SIMULATING THE EFFECTS OF INTRODUCTION OF MEMBRANE FILTRATION AT A MUNICIPAL BNR PLANT

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ABSTRACT
Sedimentation is still the most common method of biomass separation at majority of medium and large biological nutrient removal municipal wastewater treatment plants (BNR WWTP). In recent years some plants have been replacing this process with membrane separation and transforming their typical biological reactors into membrane units (MBR). This is often linked to the required increase in plant's capacity and/or improvement in effluent quality. However, such modifications significantly affect plant functioning especially in regard to operation of biological processes, energy management and solids treatment. The article presents the results of computer simulation research on effects of the introduction of membrane filtration at a municipal BNR plant. The simulations allow to compare the most important operational parameters and effluent quality for the traditional layout with secondary clarifiers and the layout with membrane biological rectors. Wastewater treatment plants' operators and decision-makers may use is it as an indication of what changes in plant operation can be expected after installing membrane filtration.

KEYWORDS
wastewater treatment plants, computer simulation, membrane filtration

INTRODUCTION

Membrane filtration as a method of biomass separation is gaining increasing interest of companies that operate municipal wastewater treatment plants (WWTPs). Many medium and large municipal WWTPs with activated sludge technology that were designed and constructed many years ago require modernization and extension (*Brepols et al., 2008; Buer, 2010*). In this process they often are faced with a barrier of space limitations on one hand, and the increasing expectations regarding effluent quality that sometimes much exceed those required by legal standards, on the other (*Min.Env.Dir, 2006*). One of the possible solutions that is considered is replacing the traditional gravitational separation of biomass in secondary clarifiers with membrane filtration. This is usually done by installing membrane modules inside biological reactors and transforming them into membrane bio-reactors (MBR). However this process increases plant's capacity and effluent quality, it also generates many consequences for operation of the biological stage, sludge processing and overall plant's energy balance. This article presents the results of computer simulation aimed at investigating practical results of such process modification on the most important aspects of WWTP's operation, such as effluent quality, energy consumption, biogas production and plant's capability of adjusting to variation in wastewater flow, pollution load and temperature.

METHOD

The research were carried on with a simple model of a hypothetical wastewater treatment plant of capacity 20000 m^3/d (97000 PE) that comprised two separate technological lines. The first line, meant to represent a typical advanced biological treatment plant, comprises of a three-stage activated sludge process configured into A_2/0 scheme and a circular secondary settler. The second line, intended to represent the plant after the modernization, includes the same biological reactor but equipped with membrane modules installed in the last sections of the reactor instead of the settler. In order to trace biogas production in the process each line has a simple separate sludge processing system that comprises of a sludge thickener and a anaerobic digestion chamber. The simulation model was developed with GPS-X™ v. 6.0 package and the flow scheme of the investigated system is presented in Fig. 1.

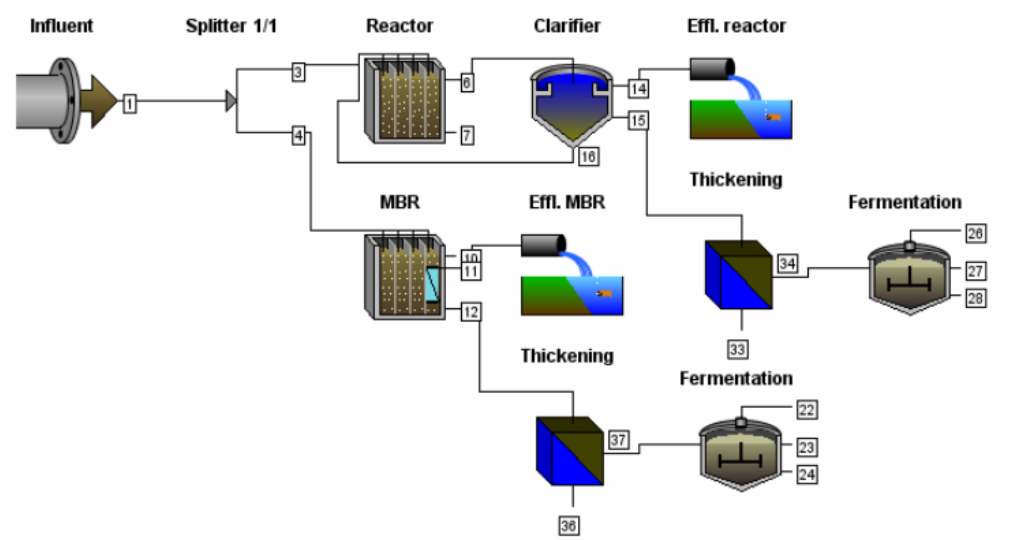

Figure 1. Flow-scheme of treatment system used in the research developed with GPS-X™ v. 6.0

