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EUROMBRA

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1 Introduction

Up to date, researches on the physical and rheological properties of activated sludge from membrane bioreactors have been developed at experimental level, with few inferences published from full-scale installations or pilot-scale installations fed with real sewage. Generally, sludge dewaterability has been reported to be very similar conventional activated sludge, even at higher suspended solids concentrations (Khongnakorn *et al.*, 2007; Pollice *et al.*, 2007). Concerning the apparent viscosity, there is a common consensus on the non-Newtonian thixotropic behaviour of the MBR sludge and most studies indicate an increasing trend with the MLSS concentration, generally better fit by the Ostwald model (Pollice *et al.*, 2007; Rosenberger *et al.*, 2002). However, the interpretation about the actual impact of such higher viscosity on the energy demand of the process is still debated. The present document reports inferences from the experimental activities carried out within the work-package WP7, concerning the physical and rheological properties of sludge collected from membrane bioreactors for municipal wastewater treatment. More in detail, studies form bench-, pilot and full-scale MBRs are presented and discussed with a focus on the (i) impact of operational conditions on sludge filterability and dewaterability, (ii) differences between CAS and MBR sludge in terms of dewatering, (iii) dewatering tests on a pilot-scale fixed volume chamber filter press. Some of these results have been already published by the EUROMBRA partners or submitted for publication in peer review journals.

2 Experimental activity

2.1 *UNITN*

The results summarized in the report derive from the experimental activity carried out at UNITN during the Year 2 and Year 3 of the project, when a large pilot-scale MBR has been run continuously and periodical characterization of excess sludge has been performed in terms of sludge filterability, dewaterability and settleability. On such data, a statistical analysis has been performed in order to assess the correlation between operational conditions (mainly temperature) and physical properties. Moreover, inferences collected during some sixty dewatering trials on a pilot-scale fixed-volume-chamber filter press are presented and discussed, with a special focus on the impact of operational pressure, polyelectrolyte added for sludge conditioning and chemical dosage on the dry matter content. This section of the report is entirely reported in a paper which has been recently submitted in revised form for publication on a peer-review journal (Guglielmi *et al.*, *submitted*).

2.1.1 Materials and methods

A large pilot-scale MBR has been operated since Oct. 2006. The plant is located at the WWTP of Lavis (Trento, Italy) and is fed with pre-screened (2 mm) municipal wastewater pumped after the grit chamber of the full scale installations. The flow-diagram and a picture of the setup are shown in Figure 1.

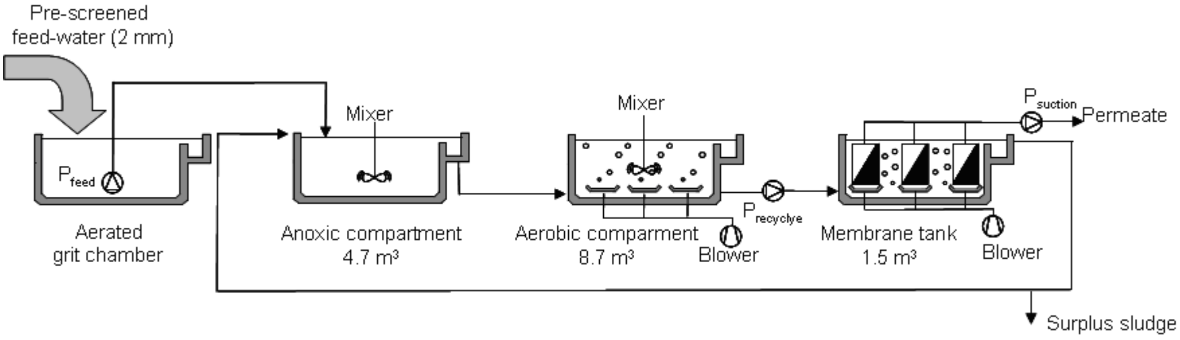

Figure 1: Large pilot scale MBR

The overall process volume is 14.9 m^3, 10% of which being due to the membrane compartment in which three membrane modules (GE Zenon ZW500d) are immersed. The membrane material is a patented hydrophilicized PVDF, with a nominal pore size of 0.04 µm and an overall membrane surface area of ~100 m^2. Both hydraulics- and biology-related parameters are monitored on-line including permeate flux, TMP, MLSS (in biotank and membrane chamber), dissolved oxygen and effluent ammonia and nitrate. After the transient phase at the plant start up, the system has been usually operated at a 20-25 days SRT (Solids Retention Time) which resulted in a pseudo steady state MLSS concentration of 6.8 ± 0.9 kg m^{-3} and; being the recycle ratio in the range 3-4, the MLSS concentration in the membrane compartment was correspondingly between 8.3 ± 1.0 kg m^{-3}. Except for some specific experiments for the critical flux assessment (data not shown) the permeate flux has been tuned in the sub critical region, i.e. at values ranging between 10 and 20 L m^{-2} h^{-1}. The influent wastewater characteristics have been monitored twice a week, by collecting 24 hours samples analysed according to the APHA Standard Methods; the values for the main macropollutants are listed in Table 1.

Table 1: Influent wastewater characteristics during the considered experimental period

Parameter	**Unit**	**Value**
COD	g m^{-3}	529.0 ± 218.8
Soluble COD	g m^{-3}	127 ± 81.0
TKN	g m^{-3}	66.3 ± 42.0
N-NH_4^+	g m^{-3}	39.7 ± 22.2
Total P	g m^{-3}	7.8 ± 5.1
TSS	g m^{-3}	294.3 ± 276.0
VSS/TSS	%	85.6 ± 8.5

Sludge characteristics have been measured weekly for dewaterability, filterability and settleability. More in detail, on each sample of sludge collected from the wastage point (membrane tank) the following parameters have been determined:

- capillary suction time according to the APHA Standard Method 2710G with a portable apparatus (Triton 304B; chromatography paper Whatman no. 17)
- αC (m^{-2}) which is related to the specific resistance to filtration α and thus depends on the deposit properties and its built-up mechanism. αC has been measured by means of unstirred dead end tests on polysulphone membrane (diameter: 47 mm; pore size: 0.22 µm) at constant pressure (0.5 bar) with on-line registration of permeate volume (Sartorius Competence CP2202; one datum per second). The data collected have been elaborated according the Carman-Kozeny equation:

  $$\frac{t}{V} = \frac{\mu \cdot \alpha C \cdot V}{2A^2 \cdot P} \cdot V + \frac{\mu \cdot R_m}{A \cdot P}$$

  Where

  t (s) is the time variable,
  V is the permeate volume (m^3),
  µ is the dynamic viscosity of permeate (Pa·s),
  α (m^{-1} kg^{-1}) is the specific resistance to filtration ,
  C (kg m^{-3}) is accumulated matter per unit of permeate volume,
  A is the membrane surface area (m^2),
  P is the operational pressure (Pa),
  R_m is the intrinsic membrane resistance (m^{-1}).

  For each sludge sample, three measurement have been carried out on different aliquots: (filtration 1) sludge itself, (filtration 2) supernatant after centrifugation (4000 g; 20 minutes), (filtration 3) supernatant after centrifugation of a sludge quote to which a $ZnSO_4$ solution is added to flocculate colloids. The first αC value accounts for all components in the sludge, the second for non settleable (colloidal matter) and solutes and the third one only for solutes. In this way, by assuming the additivity of resistances as proposed by [18], the αC of solutes was determined by filtration 3, the αC of colloids as difference between filtration 2 and filtration 3, αC of suspended solids as difference between filtration 1 and filtration 2.
- DSVI, according to the Standard Method 2710 D.

