | 14.9 | 90.7 | 7.5 | 36.8 | 8.2 | 23.8 | 0.00 |
| 268 | 1.94 | 448 | 8.0 | 47.6 | 6.2 | 32.4 | 6.6 | | |
| 211 | 1.87 | 465 | 12.5 | 48.3 | 5.8 | 32.4 | 8.2 | | |
| 150 | 1.84 | 391 | 16.5 | 44.7 | 6.4 | 30.4 | 6.0 | | |
| 287 | 2.62 | 621 | 18.2 | 72.4 | 6.5 | 43.6 | 6.8 | 27.1 | ND |
| 233 | 1.49 | 531 | 8.9 | 65.4 | 7.1 | 52.8 | 4.4 | | |

One parameter looked at carefully for operation of RO systems is SDI (silt density index). The SDI is a measure of how much water fouls or plugs a 0.45 micron filter paper. While this test has a number of practical issues relating to how meaningful the number actually is, if the 15-minute SDI is less than 3, then generally the RO systems operate well without plugging or fouling problems. Table 2 shows SDI measurements for MBR-filtrate from MBR demonstration plants operated at Point Loma, San Diego, CA and Honoliuli wastewater treatment plant, HI. Both these demonstration plants treated municipal effluent. This would be excellent feed water for an RO system.

**Table 2.** SDI Data

| Location | $SDI_{15}$ |
|---|---|
| Point Loma, CA | 1.5 – 1.8 |
| Honouliuli, HI | 1.7 – 2.7 |

Organics can foul the SDI paper, causing a high SDI reading even for waters with minimal suspended solids. This is not generally an issue with MBR-treated municipal effluent. Typically, on municipal effluent, most of the organics in the wastewater are biodegradable. Since an MBR produces water with very low BOD (typically 1-2 ppm), there are few organics in the effluent and so the SDI measurements are low.

Industrial wastewaters can be more challenging for any treatment scheme. If all organics are not biodegradable, then there will still be organics in the biologically-treated water. Whether sand filtration, UF or MBR technology is used for the solids-liquid separation step, these organics can still cause the effluent to have a high SDI value since organics may foul the SDI paper. This may or may not contribute to fouling of the RO membranes. However, typically, MBR systems do an excellent job of optimizing the biological treatment step so that the COD level after an MBR is usually lower than after conventional wastewater treatment. Hence, MBR-treated industrial effluent is less likely to have issues with organic fouling in comparison with effluent that is treated by a conventional WWTP plus sand filtration or UF. Additionally, while both MBR and UF provide a barrier to bacteria, since organics can provide food for biogrowth, the MBR system should be best able to reduce the risk of biofouling in the RO.

The level of phosphate in wastewater effluent relates more to the choice of wastewater treatment scheme – i.e. whether the process includes biological nutrient removal or a coagulation/sedimentation or coagulation/filtration step to remove phosphate. MBR technology has been shown to be able to produce water with phosphate levels as low as 0.1 ppm. This can eliminate calcium phosphate scaling in the RO.

As discussed above, UF does an excellent job of protecting the RO from upsets in a conventional WWTP, but can suffer from these upsets and become fouled. Since the MBR eliminates the secondary clarifier and the operation of an MBR tends to be much more stable, the whole process becomes less likely to suffer from upsets that can affect membrane life and increase the overall system operating costs.

## Case Studies – MBR as RO Pretreatment

### *Chemical Industry, Belgium*

The production of chemicals for film processing and printing applications requires large amounts of fresh water. In the case of a Belgian company, the water is used for cleaning purposes and additionally as the main component in the end-product, which contains up to 50% demineralised water. Besides a low salt content, the water must have a total nitrogen content of less than 1 mg/l. The production process operates in batch mode, and, since many different formulations are made, the production equipment has to be cleaned thoroughly before the next batch can be started.

To reduce costs for fresh water, a water saving plan was introduced. As part of this plan, wastewater reuse was a major goal. An RO system was selected to produce water with the required low salt content. However, the nitrogen compounds in the wastewater (nitrate and ammonia) had to be removed before the RO, since they would not be sufficiently rejected by the RO membranes. The problem was solved by installed a submerged hollow fiber MBR with 500 m2 of membrane area prior to the RO. The filtrate from the MBR is fed to the RO, and the system has been operating successfully since May 2005. The MBR treats 5 m3/hr, and the RO system operates at 50% recovery to produce 2.5 m3/hr. Water quality data for the MBR influent, effluent and RO product are shown in Table 3. The system is meeting all water quality requirements.

**Table 3.** Water Quality Data

| | MBR Influent | MBR Effluent | RO Product |
|---|---|---|---|
| BOD (mg/l) | 80 | < 5 | |
| COD (mg/l) | 500 | 400 | |
| TSS (mg/l) | 20 | | |
| Ammonia (mg/l) | 55 | < 1 | |
| Nitrate (mg/l) | | < 1 | |
| Total Nitrogen (mg/l) | 75 | | < 0.1 |
| Conductivity (µS/cm) | 1800 | | < 100 |

### *Industrial Wastewater Recycling, Australia*

An industrial company in Australia uses a large amount of water, and so wanted to reduce the volume of fresh water needed by recycling the wastewater. A biological wastewater treatment process was required to treat the wastewater to reduce the COD (Chemical Oxygen

Demand) level in the wastewater and to provide a barrier to suspended solids. A reverse osmosis (RO) system was needed to further reduce organics and color and to reduce the Total Dissolved Solids to less than 400 mg/l. MBR technology was selected for the wastewater treatment process since it was able to provide the best quality water to feed the RO, and minimize overall operating costs. After evaluating bids from several suppliers, a general contractor was selected to provide the turnkey wastewater recycling system. The system use MBR modules from the authors' company, as well as an RO System from the authors' company. This system is the first commercial system in the world to use large-diameter RO elements for water reuse, although similar modules have been operated in a demonstration plant at the City of Scottsdale, AZ. One of the reasons the MBR modules were chosen is the successful operation of these modules treating industrial effluent in Europe.

The wastewater recycling plant consists of four stages; mechanical pretreatment, the biological process, the membrane filtration system, and the reverse osmosis system. The system was commissioned in March/April 2006. After coarse impurities from the industrial process have been removed via prescreens, the mechanical pretreatment stage, the wastewater is fed into the bioreactor. After sufficient retention time in the biological tanks, the treated water is fed into the membrane tank where it is separated from the activated sludge by the membrane modules, which are submerged in the tank. The concentrated activated sludge is recycled to the aeration tank.

The MBR effluent is the feed to the RO system. Large diameter 18-inch by 60-inch RO elements, with seven times the membrane area of 8-inch by 4-inch RO elements, were selected to minimize the number of components and O-ring for ease of operation and greater reliability.

The MBR system is designed to treat 400,000 gallons per day of wastewater. The RO system then recovers 75% of the MBR effluent as product water for reuse.

## Costs of alternate pretreatment technologies

Costs of the three alternate pretreatment technologies discussed above will vary depending on issues specific to a site. Hence, rather than attempting to estimate costs, the authors have opted to compare relative costs for the three processes. Table 4 summarizes the costs that should be considered when looking at alternative treatment trains, and the cost factors are discussed below.

