

Optimization of operational parameters of the in-out ultrafiltration of tertiary waste water applying different capillary diameters

P. Buchta*, M. Heijnen*, R. Winkler*, P. Berg*

*inge GmbH, Flurstr. 27, Greifenberg, Germany, email: pbuchta@inge.ag
mheijnen@inge.ag
rwinkler@inge.ag
pberg@inge.ag

Abstract Due to the world wide drinking water shortage, tertiary waste water treatment of municipal waste water treatment plants become more and more important. The desired conditioning objectives range from wwtp effluent disinfection (irrigation, bathing water of rivers, lakes etc.) to partly or complete demineralization (drinking- and process water) by Nanofiltration or reverse osmosis systems. Because of the excellent filtrate water quality Ultrafiltration technology is going to be applied more and more in the process chain of tertiary waste water treatment.

Since February 2009 the inge watertechnologies AG is operating a pilot plant in a municipal waste water treatment plant (up to 90.000 pe) to adopt operational parameters in waste water filtration and to test different capillary diameters and their effects on UF operation.

Main focus of the tests with a new developed pilot plant unit (automatic operation of a 0,2 m² module) will be on filtration performance (flux and recovery rates) under different backwash conditions (pressure, flow rate), different pretreatment conditions (coagulation) as well as different cleaning strategies applying different capillary diameters. Additionally filtrate quality will be examined concerning an advanced treatment.

Goal of the investigations is to define the characteristic operational parameters of the different inge Multibore® UF series.

Keywords Capillary diameters, pilot plant test, tertiary waste water, ultrafiltration

PILOT PLANT TEST

Intention

inge started the pilot plant test at the waste water plant in Eching in February 2009 to investigate the operational parameters in tertiary waste water treatment. Major focus was on one hand to highlight the overall settings like adequate pretreatment, cleaning chemicals and frequencies and the effect of changes in the feed water quality (bad weather operation) on the UF membrane operation and on the other hand to optimize the operational parameters like flux rate and backwash time and therefore also the recovery rate for the different inge Multibore® capillary diameters (0.9 and 1.5 mm). Due to a higher hold up volume and a more homogeny fouling layer of the bigger capillary diameter, a higher recovery rate and a higher backwash effectivity where expected due to a formation of a more homogeny fouling layer [8].

Waste Water Treatment Plant

The filtration tests with tertiary waste water are taking place at a communal water plant at the Ammersee in Bavaria/Germany. The plant is a biological treatment plant designed for 90.000 PE, this corresponds to 3.5 mio m³ waste water per year. It consists of a mechanical cleaning with a strainer, followed by the preliminary sedimentation. Then the biological cleaning steps (nitrification/denitrification) are taking place. To remove the phosphate by sedimentation, an iron/aluminium mixture as coagulant is dosed into the denitrification pool. Eventually water runs through the final settling tank in order to separate the activated sludge flocs. The effluent of the final sedimentation tank was used as feed water for the UF test plant. The characteristic water quality parameters of the effluent of the waste water treatment plant are shown in the chapter “Feed water quality”.

Pilot Plant Setup

The pilot plant was primary designed for tests in industrial applications with an undefined feed water quality; therefore this small scaled plant could be placed very fast, without the periphery a large scale pilot test would need. The goal was to get information on settings for the UF operations as well as product quality. The module was especially designed for this plant and consists of 7 inge Multibore[®] fibre (0,9 mm capillary diameter) at a length of 1,60 m. This results in an active membrane area of 0,2 m² per module. Figure 1 shows the principle flow scheme with the help of screenshot of the control panel.

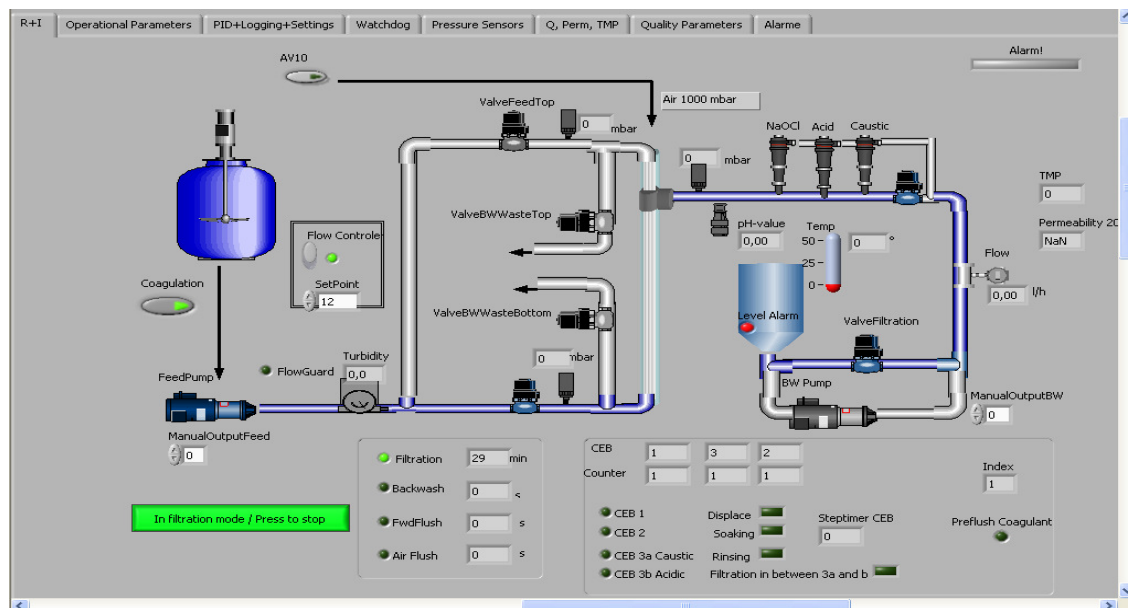


Figure 1: Screenshot of the control panel

This plant is driven fully automatic and basically consists of a feed pump, a backwash pump and a filtrate tank, chemical dosage pumps for 3 different chemicals, and different measurement devices (pH-value, turbidity, flow rate, pressure, and temperature). All pumps are controlled by frequency converters to ensure a stable flow rate. Additionally a dosage pump for coagulant and a pump for pH-adjustment are installed in the feed water pipe. The required contact time is given by the hold up volume of the feed water piping. Figure 2 shows pictures of the pilot plant at the waste water treatment plant.

