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MICROFILTRATION OF MUNICIPAL WASTEWATER FOR DISINFECTION AND ADVANCED PHOSPHORUS REMOVAL

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ABSTRACT

The objective of Research Project 02 WA 9253/4 on "Advanced Treatment of Municipal Wastewater: Microfiltration of municipal wastewater for disinfection and advanced phosphorus removal" which is supported by the BMBF (Federal Ministry for Education, Science, Research and Technology) is to show whether microfiltration (MF) is a technically feasible and economically competitive process for disinfection and phosphorus removal of secondary effluent. For bacteria and phosphorus removal, three different microfiltration systems (systems with flat sheet, tube and hollow-fibre modules) with a pore size of 0.2 μm are tested in small-scale pilot plants to find out whether they are suitable for municipal wastewater treatment. The most suitable system will afterwards be tested in one full-scale unit to obtain operational data. The monitoring program with the small-scale MF plants using the final effluent of the Berlin-Ruhleben wastewater treatment plant started in November 1993 and the results obtained so far can be summarized as follows.

Total coliforms, *E. coli*, faecal streptococci and salmonella are removed to levels below the detection limit, less than 1 cfu/100 ml in the effluent of all three MF plants.

Coliphage - as a surrogate organism for enterovirus - are significantly reduced with a 2-3 log removal, which means that the limit value for enterovirus laid down in the EU Bathing Water Directive can be met in the effluent of the MF plants.

The average concentrations for total phosphorus (P_T) in the effluent are 60 μg/l for the Memcor and the DOW units and 90 μg/l for the Starcosa unit without the use of precipitants.

With a low ferric dosage of 0.014 mol/m^3 prior to the MF, the average effluent P_T concentrations of all three MF units are lower than the target concentration of 50 μg/l (no polymer feed).

With a specific energy consumption of about 0.2 kWh/m^3 filtrate the dead-end MF (Memcor) requires at least five times less energy than the cross-flow MF. Based on the energy consumption dead-end MF should be preferred if large volumetric flows of wastewater with a low concentration of solids have to be treated.

Because of unfavourable energy consumption the tests with the cross-flow MF have been discontinued.

When using MF systems in the final effluent of wastewater treatment plants, evidence must be produced in a full-scale MF unit to demonstrate that microfiltration is really suitable for practical application. This as well as a reliable calculation of investment and operating costs are the main objectives of further investigations within the framework of this research project. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Municipal wastewater; advanced wastewater treatment; microfiltration; disinfection; advanced phosphorus removal.

INTRODUCTION

In Germany surface water is used for recreation, agriculture and as a drinking water reservoir. The use of surface water for these purposes can be limited by the discharge of wastewater. The goal in Berlin is to meet the microbiological standards of the EU Bathing Water Directive (Anonymous, 1975) and to reduce total phosphorus to levels below 0.05 mg/l to avoid eutrophication. However these are not valid control values for the effluent of WWTPs. To minimize public health risk German law requires different quality standards depending on the use of the water body (Popp, 1994). The quality regulation of the EU Bathing Water Directive is given in Table 1 and shows the imperative and guide values for bacteria and viruses. To keep this regulation in some cases it might be necessary to apply technologies in the effluent of wastewater treatment plants either for disinfection and/or for turbidity reduction by nutrient elimination. This should mainly happen in areas with sensitive receiving waters like the lake and river system in and around Berlin. Therefore, there has been increasing interest in employing low-pressure membrane filtration systems for disinfection and phosphorus reduction in a single treatment step.

Table 1. Microbiological requirements according to the EU Bathing Water Directive (Anonymous, 1975)

	sample volume	guide value	imperative value
total coliforms	100 ml	500	10000
E.coli	100 ml	100	2000
Streptococcus faecalis	100 ml	100	-
salmonella	1 l	-	0
enterovirus	pfu/10 l	-	0

The objective of this investigation was to evaluate the efficiency of microfiltration with a pore size of 0.2 µm for disinfection and advanced phosphorus reduction in municipal wastewater (Dittrich and Gnirss, 1994). Microfiltration was considered because of its feature as a physical barrier for bacteria and particles. By reducing the particles a considerable reduction of viruses attached to particles can also be expected. For advanced phosphorus removal down to a level of 0.05 mg/l P_T, ferric chloride is dosed prior to microfiltration. It can be expected that low total phosphorus concentration levels are achieved at stoichometric dose ratios much lower than in current chemical dosing practices.

