Pergamon

Wat. Sci. Tech. Vol. 38, No. 3, pp. 173–178, 1998.
IAWQ

0273–1223/98 $19·00 + 0·00

PII: S0273-1223(98)00487-9

EFFECTS OF THE MEMBRANE TECHNOLOGY ON THE DIMENSIONING OF MUNICIPAL WASTEWATER TREATMENT PLANTS

A. Seyfried, E. Dorgeloh, E. Brands and P. Ohle

Institut für Siedlungswasserwirtschaft an der RWTH Aachen, 52056 Aachen, Germany

ABSTRACT

The successful application of membrane filtration on the activated sludge process is a recent development. Two processes are most common: separate modules and submerged modules, with the former being the more promising due to the lower energy consumption. While they allow high sludge ages, conventional sludge ages are equally viable, thus allowing the use of tested and reliable dimensioning techniques. The near perfect solids retention of the membrane filtration, however, can lead to problems with the accumulation of inert solids and heavy metals in the activated sludge. In that area, further research is necessary to develop safe dimensioning methods. © 1998 Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Dimensioning; extended aeration; membrane filtration.

INTRODUCTION

In the past, the practical application of membrane technology was usually restricted to the treatment of potable water and landfill leachate. Now, membrane processes are increasingly replacing the secondary clarifier of municipal wastewater treatment plants. As a result, the question of the necessity of changes in the dimensioning strategy for municipal wastewater treatment plants arises. This paper discusses possible effects of biomass separation by membrane processes on the dimensioning of municipal wastewater treatment plants.

MEMBRANE PROCESSES FOR THE SEPARATION OF BIOMASS

Membrane processes can be classified by the degree of separation, the separation mechanisms, and the pressure applied. Figure 1 gives an overview of pressure-driven membrane processes. The degree of separation increases with each step as well as the necessary pressure.

Figure 2 shows the two methods of operation most common for wastewater treatment. Separate stage systems with cross-flow membrane modules are separated from the aeration tank. The feed flows parallel to the membrane surface at a high speed and pressures between 300 and 500 kPa. As a result, high specific permeate flows of approximately 100 to 300 l/(m^2/h) are possible. At the same time, the specific energy consumption is fairly high, it lies between 3 and 7 kWh/m^3 permeate (Krauth, 1991).

In case of the vacuum-driven membrane modules, no pressure is applied to the feed, but vacuum to the permeate instead. The membrane modules are submerged into the aeration tank, usually above the aerators to remove the cake-layer with the help of the rising air bubbles. Depending on the construction of the modules, back-wash cycles can reduce the cake-layer and to some degree the fouling even further. Both the specific energy consumption, approximately 0.2 to 0.5 kWh/m^3 permeate, and the specific permeate flow, approximately 20 l/(m^2/h) permeate, are one magnitude of order lower than those of cross flow modules. Therefore, a much larger membrane surface is needed (Kraft and Mende, 1996).

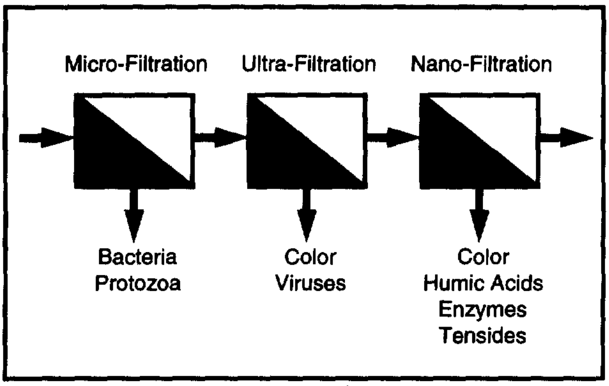

Figure 1. Types of membranes for wastewater treatment.

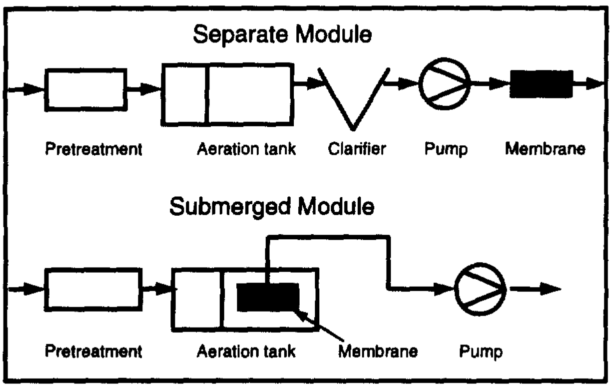

Figure 2. Flow-chart for separate and submerged membrane modules.