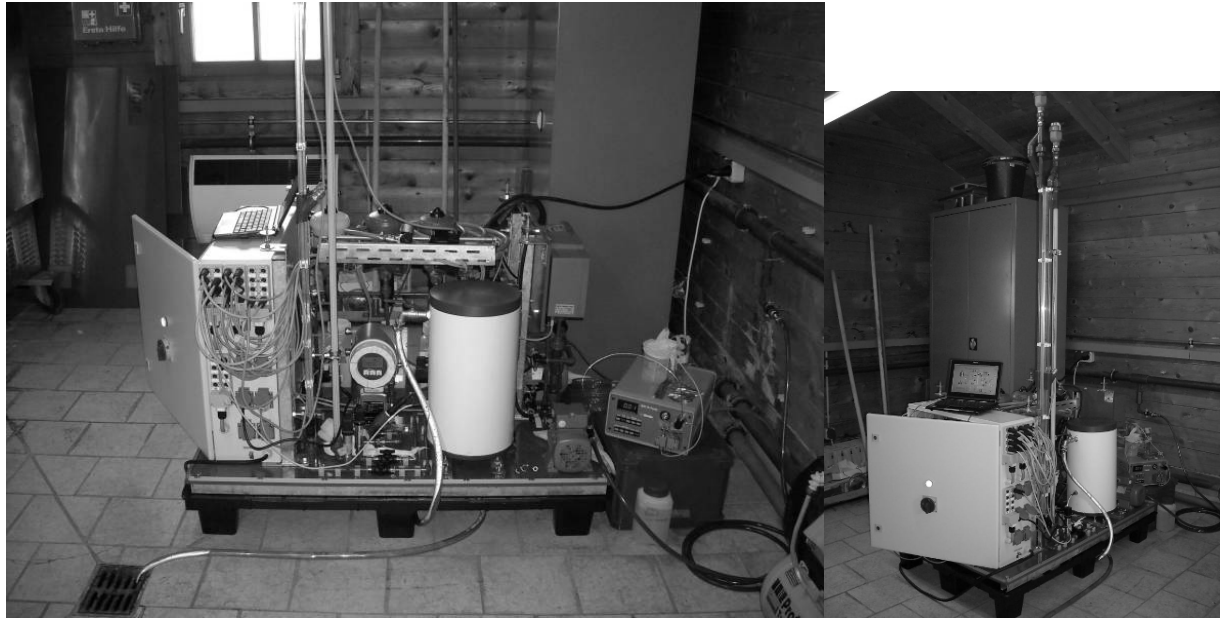


Figure 2: Pilot Plant at WWTP

Test program

After the proper installation of the plant, the following issues were figured out to ensure the test for the flux rates and the backwash procedures will proceed accurately under ideal conditions:

Table 1: Basic parameters

Issue	Method	Focus	Criteria
Pretreatment	➤ JAR tests ➤ Tests in the pilot plant	➤ pH- value; ➤ Product (Fe, Al, PACl) ➤ Concentration ➤ Contact time ➤ G-value	➤ COD removal rate ➤ Coagulant-residue in UF filtrate ➤ TMP run ➤ Backwash effectivity
CEB performance	➤ Tests in the pilot plant	➤ Chemical (H₂SO₄, NaOH, NaOCl) ➤ Concentration / pH-value ➤ Frequency ➤ Soaking time	➤ Cleaning efficiency ➤ Sustainability

After these basic conditions were figured out, the test program for the optimization of the operational settings was implemented. This test program included 3 phases with different water qualities. In each phase, the characteristic UF performance, especially the flux rate and recovery rate, was the major subject of investigation. Also the adequate pretreatment and the corresponding filtrate quality were examined. The performance of the 0,9 mm Multibore® capillaries and the 1,5 mm capillaries were compared to each other.

Table 2: Test Program

Test Phase	Turbidity [FNU]	COD [mg/l]	Water origin	Applied inge UF Multibore® capillary diameters
I	< 10	30 - 50	Effluent final sedimentation	Ø 0,9 mm Ø 1,5 mm
II	50 - 100	30 - 50	Effluent final sedimentation + biomass bio reactor	Ø 0,9 mm Ø 1,5 mm
III	50 - 100	80 - 100	Effluent final sedimentation + biomass bio reactor + effluent primary sedimentation	Ø 0,9 mm Ø 1,5 mm

Generally, the feed water quality was varied in turbidity and DOC to examine their impact on each other concerning ultra filtration performance.

Feed water quality

In average, the effluent of the final sedimentation tank showed following characteristic water quality (Table 3):

Table 3: Raw water quality

	unit	raw water
Conductivity 20 °C	µS/cm	900
Conductivity 25 °C	µS/cm	1000
UV (SAC 254 nm)	m-1	13
Filtrated Substances	mg/l	17
COD filtrated	mg/l	25
COD	mg/l	38
BOD5	mg/l	6,5
DOC	mg/l	5
Total phosphor (P)	mg/l	0,35
Ammonium - N	mg/l	0,77
Aluminium (Al)	mg/l	0,66
Iron (Fe)	mg/l	0,28
Microbiology by 20 °C (100ml)	KBE	8664
Microbiology by 36 °C (100ml)	KBE	6064
Coliforme germs (100ml)	KBE	2419
E. Coli (in 100 ml)	KBE	2419
Hardness	mmol/l	2,60

The COD concentration in the feed water was controlled daily by a rapid test method (Hach Lange). To verify the results, samples were also taken to an external laboratory periodically to measure all parameters seen above.

Figure 3 shows the fluctuations in COD during a 24 month period of the effluent final sedimentation. With the warm summer month a decrease of COD was measured. The COD fluctuated in between 20 and 40 mg/l. In spells of bad weather (heavy rainfall, thunderstorms), the turbidity increased temporarily while the COD decreased.

