8 YEARS RO-EXPERIENCE AT WTP HEEMSKERK
BIOFOULING ASPECTS

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Since late 1999 20 Mm^3/year (15 MGD) pre-treated IJssel Lake water is subjected to an integrated membrane system (IMS) at surface water treatment plant Heemskerk. The plant combines the application of ultrafiltration (UF) and reverse osmosis (RO) and was one of the first large scale IMS's (integrated membrane systems). Chemically pure HCl and 0.9 mg/L Aquacare OSM92 anti-scalant are dosed into the RO feed to avoid biofouling and scaling. The RO plant was running with a flux of 28 L/m^2.h without any chemical cleaning in the first three years. After three years the first significant MTC-decrease (mass transport coefficient) in the 2nd stage was registered leading to research into the source of this decrease. Since it concerned a MTC-decrease in the 2nd stage it was most likely to be scaling. Performed autopsy's revealed surprisingly that the decrease was caused by biofouling. This conclusion resulted into new insights into biofouling behavior. Research with bioassays for assessing the microbial growth potential of the feed water resulted into the fact that the biofilm formation in the RO was limited by phosporus (P). In the case of WTP Heemskerk, with a superiour RO-feed water quality, this limitation is most likely lifted by concentrating the anti-scalant (AS) over the length of the RO.

Keywords
Reverse Osmosis, biofouling, bioassays, growth limitation, anti-scalant

Introduction

Since the end of 1999 20 Mm^3/year (15 MGD) pretreated IJssel Lake water is subjected to an integrated membrane system (IMS) at water treatment plant Heemskerk. The direct surface water treatment plant based on the combined application of ultra filtration and reverse osmosis has the following quality control objectives:

- removal of pathogenic micro-organisms;
- removal of organic micro pollutants e.g. pesticides;
- removal of in organics (chloride, sodium, sulfate, hardness);
- biological stability.

Reverse osmosis was chosen as the barrier against all pollutants. With the application of reverse osmosis membrane fouling is a major concern. Therefore pretreatment has been a research topic for many years (Kamp 1995 and 2000). After a thorough research effort the combination ultrafiltration with reverse osmosis with ultra low pressure composite membranes was selected for the post treatment of CSF pretreated water. Because in the total treatment system no chemical disinfection will be applied removal of pathogenic micro-organisms together with membrane integrity monitoring are investigated thoroughly (Kruithof 2001 and 2003) just as organic and inorganic contaminant control and biological stability

(Kruithof 1995 and 2003). Only the highlights of the research efforts into system performance and fouling assessment of the RO are included in this paper. A recent publication in the performance of the UF has been presented in March 2007 at the MTC in Tampa (Galjaard 2007). The RO treatment has been divided over 8 RO-blocks, the chosen operating condition is a 2-1 concentrate staging with a total of 36 pressure vessels per block (24 - 12). Each pressure vessel contains 7 elements leading to a total of 2016 elements with an average flux of 28 L/h.m^2. The chosen elements are Hydranautics ULP ESPA3 8040. The RO-recovery is 82%, to prevent scaling at this recovery both acid (HCl) and anti-scalant are dosed.

System performance evaluation

First three years of operation

The RO system performance was evaluated using the mass transfer coefficient (MTC, Figure 1) and normalized feed-concentrate pressure drop (NPD, Figure 2).