**Table 4.** Cost Factors

| | Conventional WWTP + Sand filtration | Conventional WWTP + UF | MBR |
|---|---|---|---|
| Footprint | High | Medium | Low |
| Civil works | High | Medium | Low |
| Equipment - Pretreatment | Low | Medium | Medium |
| Equipment - RO | High | Medium | Medium |
| Power consumption – WW treatment | Medium | Medium | High |
| Power consumption – solids-liquid separation | Low | Medium | Medium |
| Power consumption - RO | High | Medium | Medium |
| Chemical consumption | Medium | High | Medium |
| Membrane replacement - filtration | None | High | High |
| Membrane replacement - RO | High | Medium | Medium |
| Susceptibility to upsets | High | Medium | Low |

*Footprint*

Tertiary filtration steps with sand filtration or UF require conventional wastewater treatment prior to the tertiary filtration step. Sand filtration typically requires more footprint than a UF system. Since the MBR system reduces the volume of the bioreactor tanks and eliminates the secondary clarifier, the footprint for an MBR process is much smaller than either of the other options.

*Civil Works*

Since MBR requires least tankage, the cost of civil works is lowest for MBR. For a large WWTP, sand filtration will probably be gravity sand filtration, so the cost of civil works is highest for this option.

*Equipment Costs*

The conventional WWTP plus sand filtration option uses the least equipment, so is lowest equipment cost. Both MBR and UF require membrane filtration systems. Equipment cost is of a similar order of magnitude for both systems – there is probably more variability depending on system configuration from supplier to supplier than between UF and MBR specifically. UF systems typically operate at slightly higher fluxes than MBR systems (although this depends on the quality of secondary effluent feeding the UF system), thus reducing the cost of the membrane component of the equipment for the UF system.

Since the water quality feeding the RO system is worst with sand filtration as pretreatment, the RO system following this would typically be designed at a lower flux rate, thus increasing the number of membranes, vessels, skids and equipment cost for the RO system. The difference in design parameters selected for an RO following UF versus RO following MBR is less apparent, although as more MBR systems are installed as RO pretreatment, the RO designs may be further optimized to take advantage of the improved water quality after MBR.

*Power Consumption*

The major uses of energy in the treatment scheme are the energy related to the biological treatment process, the energy for the solids-liquid separation process and the energy for the RO process.

Since the bioreactor in an MBR system operates at a high concentration of mixed liquor, the alpha factor for oxygen adsorption into the activated sludge is lower. Hence the power consumption for the MBR process for biological treatment is higher than for a conventional WWTP.

The solids-liquid separation process for a secondary clarifier followed by sand filtration is lowest because this is mainly a gravity-driven process. The power consumption for the MBR and UF processes are similar, with variation depending on the operating trans-membrane pressure of a specific membrane configuration, the operating mode recommended by the supplier, and the requirements for air to scour the membranes.

Power consumption for the RO process is expected to be highest for the conventional plant because the RO membranes are expected to suffer significant irreversible fouling, increasing the operating pressure of the process. There is insufficient data today to determine whether RO after MBR would operate at lower pressure due to less organic fouling in comparison with RO after UF.

*Chemical Consumption*

The conventional WWTP plus sand filtration uses the least chemicals for pretreatment, but the most chemicals to clean the RO system. Both the MBR process and UF process use some chemicals, but the chemical consumption of the MBR process is typically less than for the UF process. Both will also use chemicals to clean the RO system.

*Membrane Replacement*

The conventional process does not use membranes for pretreatment so there is no membrane replacement cost to factor in to the analysis. There will be a requirement to replace filter media over time, but this is typically a fairly low cost. The cost of membranes for the UF and MBR processes are a similar order of magnitude.

Since the conventional system uses more RO elements due to operating at lower fluxes, and is expected to experience more fouling and more frequent membrane replacement, the costs of RO membrane replacement for the conventional system will be higher than for the RO systems using UF or MBR pretreatment.

*Susceptibility to Upsets*

One cost factor that needs to be considered, although it can be very difficult to estimate a value at the design phase of a project, is the potential risk related to the susceptibility to upsets. While all three treatment schemes discussed are successfully used today for RO pretreatment, the risk of an upset varies. The costs of upsets can include downtime to clean the membranes, additional capital equipment to allow for additional cleanings, additional labor to monitor the process, additional power and chemical consumption due to operation with fouled membranes, and additional membrane replacement.

## Optimizing the treatment train

The optimal treatment train for a specific application requires consideration of the factors above. A primary consideration is frequently footprint. If space is limited, MBR may be the only choice of pretreatment that will fit in the available space.

A secondary consideration is whether all the water from a wastewater treatment plant will be recycled, or whether just a sidestream will be recycled. If most of the wastewater will be discharged and the discharge requirements are not particularly stringent, then a conventional WWTP may be the best option for the whole plant, with a sidestream treated to tertiary standards with either sand filtration or UF.

Another consideration is the final water quality requirement. For example, if water with very low ammonia levels after the RO is needed, MBR may be selected to minimize ammonia in the RO feed since ammonia is not well-rejected by RO at pH less than 9.

Other considerations include costs of land, civil works, equipment, power, chemicals and labor, and the length of time considered when evaluating the options. High land and civil costs tend to favor MBR technology. For a large municipal plant looking at a 20 year net present value analysis, membrane filtration pretreatment is generally favored over conventional pretreatment due to the savings in RO membrane replacement and power. For an industrial company looking at a short payback, the preference for conventional or MBR will depend on the relative cost of civil works and land versus the equipment cost.

## Conclusions

The use of RO for water reuse is growing rapidly. MBR technology can be used as pretreatment to RO for industrial and municipal effluents to provide high quality feed water to the RO, to minimize footprint and the cost of civil works, and to reduce the susceptibility of the treatment train to upsets.

The optimal treatment train for a specific application depends on a number of factors, but we expect that, in the future, MBR technology will be considered for an increasing number of reuse applications.

# Reducing Environmental Impact and operating costs through Membrane Technologies

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## Abstract

Today water is used in large quantity for several purposes and then discharged to local water system with poor quality, threatening the surface and the groundwater resources into which it is discharged. The increasing concentration of pollution and water consumption results in high operating costs and impoverishment of costal habitat.

In EU countries, the compliance with stringent effluent requirements and limitation in water withdraw (water scarcity and drought) have been forcing industry and local authorities to implement innovative “environmentally friendly” solutions and water management policy.

Although membrane technology is relatively young, continuous progresses make it a prime candidate to comply with the most restrictive discharge limits, reducing operating cost and alleviating severe water shortage across the globe. This presentation covers the use of most advanced membrane technologies (Reverse Osmosis, MBR, EDI, EDR) in industrial and municipal water treatment applications.

# Session 4

## Membrane desalination

# Membrane desalination : present and future – A researcher's perspective

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## Summary

Membrane-based desalination tends to be a necessity for coping with the serious shortage of clean water on a global scale. Membrane desalination technology dominates the scene as it possesses distinct advantages over other methods, notably the thermal processes. The main advantages are summarized as follows:

- It is cost effective and environmentally preferable, compared to competing technologies; indeed, both the specific energy expenditure and the use of chemicals are lower than in other methods. Furthermore, the membrane plants are compact and their foot-print is small.
- A variety of water sources can be effectively treated with membranes; i.e. sea and brackish-water, as well as various effluents with toxic pollutants.
- The modular design of membrane desalination plants facilitates scale-up and adaptability of the process to any plant capacity.

In this lecture the present state-of-technology will be briefly assessed. In particular, the main issues involved in development and implementation of a large scale desalination project will be outlined. An overview of the main technological features of the process will be presented with emphasis on their impact on energy expenditure and cost. An overall assessment will be summarized pointing to areas in need for technological improvements. Based on this assessment, specific topics for R&D will be outlined as well as generic scientific areas, where progress is expected to have significant cost and environmental benefits.

