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Industrial water reuse with integrated membrane system increases the sustainability of the chemical manufacturing

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ABSTRACT

The DECO water treatment facility (built and operated by Evides Industriewater B.V.) is using an integrated membrane system to produce demineralised water for the production facilities of Dow Benelux B.V in Terneuzen, the Netherlands. The system consists of large-scale continuous microfiltration (CMF) unit and two-pass reverse osmosis (RO) unit with FILMTEC™ membranes. It is the first time in the Netherlands that domestic waste water is re-used in such a large scale for industrial use. This is an excellent example of a full scale process which was adjusted to preserve scarce fresh water resources in the region. The main goal—to minimize the environmental impact and to maximize water recovery through water recycling loops, thereby supporting the chemical industry movement to improve sustainability. This paper discusses the operational experience of the first 18 months operation with wastewater.

The plant was started in 2000 and was originally designed to desalinate estuary water, due the lack of fresh water in the region. The water source was challenging due to high chemical and biological variability, which lead to operational difficulties like biofouling and high maintenance costs due to corrosion. In 2006 the plant was re-engineered to treat municipal waste water originating from the nearby city of Terneuzen. Re-engineering consisted of new RO membrane design, low pressure feed pumps and process automation adjustments. The DECO plant uses fouling resistant membranes (BW30-400/34i- FR) with a thick feed spacer. The spacer reduces the fouling potential and facilitates cleaning. In addition, the plant is using frequent preventive cleanings, which is only possible with robust membranes. These actions have led to stabile operation in terms of permeate flow and the good quality of the produced permeate (<10 μS/cm). This case shows that operational problems caused by the biologically active wastewater can be eliminated by a good plant design (membrane selection) and good operational practices.

The facility reports significant savings, 20% increase in the system recovery and 50% reduction in the operational cost (OPEX) with the implementation of the waste water treated system. The

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savings in OPEX are mainly related to energy costs and decreased use of chemicals for water treatment. In addition, the environmental impact is reduced as the city's waste water is no longer discharged to the sea, but given another life as process water.

Keywords: RO; Municipal waste water; Industrial water; Integrated membrane system; Water reuse; Fresh water; Sustainability

1. Introduction

Efficient water management is critical for industry sustainability, especially for high water consuming ones like the chemical industry. As one of the largest chemical companies in the world, Dow is committed to constantly improve the efficiency of water management in its own facilities. A prime example of this is the large production site in Terneuzen, the Netherlands, where half of its water demand is met via recycled water streams, process water and rain water [1]. The Zeeuws-Vlaanderen region where the site is located lacks a fresh water source and thus water management has been essential since the beginning of the operations [2]. The most recent step towards sustainable water management was taken when municipal waste water effluent originating from the city of Terneuzen replaced the Westerschelde estuary water as a source for process water.

Dow has outsourced the water utilities to Evides Industriewater, the largest supplier of industrial water in the Netherlands. The various water needs of the manufacturing site are answered by the DECO (*de*min and *co*oling water) treatment facility. The facility produces demineralised (demin) water (750 m^3/h), cooling tower supply water (750 m^3/h) and ultrapure water (1200 m^3/h) with various technologies, including Integrated Membrane System (IMS), ion exchange resins and multimedia filters from various feed water sources, as shown in Figure 1 [1,3]. Since the year 2000, reverse osmosis membranes have been used to produce part of the demin water, which is used for generating steam and to feed manufacturing plants. The IMS consists of a continuous microfiltration unit (CMF) and a two-pass reverse osmosis (RO) unit with FILMTEC™ membranes. The facility was originally designed to desalinate estuary water, but the primary disadvantage of the seawater