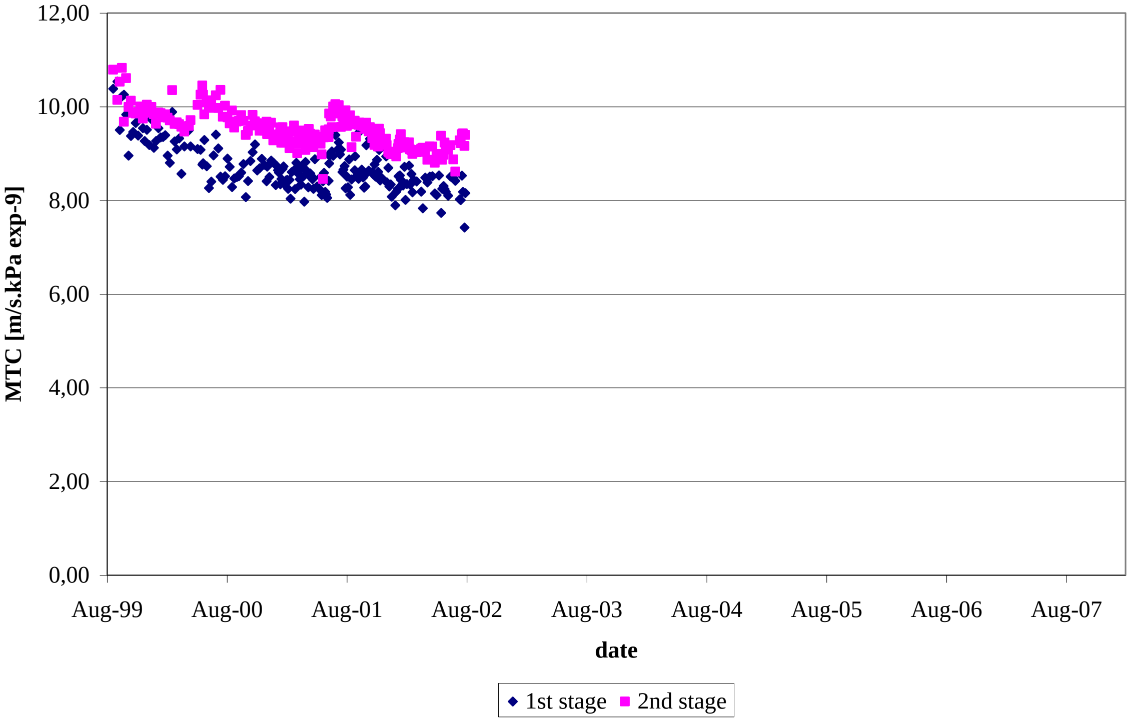

Figure 1. MTC of stage 1 and 2 during the 1st three years of operation

The full scale ULP RO installation was operated at an average flux of 28 L/m^2.h. For the first 3 years of operation system performance proved to be relatively stable. Normalized MTC decreased a bit during the first year stabilizing after that at about 8,5 x 10^{-9} m/s.kPa for the first stage and 9,5 x 10^{-9} m/s.kPa for the second stage. MTC of the second stage is therefore about 1,0 x 10^{-9} m/s.kPa higher then the first stage caused by the chosen loading schedule of the elements (elements with the lowest initial MTC in the first stage and elements with the highest MTC in the second stage). No curative or preventive chemical cleaning have been performed during these first 3 years of operation. The yearly fluctuations in MTC are being caused by fluctuations in temperature and capacity. Also the normalized feed – concentrate pressure drop (NPD) shows a stable operation during the first 3 years (Figure 2).
This exceptional system performance is most likely caused by the extensive pre-treatment (CSF + UF) leading to a superior RO-feed water quality, being in average:

- an easily assimilable organic carbon (AOC) content of <6 µg C/L;
- a phosphate content of < 0,01 mg/L (detection limit);
- a Silt Density Index (SDI) of < 1;
- a Modified Fouling Index (MFI) of <1 s^2/L.