The content of proteins and polysaccharide has been weekly measured in the sludge. A centrifugation step (4000g, 10 minutes) and the supernatant filtration on a 1.5 µm fibreglass filter have provided the sample for the suspended EPS. In turn, sludge pellets collected after the centrifugation have been re-suspended in a buffer solution and subsequently added with a cationic exchange resin DOWEX (80 $g_{resin}\ g_{VSS}^{-1}$) and stirred at room temperature for 2 hours, in order to extract the polymeric substances bound to the floc structure. On such samples, proteins and carbohydrates have been measured assuming BSA and glucose as standard, respectively. Moreover, the TOC content was determined on the same samples with cuvette test HACH-LANGE LCK385; these samples are also referred to as TOC in free EPS (TOC-EPS_f) and TOC in bound EPS (TOC-EPS_b).

Statistical analysis of the data from long term operation has been carried out to explore various interrelations among observed parameters. All the statistical analyses have been executed with the TANAGRA, a free data mining software for academic and research purposes which offers several data mining methods from exploratory data analysis, statistical learning, machine learning and databases area (Rakotomalala, 2005). The Pearson's correlation has been used for the analysis and interpretation; the correlation coefficients always lie between -1 and +1 showing perfectly negative correlation at -1 and perfectly positive correlation at +1 respectively. A value of correlation coefficient makes sense for showing a positive or negative correlation when the absolute value is more than the critical value depending upon sample size and the confidence interval (usually 95%); e.g. when the sample size is larger than 60, values of correlation coefficients higher than 0.254 (or lower than -0.254 towards -1) start showing increasing significance (Wilson, 2005).

A pilot scale fixed volume recessed plate filter press (Fraccaroli & Balzan, FB 300/1) has been used for the dewatering tests on chemically conditioned sludge. The equipment consist of two plates forming a filtration chamber (0.3 m x 0.3 m x 0.024 m; chamber volume ~ 0.0021 m^3), with a dedicate membrane pump feeding the pre-conditioned sludge. Six different commercial structured and linear polymers have been used for sludge pre-conditioning at different dosages, in a range between 5 and 25 $g_{polymer}\ kgMLSS^{-1}$, once prepared a 0.5% solution (w/w):

- Structured polymer Nalco 77113 (liquid);
- Structured polymer Nalco 77118 (liquid);
- Linear polymer Nalco 77164 (liquid);
- Cationic polyelectrolyte Geodepur Ageclar KL750 (liquid);
- Cationic polyelectrolyte Geodepur Ageclar K7375 (powder);
- Cationic acrilamide co-polymer ZETAG 7205I (powder).

Trials have been carried out at three different operational pressure (7, 11 and 15 bar) with a test duration of two hours. At the end of each trial, samples were collected from both the outer and central part of the dewatered sludge cake, in order to have a representative average sample.

Figure 2: Pilot-scale filter press for dewatering tests

2.1.2 *Results*

The trends of MLSS, CST, the $(\alpha C)_{sludge}$ (i.e. the αC of sludge itself), DSVI, temperature and TOC over the experimental period are plotted in Figure 3-Figure 8. Concerning the MLSS concentration, after the start up a quasi steady state value was reached which was constantly kept except for a sudden but indeed curbed sludge leakage on July 2007. Dewaterability, filterability and settleability were fairly good, though being somehow affected by the temperature. A further comprehension of such aspects is possible by considering the results of the statistical analysis (Table 2). The Pearson’s correlation coefficients indicate that temperature plays a significant role on all the three key parameters describing sludge characteristics viz. CST, $(\alpha C)_{sludge}$ and DSVI; all these quantities are negatively correlated with temperature. Noticeably, bound form of EPS (expressed as TOC) correlates positively whereas the free form tends to correlate negatively. On the whole, the TOC related to total extracted EPS (free + bound) correlates positively with temperature, meaning thereby higher production of organic compounds at higher temperature. This observation apparently differs from analysis reported by Wu *et al.* (2007) where the method of extraction and mode of measurement (as TOC or as Carbohydrates and Proteins) are different. Also Nagaoka *et al.* (1996) commented that high EPS causes high viscosity and accumulation on the membrane surface leading to increase in the filtration resistance. On account of such diversified inferences supported from various methods of analysis and different definitions of EPS fractions, the comparison of outcomes is rather difficult as also stated by Rosenberger *et al.* (2005). However, all these works agree on indicating the negative effect of temperature on the content of organic foulants in the liquid phase, that is also confirmed by other researches in which seasonal fluctuations of membrane permeability and critical flux are reported (inter alia Lyko *et al.* (2008), Guglielmi *et al.* (2007).

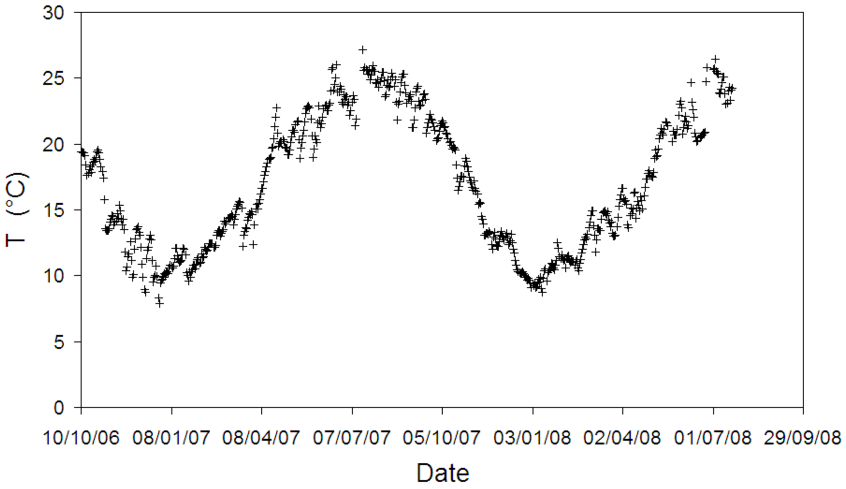

Figure 3: Temperature profile in the membrane tank during the pilot-plant operation