EFFECT OF THE MEMBRANE PROCESS ON THE WASTEWATER TREATMENT PROCESSES

The membrane filtration process has a number of consequences for the wastewater treatment processes. The specific throughput of a membrane does change with the solids load, but not the permeate quality, unlike the effluent quality from a clarifier, that degrades dramatically if a certain solids load is exceeded. Therefore, treatment systems using membrane processes can operate at high MLSS concentrations of up to 25 kg/m^3. As a result, a lower aeration tank volume is needed. In conjunction with the possible absence of a secondary clarifier, this leads to a very space-efficient wastewater treatment technology suitable especially for the expansion of existing wastewater treatment plants. The energy consumption of plants utilizing submerged membrane modules should be roughly the same as that of conventional plants. The higher air consumption for counteracting membrane fouling and the energy consumption of the vacuum pumps is partly balanced by a lower energy consumption by the stirrers and the pumping of return sludge. The life-span of the membrane modules should be at least five years, as it has not yet been necessary to change the membranes of existing wastewater treatment plants in the USA and Japan. For the other parts of the wastewater treatment plant, a life-span similar to that of a conventional wastewater treatment plant can be expected (Kollbach *et al.*, 1997).

DIMENSIONING OF THE BIOLOGICAL STAGE

In general, most static dimensioning methods for the tank volume of a wastewater treatment plant, and implicitly even dimensioning methods by dynamic simulation, are based on the simple equation:

Usually the sludge age is selected under consideration of calculations for a minimum sludge age (i.e. nitrification). The suspended solids concentration is controlled by the type of phase-separation, like sedimentation, flotation, or membrane filtration. The excess sludge production, however, consists mainly of the following fractions:

- bacteria growth
- inert substances in the influent to the biological stage
- detritus from the decay of the biomass
- eventuall precipitation sludge.

Table 1 gives an overview of a few dimensioning methods (after Wittke, 1994). The main difference between them is the way the inert material and the detritus are being taken into consideration. All have in common, that only the bacterial decay and the detritus, if applicable, depend on the sludge age.

Table 1. Dimensioning methods for the aerated tank volume (after Wittke, 1994)

	Bacterial growth	Bacterial decay	Detritus from bacterial decay	Inert solids in the influent (w/o precipitation sludge)
HSG (Dohmann et al., 1993)	Yield Substrate	Constant Sludge age	Constant Bacterial Decay	Constant Influent Solid
Sen (Wittke, 1994)	Yield Substrate	Constant Sludge age	-	Bacteria FSS / VSS
EPA (EPA, 1993)	Yield Substrate	Constant Sludge age	-	Bacteria FSS / VSS
Eckenfelder (Eckenfelder, 1991)	Yield Substrate	Constant Sludge age	-	Bacteria FSS / VSS
Kornegay (Wittke, 1994)	Yield Substrate	Constant Sludge age	-	Bacteria FSS / VSS

EFFECTS OF THE MEMBRANE FILTRATION ON THE SLUDGE STRUCTURE

Conventional methods for the phase separation, as sedimentation or flotation, return only those bacteria flocs to the aeration tank that can be easily separated from the bulk water. Subsequently, these floc-forming bacteria will predominantly grow in the biological stage. Dispersed bacteria and pin-point flocs will be washed out of system, despite their principally better access to substrate and oxygen. Membrane filtration, however, retains all particulate matter in the biological stage, including dispersed bacteria and pin-point flocs. Some types of ultra-filtration, nano-filtration and reverse osmosis will even retain extracellular by-products of bacterial growth and decay in the biological stage. Based on that, the retention capabilities can be summarized as shown in Table 2.

Table 2. Retention capabilities of phase separation methods

	Sedimentation / Flotation	Membrane Filtration
Bacteria flocs, larger particulate solids	yes	yes
Dispersed bacteria, very small particulate solids, viruses	no	yes
Precipitation products	extensive	yes
Organic nitrogen	partial	yes
NO_x-N, NH_4-N and dissolved P	no	no
Enzymes, tensides and biogenic tensides	no	partial

EFFECTS OF THE MEMBRANE FILTRATION ON THE BIOLOGICAL PROCESSES

The effects of the type of phase separation can be classified as follows:

- effluent concentrations
- sludge age
- solids concentration and tank volume
- operation and sludge handling.

Effluent concentrations. If disinfection of the effluent is necessary, a positive effect of membrane filtration is the partial or complete sanitation of the effluent or at least the reduction of THM precursors. The effluent concentrations of inorganic nitrogen compounds are not affected by the chosen way of phase separation. In that respect, practically nothing can be gained in the dimensioning of wastewater treatment plants from the use of membrane filtration. On the other hand, the effluent BOD and COD concentrations will be much lower. While their importance for receiving waters can be questioned, they can be important from the legal point of view. In Germany, for example, effluent standards of down to 40 mg/l COD (20 minutes sampling time) are enforced.

Sludge age. The sludge age does not depend on the method of phase separation. Membrane filtration allows operation of the biological stage of very high sludge ages, but the sludge age of the biological stage is the decision and responsibility of the designing engineer and the operator. Therefore, two spans of sludge age can be discerned: sludge ages of up to 25 days and sludge ages above 25 days. The dimensioning process of a plant with a more conventional sludge age of up to 25 days won't change with the use of membrane filtration. Possibly higher enzyme concentrations and a higher fraction of dispersed microorganisms may result in a higher respiration rate and lower tank volume needed. In reality, the tank volume is not very expensive, the mechanical and electrical equipment, especially the aerators, is. For that reason, it should be suitable to use the same methods of dimensioning for sedimentation/flotation as for membrane filtration.