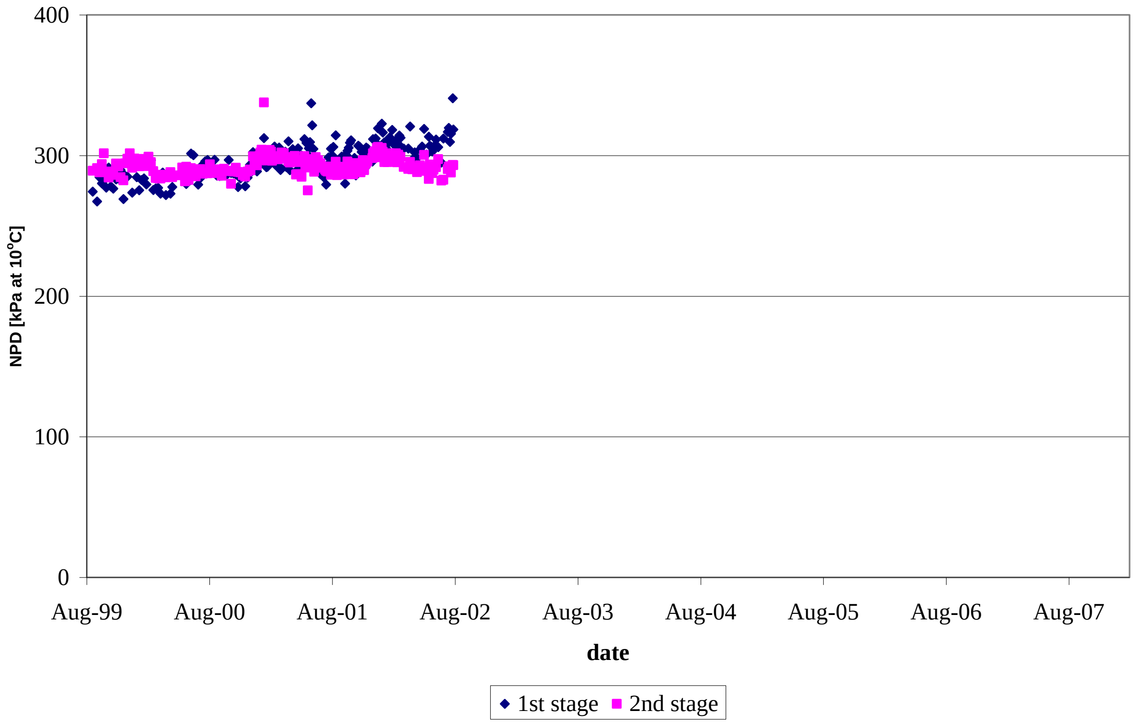

Figure 2. NPD of stage 1 and 2 during the 1st three years of operation

4th Year of operation

During the 4th year a sudden chance in the RO-performance was noticed in the MTC (Figure 3).

