Monitoring of SUR to control and enhance the performance of ultrafiltration installations treating wwtp effluent

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Abstract
The variation of quality and fouling properties of wwtp effluent over time influences the performance of ultrafiltration (UF) plants. This research reports three experiments in which the specific ultrafiltration resistance (SUR) measurement is applied to obtain more insight in quality variation an impact on UF performance. Firstly the overall performance (flux, recovery and trans-membrane pressure) of an UF pilot was compared with the SUR values of the feedwater. Secondly the effect of pre treatment was investigated. At last the relation between the slopes of filtration cycles of a UF installation and SUR measurements of feedwater were compared. The results clearly indicate that the overall performance of the UF pilot depends on the SUR values of the feedwater. The SUR values should be less than $10 \cdot 10^{12}$ m^{-2} for a stable UF performance. Also the effect of pre treatment depends on the SUR values of raw wwtp effluent. Very low SUR values (~ $4 \cdot 10^{12}$ m^{-2}) mean less effect compared to higher SUR values. The relation and correlation between SUR values of feed water and single filtration cycles of UF installations depends on the condition of the membranes in the units. Using fouled membranes the variation of SUR values corresponds to higher TMP variations than using cleaner membranes.

Keywords
Flux, Fouling, SUR, UF installations and wwtp effluent

INTRODUCTION

During the ultrafiltration (UF) of wastewater treatment plant (wwtp) effluent the performances of installations decrease with time due to the deposition of foulants in or on the membranes. Many researchers and practitioners in the field are looking for parameters to predict the fouling rate and loss of performance of ultrafiltration installations. Although high concentrations of foulants like total organic carbon (TOC), chemical oxygen demand (COD), proteins, polysaccharides, humic acids and colour are about similar to high fouling rates, also the size, nature and structure of these compounds are determining the fouling rate. In literature several tests to predict fouling properties are described (Schippers and Verdouw, 1980; Boerlage et al., 2003; Heijman et al., 2005; Kim and DiGiano, 2006). For dead-end ultrafiltration of wwtp effluent Roorda (2004) developed the Specific Ultrafiltration Resistance (SUR). This parameter provides useful information about the filterability within a short time (30 minutes) and can be measured with a simple laboratory set-up.

Next to the general complicated fouling properties of wwtp effluent, the variation of effluent quality makes it even more complicated. The quality of domestic wwtp effluent varies during night and day, winter and summer and dry or rainy weather. For industrial wwtp's it differs for every type of industry an each industrial plant will show its unique variations in effluent composition. For example, wastewater discharged from batch processes or wastewater coming from cleaning processes will have a large impact on the composition of the total wastewater and will have a direct influence on the effluent composition.

Considering the variation of quality and fouling properties of wwtp effluent there is a need to optimize the control on alterations in the effluent composition. This is essential to optimize membrane filtration processes. When it can be made possible to monitor the filtration properties and the quality of effluent online, major improves can be accomplished. Monitoring and its direct follow-up via process adjustments will result in a stable performance with increase of membrane lifetime and decreasing of cost per cubic meter produced water. This research investigates the possibility of the SUR to play this role.

MATERIALS AND METHODS

Specific Ultrafiltration Resistance (SUR)

To measure the filterability of wwtp effluent Roorda (2004) developed a parameter called Specific Ultrafiltration Resistance (SUR). The SUR is calculated from the slope of a filtration curve (t/V versus V) that is measured within 30 minutes of filtration over an ultrafiltration membrane at a constant temperature (~ 20 °C) and a transmembrane pressure (TMP) of 0.5 bar. The SUR values for effluent are within the range of $5 \cdot 10^{12}$ m^{-2} for effluent with a high filterability and $30 \cdot 10^{12}$ m^{-2} for effluent with a low filterability (Roorda, 2004).

The membranes used for all measurements are capillary ultrafiltration membranes with an internal diameter of 0.8 mm, a MWCO of 50-80 kDa and prepared of PES/PVP (type: UFC M5 ID 0.8 mm, X-Flow). New membrane modules, provided a membrane area of about $10 \cdot 10^{-4}$ m^2, are soaked for 30 minutes in NaOCl (400 ppm). After soaking the clean water flux (CWF) is measured before starting a filtration experiment. After each filtration experiment the membrane module was flushed with demineralised water and cleaned with Divos 120CL (1,25 w%) during 10 minutes at 40 °C. To get valid SUR values the CWF is measured and checked again before the next filtration experiment.