The mathematical models applied in the model are *ASM2d* for the biological reactor and for the MBR, *SIMPLE1D* for the secondary settler and *MANTISAD* for the fermentation. Membrane filtration process is modeled including membrane backwashing and calculating trans-membrane pressure (TMP). Assumed influent wastewater characteristics is a typical for the effluent from primary settlers, however for simplification no primary settlers are included in the model (*Fenu et al, 2010*). The specific values in influent are presented in Table 1.

As the purpose of the research was to determine the consequences of replacing the secondary sedimentation with of membrane filtration under various operational conditions, tested were the following operational scenarios:

- Scenario 1: Plant operation under stable conditions (constant flow and load)
- Scenario 2: Plant operation under dynamic conditions (changing flow and load)
- Scenario 3: Plant operation at low temperature conditions

For each scenario observed and compared were the changes in effluent quality, total energy consumption in the process, sludge characteristics and biogas production for the system without and with membrane filtration.

Table 1. Influent characteristics and process parameters

Parameter	Unit	Value	Parameter	Unit	Value
Influent					
BOD_5	g/m^3	113	Total nitrogen	g/m^3	37
COD	g/m^3	430	Ammonia	g/m^3	29
Total suspended solids	g/m^3	175	Total phosphorus	g/m^3	10
Biological reactor					
Flow to the reactor (Q)	m^3/d	20 000	Internal recirculation rate	-	3Q
Volume	m^3	10 000	Sludge recirculation rate	-	0,75Q
DO in aerobic zone	gO_2/m^3	2,0	MLSS (aerobic zone)	g/m^3	5000
SRT	d	16	Total airflow	m^3/d	201600
MBR					
Flow to the reactor (Q)	m^3/d	20000	Internal recirculation rate	-	3Q
Volume	m^3	10000	Sludge recirculation rate	-	0,5Q
DO in aerobic zone	gO_2/m^3	2,0	MLSS (aerobic zone)	g/m^3	11000
SRT	d	28	Backwash frequency	Min	15
Membrane flux	m/d	0,509	Total airflow	m^3/d	348300

RESULTS

Scenario #1: typical operation

Under this operational scenario the plant was operated at static conditions with constant flow and load. As one might expect the effluent quality was better for the MBR system mostly due to improved separation of suspended solids, what positively affected COD, N and P concentrations in effluent. Under constant operational conditions MBR consumes more energy than conventional system, and this increase is significant reaching about 50%. Majority of this energy in MBR is used for aeration of biomass and for cross-flow aeration (0,31 kWh/m^3).The excess sludge production in MBR is smaller (-2,8%) but this sludge contains less organic material as compared to sludge from conventional system (resp. 55% and 61%). These numbers directly translate into significantly smaller biogas production, and especially less methane that can be used for as an energy source. Thus from the energy balance standpoint the MBR system on one hand consumes more energy, and on other hand reduces the potential for energy recovery from sludge.

Table 2. Simulation results for the scenario #1

Parameter	Unit	Reactor/Settler	MBR	Rel. difference
Effluent quality				
COD	g/m^3	36	22	-40%
TSS	g/m^3	15,9	1,1	-93%
Ammonia	g/m^3	1,2	0,6	-50%
TN	g/m^3	8,6	7,9	-8%
TP	g/m^3	1,1	0,4	-63%
Energy and biogas				
Total energy	kWh/d	4782	7191	+50%
Energy efficiency	kWh/m^3	0,24	0,36	+50%
VSS/TSS ratio	-	0,61	0,56	-8%
Sludge production	kg ds/d	3416	3321	-2,8%
Biogas production	m^3/d	647	343	-47%
Methane production	m^3/d	450	246	-45%

Scenario #2: peak flow and load

This scenario represent dynamic behaviour of the WWTP. The wastewater flow, and in consequence also the pollution load, was temporarily increased by approximately 50% during the daily plant's operation. The operational parameters of both systems were followed during this event. The results obtained from this scenario are presented in Fig. 2 and in Table 3. The MBR system operates much better under the increased plant loading. As shown on the graphs in Fig. 2 there is practically no adverse effects of the increased influent flow and load on the effluent quality. Under the same conditions the system with secondary settler was not able to retain the biomass and the concentrations in effluent have increased too much, and even exceeded the allowable discharge standards for TSS, total phosphorus and total nitrogen.