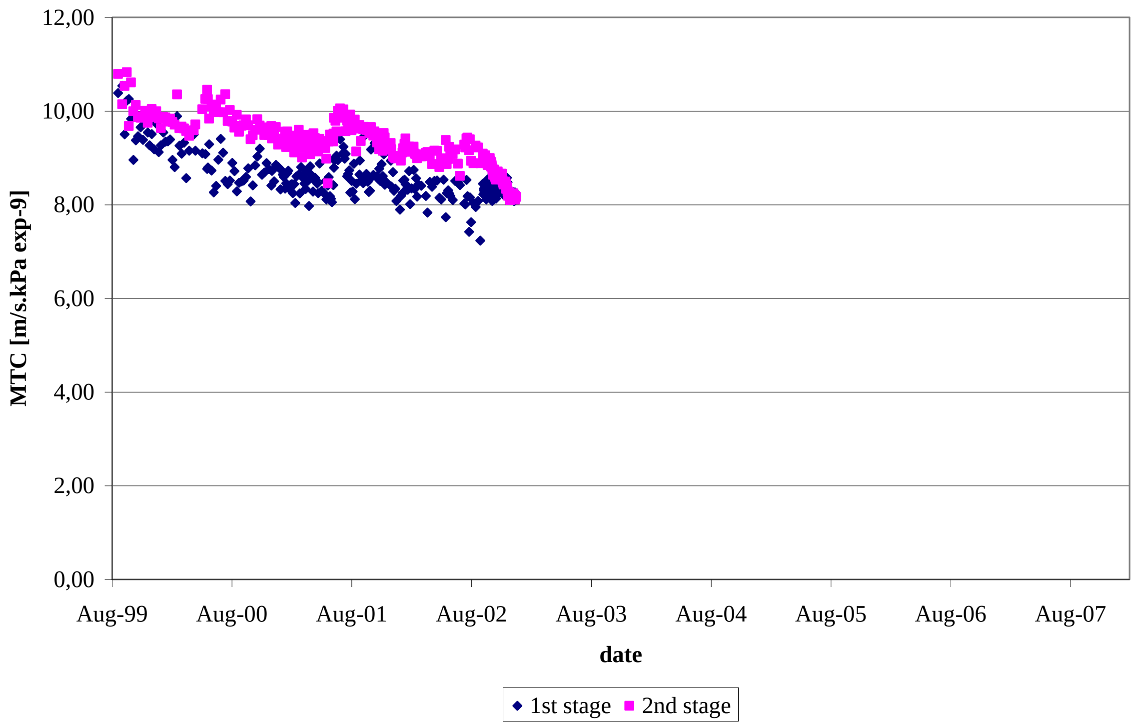

Figure 3. MTC of stage 1 and 2 during the 4th year of operation

The decrease in MTC took place mainly in the second stage of the RO leading to the presumption that the decrease was caused by scaling. To be sure on the strategy that needed to be followed membrane autopsies had been carried out. Performed autopsy's revealed surprisingly that the decrease was caused by biofouling. Visually no scaling had been detected (XPS analysis) and no inorganic compounds were found (ICP-MS). What was found was a very high concentration of ATP (adenosinetriphosphate) of approximately 150000 pg/cm^2 of membrane surface. This conclusion led to more research into the cause of this biomass accumulation since the concentration of organic and inorganic nutrients in the RO-feed water is relatively very low.

After thoroughly cleaning of all the blocks for the first time in 4 years a preventive solution was found in cleaning the membranes every summer when the feed water temperatures were high. The result of a such a preventive caustic cleaning with NaOH on the biomass accumulation is given in figure 4.

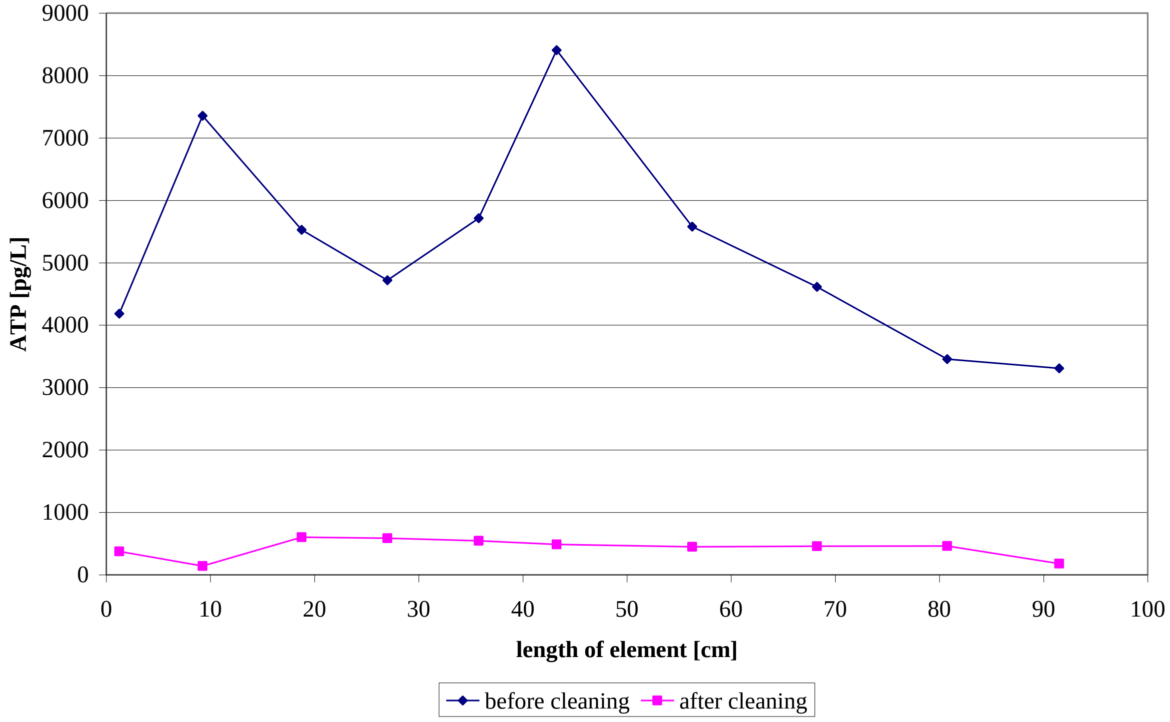

Figure 4. Effect of preventive cleaning with NaOH, pH=12, on the accumulation of biomass

Until membrane replacement August 2007

With these preventive cleanings in place each summer, biomass accumulation was more or less under control. Never the less a continuous small decrease in MTC was occurring over time (see figure 5). With a sudden decreases at the end of 2004. This decrease however was caused by a colloidal fouling incident after cleaning the reservoirs between the UF and the RO. Sand out of the concrete reservoir walls had come loose after cleaning it too roughly under high pressure, the sand was then flushed through the installation. To prevent this in the future the reservoirs have been coated after this incident.