## PRESENT STATE OF TECHNOLOGY

### Main issues in project development

A large membrane desalination project is a typical engineering project; i.e. when viewed in its entirety, during the stage of project development, one is concerned about the following four categories of issues. The same issues should be reviewed in an assessment of the present state of technology.

- *Technological issues:* Is the technology mature in general? Which particular aspects of technology need development to reduce design uncertainties and the risk associated with them? Are there variants of the technology worth considering as design alternatives?
- *Economic issues*: Careful analysis of total product cost and identification of main areas that should be considered for reduction of expenses. Main components of capital investment and possibilities for reduction.
- *Environmental issues*: The direct and indirect environmental impact should be assessed.
- *Social issues*: These issues as in any major engineering project tend to be rather critical in recent years. They include adequately informing the public on the scope of the project and all its main aspects and securing their acceptance early enough in project development.

## The typical desalination plant

The typical desalination plant[1] is comprised of the following main parts (Fig. 1):

i) **Intake water facility.** This is of particular significance in the case of seawater desalination plants where one has the choice of either an “open intake” (with intake pipes usually at the sea bottom) or “beach wells” drilled near the plant.

ii) **Pre-treatment section.** This is An important section which determines, to a large extent, the successful design and operation of the entire plant as it prepare the feed to the following (RO/NF) membrane treatment section. RO and NF membranes are prone to fouling, leading to serious operating problems if the pre-treatment process is ineffective. Intensive R&D has been carried out in the past 10 years, and it is still in progress, to develop effective pre-treatment processes. A variety of such processes in currently available, including combination of coagulants with dual granular media, coagulants with MF/UF filtration, froth flotation, etc.

iii) **Main treatment section,** comprised of high pressure pumps, energy saving devices, RO/NF membrane trains, membrane cleaning system, monitoring equipment. This is certainly the most important section, subsequently reviewed.

iv) **Post-treatment section** of product water. This treatment is usually performed by rather simple means to adjust the membrane permeate characteristics and render them comparable to potable clean water properties, regarding the trace inorganic compounds necessary for human consumption .

v) **Concentrate disposal.** Ensuring environmentally safe disposal of the concentrated brine has become an issue that has gained particular significance in recent years, especially in large desalination plants.

The plant sections that need special attention with regard to optimizing operation and minimizing cost are (ii) and (iii). Part (v) needs to be considered in respect of minimizing environmental impact of desalination operations. Obviously, under some conditions (e.g. rather large, land-locked, desalination plants), handling concentrates with a minimum of environmental impact may incur significant expenses, impacting on overall process economics.

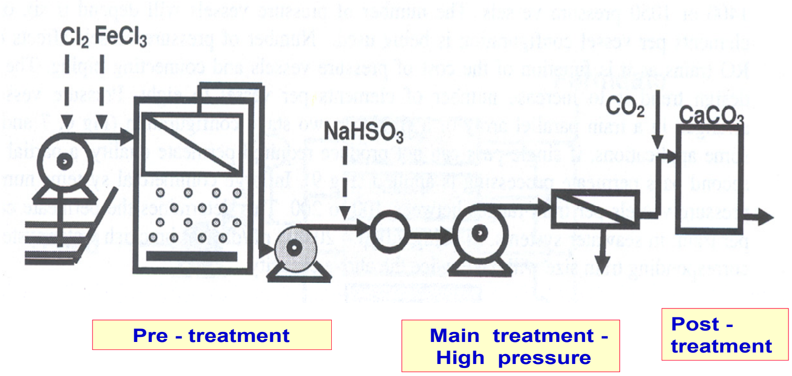

**Figure 1.** RO system with membrane (MF/UF) pre-treatment

## Key components and features of the main treatment section

The components of the main treatment section are as follows:

- *High pressure pumps.* This is a rather mature area of technology that only needs some system design improvements.

- *Energy recovery devices*. Development and use of these devices was a major factor in significant desalination cost reduction during the past 10 years.
- *Pressure vessels with membrane elements*. Major components of the complete pressure vessel assembly include:
  - The pressure vessel itself and its various design features (mode of connecting elements, o-rings, feed inlet and permeate outlet design, etc)
  - The membrane module, which is the “heart” of the desalination process. The spiral wound modules (SWM) dominate the market for (RO and NF) desalination plants. The main features of SWM that need special attention are the membrane itself (and the specific physicochemical properties of its active surface layer), and the feed-side and permeate side spacers (Fig. 2). The active layer of the membrane and the feed or concentrate side spacer are of critical importance for optimizing membrane element and overall plant performance. A view of the active layer is shown in Figure 3.

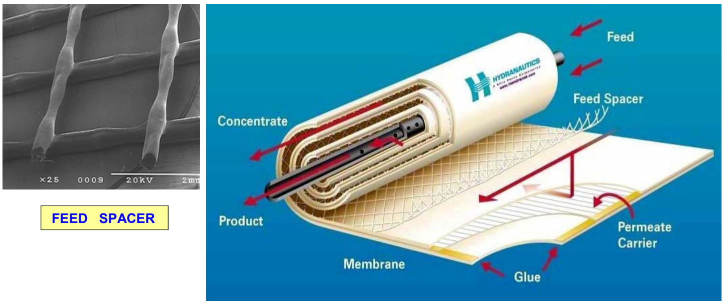

**Figure 2.** Details of spiral wound membrane elements.

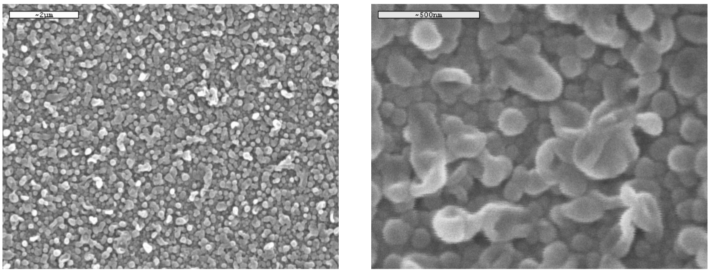

**Figure 3.** RO Polyamide Membranes (top view of active layer)

## Economics of Desalination

Figure 4 provides a summary[2] of the itemized percentage costs for seawater desalination. The main cost factors comprising ~86% of the total cost are: electrical energy consumption (42%), capital expenses (28%), membrane replacement cost (7%) and chemicals (9%). These factors are in fact related with areas where technological improvements are possible with concomitant cost reduction. Furthermore, it is evident that there is scope in focusing on reduction of specific energy consumption as it can lead to both cost and environmental benefits.