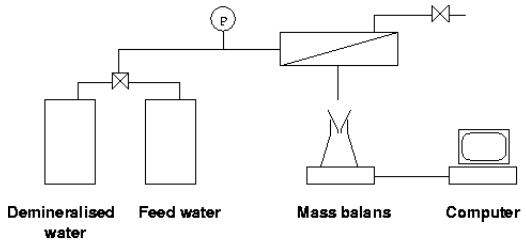

Figure 1. Schematic drawing of the laboratory set-up for SUR measurements.

Ultrafiltration plants

Research was performed at two locations in the Netherlands (Horstermeer and Sas van Gent). At the wwtp Horstermeer municipal effluent is treated by an UF pilot plant after a curved sieve (mesh size of 0.45 mm) and dual media filtration. The dual media filter consists of an upper layer of anthracite and a bottom layer of sand. Coagulant ($AlCl_3$) is dosed inline to the feed water and is mixed with the feed water in a static mixer before entering the filter column. Flocculation takes place above and in the filter bed. Beside the coagulant also methanol is dosed for denitrification. The maximal capacity of the UF pilot is 10 m^3/h and consists of two 8 inch X-Flow modules with a length of 1.5 meter each. Total membrane area is 70 m^2. During operation the flux, trans-membrane pressure (TMP) and temperature are automatically monitored.

The UF plant in Sas van Gent treats industrial effluent from a foods producing factory. The wwtp effluent first passes a dual media filtration unit containing anthracite and sand. $FeCl_3$ (2.5 mg/l) is dosed inline to the feed water and flocculated above and in the filter bed. After the dual media filter again $FeCl_3$ (1 mg/l) is dosed in order to increase the performance of the ultrafiltration units. Beside the $FeCl_3$ also sodiumhypochlorite is dosed to prevent biological growth. The total UF plant consists of several UF units with a total membrane area of 3120 m^2. The UF plant feeds a RO membrane plant for further water polishing. During operation different parameters were automatically monitored but relevant for this research were flux, TMP and temperature.

Table 1. Characteristics of UF plants at wwtp Horstermeer and Sas van Gent

wwtp	Horstermeer	Sas van Gent
Membrane type	X-Flow (UFC M5)	X-Flow (UFC M5)
Membrane material	PES (PVP)	PES (PVP)
Membrane aera (m^2)	70	3120
Pore size (nm)	20-30	20-30
Capacity (m^3/h)	10	175
Wastewater	municipal	industrial
Type	pilot	full scale

Experiments

Wwtp Horstermeer

The UF pilot was operated over a period of four weeks. During the research period the flux and recovery were increased (Table 2) each week. Beside the operation of the UF pilot the filterability of the feed water (filtrate of the dual media filter) was measured by performing SUR measurements. Each day, 2 or 3 SUR measurements were performed. After measuring the SUR values were compared with the performance of the UF pilot.

The performance of the UF pilot was defined as *bad* when the TMP exceeded the 1 bar limit within 1 day. *Good* performance means the TMP did not exceed 1 bar during 1 day.

Table 2. Process conditions of UF pilot installation at wwtp Horstermeer during the period 5/4/06 – 26/4/06.

Date	Flux (l/m^2h)	Recovery (%)	Backflush (h^{-1})	Chemical cleaning (d^{-1})	Duration of chemical cleaning (h)
5/4/06-6/4/06	43	63	4	2	1,5
10/4/06-12/4/06	57	73	4	3	1,5
18/4/06-20/4/06	71	78	4	3	1,5
24/4/06-26/4/06	86	82	4	6	1

Wwtp Sas van Gent

At the wwtp Sas van Gent two different experiments were performed. During the first experiment the effect of different pre treatment steps (first coagulation- dual media filter-second coagulation) on the SUR values is investigated. With the second experiment the relation between SUR values of UF feed water (dual media filtrate after second coagulation) and TMP increase of the UF installation during one filtration cycle was investigated.

The effect of various pre treatment steps on the filterability was investigated during three months (6/9/2006 – 7/12/2006). Four samples were taken twice a week at the same time. These samples were: raw wwtp effluent (before first coagulation), coagulated wwtp effluent (after first coagulation), dual media filtrate (after dual media filter) and UF feed water (after second coagulation). Directly after sampling the SUR values were measured.