While the membranes were still under good conditions (MTC and retention) the feed pumps where not able to deliver the necessary feed pressure during winter of 2006/2007 (15 bar) indicating membrane replacement before the winter of 2007/2008.

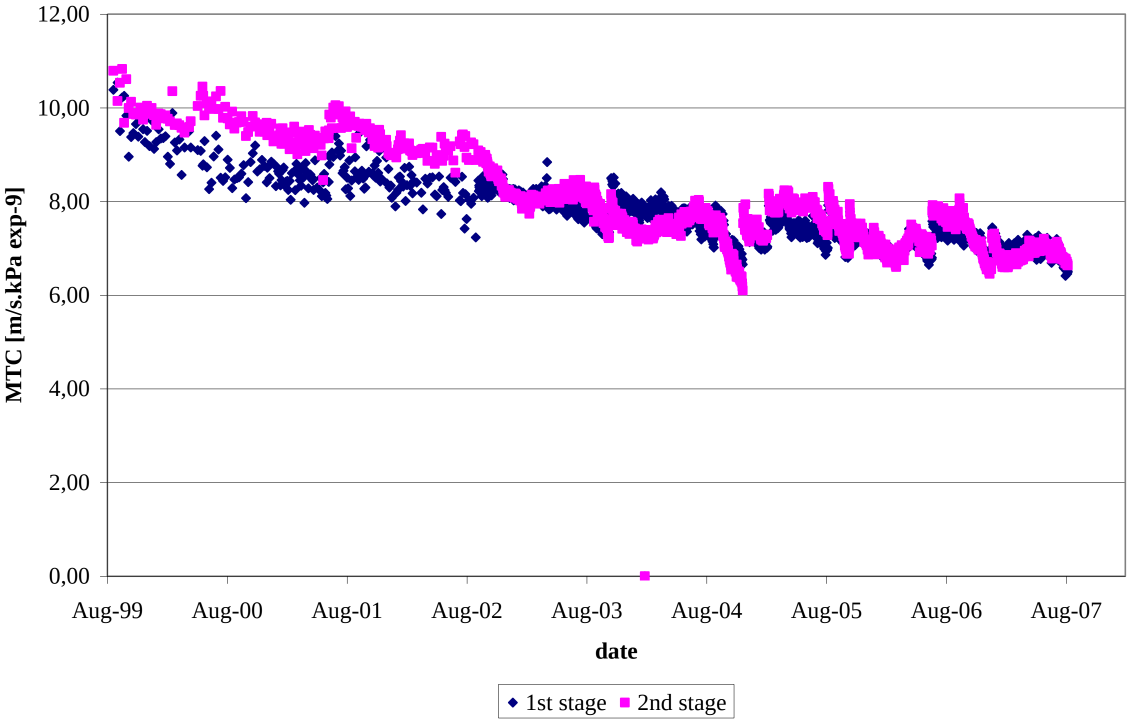

Figure 5. MTC of stage 1 and 2 from start until membrane replacement

Problem description and set-up experiments

It was remarkable that biofouling occurred in the 2nd stage. In most, if not all, the other facility's having problems with biomass accumulation, leading to frequent cleanings, the biomass accumulation took place in the first stage, even only in first elements, of the RO (Schippers, 2004). So why is this phenomena occurring, what is causing it and how could it be prevented?
Another issue leading to the need of an answer of the above is the fact that the replacement of the acid dose with an increase of the anti-scalant dose will lead to a significant cost reduction. However this could have an effect on the fouling behavior, not only on possibility of scaling but maybe also on the organic and inorganic nutrients leading to biofouling.