Table 2. Design characteristics of the three pilot plants

	DOW	**Starcosa**	**Memcor**
required prescreening	50 µm	1000 µm	500 µm
membrane type	flat sheet	hollow tube	hollow fiber
material of the membranes	fluoro polymer	polypropylene	polypropylene
number of modules x membrane surface area	4*30 m²	1*10 m²	2*10 m²
external/internal fibre diameter (d_e/d_i)	-	2.6 mm/ 1.8 mm	0.65 mm/ 0.31 mm
effective membrane surface area	120 m²	10 m²	42 m²
mode of operation	cross flow	cross-flow	dead-end
backwash medium	filtrate	filtrate/compressed air	compressed air

EXPERIMENTAL PROCEDURE

During the first phase of the pilot study, three microfiltration plants (DOW, Starcosa, Memcor) were operated in parallel, to test which system was the most suitable for large-scale application in wastewater treatment. DOW and Starcosa tested cross-flow plants, DOW with a flat sheet membrane and Starcosa with a hollow-fibre membrane. Memcor used the dead-end mode with a hollow-fibre membrane. All design characteristics are given in Table 2. Specific test objectives include: effluent quality, long-term flux performance, energy consumption, frequency of chemical cleaning and backwash.

The feed water of the pilot plants is secondary effluent from the Ruhleben WWTP (Berlin), which operates with biological phosphorus and nitrogen removal (Peter and Sarfert, 1989). Figure 1 shows a sketch of the experimental set-up with the different process steps: precipitation/flocculation - prescreening - microfiltration.

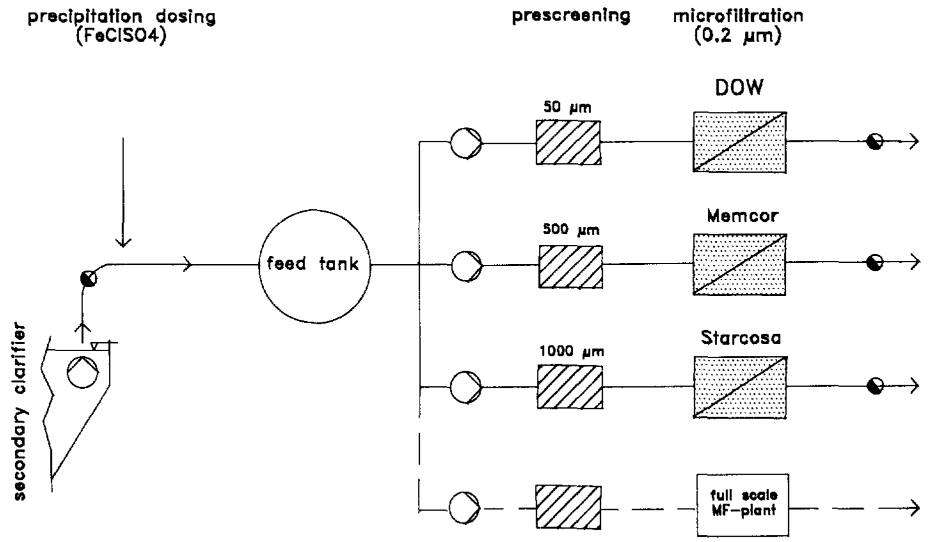

Figure 1. Schematic of microfiltration set-up.

The small-scale microfiltration plants operate at an average flow of 2 m^3/h.

RESULTS

The trial was commenced without chemical dosing to assess the level of phosphorus removed solely by the MF and the main objective was the optimization of the MF process by the three companies. For this period of six months the operational data of the MF units is presented in Table 3, in which only steady conditions are considered. The Memcor unit provided superior performance with respect to flux stability and chemical cleaning. The effective membrane surface area of the Memcor unit is the external hollow-fibre surface area considering the filtration direction. Memcor uses the internal nominal fibre surface area in calculations and would report fluxes approximately twice as high as these figures. While the Memcor dead-end plant reached a relatively constant net flux between 40-45 $l/(m^2\,h)$ the net flux of the cross-flow plants was lower and very unsteady. The net flux takes into consideration that the plants produce no filtrate while backwashing and/or use filtrate for backwash. Figure 2 presents the net flux of the three units. The decreasing filtrate flux of the cross-flow units seem to be the consequence of ineffective chemical cleaning and an insufficient hydraulic within the flat sheet modules (DOW).