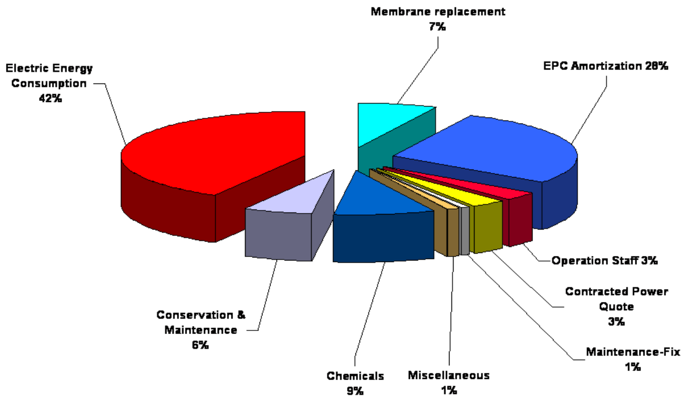

**Figure 4.** Itemized percentage costs – Seawater desalination (source: PRIDESA[2]).

Specific energy consumption has been steadily decreasing[3] over the past 25 years (Fig. 5) due to technological developments mainly related to improvement of membrane active layer properties and to increased energy efficiency after the introduction of energy saving devices. Thus, at present large RO plants can achieve a specific energy expenditure as low as ~3.50 kWh/$m^3$. It is instructive to examine the distribution of energy usage in a RO sea-water plant with partial second stage (Figure 6). The energy losses due to pressure drop in the membrane trains, despite the increased overall efficiency, dominate. At the same time this distribution and type of energy losses clearly show the direction R&D should take to achieve substantial benefits. Suffice it to say here that careful assessment of energy losses, as well as exergetic considerations, suggest that the reduction of specific energy consumption down to ~2.50 kWh/$m^3$ over the next 7-10 years should be an achievable target. R&D needs that would aid in this direction are subsequently outlined.

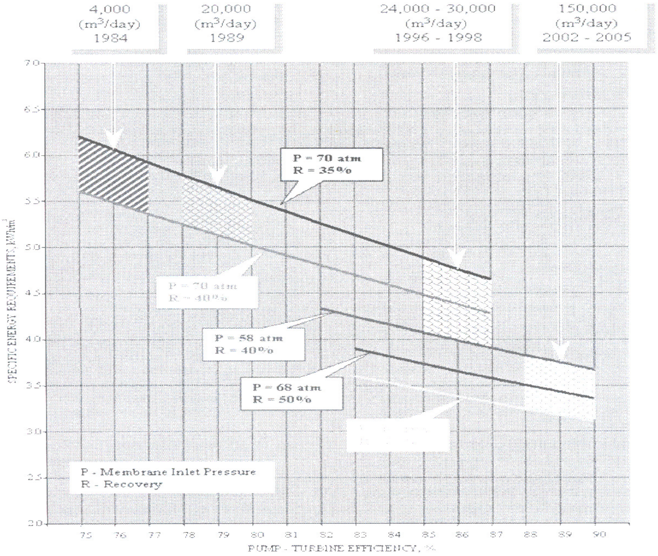

**Figure 5.** RO plants: Reduction of specific energy over the past 25 years; Glueckstern[2].

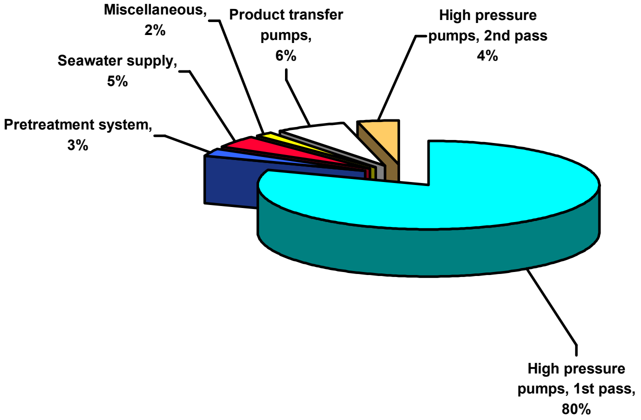

**Figure 6.** Distribution of energy usage in RO desalination plant with partial 2nd stage[2].

## Environmental issues

Aside from the energy requirements of desalination, outlined above, other aspects of the technology with possible environmental impact include:

- Disposal of concentrate, and the chemicals contained therein.
- Materials requirements; there is scope, and efforts made, to minimize use of stainless steel and other metals in favor of plastic materials.
- Land use is the only other, albeit relatively insignificant, environmental issue.

It will be noted that environmental impact studies of new desalination plants should be of a broader scope, taking into account not only the possible environmental burden due to RO plant operation, but also the associated significant benefits to human welfare resulting from the availability of clean potable water. Along these lines, it would be necessary to carry out ***comparative impact assessment studies of alternative approaches/scenarios for combating water scarcity***; such alternatives include the use of bottled water, or transfer of clean surface water (if available) over long distances, and should consider the environmental burden associated with them. These comparative studies, of the Life Cycle Impact Assessment type, would be necessary to settle arguments, for and against membrane desalination plants, that are occasionally raised.

# RESEARCH NEEDS FOR TECHNOLOGICAL IMPROVEMENTS

## R&D needs based on economic and technological objectives

The following areas may be readily identified:

*1. Reduction of specific energy expenditure*

This target can be served by improving:

- The membrane surface properties. There is a host of physico-chemical properties that play a dominant role in the effectiveness of separation and the permeation flux characteristics of the membrane, including hydrophobicity, surface charges, chemical resistant to oxidants, etc.
- The membrane module design ; e.g. feed-side spacers, membrane element configuration, pressure vessel design. Here again, significant R&D work is carried out, since pressure drop and smooth plant performance depend on these design features. For example, the

geometry of spacers is shown to play a key role in determining the pressure drop directly, and indirectly by reducing concentration polarization effects (e.g. Koutsou et al [4-6])

- Ancillary equipment design and operation. Possible efficiency improvements of energy exchangers fall in this category.

*2. Reduction of plant fixed expenses*

- Improvement of main equipment, and plant design. Significant progress has been made by introducing large membrane elements very recently; i.e. 16-inch elements instead of the current 8-inch industry standard. There appears also scope in pursuing an improvement of the current pressure vessel design, at least for some types of applications.
- Reduction of plant foot-print and complexity is still desirable. Pursuing a more compact design, with reduced piping complexity is a valid target.

*3. Reduction of operating expenses*

- Optimization of additives employed is a significant target; optimizing the use of coagulants , anti-foulants (biocides, etc) and anti-scalants is worth pursuing.
- Development of effective fouling mitigation techniques has been an R&D target for the past 2-3 decades with significant results. Yet, problems (often unexplained) continue to hinder smooth plant operation. Reduction of membrane chemical cleaning frequency, with concomitant reduction of wasted water and chemicals, as well as of membrane degradation can lead to very significant cost benefits.
- Improvement of plant monitoring and control techniques, could significantly contribute to smooth plant operation and cost reduction.

*4. Other important areas*

- Utilization of Renewable Energy sources, as much as possible, is a goal of paramount importance. This is currently achieved only for small scale desalination plants.
- Improvement of techniques of concentrate treatment and disposal, is currently studied mainly for plants fed with seawater. Acute problems exist in the case of inland desalination plants.

## Generic research areas

The preceding technological targets can best be served by parallel progress in generic research areas. Such areas of basic research, pursued by many scientists at present, are summarised as follows:

- Membrane materials
    - Composite materials with special properties, functionalised polymeric materials to impart specific properties to the membrane, new materials involving nano-tubes, are included in this research field which is considered fertile.
    - Membrane surface property restoration; there is a need to extend the life of used membranes which tend to age and be degraded for various reasons.
- Membrane surface – species interaction

  Basic research to deal with the following problems is rather extensively carried out and it is foreseen to continue and to bear fruits.
    - Membrane fouling by organic and/or colloidal species (e.g. Yiantsios et al [7])
    - Rejection of toxic dissolved organic species; i.e. micro-pollutants and emerging contaminants rejection (e.g. Plakas and Karabelas[8])
    - Causes and means to counter membrane degradation, as well as development of basic understanding of surface property restoration techniques.
- Transport phenomena

  Improvement of computational and experimental tools to study momentum and mass transfer phenomena:

  - Within membrane elements and related process equipment.
  - To facilitate membrane spacer studies and optimization.