A variety of techniques, initially developed for determining the biological stability of treated water, is available for determining the microbial growth potential (MGP) of the feed water. The applied bioassays for this research were:

- the assessment of the concentration of easily assimilable organic carbon (AOC), based on determining the growth of two pure cultures of bacteria in samples of pasteurized water (Van der Kooij, 1992);
- the biomass production potential (BBP) test based on measuring the maximum growth yield of the indigenous microbial population in water samples. This method, which has been introduced as alternative AOC method (Stanfield and Jago, 1985) was adapted by using glass containers identical to those used in the AOC test. The BPP test can also be used for determining the limitation of microbial growth by phosphorous (P);

- the biofilm monitor (Van der Kooij, 1992) enabling the determination of the biofilm formation rate (BFR);
- the membrane fouling simulator (Vrouwenvelder, 2006) which is an on-line fouling monitor measuring a very accurate pressure drop and biomass accumulation (MFS).

These assays were conducted on the raw feed water of the RO, after acid and anti-scalant dose and on the concentrate of the RO to get more insight into the biofouling aspects of the RO.

Results bioassays

Influence anti-scalant dose on AOC

A summary of the results is given in table 1. The measured AOC content of the RO-feed water after acid dose is relatively low with an average of 5,6 µg/L, compared to levels that lead to microbial growth (>25 µg/L). The influence of the anti-scalant dose on top of this background average is not noticeable under the current dose of 0,9 mg/L. An increase of the anti-scalant dose to 5 and respectively 50 mg/L leads to a minor increase in AOC to a total of respectively 7,0 and 9,8 µg/L which are still far below critical levels. However in the concentrate of the RO measured AOC levels under the current operating conditions are getting critical (average 25,4 µg/L). This is of course no surprise with an overall recovery of 82%. The found value is almost the feed water value times a concentrating factor of 5.

Table 1. AOC concentrations of RO feed and concentrate

sample point	**AOC [µg/L]**
RO feed after acid	5,6
RO feed after AS	
- 0,9 mg AS/L and acid	4,1
- 5,0 mg AS/L	7,0
- 50 mg AS/L	9,8
RO concentrate (RO feed acid and 0,9 mg AS/L)	25,4

The measured TOC (total organic carbon) values of pure anti-scalant OSM92 and permatreat 191 are respectively 36,5 and 37,5 g/L.

Results biofilm monitor and membrane fouling simulator

Biofilm monitors were placed on the feed and the concentrate of the RO. The monitors were used for a period of 3 months. The AOC level of the concentrate suggested that some growth could occur in the concentrate stream however the biofilm formation rate (BFR) measured with the biofilm monitor on the concentrate is very low and more or less the same as the BFR of the feed water. The results of the biofilm monitor experiment is shown in figure 6. The accumulation of biomass stabilized after 20-30 days indicating no growth and therefore very low BFR values.

The membrane fouling simulator gave similar results after 40 days there was still no increase in pressure difference with or without the anti-scalant or on the concentrate of the RO.