To investigate the relation between SUR values of the UF feed water and the TMP increase, data of two UF units (UF 1 and UF 4) were collected from the control computer of the UF-RO plant. With these data the slope of a single filtration cycle (20 minutes) was measured at the same time as a SUR measurement (Figure 2). The numbers were only used when the R^2 of the line was ≥ 0.7. Besides, the increase of TMP was normalised for temperature and flux. The nominal temperature and flux were respectively 20 °C and 60 l/m^2h

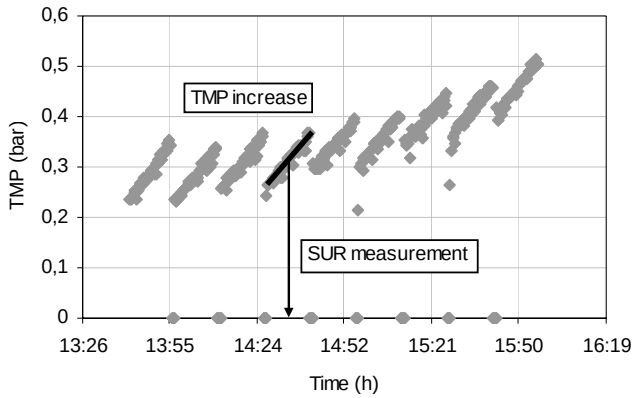

Figure 2. Example of filtration cycles during ultrafiltration and the moment that SUR measurements are performed of the UF feed water.

RESULTS AND DISCUSSION

Wwtp Horstermeer

Table 3 presents the overall performance of the UF pilot from 5/4/06 – 26/4/06.

Table 3. Performance of UF pilot installation at wwtp Horstermeer during the period of 5/4/06 – 26/4/06

Date	Average TMP (bar)	Flux (l/m^2h)	Average permeability (l/m^2hbar)	Average SUR ($10^{12}m^{-2}$)	Performance (good/bad)
5/4/06	0,17	43	330	14,4	good
6/4/06	0,19	43	290	14,5	good
10/4/06	0,40	57	214	23,3	bad
11/4/06	0,35	57	213	9,8	good
12/4/06	0,35	57	213	10,8	good
18/4/06	0,44	71	214	24,6	bad
19/4/06	0,39	71	223	11,6	good
20/4/06	0,34	71	251	12,7	good
24/4/06	0,52	86	206	10,5	bad
25/4/06	0,48	86	210	10,2	bad
26/4/06	0,41	86	237	9,2	good

Table 3 shows clearly that the performance of the UF pilot depends on the SUR value of feed water. With a flux of 43 l/m^2h and average SUR values of approximately $14 \cdot 10^{12}$ m^{-2} no problems were observed. When higher fluxes (57 and 71 l/m^2h) are applied problems are observed when the SUR values are $\geq 20 \cdot 10^{12}$ m^{-2}. Good performance was only obtained when the SUR values were in the range of $9 – 13 \cdot 10^{12}$ m^{-2}. During the last week (24/4/2006 – 26/4/2006) an even higher flux (86 l/m^2h) was applied. This flux resulted in bad performance when the SUR values are $\geq 10 \cdot 10^{12}$ m^{-2}. Average SUR values below $10 \cdot 10^{12}$ m^{-2} presented good performance. In figure 3 an operating window is presented relating the SUR and apllicable flux of table 3.

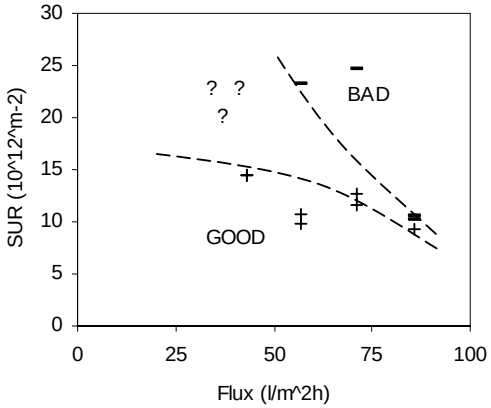

Figure 3. Operating window showing the relation between SUR values and flux of the UF pilot plant at wwtp Horstermeer.