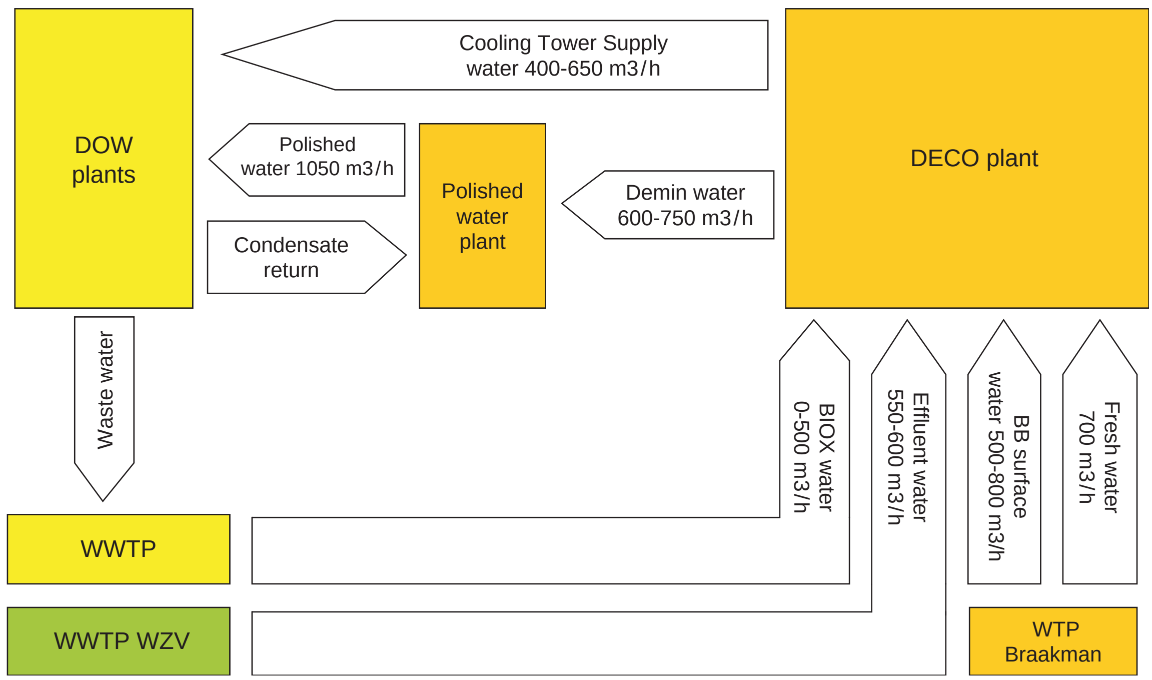

Fig. 1. Overview of water flows.

was its inconsistency. The Westerschelde estuary is very dynamic with varying seasonal water quality, in both chemical and biological terms. In addition, the water shows considerable fluctuations in suspended solids load due to the tides and the nature of the water intake (next to a harbor dock with incoming and outgoing ships and barges). This led to operational challenges such as biofouling and high maintenance costs due to corrosion and the partners decided to evaluate alternative feed water sources [3,4]. In 2006, the plant was re-engineered to treat municipal wastewater effluent originating from the households of 55,000 inhabitants in the Terneuzen city. This paper discusses the operational experience of the first 18 months operation with treated municipal wastewater.

2. Methods

2.1. IMS retrofit from seawater feed to effluent feed

The process flow diagram of the retrofitted system is presented in the Figure 2. The effluent from the waste water treatment plant is transported via 7 km pipeline to a storage tank (1500 m^3) in order to minimize the hydraulic load variations during night time. At the same time, the water can be disinfected with sodium hypochlorite (NaOCl) and ammonium salt (NH_4Cl) to reduce the biofouling risk in the IMS. From the storage tank, the water is transferred to DECO site via another 7 km of pipeline.

Upon arrival to the facility, the pH can be adjusted with sulfuric acid (H_2SO_4) prior feeding it to the CMF units. There are in total 8 units, from which 7 are in operation. The hardware remained unchanged in the retrofit, but the operation was adjusted for waste water by reducing the operation flux.

There are two RO units in place and the configuration is as follows: 28:16 pressure vessels in the first pass and 16:6 pressure vessels in the second pass. Each pressure vessel is housing 6 standard 8″ elements (in total 792). The design capacity of each RO unit is 150–175 m^3/h. Antiscalant (Genesys LF) is dosed at concentration of 3.5 mg/l prior to RO. The SWRO units in the first pass were re-engineered to low pressure RO units. This included changing the feed pumps to low pressure pumps and the RO membranes to brackish water membranes. In addition, modifications were done in process automation. The second pass of the RO units remained same as with the SWRO system.

The selected brackish water membrane was a fouling resistant membrane (BW30-400/34i-FR), whose unique surface chemistry increases the resistance against biofilm build up while providing constant salt rejection. The membrane is packed into element with wide (34 mil) feed spacer which lessens the impact of the fouling even further and enhances the effectiveness of cleaning.