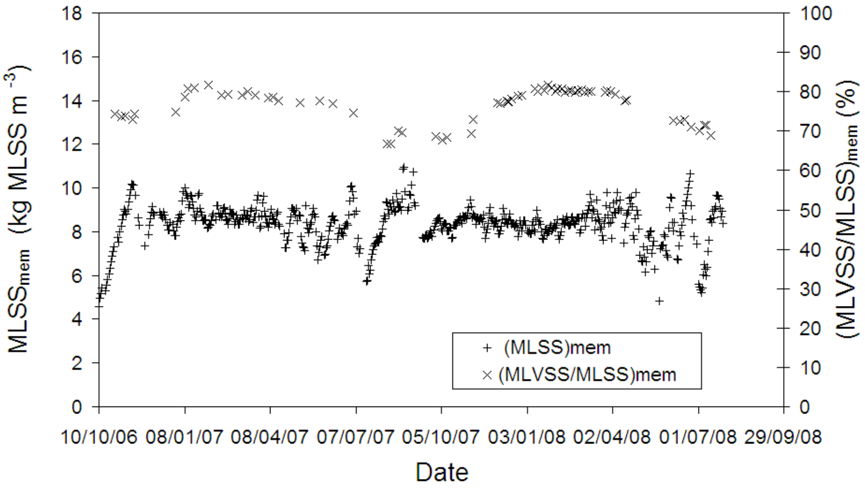

Figure 4: MLSS and MLVSS/MLSS ratio in the membrane tank

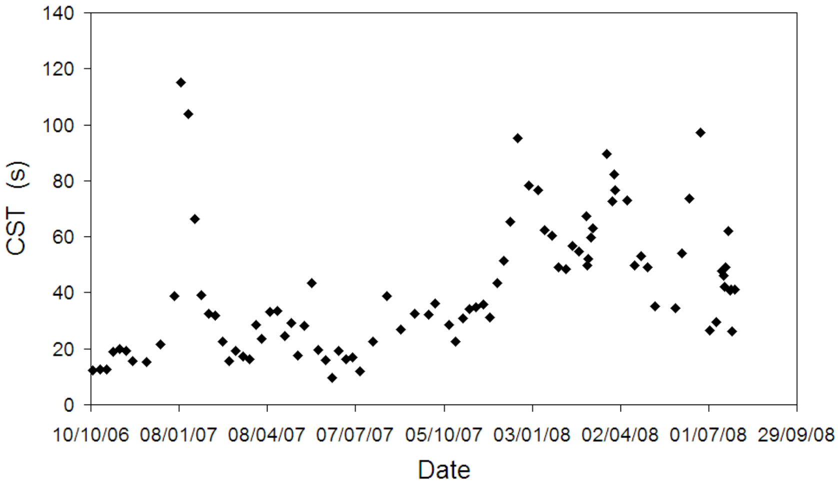

Figure 5: Trend of CST of surplus sludge during the experimental activity

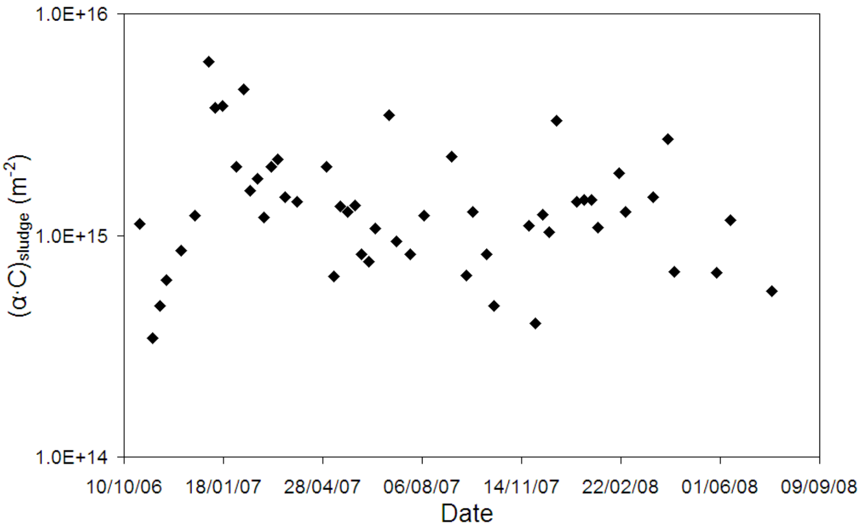

Figure 6: Sludge filterability measured on the excess sludge withdrawn from the membrane chamber

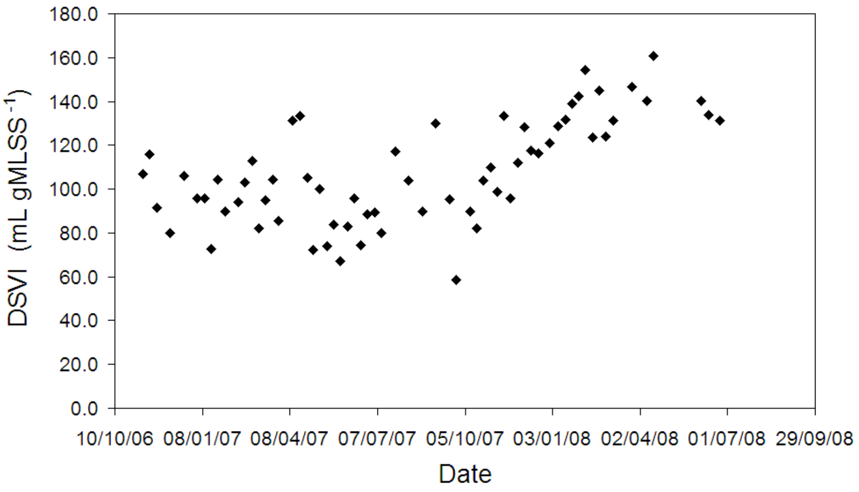

Figure 7: Surplus sludge settleability during the experimental period

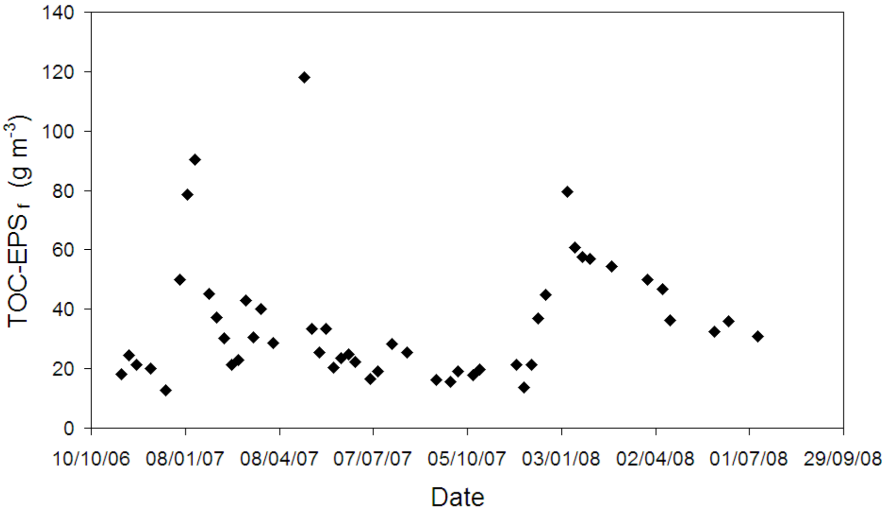

Figure 8: TOC concentration in the supernatant of surplus sludge (used for free EPS analysis)

The positive correlation of TOC content in free EPS with sludge characteristics indicators (CST, $(\alpha C)_{sludge}$) approves the role free EPS in filtration behaviour. Combining the effect of temperature and EPS on CST, $(\alpha C)_{sludge}$ and DSVI, it can be argued that higher EPS-organics at higher temperature should lead to poor dewaterability and filterability as contrary to the observation (CST, $(\alpha C)_{sludge}$ -T correlation).This should be given further attention as the major component of EPS (as TOC) is of bound form, while free form correlates opposite which presumably impacts directly on CST and $(\alpha C)_{sludge}$; this analysis becomes more clear from the positive correlation of CST and $(\alpha C)_{sludge}$ with free EPS, while they show no correlation with bound or total EPS (as TOC). Furthermore, inferences from other authors (Li *et al.*, 2003) could be relevant here suggesting that high (bound and total) EPS concentration leads to larger flocs buffering the shear force between flocs and it prevents deflocculation which in turn improves the filterability. Moreover, the poor correlation of both bound and free proteins and carbohydrates with sludge physical properties seems to suggest other organics (such as humics) to play a major role on sludge dewaterability and filterability in this case.