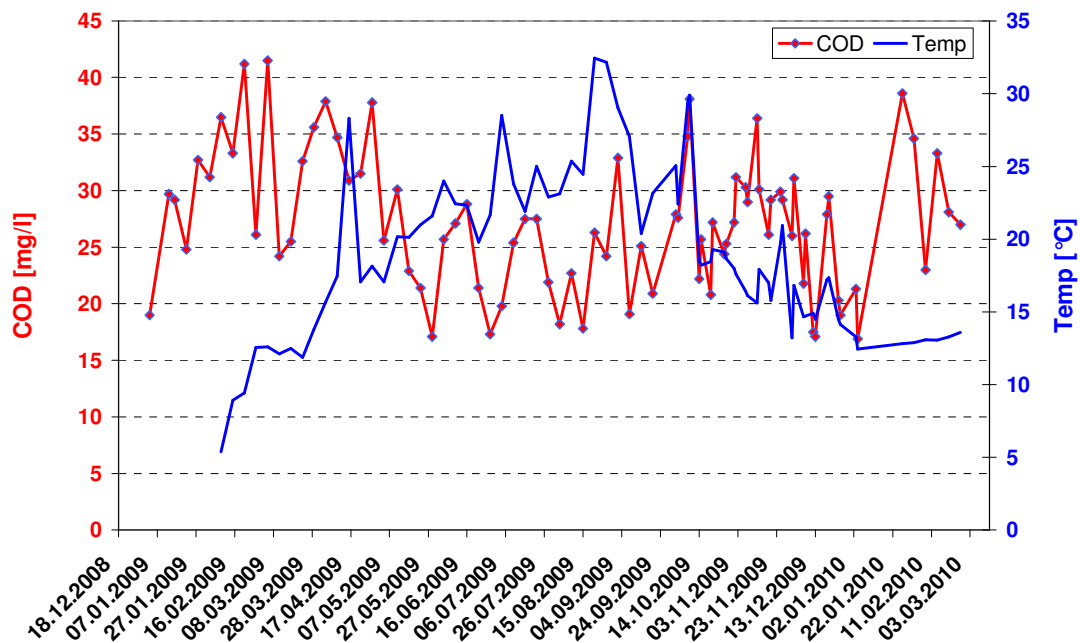


Figure 3: COD and temperature: seasonal fluctuations

RESULTS

Pretreatment

In a series of Jar tests [9], different coagulants were compared concerning their COD removal characteristic at different pH- values. The set points for the pH-value varied in between 6,0 and 7,0, the ideal pH range for the formation of insoluble Al/Fe hydroxides [11] as well as DOC removal [5]. As coagulants, FeCl_3 , FeCl_3/Al mix and 2 different polyaluminium chlorides were tested.

Finally the PACl named “Sachtoklar” was chosen due to its highest COD removal rate of > 40 %.

To define the adequate dosage amount, a further test was done with different Al concentrations in between 1 and 7 mg Al/l [6], corresponding to 0,2 – 1,5 mg Al/mg DOC. Figure 3 shows, that a dosage amount of approx 2,5 mg Al/l (corresponding to 0,5 mg Al/ mg DOC) showed the most effective COD removal rate.

An impact of the variation of the pH- value in between 6 and 7 could not be measured; therefore the pH value in the feed water was adjusted to 6.9.

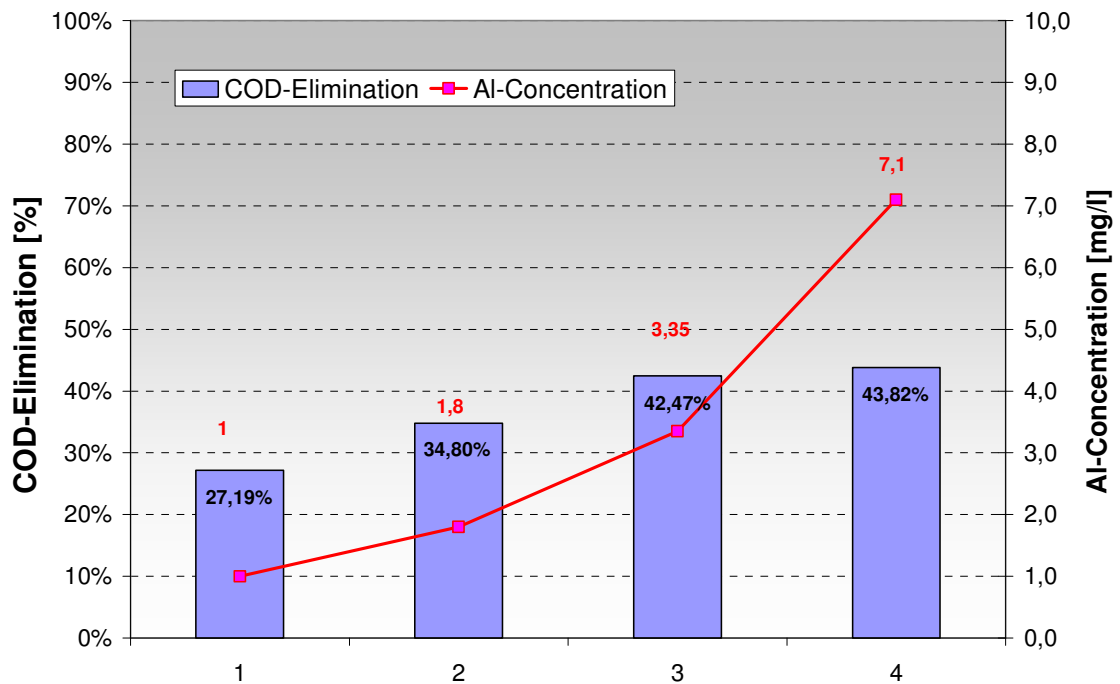


Figure 4: Al dosage and corresponding COD removal rate at pH 6.9

The aluminium residue in sample 1 to 3 remained below 1 % of the dosage amount, therefore far below 0,1 mg/l, which meets the WHO targets [12]. The test in the pilot plant showed also the big impact of the coagulation on the UF operation during a failure of the PACl dosage pump (Figure 5).

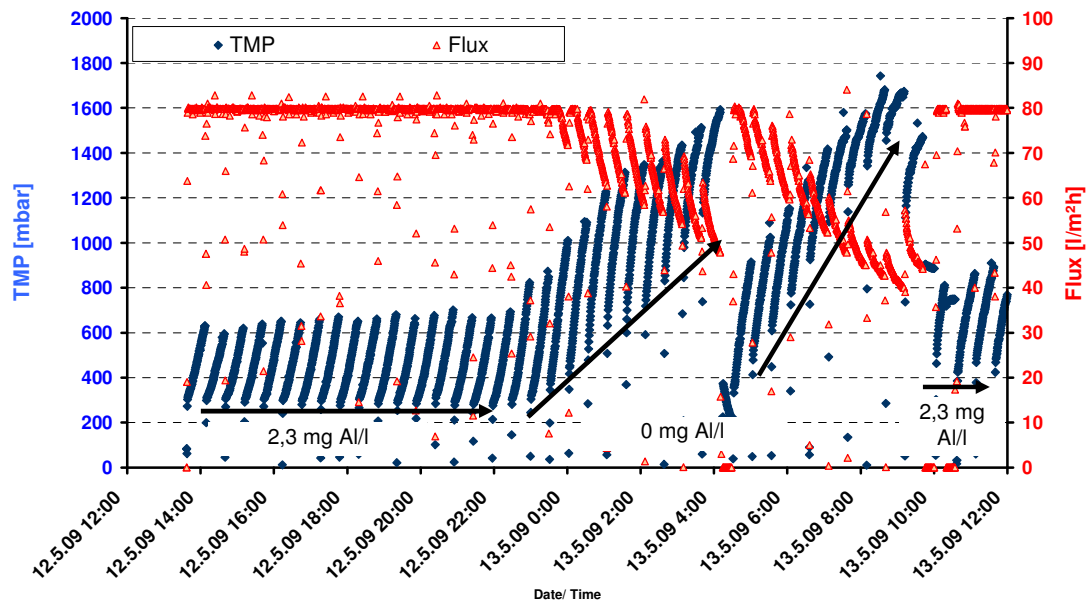


Figure 5: PACl- dosage pump failure

The figure shows that directly after the dosage pump failure, the TMP increased. Within a filtration interval of 30 min the TMP rose about a factor of 1.4. Much more problematic

was the loss of backwash efficiency, which led to a continuous pressure increase, so within hours the TMP climbed above 1 bar. Compared to the operation with coagulation (backwash efficiency > 99%, stable operation) the efficiency without dosage of the coagulant was only 80%, therefore the initial TMP after the backwash was doubled within 5 filtration cycles. Although the CEB with caustic and acid was able to recover the membrane completely, an operation without coagulant is not preferable: it would led to more than 12 CEBs per day, each 30 min long and a worse filtrate quality (see chapter “Filtrate quality”).