- Effect of various rejected species on the environment, mainly the aquatic environment and soil.
- Integrated approach to desalination system design and assessment of operation.
  Generic tools developed in other fields of engineering science would have to be adapted for such applications. Advanced system optimization techniques and the Life Cycle Assessment methodology are tools to be applied to desalination project and plant design.

## Concluding remarks

As overall assessment of the present status of membrane desalination shows that this technology has made very significant advances, especially over the past 10 years. Though, still considered by many as a relatively “young” technology, it has reached a rather high level of maturity. Membrane-based desalination plants are rapidly becoming the technology of choice, due to their comparative technological, economic and environmental advantages. It is also significant to stress that technological developments spear-headed by membrane desalination have had a tremendous positive impact on the entire water and waste-water treatment field.

To summarize, significant technological and scientific challenges still lie ahead; notably the reduction of specific energy expenditure and further minimization of overall environmental impact. The contribution of multi-disciplinary, innovative R&D is considered critical for improving membrane desalination, for the benefit of people on this earth.

## References

1. Wilf M., “Fundamentals of RO-NF Technology”, Proceedings, *International Conference on Desalination costing*, 6-8 December 2004, Lemessos, Cyprus, pp.18-31.
2. Diaz-Canze J., Farinas M., Jimenez A., “Spanish cost data illustrate RO’s competitiveness”, *Desalination & Water Reuse*, Vol. 15, No 1, pp. 10-17, 2005
3. Glueckstern P., “History of Desalination Cost Estimations”, Proceedings, *International Conference on Desalination costing*, 6-8 December 2004, Lemessos, Cyprus, pp.1-17.
4. Koutsou C.P., Yiantsios S.G., Karabelas A.J. “Membrane Module Performance Optimization Using CFD Simulation of Flow Through Narrow Channels with Spacers”, Proceedings, *IDA World Congress on Desalination and Water Reuse,* Maspalomas, Gran Canaria, Spain*,* October 21-26, 2007
5. Koutsou C.P., Yiantsios S.G., Karabelas A.J., “Direct numerical simulation of flow in spacer-filled channels: effect of spacer geometrical characteristics”, *J. Membr. Science* , 291, pp 53-69, 2007
6. Koutsou C.P., Yiantsios S.G., Karabelas A.J. “A numerical and experimental study of mass transfer in spacer-filled channels: Effects of spacer geometrical characteristics and Schmidt number”, *J. of Membrane Science,* vol. 326*,* pp 234-251, 2009.
7. S.G. Yiantsios, D. Sioutopoulos, A.J. Karabelas, “Colloidal fouling of RO membranes: An overview of key issues and efforts to develop improved prediction techniques,” *Desalination*, 183, (2005), pp. 257-272.
8. K.V. Plakas, A.J Karabelas, Membrane retention of herbicides from single and multi-solute media: The effect of ionic environment, *J. Membr. Sci*ence, 320 (2008) 325–334.

# Exploring MBR technology as pre-treatment in reverse osmosis seawater desalination

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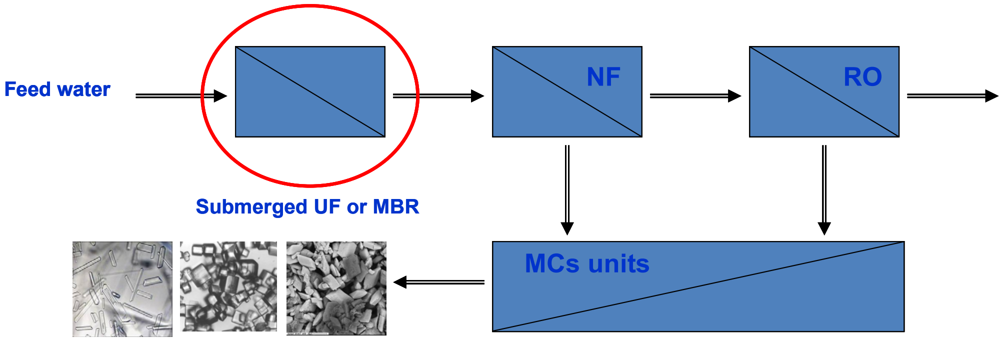
## Introduction

The fundamental idea which aims the MEDINA consortium is the possibility to overcome current limitations and to improve traditional desalination practices - by increasing water quality, increasing recovery factor, reducing impact of brines and preventing membrane fouling thus achieving a generalized reduction of the cost for desalted water – by using integrated membrane systems working on the concepts of zero-liquid or quasi-zero-liquid discharge [1]. According to this strategy an integrated membrane system (Scheme 1) where membrane operations, like Nanofiltration, Microfiltration and Ultrafiltration, are used as pretreatment steps to RO is proposed. Furthermore, Membrane Contactors, in the form of Membrane Distillation and/or Membrane Crystallization, are integrated into the process to increase water recovery factor and to convert the huge amount of brine produced in valuable crystals with the required structure (polymorphism) and morphology (size, size distribution, shape, and habit).



**Scheme 1.** The flow sheet of an integrated membrane system proposed in the MEDINA project.

However, the necessity to control the crystallization kinetics is linked with the nature and the amount of organic molecules existing in the highly concentrated brines of the NF and RO. These substances, other than act as foulant for RO membranes, would be incorporated into the crystal lattice then hindering the crystallization kinetics, leading to the cessation of growth or to the production of crystals with undesired properties.

In this logic the possibility to use membrane bio-reactor (MBR) technology [2] as pre-treatment for sea water, in order to reduce natural marine substances and organic molecules deriving from the increasing pollution of the marine coasts, will be useful: (1) to reduce organic fouling and bio-fouling of membranes and (2) to control the crystallization kinetics and crystals characteristics.

Although technically MBR technology has been demonstrated to be suitable for the removal of organic polluting/foulant compounds from municipal wastewater by achieving high-quality effluents [3], two issues still remain open for its full introduction in water desalination:

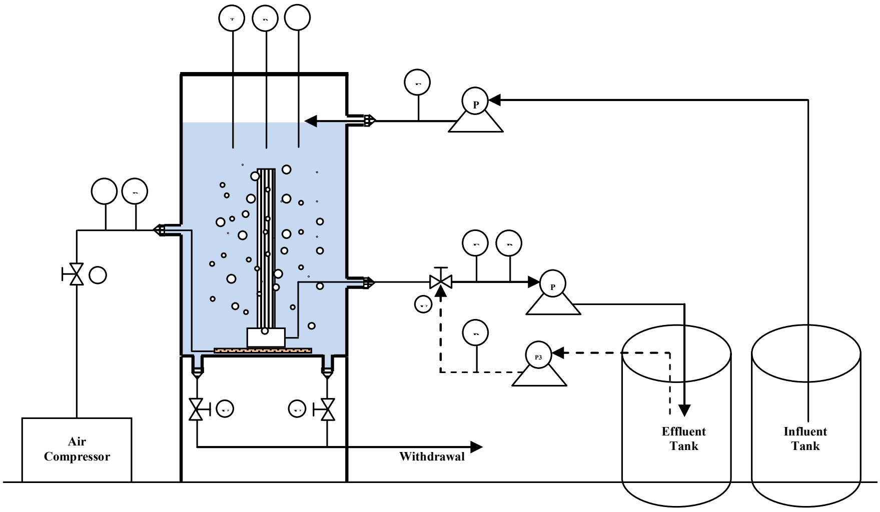
maintaining a high level of efficiency even in medium and high saline environments and its costs. Whilst some studies have been conducted that have identified the onerous impacts of saline shock on conventional bio-treatment in terms of COD removal [4,5], very few have focused on the use of MBRs as a feed water pretreatment step for desalination purposes [6]. Nevertheless, the numerous advantages already exhibited by MBRs in municipal water treatment processes are encouraging, prompting further exploration of the potential applications of this technology to reduce/eliminate (bio)fouling from feed water in desalination. With respect to costs, MBR is considered a high-tech process with high initial investment costs when applied to wastewater treatment. However, this is not the case when MBR is used to treat seawater, the typical total organic carbon concentration of which is reported to be in the range of 1.0-3.0 mg/L. Under such conditions the use of MBR technology, especially in the submerged configuration, could be particularly cost-effective. This justifies the research action included in the MEDINA project, which aims to study the effectiveness of MBR as pre-treatment stage in seawater desalination.