Table 2: Pearson's correlation coefficients pertaining to sludge properties

Parameters → ↓	**TOC-EPS$_f$**	**TOC-EPS$_b$**	**CST**	**$(\alpha C)_{sludge}$**	**$(\alpha C)_{sol+coll}$**	**DSVI**	**T**	**MLSS**
TOC-EPSf	1	0.207	0.656*	0.483*	0.670*	-0.295*	-0.237	0.266
TOC-EPSb	0.207	1	-0.169	-0.247	-0.124	0.082	0.455*	0.048
CST	0.656*	-0.169	1	0.536*	0.658*	0.437*	-0.436*	0.236
$(\alpha C)_{sludge}$	0.483*	-0.247	0.536*	1	0.309*	-0.140	-0.435*	0.128
$(\alpha C)_{sol+coll}$	0.670*	-0.124	0.658*	0.309*	1	-0.090	-0.580*	0.145
DSVI	-0.295*	0.082	0.437*	-0.140	-0.090	1	-0.332*	0.291*
T	-0.337*	0.455*	-0.436*	-0.435*	-0.580*	-0.332*	1	-0.238
MLSS	0.266	0.048	0.236	0.128	0.145	0.291*	-0.238	1

* Significant correlation at 0.05 level (2-tailed)

The $(\alpha C)_{sludge}$ correlates positively with CST, as expected; its dependency with Temperature and EPS is mostly similar to that with CST. Noticeably, while CST correlates with DSVI, the $(\alpha C)_{sludge}$ does not; the correlation of free EPS (as TOC) with $(\alpha C)_{sludge}$ is weaker than that with CST. The impact of solutes, colloids and suspended solids on the $(\alpha C)_{sludge}$ is shown in Figure 9: in agreement with Wisniewski and Grasmick (1996), once reached the steady state conditions the suspended matter resulted to be the most relevant factor affecting filterability, although a clear increase of the impact of solutes was observed at lowest temperature, when also CST showed a sudden increase.

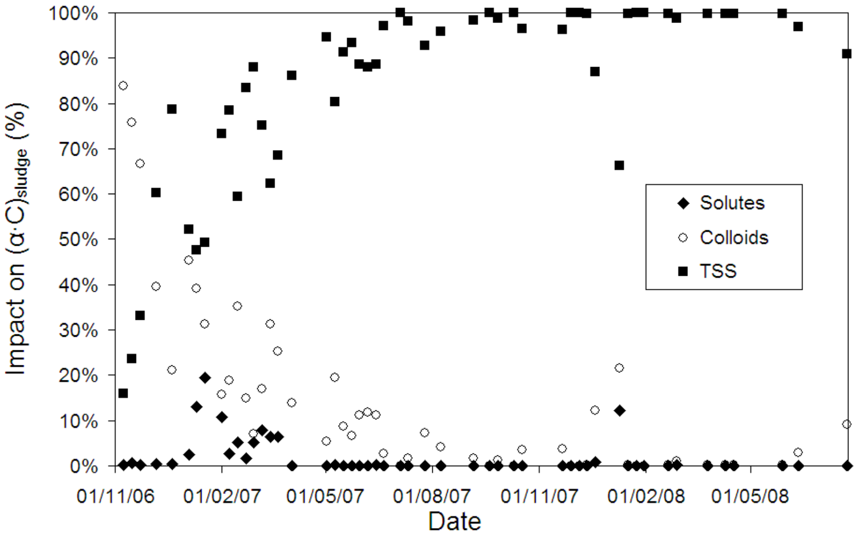

Figure 9: Percent role of solutes, colloids and suspended solids on the $(\alpha C)_{sludge}$

The DSVI positively correlates with CST indicating that the filtration behaviour might as well be associated with the settling behaviour; this infers that sludge with good settleability should show better ease to filtration, however, no correlation with $(\alpha C)_{sludge}$ puts ambiguity in accepting DSVI as relevant parameters with reference to filtration behaviour understanding.
The MLSS is not well correlated with any of the parameters mentioned in Table 2; a weak positive correlation with DSVI and free EPS (as TOC) can be attributed to extracellular organic materials influencing the settling behaviour at higher MLSS. Few researches (Nagaoka *et al.*, 1996; Shimizu *et al.*, 1996) commented that filtration resistance increases with increase in MLSS; and more recent researches (Wu *et al.*, 2007; Rosenberger and Kraume, 2002; Hong *et al.*, 2002) suggest that MLSS can possibly correlate with fouling/filtration related parameters only at very high concentrations.

About 60 dewatering tests were performed over the whole experimental period, under steady state sludge age. The behaviour of the different chemicals dosed at different pressure values are summarised in Figure 10, Figure 11 and Figure 12.