To test the impact of the G-value during floc formation, different pipe diameters were installed. Therefore G-values of 50, 400 and 800 s⁻¹ were tested. Compared with the experience in the operation of sand filters, were low G-values require long contact times to create a filterable floc characteristic [1], the UF seemed to be not affected by the floc structure so clearly. Also the filtrate quality remained the same applying different G-values.

To ensure an optimized mixing-in of the coagulant, a static mixer was installed in the feed water pipe [2]. If a good mixing-in of the coagulant at the dosage point was ensured, the G-value for floc formation seemed to be not relevant (Figure 6) in this application. Table 4 summarizes the settings for the coagulation process:

Table 4: Coagulation paramaters

Coagulant	Sachtoklar
Dosage rate	2-3 mg Al/l
pH-setpoint	6,9
Contact time (@ 15°C)	45s
Mixing in	Feed pump+ static mixer
G-value during floc formation	50 s ⁻¹

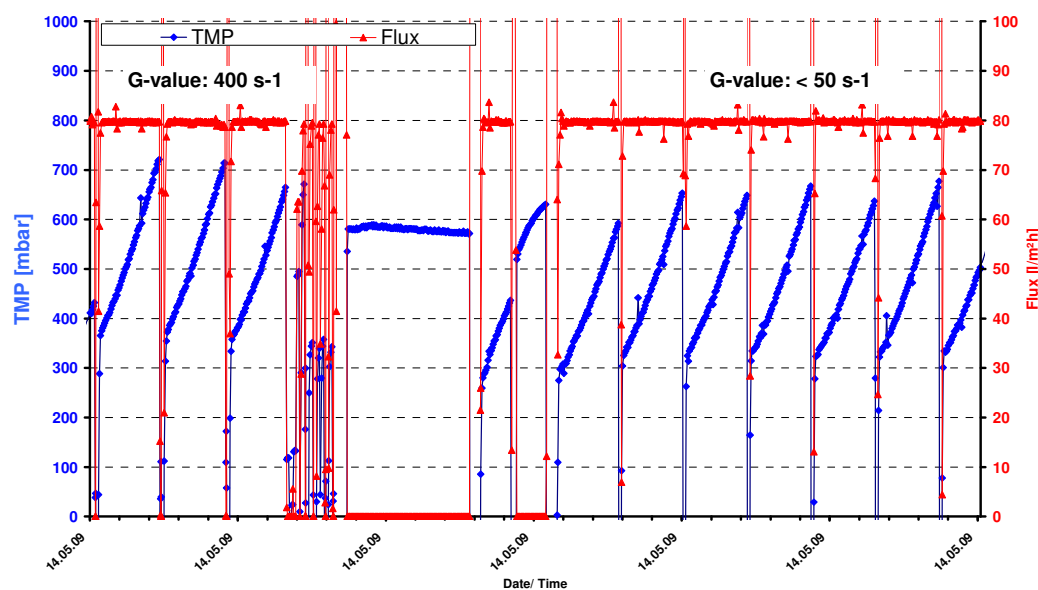


Figure 6: Impact of the G-value during floc formation on the TMP

CEB Cleaning (Chemical Enhanced Backwash)

The pilot plant was equipped with the common CEB chemicals for acidic, caustic and oxidative cleanings like sulphuric acid, 32 %, sodium hydroxide, 32% and sodium hypochlorite, 14%. The aim was to stabilize the permeability by releasing daily CEBs to avoid frequent CIP cleanings. Therefore the downtime of the plant can be reduced. Another advantage of the fully automatic released, max 30 min lasting CEB is compared to a CIP cleaning that there is no manpower needed.

To avoid AOX formation ($\text{Cl} + \text{DOC}$), the strategy was to clean the membranes with caustic ($\text{pH} > 12,0$) and acid ($\text{pH} < 2,0$) CEBs. If UF is installed as pretreatment to RO, this CEB strategy eliminates the risk of damaging the oxidant- sensitive RO modules

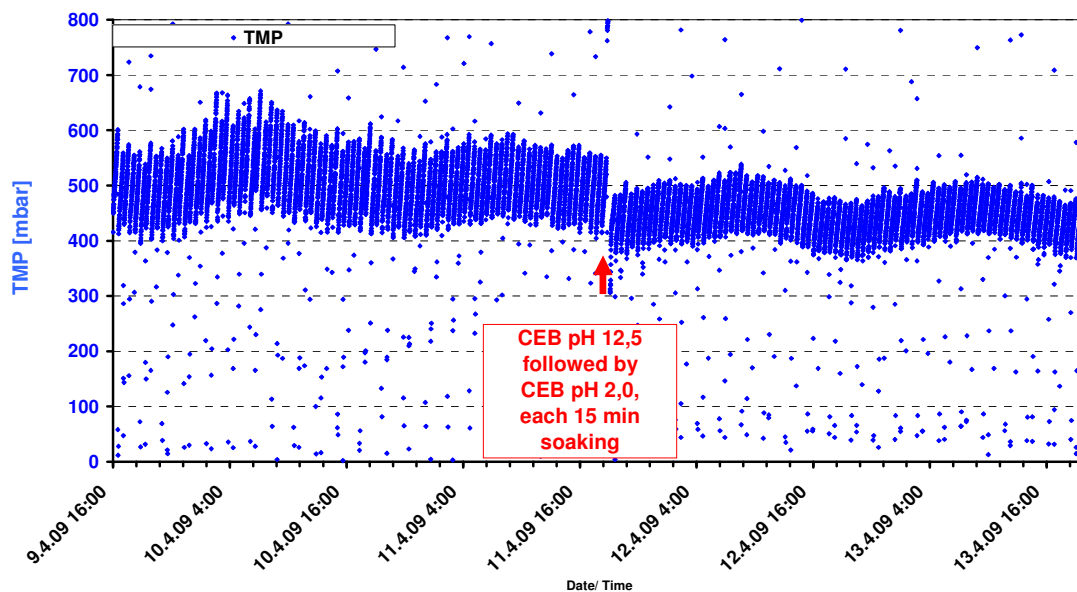


Figure 7: TMP and CEB

Figure 7 shows that the operation after the CEB resulted in lower TMP ranges than before the CEB. During the tests periods, the TMP levels remained stable due to the good coagulation performance. Anyway, one CEB per day was released to maintain a clean filtrate side (to prevent the piping from biofilm formation) and to operate continuously with a clean membrane surface.