Table 3. Operational data (average values) from trial periods with steady conditions

		DOW (120 m²)	Starcosa (10 m²)	Memcor (42 m²)
trial period		5/6-5/16/94	4/25-5/16/94	1/12-5/16/94
	d	10	22	115
backwash interval	min	45	10	15
Q_{inf}	m^3/h	49	5	2.02
Q_{co}	m^3/h	32	12.5	0.27
Q_r	m^3/h	80	22.5	-
w	m/s	12	14	-
specific flux*	l/m^2 h	13.8	35	41.6
output (effluent/influent)	%	34	70	85
p_1	bar	1.35	0.95	1.3
p_3	bar	0.71	0.21	0.4 - 0.9
Δp	bar	4	6	-
interval of chemical cleaning	d	5	5	4
used chemicals	-	Ultrasil 10 and H_2O_2/acetic acid	caustic soda or citric acid	caustic soda and Memclean
dissolved in	-	drinking water	drinking water	drinking water

* no filtrate production while backwashing and/or use of filtrate for the backwash process

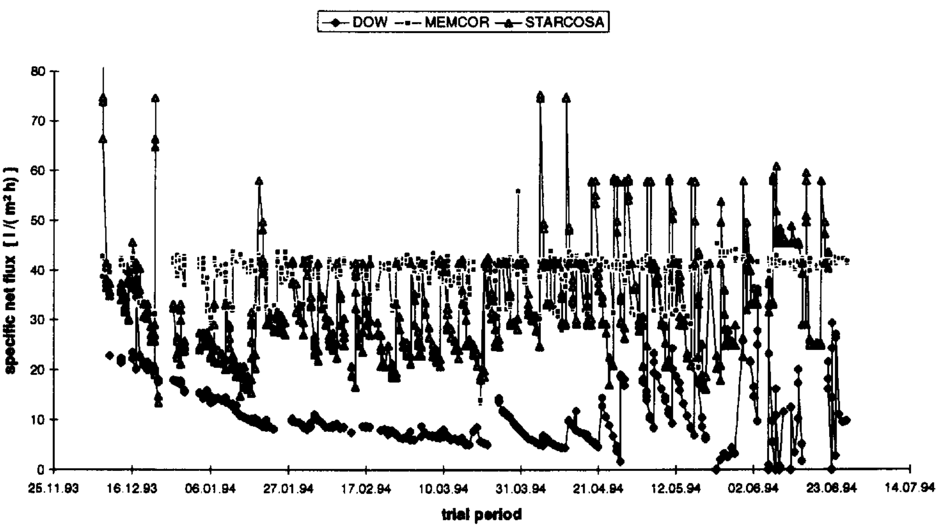

Figure 2. Specific net flux of the three plants (period without precipitation: 11/25/93 - 5/17/94).

Phosphorus

The average phosphorus concentrations in the effluents are compared for the period without and with precipitation in Table 4. A considerable reduction in total phosphorus was achieved by the membrane without precipitation: 60 µg/l in the effluent of the Memcor and the DOW units and 90 µg/l in the case of the Starcosa unit. With a low ferric dosage of 0.014 mol/m^3 prior to the MF the average effluent P_T concentrations of all three MF units were lower than the target concentration of 50 µg/l (no polymer feed).

Table 4. Phosphorus concentrations (average values) in the influent and in the effluent of the MF pilot plants with and without chemical dosing

			influent	effluent		
				DOW	Starcosa	Memcor
without ferric dosing (12/7/93 - 5/18/94)	P_T	µg/l	186	62	93	60
	P_{Tf}	µg/l	93	-	-	-
	PO_4-P_f	µg/l	< 30	< 28	52	< 26
with ferric dosing (0.014 mol Fe/ m^3) (5/19/94 - 7/26/94)	P_T	µg/l	120	49	43	35
	P_{Tf}	µg/l	70	30*	33*	27*
	PO_4-P_f	µg/l	33	10	11	7

* average values from: 6/7/94 - 7/26/94

Microbiology

The results for *E.coli* and coliphage, as measured in the influent and in the effluent of all three MF units are presented in Figure 3 and Figure 4, respectively. Total coliforms, *E.coli* (Fig. 3), faecal streptococci and salmonella are all below detection limit, less than 1 cfu/100ml in the effluent of all three MF units.