## Experimental

UltraPes hollow fiber membrane (70 kDa MWCO, from Membrana, Germany) were used to assemble the one-side potted modules with the total membrane area *S* of 0.08 $m^2$. Modules were prepared in non-carterised configuration to allow more freedom for fibers motion.

Membrane, in vertical arrangement, were used in the bench-scale plant, with a working volume of 20 L, showed in Scheme 2 and operated in submerged conditions, in outside-to-inside filtration mode. Air sparging, by a diffuser, was operated from the bottom of the module by using an air compressor. The effluent has been drawn through the module, by a peristaltic pump, towards an effluent tank. Back-flushing have been operated by using a back-flushing pump.

Seawater from the Tyrrhenian coast (Belvedere Marittimo, Italy) was used to feed the plant without any initial pre-treatment. Water was taken 2-3 meters from the estuarine of a little river in which the water from a traditional depuration plant is discharged after treatment. Water characterization was carried out by a Shimadzu $V_{CSN}$-TOC analyzer for TOC measurements. Sea water have been stored for almost 90 days, at 20±1 °C, before using it in the experiments. In some tests, Humic Acid has been added to seawater in order to increase the initial TOC content.



**Scheme 2.** Laboratory-scale MBR plant used in this work.

Experiments have been carried out by operating at different trans-membrane pressure *TMP* (kPa), flux $J$ (L $m^{-2}$ $h^{-1}$), and aeration operation mode (continuous or intermitted) to characterize the system. At the beginning of the experimental section, the filtration resistance $R_t$ ($m^{-1}$) of the membrane was determined by using the Darcy’s law:

$$J = \frac{TMP}{\mu R_t} \tag{1}$$

where $\mu$ (Pa s) is the viscosity of the permeate (water). The intrinsic resistance for a new module $R_m$ was estimated by pure water permeation. Equation 1 was also used to evaluate the increase in resistance to permeation during the experiments with seawater (SW) due to membrane fouling.

## Results and Discussion

Figure 1 shows the variation of the trans-membrane pressure with the time at a constant flux of 11 L $m^{-2}$ $h^{-1}$. At the time t = 0 the *TMP* was 20 kPa and air was supplied continuously with a flux of 7.6 $m^3$ $h^{-1}$ $m^{-2}$. After a period of almost 1 h, the system reached a stationary condition of 22 kPa *TMP* which remained constant for 5 h of operation. At this point filtration was interrupted and a back-flushing section of 10 min was efficacy for the complete recovery of the original *TMP*. However, after almost 50 minutes after back-flushing *TMP* increased again up to 22 kPa and remained stable at this point. This behavior might be due to the partial plugging of the membrane pores by suspended particles existing in the untreated feed water. After almost 8 h of operation at constant *TMP* (22 kPa), air was stopped and the system was left to operate in quiescent conditions for 13 h. In this period the *TMP* increased from 22 to 29 kPa due to accumulation of particles nearby the membrane surface. Upon restarting aeration, *TMP* decreases and in 2.5 h it stabilized at 23 kPa. This demonstrated that upon restarting aeration, reversible fouling and/or concentration polarization were eliminated. However, as the *TMP* were not completely recovered, some irreversible fouling due to cake deposition in the membrane pores occurred. Therefore, results reported in Figure 1demonstrated that whilst increase in liquid transfer resistance might occur in a reversible way while keeping aeration, polarization phenomena and/or reversible fouling in combination with some irreversible fouling occurs if aeration is not active. This would induce severe loss of performance in the case of long operation time.

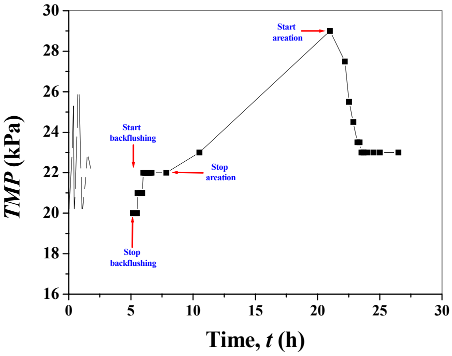


**Figure 1.** Variation of the trans-membrane pressure *TMP* with the time *t* during the experimental section.

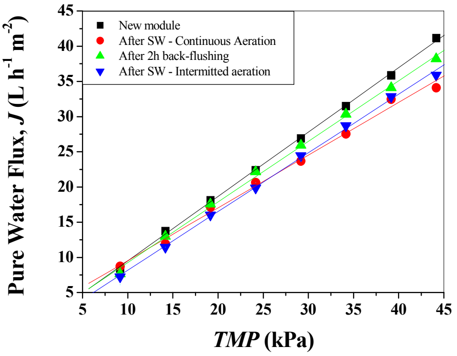


**Figure 2.** Variation of the pure water flux *J* with the trans-membrane pressure *TMP* after each experiment.

Membrane resistance was estimated by using Equation 1 performing two different experimental sections: one in which continuous aeration was operated and the second where intermitted aeration (10 min ON/10 min OFF) was applied to the module. Figure 2 shows the variation of the pure water flux $J$ vs. the trans-membrane pressure $TMP$ before the tests (new module), after SW filtration with continuous aeration, after a back flushing section of 2 h, and after SW filtration with intermitted aeration. From the slope of the lines the intrinsic resistance of the module was find to be $R_m = 3.93 \text{ x } 10^{-9} \text{ m}^{-1}$. At the end of the continuous aeration test the resistance increased of more than 22% ($R_t = 4.80 \text{ x } 10^{-9} \text{ m}^{-1}$). After two hours of back flushing, the final resistance decreased to $R_t = 4.17 \text{ x } 10^{-9} \text{ m}^{-1}$, corresponding to an increase around to 6% with respect to initial value. This variation or $R_t$ is in the same order of magnitude of the increase in $TMP$ (~ 4.5%) observed at the end of the tests. After the intermitted aeration test, the resistance was found to be $4.31 \text{ x } 10^{-9} \text{ m}^{-1}$, corresponding to a value 10% higher with respect to the intrinsic membrane resistance $R_m$.

Figure 3 compares fluxes against $TMP$ for SW filtration in the two aeration modes. The figure demonstrates as, in the case of intermitted aeration, the limiting flux $J_\infty$ is 21.01 L $\text{m}^{-2}$ $\text{h}^{-1}$, only 0.4 % lower that the case of continuous aeration for which $J_\infty = 21.11 \text{ L m}^{-2} \text{ h}^{-1}$. Accordingly, system performance in intermitted aeration conditions does not substantially decrease with respect to continuous aeration, with consequent gain, however, in terms of energy consumption.