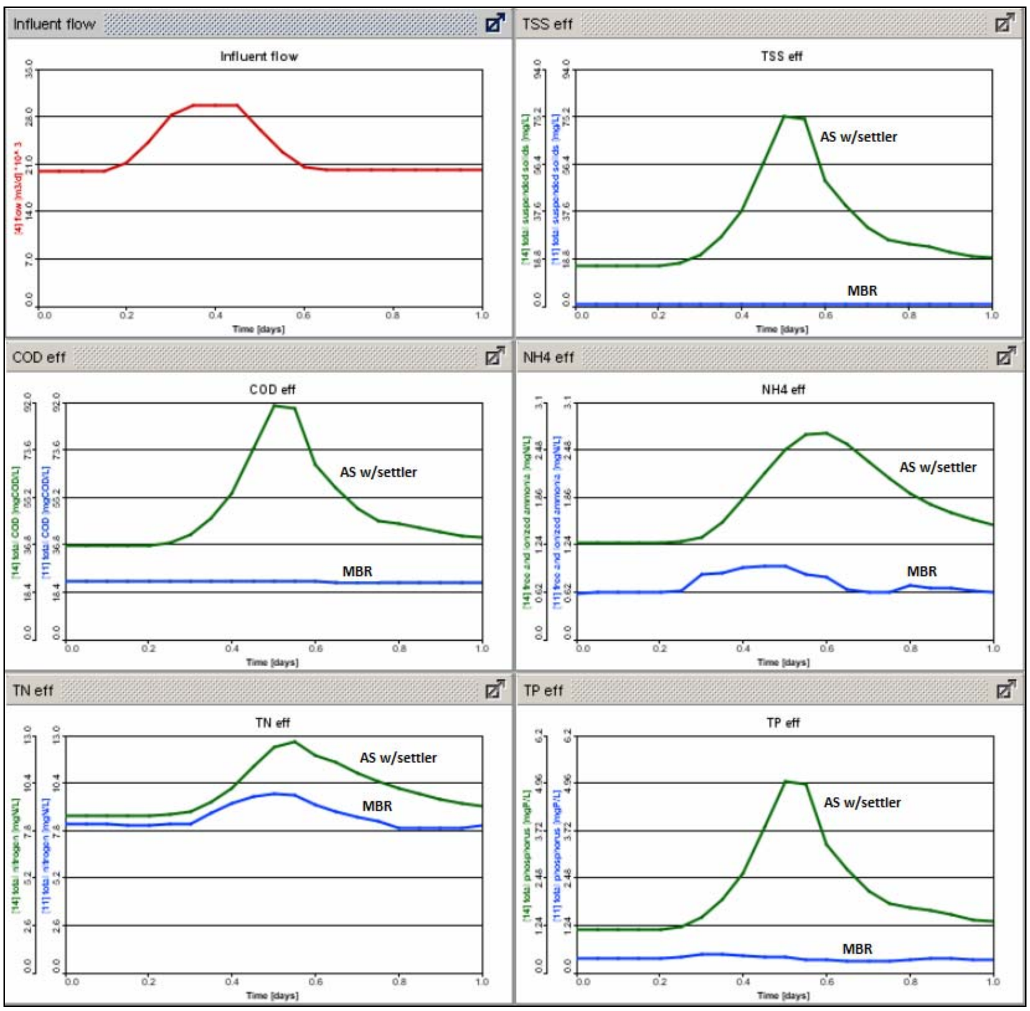

Figure 2. The results of dynamic simulation of scenario #2 – effluent quality for the conventional system and for the MBR (GPS-X™ v.6.02).