In times of a changing feed water quality (in bad weather, technical failures like coagulation pump failure (Figure 5) or changes in the feed pH-value), more CEBs became necessary.

CIP cleaning (Cleaning in place)

After 8 month of continuous operation, the module's permeability decreased from 300-500 to 100-200 l/m²hbar. The CEB procedure wasn't able to recover the membranes permeability up to the initial value. One reason might be an extra dosage of a positive charged polyelectrolyte in the digester of the sewage plant, which was installed by that time. These polymers are often used to improve the dewatering capacity of the digested sludge are known to cause heavy fouling on the membrane surface, even in very little concentrations.

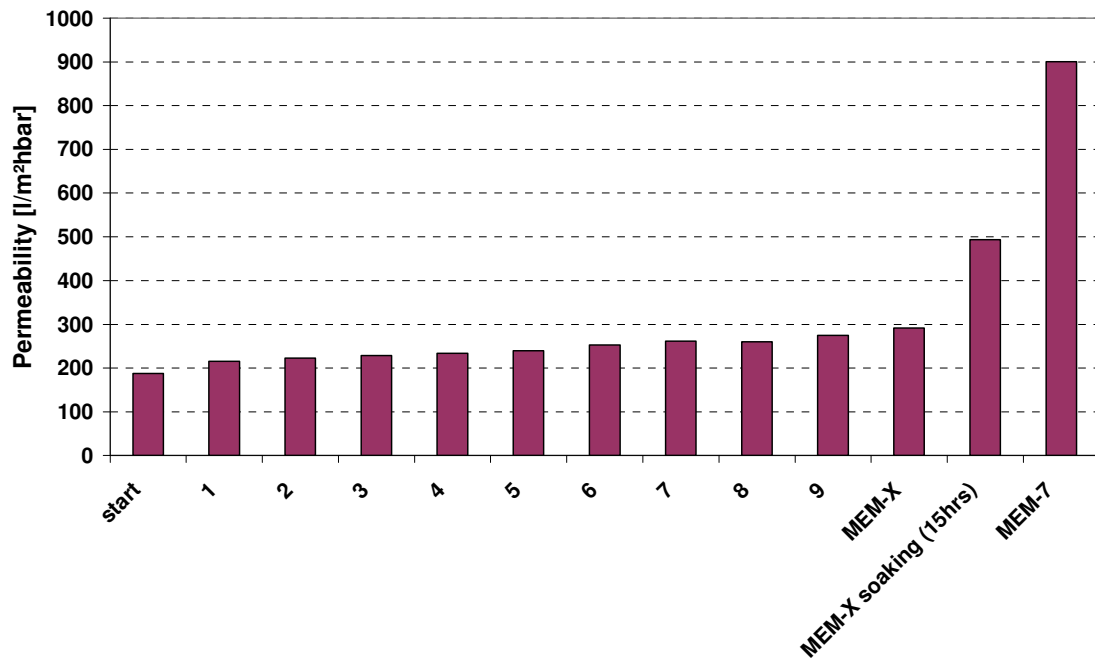


Figure 8: CIP cleaning

Therefore a CIP cleaning (CIP procedure see inge CIP guidelines [4]) was released. Figure 8 shows that the fouling wasn't too easy to remove. Cleaning steps 1 to 9 (caustic, chlorine and acidic CIPs) did not show any effect on the permeability. Due to the promising results made at the IWW Water Center with a cleaning agent at a German waste water treatment plant [7], MemX and Mem 7 were introduced. Finally Mem-X could improve the permeability magnificently. The following acidic cleaning step with Mem-7 was able to recover the membranes' permeability completely.

Operation with tertiary effluent (Phase I)

Due to the characteristic water quality of the tertiary waste water, the turbidity (here: corresponding with suspended solids 1:1) never exceed 50 NTU (50 mg/l TSS). Therefore the 0.9 mm capillary was capable to filter the water reaching high recovery rates > 92%.

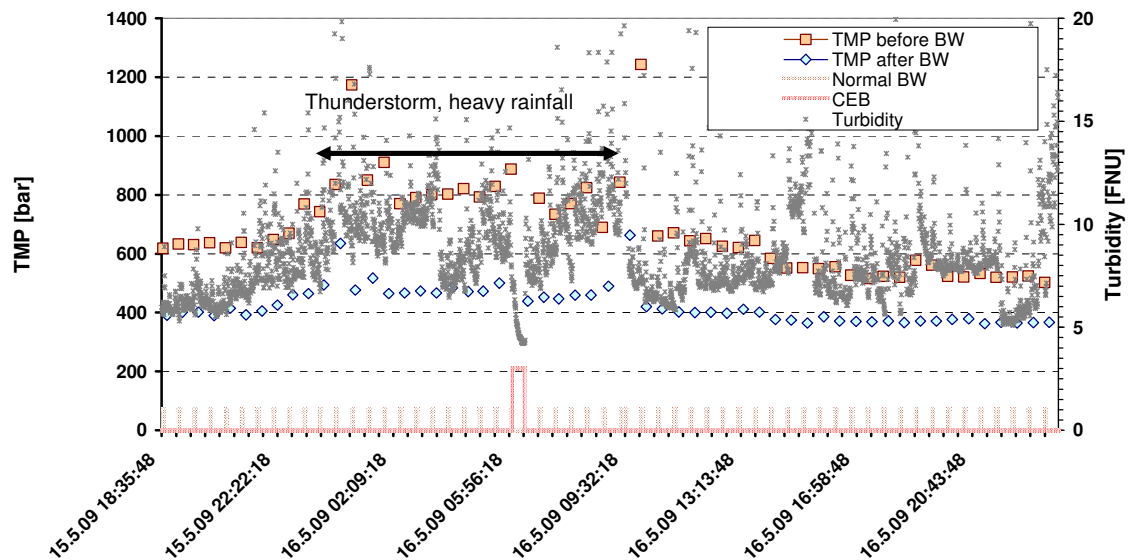


Figure 9: inge Multibore® 0.9 mm in operation

Due to the highly efficient backwash procedure, the TMP always reached its initial baseline during operation (Figure 9; the graph shows 5 min average values before and after a backwash with filtrate to illustrate the effectivity of the backwash). Even in spells of bad weather, temporarily the operation took place at a higher TMP level, but also remained stable. After the water quality normalized again, also the TMP level returned to its characteristic base line. Following operational settings were applied successfully (Table 5):

Table 5: Results of phase I, 0.9 mm and 1.5 mm Multibore®

Capillary Ø	0,9 mm	1.5 mm
Pretreatment	300 µm prefilter, 1.5 mg Al/l	
Flux rate	80 l/m²h	80 – 100 l/m²h
Filtration time	30 min	50 min
Backwash	230 l/m²h, 45s	230 l/m²h, 50s
Chemical enhanced backwash	Acid, pH 2.0 + caustic, pH 12.5, 1/d, 15 min soaking	
Recovery rate	Approx. 92 %	Approx 95 %

Figure 10 compares the recovery rates at a flux rate of 80 l/m²h reached with different filtration times. The reason for the higher recovery rates reached with the 1.5 mm capillary is based on the shorter backwash times which were realizable with the 1.5 mm capillary. Probably the bigger hold up volume of the 1.5 mm MB led to a less compact fouling and a more homogeny backwash, therefore the backwash times could be reduced.