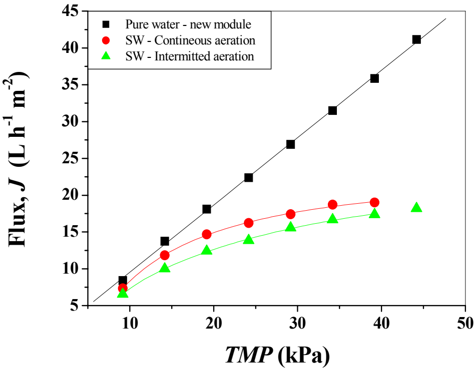


**Figure 3.** Trans-membrane flux $J$ as function of $TMP$ during filtration of SW in continuous and intermitted aeration regimes.

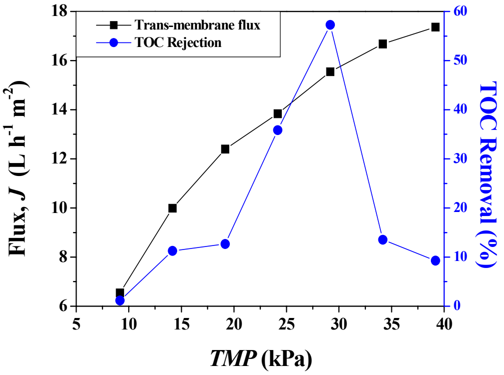


**Figure 4.** Trans-membrane flux $J$ and TOC removal in seawater filtration test as function of $TMP$ in continuous aeration mode.

On what concerns TOC removal, comparison of TOC measured on newly taken water from the sea and after 90 days stored at 20 °C showed a reduction from 2.9 to 1.6 mg/L, accounting for the degradation of organic matter by the action of marine organisms existing in seawater. In Figure 4 the rejection of TOC after the membrane filtration with respect to $TMP$ and flux is reported. As shown in the figure, TOC rejection increases with $TMP$ until the maximum value of ~ 60 %, achieved for $TMP$ around to 30 kPa and a flux of 16 L $\text{h}^{-1}$ $\text{m}^{-2}$. This is due to the fact that water flux increases more than solute flux by increasing the driving force. However, for a further increase of $TMP$ and $J$ a reduction of TOC rejection is observed due to the increase of transport of organic molecules through the membrane above a certain driving force.

## Conclusions

This work attempts for the first time to explore the use of submerged membrane bioreactors technology as pre-treatment step in desalination to reduce natural/polluting organic matter existing in feed seawater. In the logic of the MEDINA project, by achieving this purpose would allow to reduce significantly RO membranes bio-fouling and to eliminate exogenous molecules that will affect/hinder crystallization kinetics in membrane crystallizers. An appreciable reduction in TOC in sea water when keeping it at 20°C for three months demonstrated a certain biological degradation of organic substances by marine microorganisms. The effect of the different operative parameters (trans membrane pressure, flux and aeration mode) on the system performances has been investigated. Experimental results demonstrated that a TOC removal up to 60 % for the sole filtration stage can be achieved, depending on the process conditions, by using 70 kDa MWCO membranes. These preliminary results encourage further researches addressed to increase the biological degradation of organic matter in seawater and to increase TOC rejection in the filtration step by using membranes with lower MWCO.

## Acknowledgement

Authors would like to thank the MEDINA project (contract number 036997) for financial support of this work.

## References

[1] E. Drioli, E. Curcio, G. Di Profio, F. Macedonio, A. Criscuoli (2006), Chem. Eng. Res. Des. 84, 209-220; E. Drioli, E. Curcio, A. Criscuoli, G. Di Profio (2004), J. Memb. Sci. 239, 27-38.

[2] S. Judd, C. Judd (2006), The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment, Elsevier.

[3] S. Rosenberger, C. Laabs, B. Lesjean, R. Gnirss, G. Amy, M. Jekel, J.C. Schrotter (2006), Water Res. 40, 710–720.

[4] M.F. Hamoda, I.M.S. Al-Attar (1995), Water Sci. Technol. 31, 61–72.

[5] A. Uygur, F. Kargi (2004), Enzyme Microb. Technol. 34, 313–318.

[6] C. Visvanathan, N. Boonthanon, A. Sathasivan, V. Jegatheesan (2002), Desalination 153, 133-110.

# MEDINA Project: "Seawater Characterisation and Membrane Autopsies Tools for Better Design and Operation of SWRO plants"

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Despite the improvements of RO technology for seawater desalination, membrane fouling in seawater RO systems remains a major operational problem. Membrane autopsy is a key tool since it enables a diagnosis of the root causes leading to a loss of hydraulic performances. This identification of specific foulants enables to take appropriate measures for expanding membrane life time. Among the techniques used for membrane autopsy, general analyses for organic/inorganic matter allow a rapid screening of foulants collected on RO membranes, but do not provide an accurate identification of foulants.

One of the aims of the European project "MEDINA" is to deeply understand fouling, its origin and mechanisms, by developing advanced analytical tools which would enable to identify the components of foulants. Four RO modules, located in front position of a pressure vessel from the 1st pass of a RO desalination plant, were autopsied and the fouling of these membranes was investigated using these advanced tools.

The monitored hydraulic performances (permeability, pressure drop and salt retention) of these RO membranes, normalized using ASTM D 4516 - 00, did not show major variations.

First, general analyses showed that organic matter represented 60% of the dry deposit and that iron was present at a relatively high level in the fouling layer. Dry matter and iron content remained at a relatively steady level, despite chemical cleanings (Figure 1 and 2). However, chemical cleaning was able to remove manganese and the associated manganese oxidizing bacteria (Figure 3).

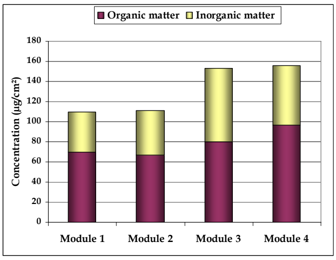

**Figure 1.** Repartition of organic/inorganic matter.

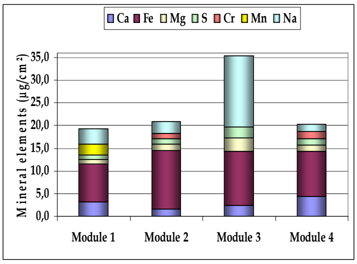

**Figure 2**. Inorganic element within the deposit.

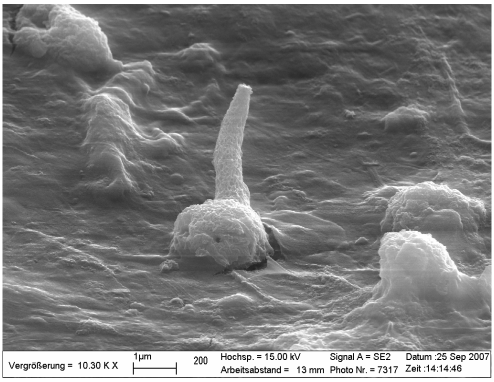

**Figure 3.** Manganese oxidizing bacteria.

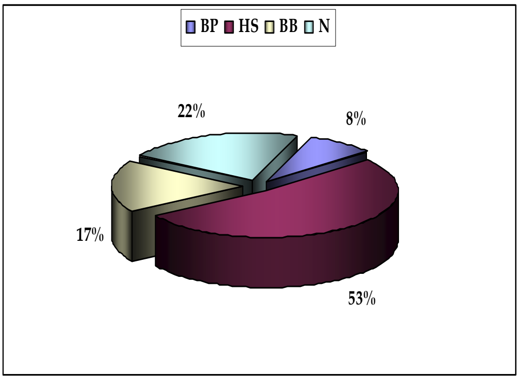

**Figure 4.** DOC fractions repartition (BP: Biopolymers, HS: Humic substances, BB: Building Block, N: Neutrals).

Flash pyrolysis followed by GC/MS enables to determine major organic compounds classes present in the fouling layer. First results showed the predominance of sugar and aminosugar derivatives, compounds that are typical of biofouling material (Figure 5). Moreover, results put into evidence that deposit was mainly from bacterial origin which was confirmed by the predominance of C16 derivatives in the chromatograms obtained after Thermochemolysis GC/MS (Figure 6).