The permeate of the IMS system is mixed with demineralised water produced in the ion exchange system and then finally supplied to Dow. The concentrate of

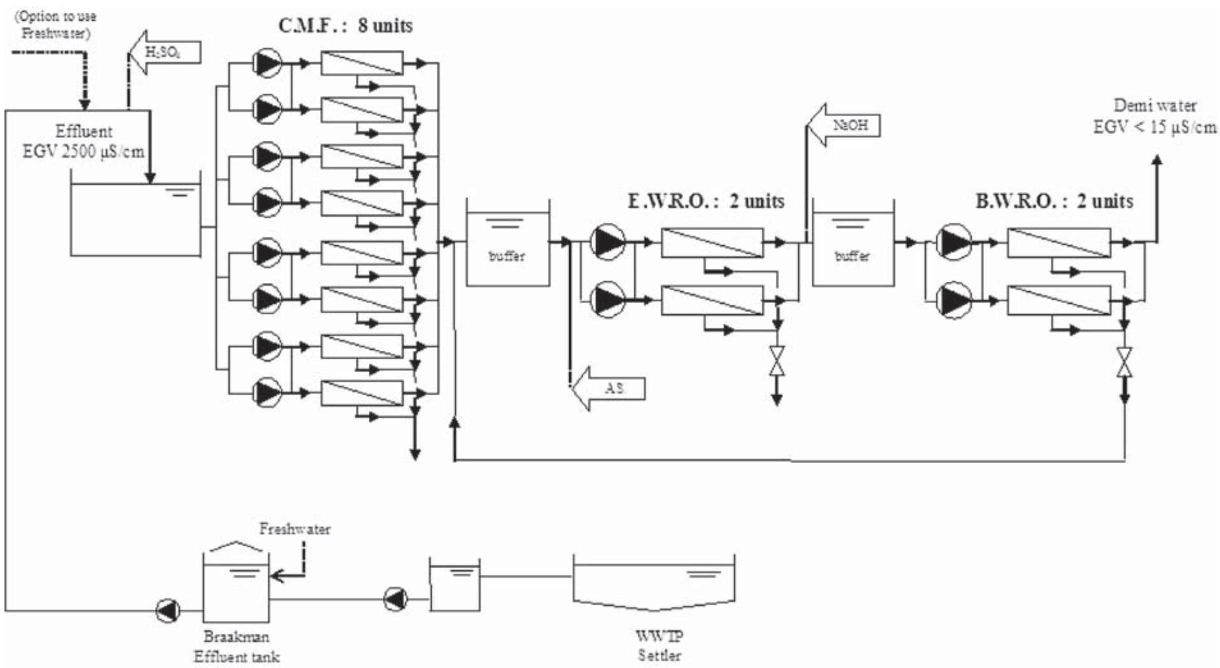

Fig. 2. Process flow diagram of the retrofitted system.

Table 1
Feed water analysis.

	Unit	Sea Water	WWTP Effluent
Temperature	°C	25	13.5
pH	—	8.1	7.1
Na	mg/L	7,123	300
Sulfate	mg/L	1,546	100
Chloride	mg/L	12,820	480
Total phosphate	mg/L	0.12	0.5
Ammonia	mg/L	0.22	8.0
Chemical oxygen demand (COD)	mg/L	N/A	50
Total organic content (TOC)	mg/L	2.2	9.8
Total dissolved solids (TDS)	mg/L	18,000	1,200
Total suspended solids (TSS)	mg/L	20	5.4

the integrated membrane system is mixed and directly discharged to the Westerschelde.

Table 1 is a comparison of the water quality from two feed sources: sea water and waste water. The primary disadvantage with the sea water was its inconsistency. In contrast, the effluent of the community waste water treatment plant (WWTP) is very consistent in quality. The average effluent water quality is controlled according to discharge standards for surface water to the Westerschelde. The inlet water quality is strictly monitored and in case of off-spec effluent, the membrane units can use fresh surface water as feed water [3].

In order to highlight the benefits of the retrofit, the main operational parameters of the first pass RO with sea water (SWRO) and effluent water (EWRO) are presented in the Table 2. The presented data are design values derived from the computer simulation (ROSA). The simulations were done by using the TDS and temperature given in the raw water analysis (Table 1) and in both cases, the system was simulated with new membranes to allow a direct comparison. The main benefits are the increased system recovery and the decreased energy consumption.

Table 2
Main design parameters of the first pass RO before and after retrofit.

Operation parameter	SWRO	EWRO
Flux (l/m²/h)	20.99	20.99
Recovery	54.99	75
Raw Water Flow to system (m³/h)	343.50	243.64
Feed pressure (bar)	40.77	13.49
Specific Energy (kWh/m³)	2.57	0.62
Permeate quality, TDS (mg/l)	92.02	10.85
System Recovery (%)	50.95	71.84

3. Results and discussion

3.1. Plant performance with effluent water

A successful operation of a membrane plant requires the combination of good plant design and good operational practices. Owing to the natural tendency of waste water, the feed water is still biologically active and the combination is needed in order to eliminate operational problems caused by biofouling.