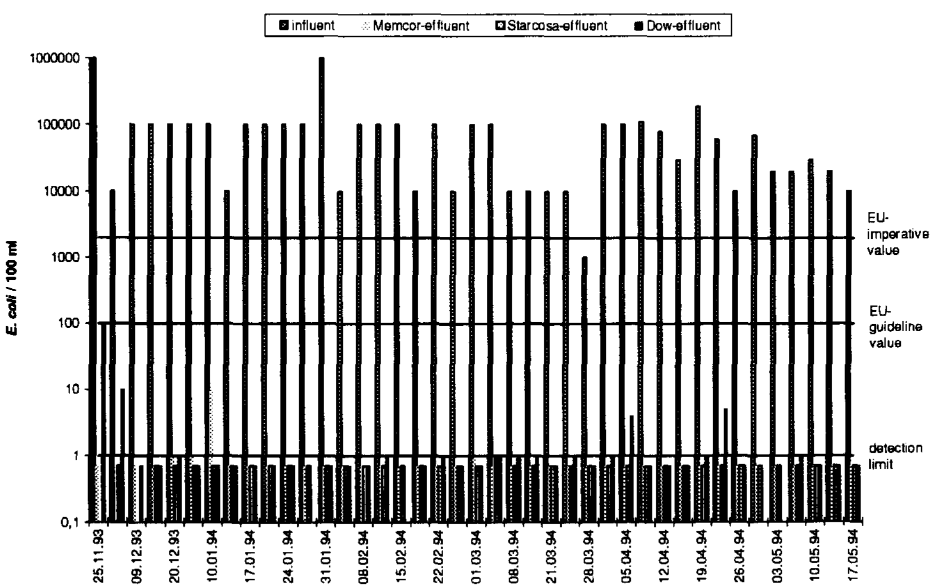

Figure 3. *E.coli* in the influent and in the effluent of the MF plants (composite sample); period without precipitation 11/25/93 - 5/17/94.

Coliphage - as a surrogate organism for enterovirus - are significantly reduced with a 2-3 log removal (Fig. 4), which means that the imperative value for enterovirus laid down in the EU Bathing Water Directive can be met in the effluent of the MF plants (based on experimentally determined enterovirus/coliphage ratio of 1/1000 for municipal wastewater).

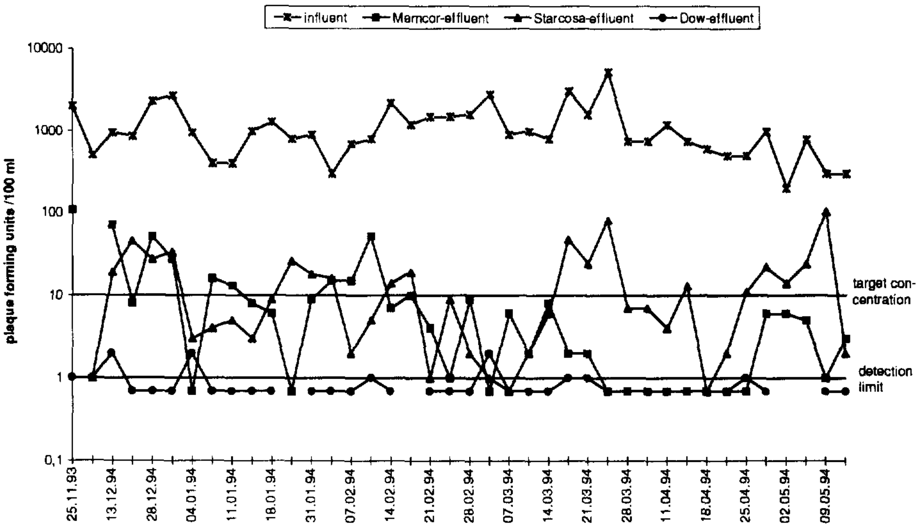

Figure 4. Coliphage in the influent and in the effluent of the trial plants (period without precipitation: 11/25/93 - 5/17/94).

Energy

The operation costs are mainly caused by the energy consumption. Therefore the energy for feed pumps and compressors is calculated on the measured data (presented in Table 3). With an energy consumption of about 0.2 kWh/m^3 per filtrate the dead-end MF requires at least five times less energy than the cross-flow units. Based on this result dead-end filtration is qualified for the treatment of municipal wastewater with low concentrations of suspended solids. Due to the fact that the higher energy consumption of the cross-flow plants is so evident, the trials with these plants have been discontinued.

OUTLOOK

Inorganic membranes seem to have some important advantages in comparison with the organic membranes tested so far. To mention are the higher flux, better recovery through cleaning chemicals and a longer expected lifetime of the membranes. Therefore since January 1995 a second monitoring programme has been carried out where the dead-end system with the organic membrane is compared with a dead-end system with an inorganic (ceramic) membrane.

In general the performance and the reliability of the microfiltration system has been very satisfactory, but the tested systems with a filtrate capacity of 1-2 m^3/h are too small for a scale-up. Therefore it is necessary to run the next trials with a larger unit to evaluate the operation and capital costs for the microfiltration in a given application.

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NOMENCLATURE

Abbreviation	unit	Explanation
P_T	µg/l	total phosphorus (original sample)
P_{Tf}	µg/l	dissolved total phosphorus (filtered sample)
PO_4-P_f	µg/l	orthophosphate (filtered sample)
PEA	-	phosphate elimination plant
pfu	-	plaque forming unit
p_1	bar	pressure at the entrance of the module
p_3	bar	pressure at the end of the module
Δp	bar	pressuredrop along the module (p_1-p_2)
Q	m^3/h	flow
TOC	mg/l	total organic carbon
w	m/s	flow velocity
β	-	stoichiometric dosing ratio of iron to phosphorus

Indices

co	concentrate
r	recirculation
inf	influent