SSCP (Single Strand Conformational Polymorphism) analysis was used to characterize the diversity of total and active bacteria, through respectively the analysis of DNA and RNA of microorganisms present at the membrane surface. Clones libraries were also built to identify the bacteria species present in the deposit whose major group consisted of betaproteobacteria (Figure 7).

Moreover, in an attempt to correlate RO feed water quality and membrane fouling, RO feed water was sampled at the same time as RO modules. A deeply characterization of the organic and microbial content was conducted. In this aim, in the frame of Medina project, a special effort was made on the development of new water quality indicators and advanced analytical tools to assess the fouling potential of seawaters, beyond usual parameters, such as SDIs and turbidity.

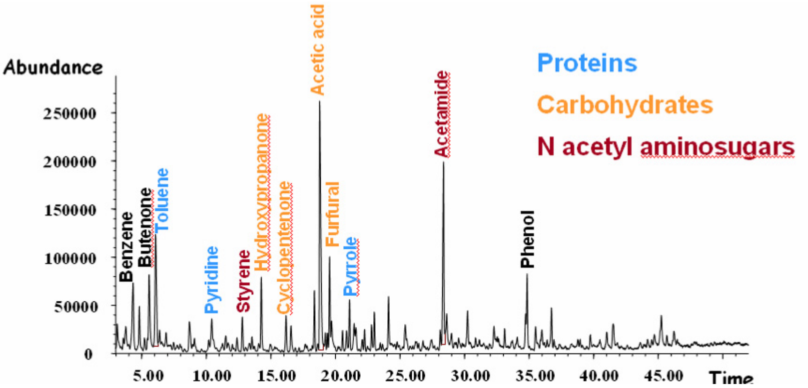

**Figure 5.** Pyrochromatogram of deposit.

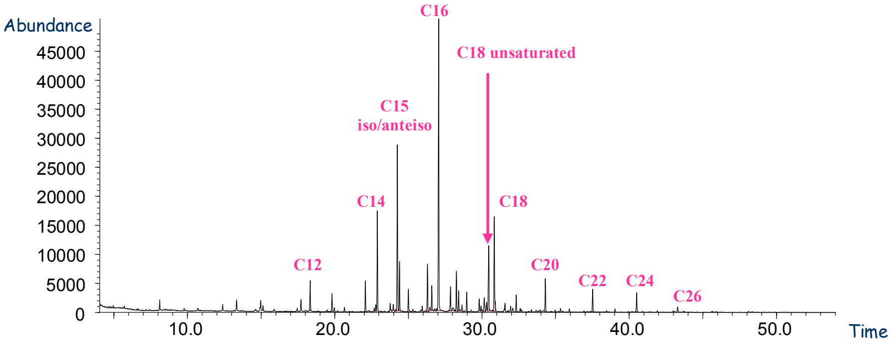

**Figure 6.** Fragmentogram m/z 74 of the total fraction from deposit.

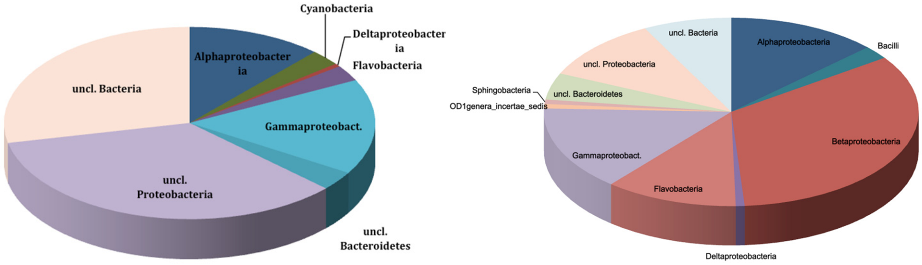

**Figure 7.** 16S rRNA gene clone library results: major bacterial groups present in RO feed water (a) and in RO deposit (b).

First, natural organic matter content was investigated using liquid chromatography with on-line dissolved organic carbon detection (LC-OCD).

This measurement showed that biopolymers represented only 8 % of total DOC (around 1mgC/L) whereas humic substances were the main components representing more than 50% of total DOC (Figure 4). Moreover, a BDOC (biodegradable dissolved organic carbon) protocol adapted to seawater conditions was also developped to evaluate the biofouling potential. The biofouling potential was determined by calculating the decrease of DOC for each of the fractions detected by LC-OCD before and after incubation. The results showed that RO feed water presented a low fouling potential.

16S RNA gene profiles put into evidence that RO feed water bacterial community differed from the RO deposit in its components’ relative abundance. Clone libraries showed that betaproteobacteria, which were the most abundant species in the deposit, were not present in the RO feed water at significant concentrations (Figure 7).

## Acknowledgements

This work was financially supported by the EU-MEDINA project (Membrane- based desalination – An Integrated approach) (project number: 036997).

## References

1. S. Huber, LC-OCD applications. 2007 07/05/07 Available from: http://www.doc-labor.de/
2. T. Tran, B. Bolto, S. Gray, M. Hoang, E. Ostarcevic (2007), An autopsy study of a fouled

reverse osmosis membrane element used in a brackish water treatment plant, *Water Research*, 17 (9), pp 3915-23.

3. F.-S. Zhang, C.-Y. Lin, L.-Z. Bian, G. Glasby, V. Zhamoida (2002), Possible evidence fort he biogenic formation of spheroidal ferromanganese concretions from the eastern gulf of Finland, the Baltic Sea, *Baltica*, 15, pp 23-29
4. A. Bruchet, C. Rousseau, J. Mallevialle (1990), *Journal AWWA*, 82 (9), pp 66-74
5. G. Schaule, S. Rapenne, M. Strathmann, S. Grobe, C. Robert, V. Jacquemet, Autopsy of RO desalination membranes: Part 1 Microbial characterization of foulants, MDIW2008 Conference "Membranes in drinking water production and waste water treatment ", October 20-22, 2008, Toulouse, France.
6. L. Mondamert, J. Labanowski, J.-M. Berjeaud, S. Rapenne, J.-P. Croué, Autopsy of RO desalination membranes. Part 2. Chemical characterization of the foulants, MDIW2008 Conference "Membranes in drinking water production and waste water treatment ", October 20-22, 2008, Toulouse, France.
7. S. Salinas Rodríguez, M.. Kennedy, J. Schippers, G. Amy, Organic foulants in estuarine and bay sources for seawater reverse osmosis – Comparing pre-treatment processes with respect to foulant reductions, MDIW2008 Conference "Membranes in drinking water production and waste water treatment ", October 20-22, 2008, Toulouse, France

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