The variations in the effluent water temperature and salinity (conductivity) during the first 18 months are presented in Figure 3. The temperature shows seasonal variations from 8°C in winter to 20°C in the summer

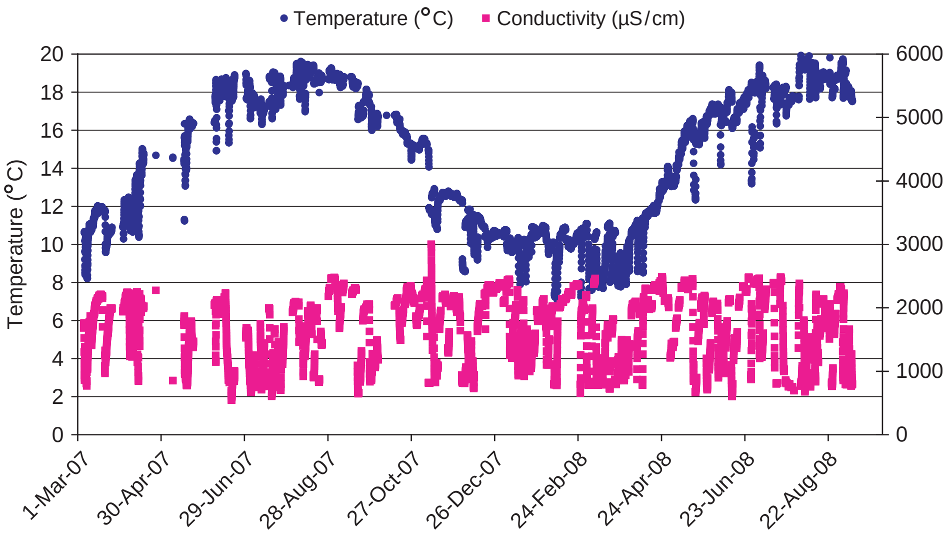

Fig. 3. Feed water temperature and salinity variations.

time, but the variation is smaller than it was with sea water where temperatures could range from 15–33ºC [4]. Similarly, the effluent conductivity varies between 1000–2500 μS/cm whereas sea water could range between 25 000 and 40 000 μS/cm and changes could occur in couple of days [4].

As no hardware changes were done in the CMF unit, it continues to be the bottleneck of the operation as previously explained by Agtmaal et al. [3]. The low operational capacity (water output) of the CMF unit allows only one RO unit to run at a time. The units are alternated on a daily basis (one day off/one day on).

The performance of the RO units are monitored via normalized permeate flow, normalized salt passage and feed to concentrate pressure drop. The normalized permeate flow together with the cleaning in place (CIP) activities for one skid is shown in Figure 4. Regardless of the high fouling tendency of the waste water, the permeate flow has remained at sustainable level and the feed to concentrate pressure drop (Δp), shown in Figure 5, has also remained stable. The data illustrates the importance of correct operational practices. Evides has taken the proactive approach with preventive cleanings combined with regular maintenance cleanings to avoid irreversible

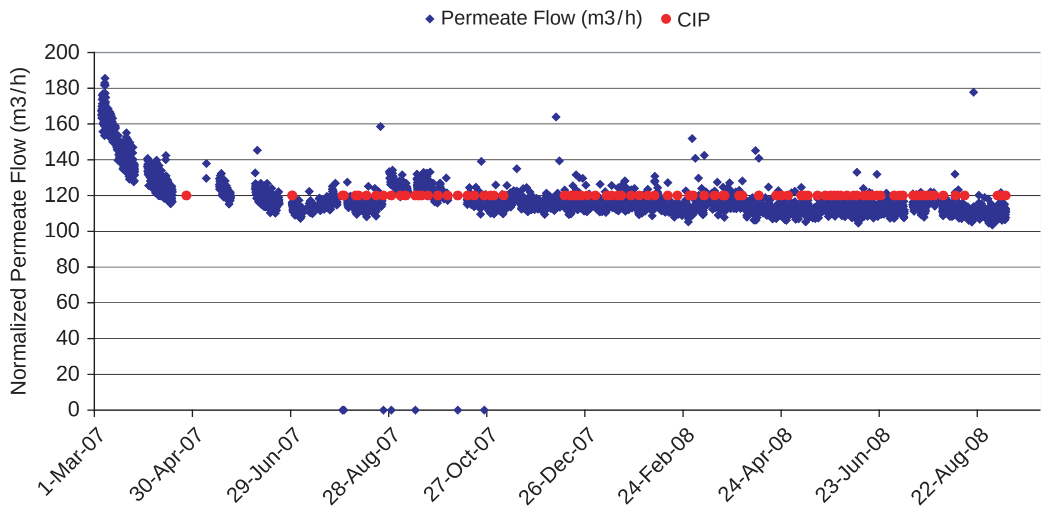

Fig. 4. Normalized permeate flow of skid 1.