The results from table 3 are in line with the findings of Roorda (2004). His pilot plants tests at different wwtp's in the Netherlands showed that SUR values below $10 \cdot 10^{12}$ m^{-2} seem to be a precondition for stable performance with high fluxes ($\geq$100 l/m^2h).
However based on this experiment it seems that fluxes of 60 – 80 l/m^2h are preferable at the wwtp Horstermeer. At these fluxes the membrane should be chemically cleaned three times a day and the recovery will be 75 – 80%. Nevertheless, these settings can only be applied when the SUR values are $\leq 10 \cdot 10^{12}$ m^{-2}. When the SUR values of the feed water

are in the range of 15 – $30 \cdot 10^{12}$ m^{-2} an extra chemical cleaning will be necessary or a lower flux should be considered. This will prolong the UF operation time and decrease potential operational problems.

Wwtp Sas van Gent

SUR and pre treatment UF

In figure 4 the effect of the pre treatment steps (first coagulation - dual media filter - second coagulation) on the filterability are presented. During the research period the source of the raw wwtp effluent was changed. From 6/9/2006 – 11/10/2006 raw wwtp effluent was taken after a pond passage of 2 – 3 days. From 13/10/2006 – 7/12/2006 effluent was taken directly after the secondary clarifier of the wwtp Sas van Gent.

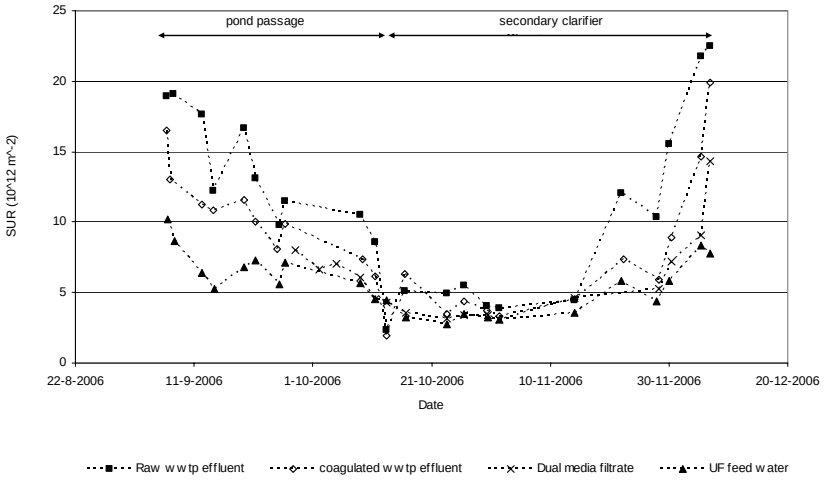

Figure 4. SUR values found for raw wwtp effluent, coagulated wwtp effluent, dual media filtrate and UF feed water at the UF plant of wwtp Sas van Gent during the period 6/9/2006 – 7/12/2006.

Figure 4 shows a significant effect of the pre treatments steps on the SUR values of the raw wwtp effluent. Especially the $FeCl_3$ coagulation (2.5 mg/l) shows a large effect. The average (relative) SUR decrease by the first $FeCl_3$ coagulation was 23%. The effect of the dual media filter was less. The average decrease of SUR by dual media filtration was 9%. As last, the second $FeCl_3$ coagulation (1 mg/l) decreased the SUR value with an average of 10%.

Roorda (2004) also investigated the effect of pre treatment at different wwtp's in the Netherlands with SUR measurements. His tests with coagulation as well as multi media filtration showed a decrease of the SUR of approximately 20% to 30%. The amount of decrease was greatly depending on the local conditions.

Figure 4 shows also a period (13/10/2006 – 14/11/2006) with less absolute decrease of SUR values by pre treatment. During this period the average SUR value of raw wwtp effluent was $4.0 \cdot 10^{12}$ m^{-2} which means a very good filterable wwtp effluent. Probably in practice pre treatment is not strictly needed or can be less intensive during this period. This could save coagulants and decrease operational costs.

SUR and TMP increase

In figure 5 and 6 the measured SUR values of UF feed water and the increases of TMP of the UF units during one filtration cycle are evaluated for potential relationship. Figure 5 shows the relation for the period 6/9/2006 – 11/10/2006. During this period raw wwtp effluent was taken after pond passage. Figure 6 shows the relation when raw effluent was taken directly after the secondary clarifier (13/10/2006 – 7/12/2006).