Table 3. Results of simulation of peak influent flow and load on plant's operation (scenario #2)

Parameter	Unit	Reactor/Settler	MBR	Rel. difference
Energy and biogas				
Total energy	kWh/d	4947	7511	+52%
Sludge production	kg ds/d	3400	3344	-2,8%
Biogas production	m^3/d	647	344	-47%
Methane production	m^3/d	450	248	-45%

The simulated dynamic event did not have significant effect on daily energy consumption and biogas production as it is shown in Table 3. As compared to normal plant operation (scenario #1) the energy consumption has increased by 3% for the AS system with settler and by 4,5% for the MBR, and it is still by 52% larger for the MBR system. No changes were observed in excess sludge and biogas production.

Scenario #3: low temperature operation

Continuous operation of a wastewater treatment plant under low temperature conditions simulating winter conditions was tested in this scenario. The wastewater and blower inlet air temperatures were lowered from 20°C (as in scenarios #1 and #2) to 14°C and 6°C, respectively. Simulated was steady state plant operation under these conditions. The results are presented in Table 4.

Table 4. Results of simulation for plant's operation under low temperature conditions (scenario #3)

Parameter	Unit	Reactor/Settler	MBR	Rel. difference
Effluent quality				
COD	g/m^3	52	22,6	-56%
TSS	g/m^3	31	1,1	-96%
Ammonia	g/m^3	3,6	0,9	-75%
TN	g/m^3	10,9	8,0	-27%
TP	g/m^3	1,9	0,2	-89%
Energy and biogas				
Total energy	kWh/d	4297	6757	+57%
Energy efficiency	kWh/m^3	0,21	0,34	+50%
VSS/TSS ratio	-	0,64	0,58	-9%
Sludge production	kg ds/d	3417	3494	+2,2%
Biogas production	m^3/d	833	486	-42%
Methane production	m^3/d	572	348	-39%

At low temperatures the MBR system's technological efficiency is similar to the operation under normal conditions. The differences in effluent concentrations for COD, TSS and TN are insignificant and they all meet the required effluent standards. Total P effluent concentration is even smaller at lower operational temperature (0,2 vs. 0,4 gP/m^3). Under the same temperature conditions the system with the secondary settler indicates reduced technological efficiency in regard to all pollution indicators in the effluent and with the concentration increasing in the range from 26% (total nitrogen) to about 95% (TSS). As it could be expected the ammonia concentration al lower temperature recorded the largest increase of 200% (from 1,2 to 3,6 $gN\text{-}NH_4/m^3$).

Low temperature stimulates the reduction in energy demand, mainly in the part used for aeration of biomass. This can be observed for both, the system with the settler and for the MBR, however this reduction is relatively smaller for the MBR (6%) than for the traditional system (10%). Still, the energy efficiency is much better for the traditional system (0,21 kWh/m^3) than for the MBR (0,34 kWh/m^3). With the decrease of temperature the biogas production increases in both systems, but more for the MBR (by 42% as compared to 29%). This is caused by reduced biomass mineralization reflected by the increased value VSS/TSS ratio. Still the activated sludge in the MBR system is more stabilized than the sludge in the traditional system (VSS/TSS ratio equal to 0,58 vs. 0,64).

CONCLUSIONS

The membrane bioreactors are gaining increased interest of WWTPS' operators especially when it is necessary to increase the plant capacity at limited space availability or to improve the effluent quality. The simulation research performed for a hypothetical plant of capacity 20000 m3/d (97000 PE) show that replacing traditional secondary sedimentation with membrane filtration with membrane modules installed inside the biological reactor (MBR) can improve plant's technological efficiency and reliability. In all three tested operational scenarios (normal operation; peak flow and load; low temperature) the MBR line ensured low and stable pollution concentrations in the effluent that were below the required standards. Under the same conditions the line with secondary settler often experienced technological problem with maintaining required effluent quality.

The benefits of technological efficiency and reliability of the MBR system are somewhat outweighed by the increased energy consumption (about 50%) by and the reduced biogas production (by about 42%) what limits the possibility for energy recovery. The increased energy consumption is mostly due to the required intensive cross-flow aeration of membranes, and the reduced biogas production due to the increased mineralization of sludge in the MBR systems at SRT reaching 28 days. Thus, the energy balance of the MBR systems is distorted. In Considering the above the benefits of application the membrane filtration at WWTPs are not always very obvious and plants' operators should carefully study all pros and cons in local circumstances before making the decision. Computer simulation can be a useful tool in such analysis.

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