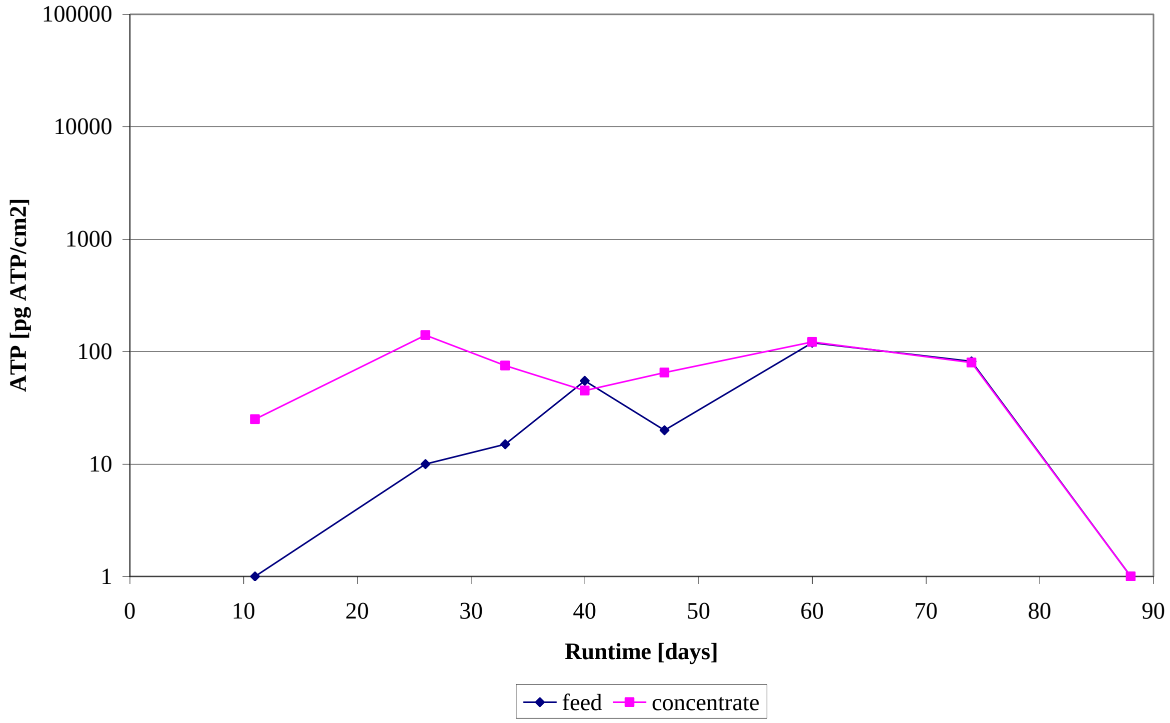

Figure 6. Total accumulation of ATP found within the biofilm monitor

Influence anti-scalant on the biomass production potential (BPP)

The results of the biomass production potential tests are given in table 2. The RO-feed water with acid and antiscalant (0,9 mg/L) shows absolutely no growth, the measured BPP is 0,6 ng ATP/L. Which is not significantly different from the BPP on the feed water with no anti-scalant (1,9 ngATP/L). Increasing the anti-scalant dose to 5,0 mg/L generates comparable BPP values (1,3 ng ATP/L). The RO-concentrate (feed consists out of acid and 0,9 mg AS/L) gave a BPP of 45 ng ATP/L which can be considered as some growth. To be sure that the growth is not limited by a shortage of AOC. A considerable amount of acetate (1 mg/L) is dosed to the samples of the raw feed (only a acid dose) and the feed water after the anti-scalant dose. Where the extra amount of acetate gave no increase of BPP in the feed water after the acid dose (1,9 to 7,1 ng ATP/L) ,it led to an enormous increase in the feed water after the anti-scalant dose (0,6 – 416 ng/L). This clearly indicated that the growth was not limited by C but was caused by the anti-scalant. In the test were phosphate was added (1 mg P/L) at the feed water of the RO after the acid dose the BPP increased from 1,9 – 178 ng ATP/L. From this results can be concluded that the growth is clearly limited by P. And in practice the anti-scalant which consist out of aminotrimethylenephosphonic (ATMP) is most likely the source for this P.

Table 2. BPP values of RO feed and concentrate

sample point	**BPP [ng ATP/L]**
RO feed after acid	1,9
RO feed after acid and AS (0,9 mg/L)	0,6
RO feed after acid and AS (5,0 mg/L)	1,3
RO concentrate (RO feed; acid and 0,9 mg AS/L)	45
RO feed after acid and 1 mg C/L	7,1
RO feed after acid and AS (0,9 mg/L) and 1 mg C/L	416
RO feed after acid and 1 mg P/L	178

Conclusions

The current pre-treatment in front of the RO which consists out coagulation, sedimentation, rapid sand filtration, active carbon filtration and ultrafiltration results into superiour RO-feed water quality with a low growth potential. The AOC levels and the biofilm formation rate are very low. However biofouling occurs at the end of the second stage. From the biomass production potential tests it can be concluded that this biofouling is limited by phosphorus. This means that biofouling is not occurring when phosporus is not present even when an excess of AOC is available. The phosphorus needed is not naturally present in the feed water but most likely added by the anti-scalant dosage. Based on this research a phosphorus free anti-scalant is preferred.

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