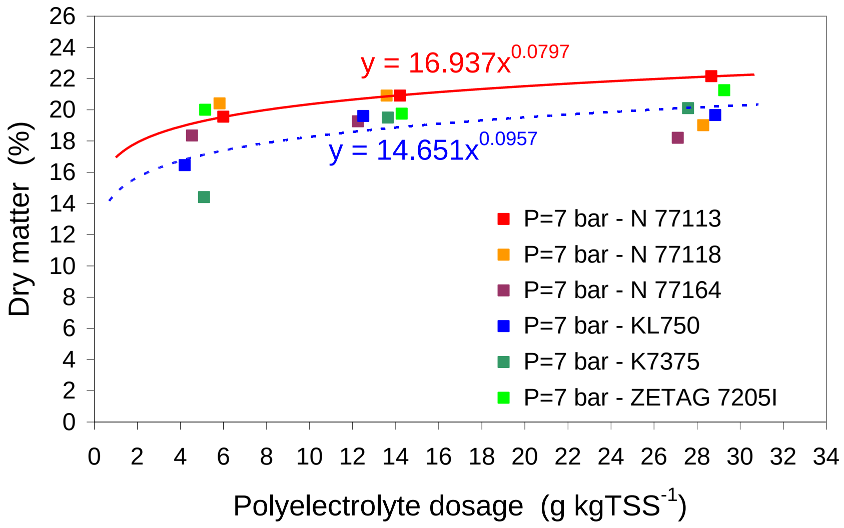

Figure 10. Dry matter in dewatered sludge at 7 bar

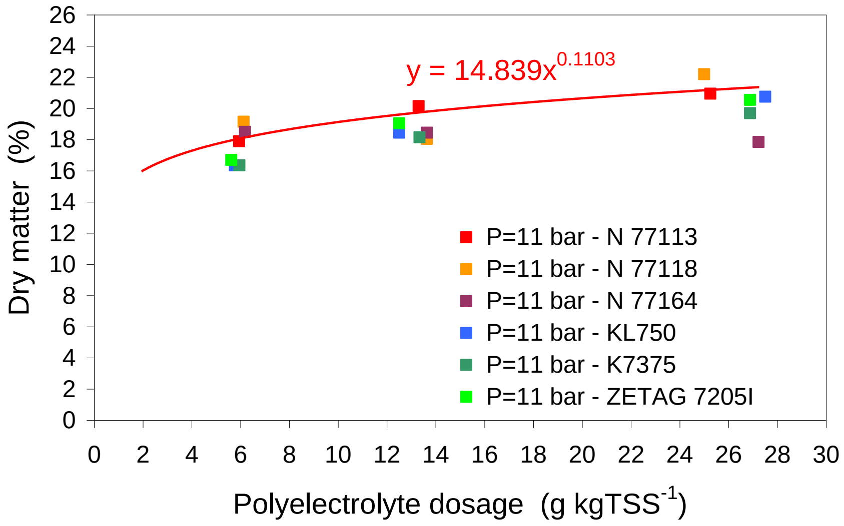

Figure 11: Cake dryness of dewatered sludge at 11 bar

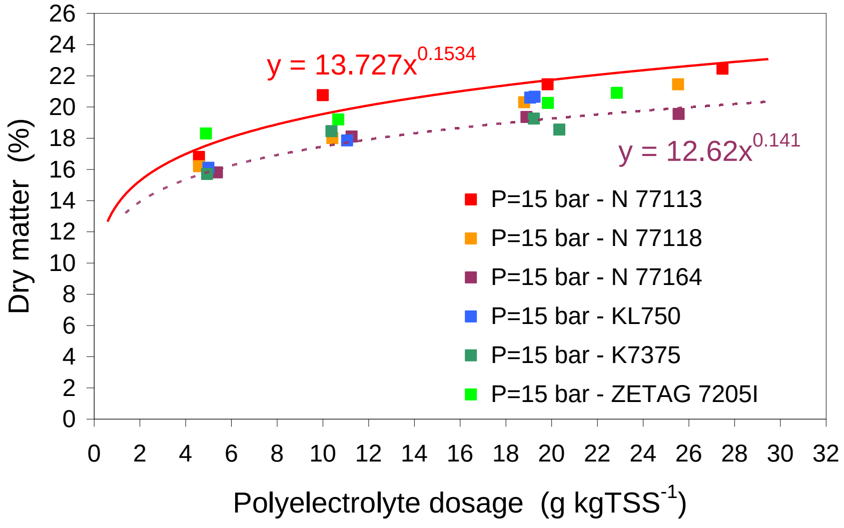

Figure 12: Cake dryness of dewatered sludge at 15 bar

Regardless with the type of polymer used, dosage seemed to cause a minor impact on the final dry matter content, which is generally well described by a power-law. In order to ensure the sludge fed to the filter-press does not change its dewaterability propensity, the capillary suction time was routinely measured at regular intervals. Over the whole experiments performed, the DM% ranged between 14 and 24%, with better results for the liquid structured polymer N 77113 and the powder acrilamide cationic polymer ZETAG 7205I. The values obtained are lower than those reported in technical literature for filter press devices (Metcalf & Eddy, 2003) which, however, are mostly referred to combined sludge conditioning with lime and polymers. Furthermore, the results obtained during some spot tests performed with ZETAG 7205I and N77113 on sludge samples collected from the aerobic digestion compartment of the full scale municipal wastewater treatment plant in Lavis seem to suggest there are no differences between the conventional activated sludge and the MBR sludge when in the same range of sludge age. The Lavis WWTP is a CASP for denitrification and nitrification and it is operated at a sludge age of ~15 days; the additional SRT in the aerobic stabilisation tank is 10 days and the sludge is usually dewatered by means of a belt-press device. Compared with the surplus sludge of the membrane bioreactor, trials carried out at 11 and 15 bar on samples of surplus sludge collected from the aerobic digestion of the full scale CASP plant (MLSS ~ 10 kg m^{-3}) gave even slightly lower values of dry matter content with the same polymer and in the same range of polyelectrolyte dosage (15-20%).

2.1.3 Conclusions

Surplus sludge sample have been collected from a large pilot scale MBR and analysed in terms of dewaterability, filterability and settleability over an experimental period of almost two years. The three physical properties have been found to be negatively correlated with to temperature, with increasing values at lower temperatures; this is probably to be ascribed to the higher content of organics in the liquid phase which also affects the role of colloids and solutes on the overall sludge filterability.

Tests carried out on a pilot scale filter press compared the effect of different operational pressures, chemicals and dosage on the dry matter content after 2-hours filtration tests. The results pointed out the major role of polymer in influencing the final moisture of the cake, with no significant variations at different dosages and pressures; a powder cationic acrilamide-based polymer and a structural polymer in liquid form were proven to achieve the best dewatering performances.

2.2 UM II

The aim of the study was to investigate the dewatering behaviour of MBR sludge, and particularly the influence of high total suspended solids concentration, on viscosity and on the key dewaterability indicators:

- the specific resistance to filtration;
- the capillary suction time;
- the dryness limits;
- the compressibility factor.

2.2.1 Materials and methods

Rheological experiments are performed on a rotational controlled stress rheometer (Haake, Rheostress RS 100, Thermo Fisher Scientific) coupled with Rheostress RS software version 2.3P. Stress is applied to the sludge and the resultant strain is measured and recorded. The software allowed also subsequent data analysis. A coaxial cylindrical measurement device with a double gap measuring system is used. The temperature is maintained constant at 21.5 ± 0.1°C. The volume sample used for each measurement is 7 ml. The measurement protocol consists in an exponential increase of the shear stress from 0.01 to 185 Pa in 3 min. It is rapid enough so that the flocs sedimentation is avoided. This measurement is verified to be in laminar shear flow conditions. Experimental results are analysed through two representative curves (Figure 13). The Figure 13(a) shows the evolution of the measured apparent viscosity as a function of shear stress. In our experiments, the evolution of the apparent viscosity as a function of the shear stress can be decomposed in three parts

1) First, the viscosity is approximately constant because the stress applied to the material is low enough to avoid modifications of the sludge structure and the disruption of the interactions between the solid particles. For this range of stress values, the sludge is in a linear elastic state and behaves like a solid;
2) In the second part of the curve, the viscosity decreases (rheofluidification) because the stress applied to the sludge is high enough to initiate structural modifications of the sludge and the flow of the sludge network. The stress which is necessary to induce the flow of the sludge is called the yield stress τ_c. In the case of suspensions, the yield stress is the stress required to overcome the cohesion forces between the solid particles;

3) in a third part, for the highest stress values, the viscosity tends towards a limit and becomes almost constant. This part will be characterized by the limit viscosity denoted μ_∞.