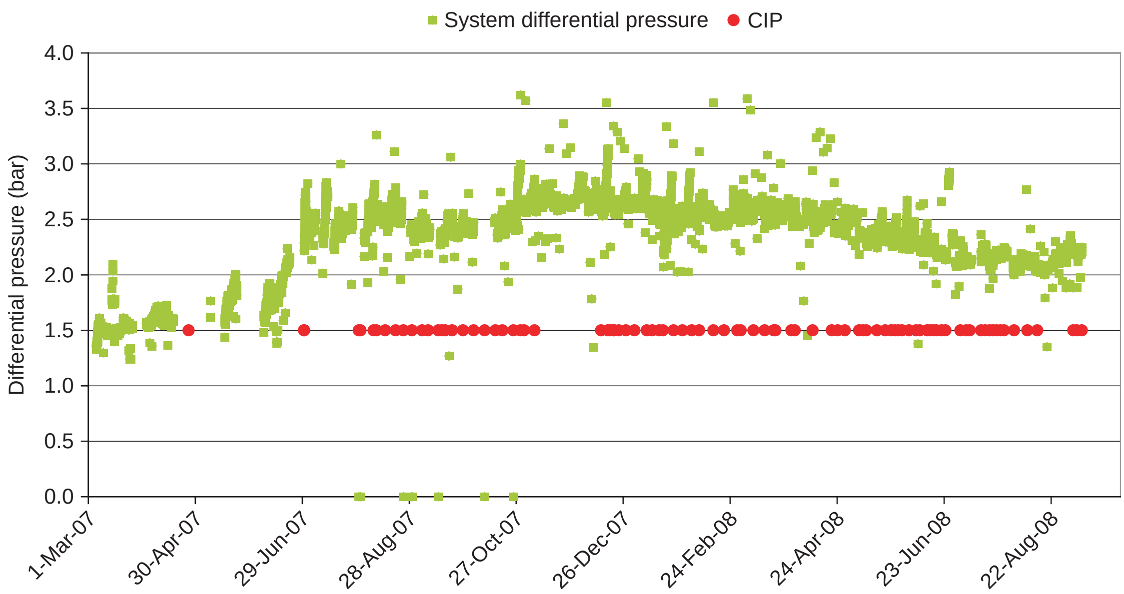

Fig. 5. Differential pressure of skid 1.

loss in the performance. This has proven to be a very successful tactic. Preventive cleanings were gentler, including a short 1 h recirculation with NaOH at pH 11 and temperature of 30ºC. Maintenance cleanings were done at pH 12 (NaOH) and temperature of 30ºC. The cycle of 1 h circulating +0.5 h soaking was repeated 4 times. The cleanings were normally performed only for the first stage and only every 5 to 10 times the second stage was cleaned as well. Acid cleanings (pH 2.1 and temperature of 30ºC) were done on quarterly basis for both stages. Unlike the old SWRO system, no special chemicals were used to aid cleanings. The cleaning procedures are well within the membrane suppliers cleaning guidelines. Frequent cleanings are often expected to reduce the life span of some membranes. The critical factor to withstand frequent cleanings is the robustness of the membrane and the correctly performed CIPs, not exceeding the general guidelines given by the membrane manufacturers. The operational data show no evidence on performance decline due the cleanings. The normalized salt rejection has been maintained very stable between 98 and 99% throughout the operation period (Figure 6).

In the operation of the RO units, the feed water change has been positive as the performance has been good over the first 18 months. When compared to SW feed, the plant recovery has increased by 20%, which corresponds to saving in water intake of 3 million m³/a. The reduced water intake also enables reduction of the used operational chemicals. On an economical basis, the facility reports operation savings up to 50%, caused by lower energy need (reduced by 5000 MWh/a) and reduced amount of operational chemicals (500 ton/a).