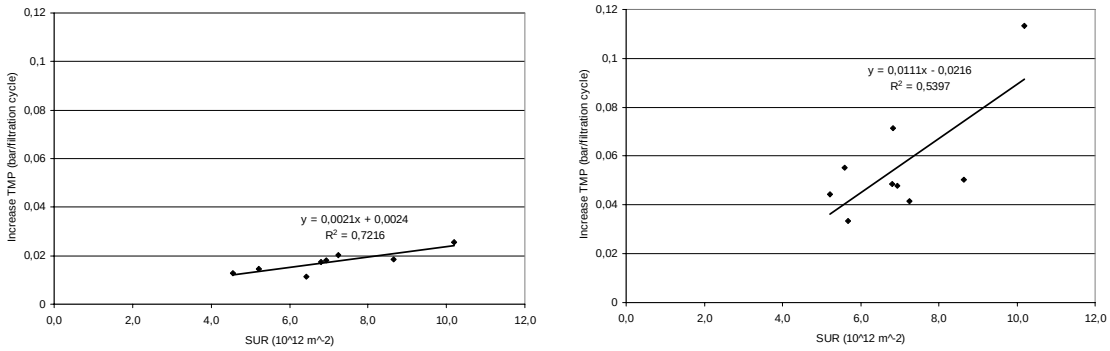

Figure 5. Relation between SUR values of feedwater UF and TMP increase during one filtration cycle of UF unit 1 (left) and UF unit 4 (right). Measurements were performed in the period 6/9/2006 – 11/10/2006.

Figure 5 presents a different relation for both units. The influence of the SUR values on the TMP increase is much higher for UF unit 4 compared to UF unit 1. This difference can be explained by the life time of the membranes in the units. The membranes in UF unit 1 were replaced half a year before this experiment. The membranes in UF unit 4 are 4 years old, therefore chemically worn and more fouled. The extra resistance due to fouling needs a higher operational pressure, leading to a higher increase of TMP in time due to the compressibility of the cake layer.

The different correlation is also a matter of the lifetime of the membranes. SUR measurements are always performed with clean membranes to obtain valid values. The 'cleaner' membranes of UF unit 1 will be better comparable with the SUR than the 'fouled' membranes of UF unit 4.

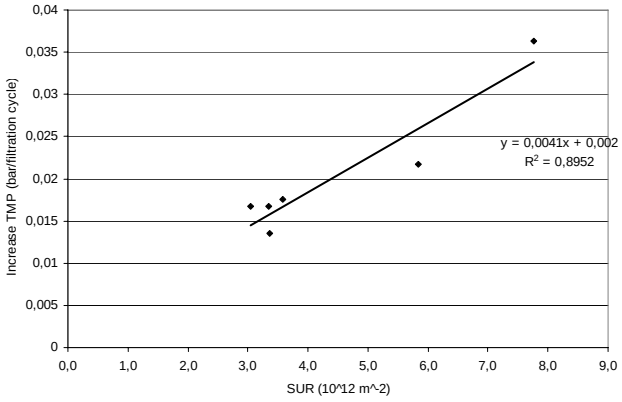

Figure 6. Relation between SUR values of feedwater UF and TMP increase during one filtration cycle of UF unit 1. Measurements were performed in the period 13/10/2006 – 7/12/2006.

Figure 6 partly confirms the findings of figure 5. Also a good correlation can be observed. Unfortunately no related data was obtained from UF unit 4. All slopes of the single filtration cycles have a R^2 below 0.7. Nevertheless it seems that the SUR values of the feed water can be related to the measured filterability (increase of TMP) in the UF units. But the life time of the membranes plays an important role.

CONCLUSIONS

The overall performance of the UF installation at wwtp Horstermeer depends on the SUR values of the feed water. Good performance with fluxes of 57 and 71 l/m^2h was only obtained when the SUR values were in the range of $9 - 13 \cdot 10^{12}$ m^{-2}. With higher fluxes ($80 - 90$ l/m^2h) the critical SUR becomes lower ($9 \cdot 10^{12}$ m^{-2})

The overall effect of pre treatment depends on the SUR values of the raw wwtp effluent at Sas van Gent. The effect decreases with decreasing values of the SUR. Therefore, it may be considered and investigated if pre treatment is needed during a periods of lower SUR values.

At the UF plant Sas van Gent a clear relation and correlation between SUR and TMP increase was found twice for UF unit 1. The relation and correlation were less for UF unit 4. Probably, this difference is caused by the life time and therefore performance of the membranes.

Considering all findings it is firm that the SUR parameter is a valuable tool to evaluate the filterability for (dead-end) UF systems treating wwtp effluent. Next to this the SUR parameter can not only be used to monitor the filterability of wwtp effluent but can also be used to adjust the pre treatment. As shown here, good filterable wwtp effluent is a requirement for stable UF process operation.

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