Figure 13(b), shear strain (γ) versus stress (τ), is useful to describe the solid behavior of the sludge before the flow occurs. From this representation, three parameters are easily calculated: G, τ_c and γ_c. G, the shear modulus, corresponds to the inverse of the slope of the first linear part of the curve and represents the rigidity of the sludge network. The critical yield stress, τ_c, limits the linear elastic domain; γ_c is the corresponding critical shear strain. Provided the values of τ_c and γ_c, the energy of cohesion of the network sludge, E_c, is calculated according to the following equation :

$$E_c = 1/2 \times \tau_c \times \gamma_c$$

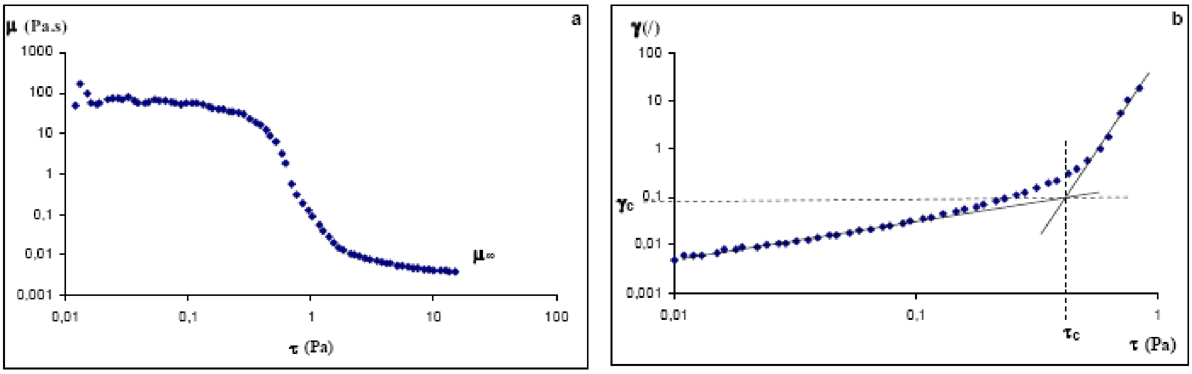

Figure 13: Apparent viscosity vs shear stress (a) and shear strain vs shear stress (b)

In order to correlate the viscosity value to other parameter, the Table 3 summarized the methodologies used. The following parameters are obtained during the experimental campaign which are described more in detailed in the WP3-reporting activities. Experiments where carried out in a lab scale submerged membrane bioreactor SMBR equipped with hollow fibre bundles as described in Lebegue *et al.* (2008). the reactor was fed with a simple, entirely biodegradable synthetic substrate composed of acetic acid [CH_3COOH] and nutrient salt, ammonium nitrate, [NH_4NO_3] providing nitrogen and diammonium hydrogen phosphate [$(NH_4)_2HPO_4$] providing phosphorous , the COD/N/P ratio was taken as equal to 100/5/1. The experimental conditions are an organic load from 0.9 to 4 kg m^{-3} d^{-1}, an SRT range from 20 to 60 days and an HRT from 10 to 1 day.

Table 3: Measured parameters and methodologies

Parameters	Methodologies
COD	Digestion method and Colorimetric determination
TSS, VSS, SVI	According to APHA (1992)
Granulometric distribution	Malvern Mastersizer
Apparent viscosity	Haake Rheometer (Rheostress RS 100)
SFR, s and Slim	Stirred and pressurized filtration cell (Amicon 8010) with membrane cellulose nitrate, 0.2 μm (Sartorius)
CST	According to method 2710G, APHA (1992) by Triton 319
SMP (Proteins,Polysaccharides)	Lowry method using Bovine Serum Albumin as the standard Anthrone method using sucrose as the standard

2.2.2 *Results*

The trend of apparent viscosity at different suspended solids concentration for the two experimental setups operated at UMII is depicted in Figure 14.

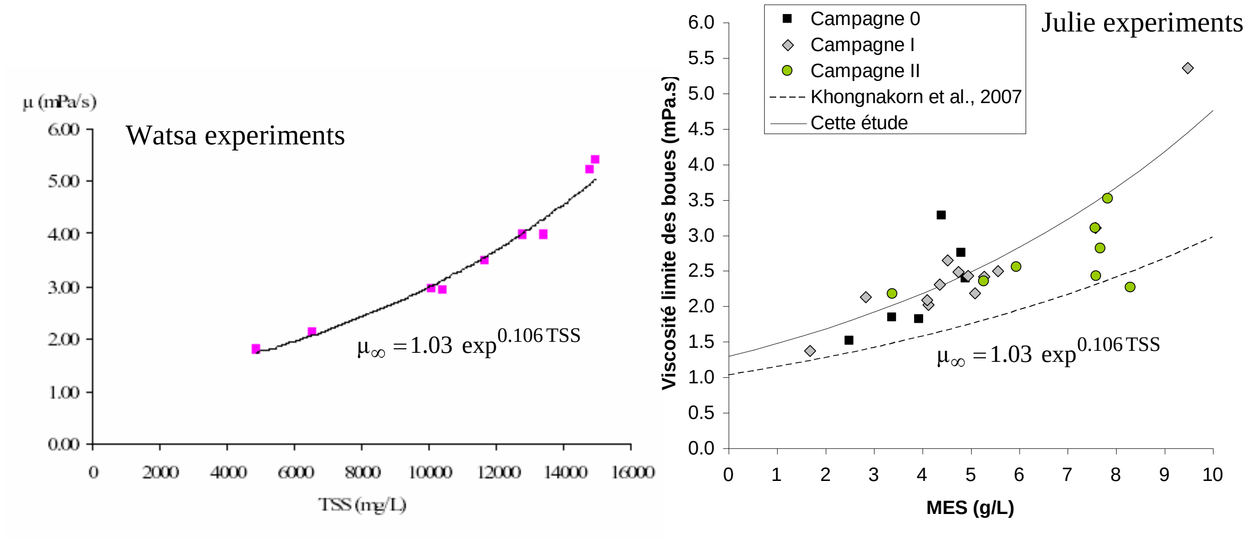

Figure 14: Apparent viscosity vs. time during long term experiments

In both cases, an exponential law is found to be suitable to describe the variation of the viscosity as a function of TSS. Nevertheless, despite high TSS concentration, the viscosity value stays approximately close to the one measured on activated sludge at 4 g TSS.L^{-1} (5 mPa.s, Jin et al.(2004)).

The CST, like viscosity, is related and dependant on the suspended solids concentration (Figure 15). The experiments show indeed a more or less constant increase of the CST with the TSS concentration. Nevertheless, high values of CST are always linked to a biological dysfunction (load, pH, …) and could play a quick dysfunction sensor issue.

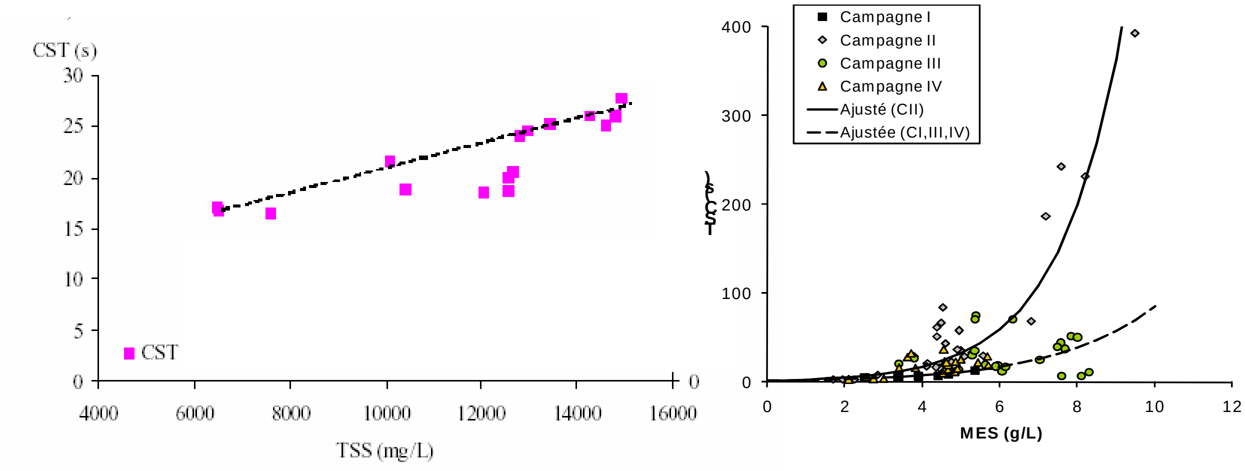

Figure 15: CST vs. time during long term experiments

No real increase of SRF is observed with the TSS concentration, demonstrating that the filterability of the MBR sludge is independent of the TSS concentration.