At sludge ages above 25 days, one operates outside the confidence interval of most current dimensioning methods. Nevertheless, it should be remembered that such long sludge ages are not a particularly new process. Earlier, it was called extended aeration and went out of favor with rising oil prices. The following items, however, are important for dimensioning plants with a high sludge age and membrane filtration:

- The average concentrations of all inert material in the activated sludge, including heavy metals, correlates linearly to the sludge age. Therefore, dimensioning methods based on measured non-volatile solids are more suitable. Furthermore, if land application of the excess sludge is planned, the heavy metal concentrations in the influent, averaged over one sludge age, have to be measured.

- The BOD, usually measured over a period of 5 to 7 days, is not the best parameter to describe processes at sludge ages in excess of 25 days. The use of COD or TOC should give better results.

Solids concentration and tank volume. The solids concentration in a system with membrane filtration can be raised up to 25 kg/m^3. This allows much smaller tank volumes. On the other hand, smaller tanks mean shorter hydraulic retention times and steeper peaks in the effluent. Figure 3 shows the simulated effect of an ammonia peak on the effluent concentration for a small and a large tank containing the same amount of autotrophic bacteria (Y = 0.2, kd = 0.04 1/d, Ks = 1.4 mg/l, μmax = 0.7 1/d). This can be important to remember, if the receiving waters are sensitive to concentration peaks.

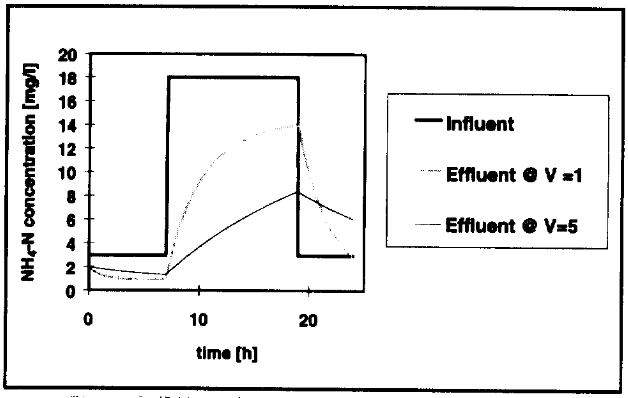

Figure 3. Effect of an ammonia peak on the effluent.

Operation and sludge handling. The air scouring effect is important for the operation of submerged membrane modules. Therefore, any aeration control strategies should not be based on the dissolved oxygen only. If the membranes retain extracellular enzymes from the biomass, they are likely to retain biogenic tensides as well. This can lead to problems with foam. Other problems can be expected with sludge handling. Since the selection mechanism of sedimentation or flotation is absent, the excess sludge will contain a higher degree of finely dispersed solids. For this reason, good separation efficiency of any sludge dewatering equipment is important. Otherwise, solids in the recycle flow will gradually build up in the biological system.

CONCLUSIONS

The biological stage of a wastewater treatment plant using membrane filtration can be designed for conventional sludge ages based on existing dimensioning methods. The tank volumes will be lower, the energy consumption equal or higher, the effluent concentrations equal or lower, and the effluent peaks higher than those of a plant using conventional phase-separation methods. Even though it is time-consuming due to the long sludge ages, additional research is necessary for longer sludge ages. For example, the yield, decay coefficients, and the fractions of inert detritus should be measured for as many existing plants as possible in order to improve existing dimensioning methods.

REFERENCES

Dohmann, M. *et al.* (1993). Bemessung der Belebungsbecken nach dem Ansatz der Hochschulgruppe (HSG-Ansatz). *Korrespondenz Abwasser*, Heft 8/1993, 1240.

Eckenfelder, W. W. Jr. (1991). *Principles of water quality management.* Krieger Publishing Company, Malabar, Florida, 259.

EPA (1993). Nitrogen Control. U.S. Environmental Protection Agency, Technomic Publishing Company, Lancaster, Pennsylvania.

Kollbach, J., Dorgeloh, E. and Ohle, P. (1997). Ersatz einer Nachklärung bei kommunalen Kläranlagen durch den Einsatz von Membranverfahren. In: *Schriftenreihe Gewässerschutz - Wasser - Abwasser*, Band 158, 25/1-25/11

Kraft, A. and Mende, U. (1996). Niedrig Energie Membranverfahren zum Biomasserückhalt in Abwasserreinigungsanlagen, *Verfahrenstechnik und Chemieingenieurwesen, VDI/GVC Yearbook 1996*, 67-89

Krauth, Kh. (1991). Erhöhung der Biomasse durch Ultrafiltration bei aerob und anaerob betriebenen Bioreaktoren. *Korrespondenz Abwasser*, Heft 9/1991, 1150-1164

Wittke, B. (1994). *Vergleich amerikanischer und deutscher Ansätze zur Bemessung von Belebungsanlagen zur Stickstoffelimination*, Diploma thesis, Institut für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, p. 53