Further modifications to the system are planned in order to increase the total output of the plant. Currently the CMF units cannot deliver enough filtrate to feed both RO units simultaneously and thus an upgrade is needed. Based on a successful pilot trial, a membrane bioreactor (MBR) will be implemented in the Terneuzen WWTP. Implementation will increase the total output of the WWTP and allow more water for reuse purposes. Additional benefits can be obtained as the MBR can deliver better permeate quality compared to the current CMF permeate as the pilot has shown [5]. Therefore, the CMF units will be removed at the end of 2009 and the MBR permeate will be directly used as feed water to RO.

Summary and conclusions

The case story presented here has shown that a municipal waste water effluent can be successfully reused for industrial purposes and that existing treatment units can be converted to reuse waste waters in cases where water treatment facilities are in close vicinity to each other. The DECO plant is an excellent example of a full scale industrial process which was adjusted to preserve scarce fresh water resources and the successful experience of the plant can be leveraged to other similar locations.

The DECO facility reports significant savings, 20% increase in the system recovery and 50% reduction in the operational cost with the implementation of the waste

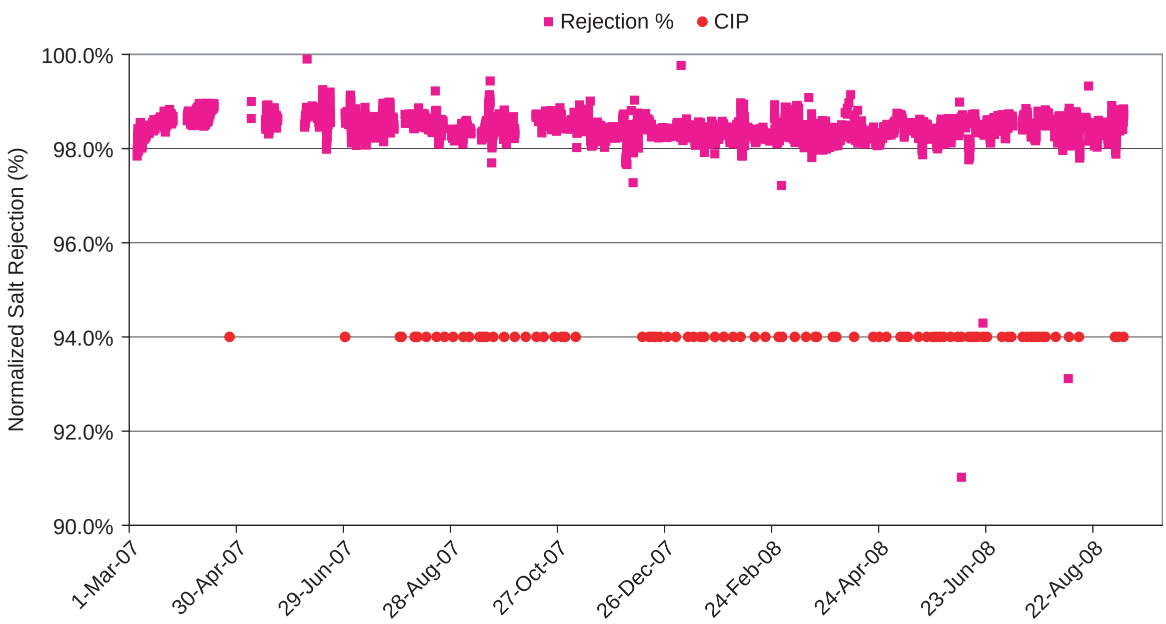

Fig. 6. Normalized Salt Rejection of skid 1.

water treated system. The savings in OPEX are mainly related to energy costs and decreased use of chemicals. In addition, the environmental impact is reduced as the city's waste water is no longer discharged to the sea, but given another life as process water.

By maximizing water recovery via water recycling loops, sustainable chemical manufacturing can be achieved, with less impact on the environment and more water available for non-industrial uses. The installation of this waste water treatment system is in line with Dow's 2015 Sustainability Goals, recognizing that sustainable water management is good for communities and the environment and can generate cost savings.

Awards

The water treatment system described here represents the first time in the Netherlands that domestic waste water has been recycled on a large scale for industrial use. The initiative has been rewarded the Environmental Award 2007 of the Province of Zeeland (Zeeuwse Milieuprijs), the Dutch VNCI Responsible Care Award 2007, the European Cefic Responsible Care Award 2007, the ICIS Innovation Award 2008 for the Most Innovative Corporate Social Responsibility Project, and an IChemE water award.

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