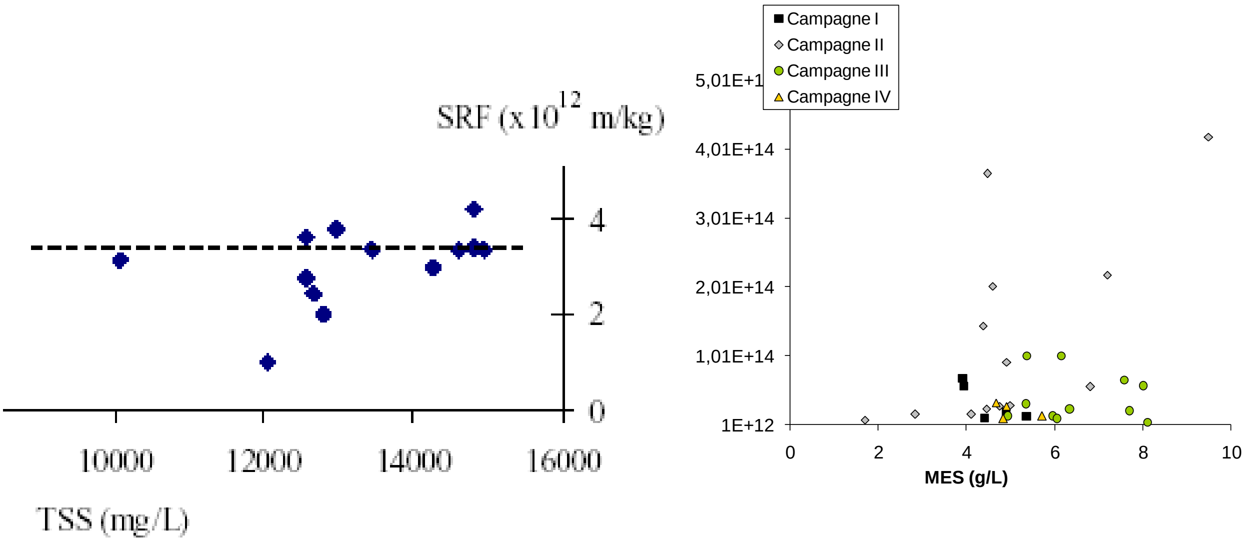

Figure 16: SRF vs time during long term experiment

Considering the SRF trend on the left side of Figure 16 a quite constant value was observed, close to 3 10^{12} m.kg^{-1}, which is and sensibly lower than the ones obtained for activated sludge, ranged from 4 to 12 10^{13} m.kg^{-1}.

Finally, the dryness limits decrease with the TSS concentration. This result is coherent with the CST evolution and with the fact that the quantity of bound water, or “non free” water, increases with the TSS concentration.

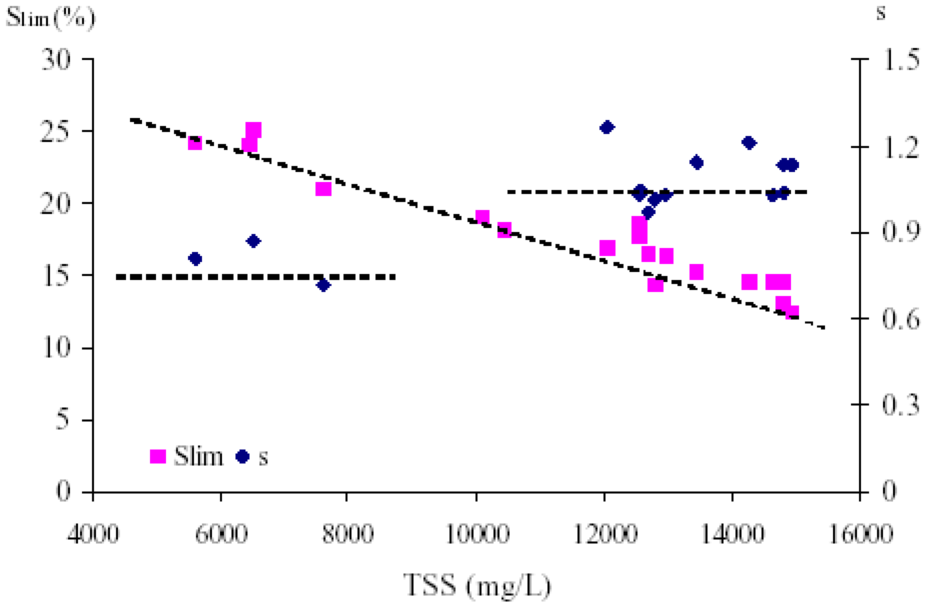

Figure 17: Dryness limits (Slim) and compressibility factor (s) vs time

2.2.3 Conclusions

The objective of this work was to study the dewatering behaviour of MBR sludge, and particularly the influence of high total suspended solids concentration, on the key dewaterability indicators like the specific resistance to filtrate, the dryness limits, the compressibility factor and the capillary suction time. Operating conditions are chosen to obtain MBR sludge with constant characteristics, expect TSS concentration. The results confirm the TSS concentration influence on the sludge viscosity. The high viscosity obtained for high TSS concentration can be unfavourable to an efficient mixing in the MBR unit, as well as to acceptable membrane permeability (Khongnakorn *et al.*, 2007). However, characteristics close than CAS are obtained with high TSS concentration although the sludge presents high compressibility property and a large part of bound water. This large part of bound water seems to not disturb the filterability of the sludge, which stays relatively good in comparison with CAS. As a consequence of the results, the morphology and the physical properties of the sludge flocs are supposed to have more significant influence on dewaterability than the TSS concentration.

Consequently, high SRT conditions in MBR system, and high-TSS concentration, can be coherent with an efficient sludge post-treatment. However, a relatively low dryness limit is obtained, that can be problematic for sludge management and/or sludge specific valorisation. Consequently, specific temporary events (e.g. temperature increase, oxygen concentration, peak load …) had a bad effect on the microorganisms activity, and thus the presence of soluble microbial compounds in the reactor, can affect greatly the dewaterability parameter and also the mixing and aeration performances in the system, and at least, in MBR unit, the membrane fouling.

2.3 EV

The Erftverband operates two large scale membrane bioreactors: data on sludge dewaterability with large scale centrifuges are reported and compared with those from conventional activated sludge plants.

2.3.1 Materials and methods

The Rödingen MBR (3.000 p.e.) is operated with simultaneous sludge stabilisation and intermittent denitrification. The submerged hollow fibre membranes are situated in external filtration tanks. A 0.5 mm fine screening is in the sludge recycle as a bypass. The overall average sludge production is 0.48 kgMLSS $kgCOD_{rem}^{-1}$. The average SRT is 38 days. Sludge dewatering is off-site. The Nordkanal MBR (80.000 p.e.) is operated with simultaneous sludge stabilisation and pre-denitrification. The submerged hollow fibre membranes are inside the nitrification tanks. The overall average sludge production is 0.55 kgMLSS $kgCOD_{rem}^{-1}$. The average SRT is 25 days as can be calculated from the actual operational data in Table 4. Sludge dewatering is on-site with a centrifuge. Additional tests were performed to remix debris from the fine screening with the surplus sludge before sludge dewatering.