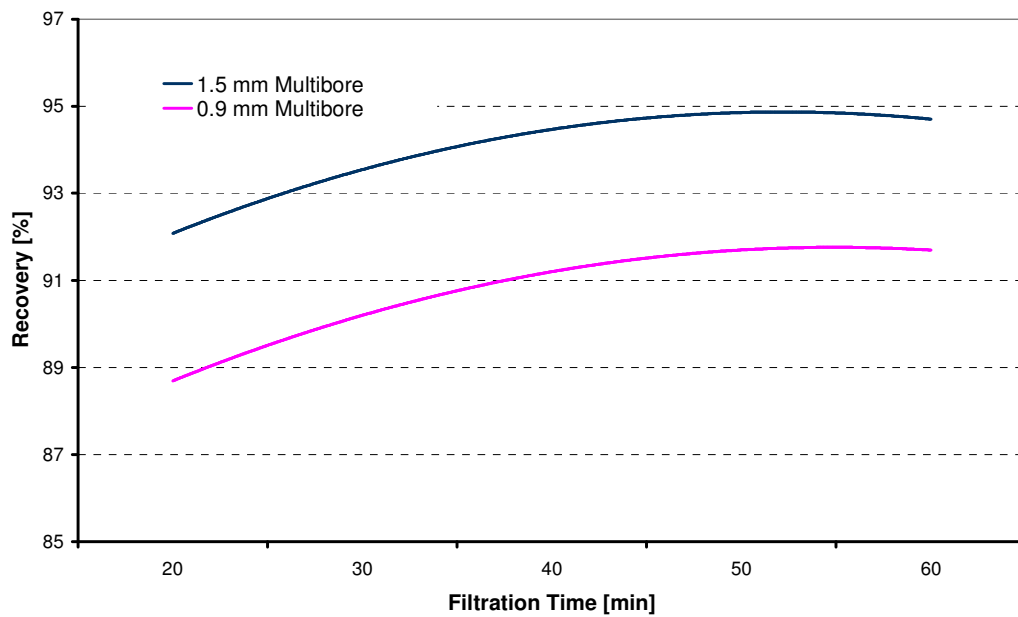


Figure 10: Recovery rates at 80 l/m²h, 0.9 and 1.5 mm Multibore[®]; Phase I

Operation with turbidity > 40 NTU, Phase II and III

To simulate a waste water treatment plant with worse effluent quality, the effluent was enriched with biomass from the biological waste water treatment tank to create a higher suspended solids concentration in the feed water to the UF. Daily batches were prepared. The biomass was filtered with a 300 µm filter before it was mixed to the effluent water. In phase III effluent from the primary sedimentation (COD = 500 mg/l) was mixed in additionally. In a first step, the performance of the 1.5 mm capillary was figured out. The major focus was on the recovery rate, therefore the filtration times and the backwash times were examined closely.

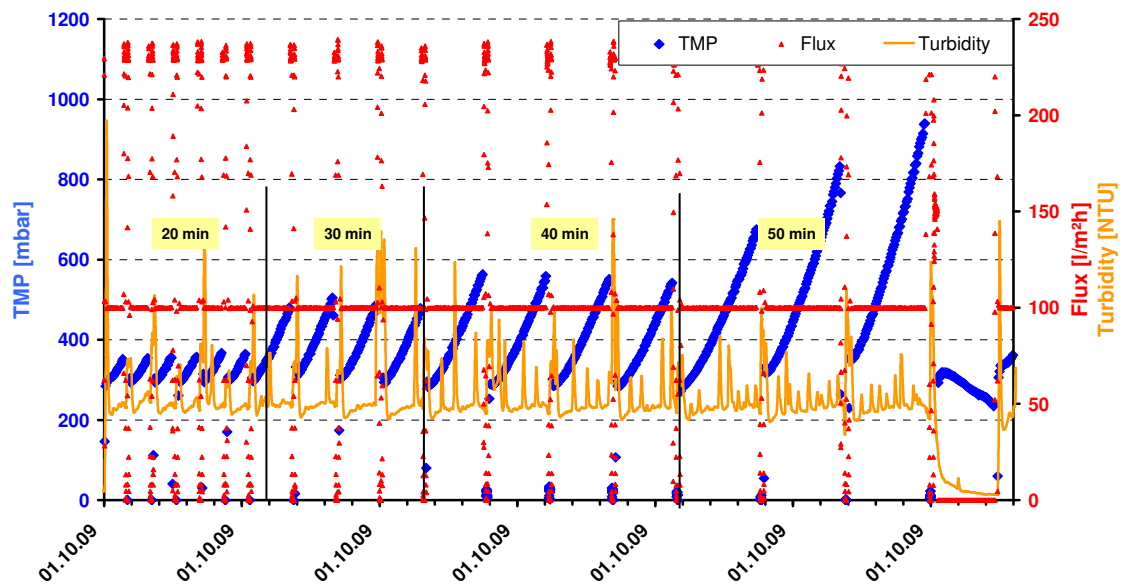


Figure 11: 1.5 mm Multibore® @ flux rate 100 l/m²h and turbidity > 50 NTU

Figure 11 gives an impression of the impact of the change in the operation parameters on the TMP, eg the filtration time. The 1.5 mm Multibore® ensured a stable operation in this example with water quality (turbidity > 50 NTU) up to a filtration time of 40 min at a flux rate of 100 l/m²h.

The results of the experiences were made with the 0.9 and 1.5 mm Multibore® membrane is shown in

Table 6. Operating the 1.5 mm Multibore[®], average turbidities during the filtration intervals of up to 80 NTU were handled, while the 0.9 mm capillary was tested up to 50 NTU. Therefore a recovery rate of almost 92 % was reached with the 1.5 mm MB.

Table 6: Results of Phase II , 0.9 and 1.5 mm Multibore®

Capillary Ø	0.9 mm	1.5 mm
Feed water quality	COD = 40 mg/l Turbidity = 50 NTU,	COD = 40 mg/l Turbidity = 50 - 80 NTU
Coagulation	1,5 mg Al/l	
Flux rate	80 l/m ² h	80 – 100 l/m ² h
Filtration time	30 min	40 min
Backwash	230 l/m ² h; 70 s	230 l/m ² h; 50 s
Forward Flush	100 l/m ² h, 40s	100 l/m ² h, 40s
Chemical enhanced backwash	Acid, pH 2.0 + caustic, pH 12.5, 1/d ,15 min soaking	
max recovery rate	approx 86 %	91,7 – 92,4 %

Figure 12 shows that the maximum recovery rate was reached at a filtration time of 40 min, a longer filtration time resulted in an extraordinary extension of the backwash time.