Table 4: Operational data from the MBR plant in Rödingen and Nordkanal

Average values	**Unit**	**Rödingen**	**Nordkanal**
Daily inflow	$m^3 d^{-1}$	540	15000
Total COD in	$g m^{-3}$	680	580
Total Nitrogen in	$g m^{-3}$	72	52
Ammonia in	$g m^{-3}$	50	40
BOD/COD ratio		0.7	0.4
COD out	$g m^{-3}$	18.90	18.40
Ammonia out	$g m^{-3}$	0.15	0.36
TON out	$g m^{-3}$	13	5
Temperature	°C	15	15
MLSS	$kg m^{-3}$	11.5	11.9
SRT	d	38	25

2.3.2 *Results*

Operational values of the large scale MBR plants have been compared to the respective values of several CAS.

of several CAS.

Figure 18 shows the sludge production from the bioreactor compared to the annual inflow to the plants. The sludge production from the Nordkanal MBR (filled dot) seemingly exceeds the sludge production of similar sized plants. However it is the only plant with a capacity of more than 4,000,000 m³ per year without primary settling. The organic loading in the influent of the bioreactor thus is approximately 30 – 40 % higher than the influent of the other plants. The sludge production form primary settling is not accounted for in this graph.

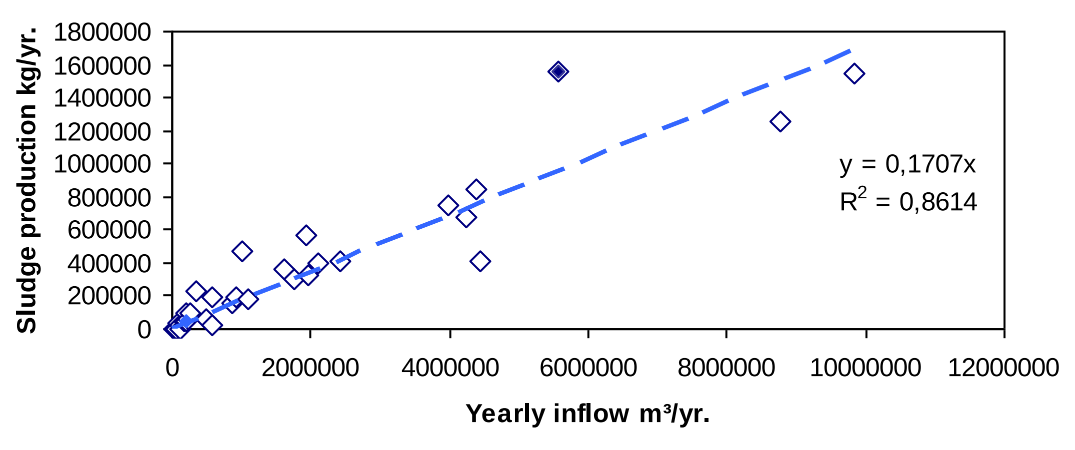

Figure 18: Biological surplus sludge production at different WWTP operated by EV (year 2007)

The dewatering results of 17 WWTPs have been compared on the basis a long time series of grab samples from the dewatered sludge that where taken at least twice a year and were analyzed at the Erftverband's central laboratories. Sludge treatment at the Erftverband is semi-centralized. Sludge from smaller installations is stored on site and periodically transported to larger plants, where it is further treated or dewatered. The sludge is eventually mixed with sludge form other installations and dewatered with centrifuges, chamber filter presses or belt presses. Among the plants with on-site dewatering 4 plants employ simultaneous aerobic sludge stabilization in the bioreactor, including the Nordkanal MBR. All other 13 plants use anaerobic digesters for sludge treatment. Due to the treatment concept the dewatered sludge on these sites may sometimes be a mixture of sludge from anaerobic digesters and contact stabilization plants.

Figure 19 shows the dewatering results in terms of dry solids content of the dewatered sludge. As expected the sludge from anaerobic digesters in general reaches higher dry solids content than that from contact stabilization plants. The dewatering results of the Nordkanal MBR sludge are similar to those of other aerobically stabilized sludge.

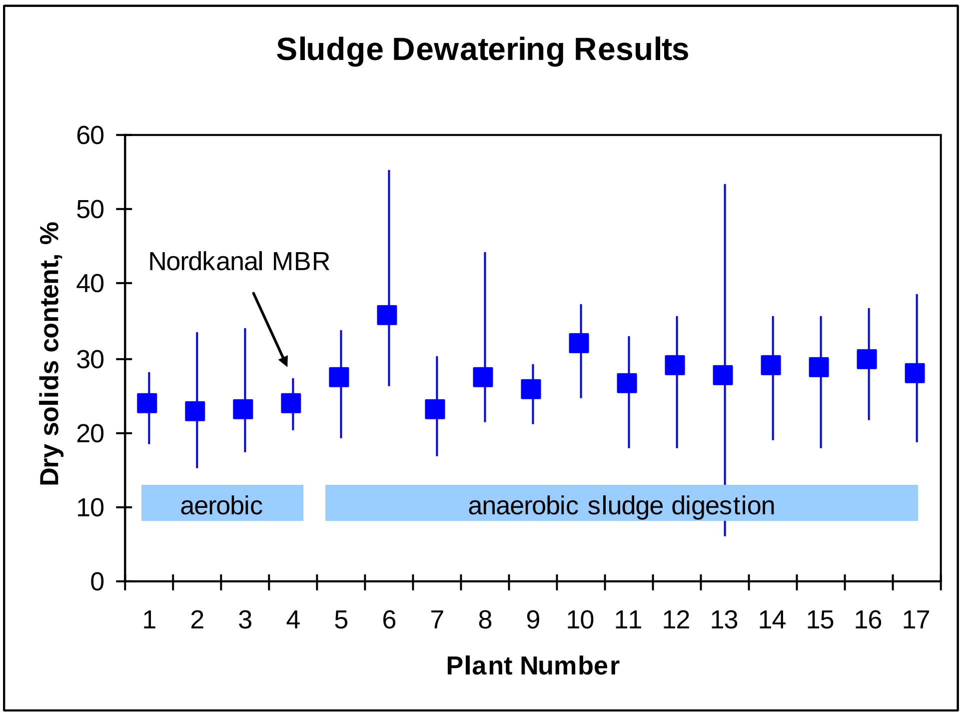

Figure 19: Average, minimum and maximum values of the dry solids content of the dewatered sludge at the Erftverbands' WWTPs

At Nordkanal the sludge dewatering was enhanced by remixing debris from the 1.0 mm influent fine screening to the surplus sludge. During this test, the maximum MLSS concentration in the dewatered sludge thus could be augmented from 25% up to 30 – 35 %. The overall amount of dewatered sludge decreased from an average of 14.2 m^3/d in 2005 and 2006 to a present average value of 13.5 m^3/d.

2.3.3 Conclusions

Sludge production and sludge dewaterability at the large scale MBRs are comparable to CAS that are operated under similar conditions in terms of SRT and surplus sludge treatment.

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