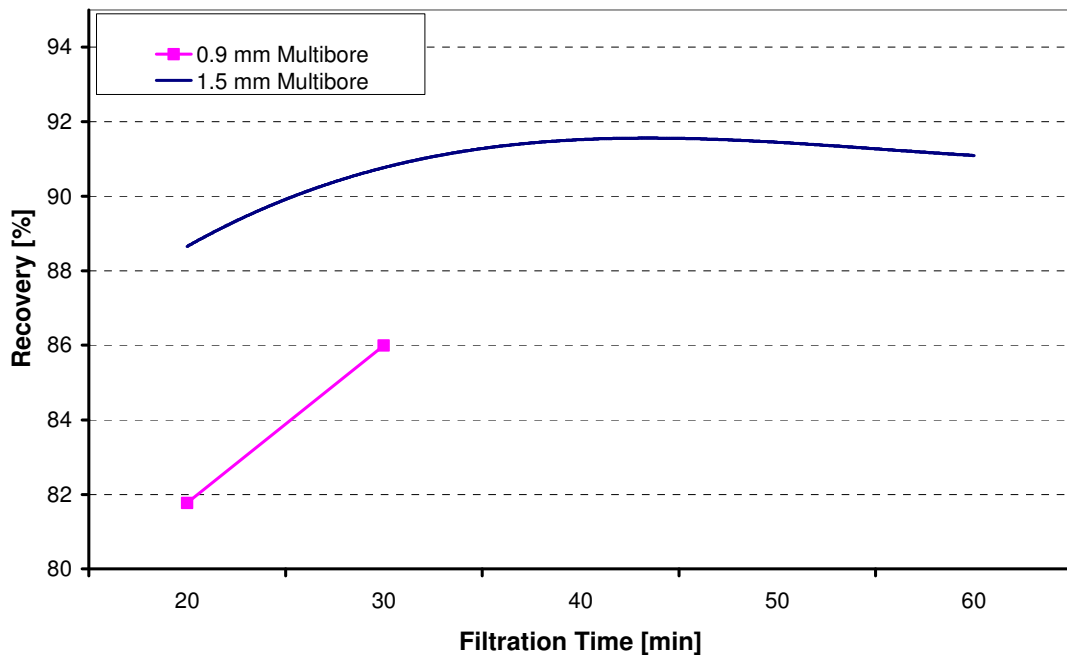


Figure 12: Recovery rates at 80 l/m²h, 0.9 vs. 1.5 mm Multibore®; Phase II

To simulate an overloaded biological treatment, the COD concentration was increase up to 100 mg/l by adding effluent of the primary treatment. Unfortunately this seems to be not the right way for the simulation, the UF plant didn't showed any significant change in operation.

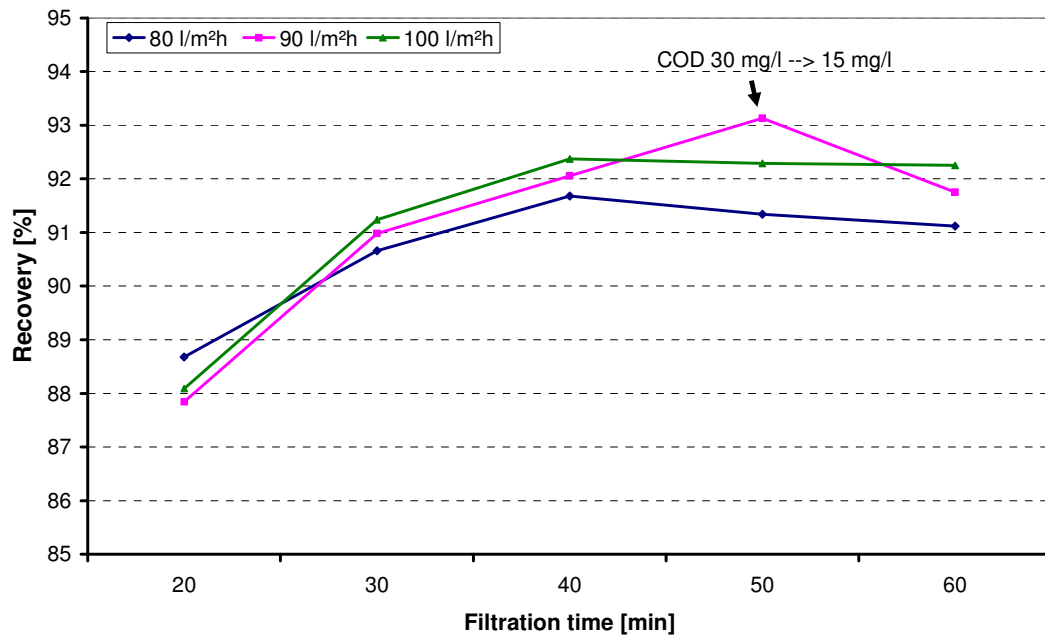


Figure 13: Recovery rates, 1.5 mm Multibore[®], different flux rates and impact of the COD

On the other hand a reduced COD (30 to 15 mg/l, Figure 13) was experienced during a longer spell of bad weather. In those times, the plant showed a much better performance, so higher recovery rates could be realized at lower COD contents due to lower backwash times.

Filtrate Quality

Table 7 shows an analysis of relevant water parameters.

Table 7: UF product quality

	unit	UF filtrate
pH-value	-	7,0
Conductivity 20 °C	µS/cm	900
Conductivity 25 °C	µS/cm	1000
UV	m ⁻¹	11
TSS	mg/l	/
COD filtrated	mg/l	/
COD	mg/l	15
BOD5	mg/l	2,5
DOC	mg/l	3,2
Total phosphor (P)	mg/l	0,024
Ammonium - N	mg/l	0,66
Aluminium (Al)	mg/l	0,36
Iron (Fe)	mg/l	0,046
CFU 20 °C (1ml)	ml ⁻¹	484
CFU 36 °C (1ml)	ml ⁻¹	476
Coliforme germs (100ml)	100 ⁻¹ ml ⁻¹	0
E. Coli (100 ml)	100 ⁻¹ ml ⁻¹	0

Referring to the feed water analysis (chapter “Feed water quality”), following elimination rates can be calculated by the hybrid process of coagulation and UF (Figure 14):

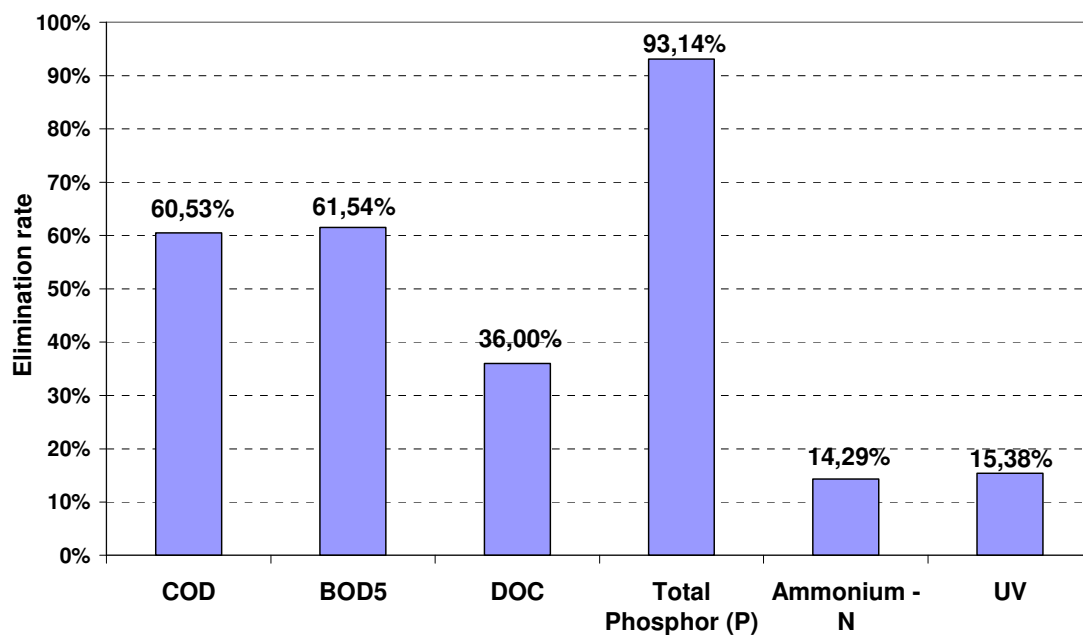


Figure 14: Elimination rates

COD and BOD elimination rates were calculated by using the homogenized COD/BOD concentration.

An improper sample point (PCV) probably caused the exceptionally high concentration of micro-organisms (plate counts) in the filtrate. Coliforme germs were not detectable in the filtrate; therefore the filtrate quality meets EPA “Water Reuse Guidelines” [3].

To avoid a bacterial regrowth in the filtrate tank, periodical (8 weeks) disinfections with chlorine were released.

To evaluate the filtrate quality concerning a further treatment with RO or NF technology, the SDI (Silt Density Index) was measured (according the demands of ASTM 4189-07, [10]) during the different test periods, especially during coagulation tests.

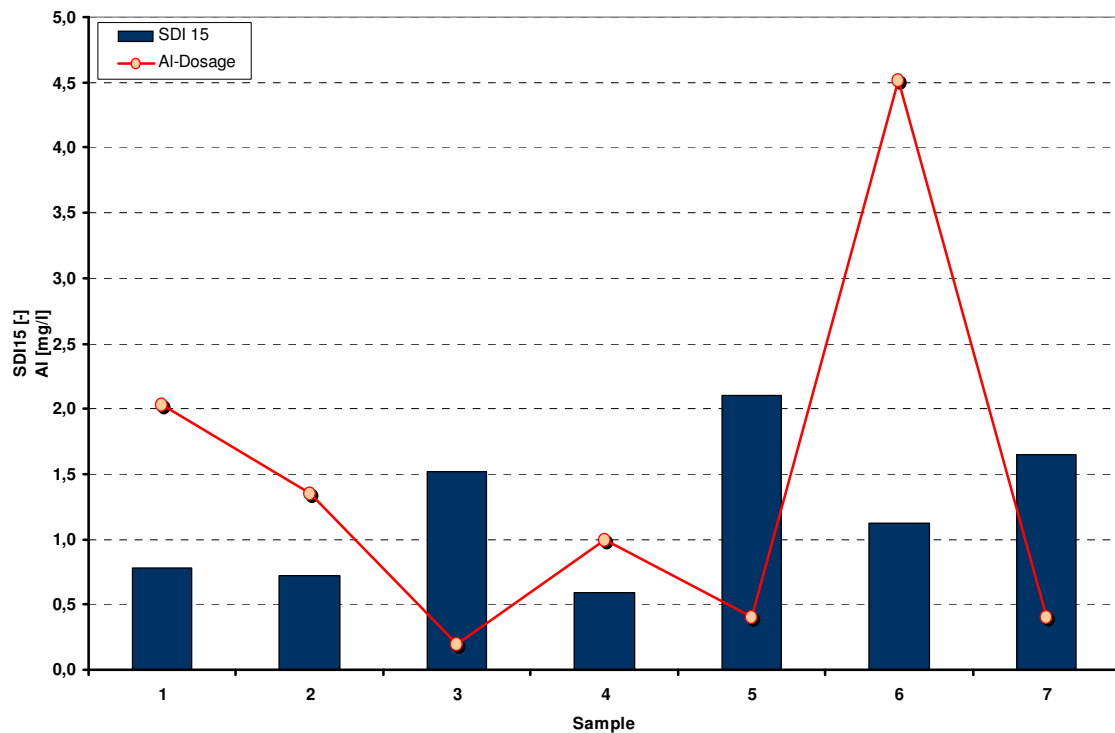


Figure 15: SDI in the UF filtrate and Al dosage

An optimum aluminium dosage rate of in between 1 and 3 mg Al/l resulted in the lowest SDI value (Figure 15). Therefore a SDI value below 1 was achievable at optimum coagulation conditions.

CONCLUSIONS

After almost one year of pilot tests, following conclusions can be drawn:

- Coagulation as pretreatment to the UF is absolutely necessary to guarantee a stable and controlled process and to provide best filtrate water quality.
- The CEB procedure was capable to remain membranes' permeability. In terms of extraordinary fouling caused by an unproportional dosage of polyelectrolyte in the WWTP- process, CIP cleanings could recover the membranes' permeability completely.
- The inge Multibore[®] fibre with 0.9 mm diameter was absolutely suitable to treat the tertiary waste water at the WWTP in Eching; Recovery rates of 92 % were reached.
- The inge Multibore[®] fibre with 1.5 mm diameter reached higher recovery rates than the 0.9 mm capillary (up to 95 %) and was additionally suitable for filtration of a feed water with a higher suspended solid content of up to 100 NTU at recovery rates > 90%.
- The backwash with filtrate was always capable to remove the particulate fouling layer; the operation remained stable without applying enhanced backwash procedures with air.
- By the hybrid process of coagulation and ultrafiltration the dissolved organic water content could be significantly reduced. The filtrate was pathogen free and reached a SDI value of <1, therefore the water meets all demands for irrigation and should be suitable for further RO/NF treatment

Outlook

Since February, experiments with alternative cleaning strategies (pressurized backwash @ 3 bar, air supported flushing) are proceeded to figure out, if the recovery rate can be improved. Results will be presented at the MDIW conference 2010 in Trondheim. Additionally inge UF membranes were compared with inge MF membranes concerning their corresponding operational settings.

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