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Wastewater reuse through RO: a case study of four RO plants producing industrial water

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ABSTRACT

Because of water scarcity in some regions of the Netherlands and new environmental concepts of water withdrawal, Dutch industrial water production has been shifting from surface water or scarce groundwater to wastewater in recent years. Because of this transformation, it is important to evaluate the advantages and disadvantages of using wastewater treatment plant (WWTP) effluent as a source to produce industrial water, and to gain knowledge about water recycling and treatment. Reverse osmosis (RO) treatment is mostly used to produce water for industry. Four selected Dutch RO plants producing industrial water are analysed in this paper. Demineralized Water Plant (DWP) DECO and DWP Sas van Gent are using WWTP effluent as source water; DWP Baanhoek and DWP Botlek are producing industrial water from surface water. The alternative water source alters pre-treatment needs and RO operations. Compared to surface water, WWTP effluent requires more pre-treatment to prevent UF and RO membranes from fouling. Detailed comparisons between both types of RO plants were made based on the following criteria: 1. Feed water qualities, including the seasonal changes for the surface water and quality fluctuation for WWTP effluent; 2. Pre-treatment methods in compliance with the feed water situation; 3. RO operational problems during both surface water and effluent water desalination; 4. Risk of effluent water quantity shortage and quality insufficiency and management. Finally, the practice and experiences of the RO plants are summarized.

Keywords: Reverse osmosis; Water reuse; Industrial water; Bio-fouling; Demineralised water; Pre-treatment

1. Introduction

Freshwater scarcity is becoming obvious along with the population growth and the industrial expansion. The expanding industries are increasingly resorting to other water sources, mainly recycled water. As the popularity of tertiary treatment of municipal wastewater and the emergence of new environmental concepts of water withdrawal increases, the reclamation of WWTP effluent for industry becomes feasible.

In the Netherlands, the water resources are moderate with an Actual Renewable Water Resources of 5,539.0 km^3/capita/a, while the world average is 8,209.9 km^3/capita/a according to the FAO (Food and Agriculture Organization of the United Nations) statistic 2007 [1]. However, the Dutch water problems, such as the risk of saltwater intrusion and the uneven distribution of Dutch water resources, are noteworthy. Because 24% of Dutch land area is below sea level, increasing the exploitation of groundwater

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increases the risk of saltwater intrusion. In the delta area of southwest Netherlands, the land and islands are surrounded by brackish water or seawater, so freshwater is scarce. Clean water sources, e.g., groundwater and surface water, should preferably be used for drinking water, while industrial water should have a lower quality water source, e.g., brackish water and reclaimed wastewater [2]. Dutch industrial water production has been shifting from surface water or scarce groundwater to wastewater in recent years.

Reverse osmosis (RO) treatment is mostly used to produce water for industry, due to the low water conductivity requirements. Industrial water treatment plants DECO and DWP Sas van Gent are located in the delta area of the Netherlands. At these plants, RO processes have been successfully employed to reclaim wastewater for industries. However, the RO membrane bio-fouling is still a major challenge in desalination and especially in wastewater reclamation. Effluent water is rich in organic carbon, nitrogen and phosphorus and, together with high water temperatures, it has a high potential for RO bio-fouling. Therefore, pretreatment techniques are being investigated repeatedly as the main solution to control membrane fouling. MF and UF are the options to remove suspended solids and colloidal materials [3], but UF performs better in terms of colloidal removal than MF [4]. In-line coagulation is efficient to remove organic matter [5,6], phosphorus [7,8], silica [9], as well as extracellular polymeric substances (EPS) [10]. Granular activated carbon (GAC) filtration can achieve remarkable reduction of turbidity, COD and TOC. However, the SDI (Silt Density Index) test of GAC filtrate indicates a fouling potential on RO membranes [11]. MBR is used to remove organic matter and nitrogen, offering a stable filtrate quality for RO. The biomass in MBR can play a role in total estrogen and virus removal as well [3].

Besides the RO operational challenges, permeate water quality is another concern when reusing the effluent water for industrial installations. Relying on the barrier of RO membranes, almost all contaminants can be rejected very efficiently, except the small, hydrophilic, uncharged molecules, such as boron [12,13], methanol, formic acid, formaldehyde and urea, which are ineffectively removed by RO [14,15].

In this paper, four selected RO plants producing industrial water are studied relating to the characteristics of different types of feed waters, UF/MF pretreatment systems and RO performances, in order to summarize the current experiences of effluent desalination and to explore the technical bottlenecks. DECO and DWP Sas van Gent are used to reclaim WWTP effluent for industrial utilities; Baanhoek and DWP Botlek are producing industrial water from surface water.

2. Brief details of RO plants

Brief information of the above mentioned RO plants is listed in Table 1.

DECO treats effluent from a MWWTP (Municipal Wastewater Treatment Plant) to produce demiwater for the PW plant (Polished Water Plant). The demiwater is afterwards polished by mixed bed ion exchange and then used to feed high-pressure boilers in a chemical site in Terneuzen. The plant consists of CMF (continuous microfiltration) and two-stage reverse osmosis membranes (EWRO-BWRO). Before the effluent is delivered to the plant, sodium hypochlorite (NaOCl) and ammonium salt (NH_4Cl) is dosed to reduce the biofouling risk in the membrane system, and then effluent water is transported to a buffer tank (1500 m^3) in order to adjust effluent flow fluctuation from the MWWTP. The pH of the effluent is adjusted

Table 1
Brief information of the RO plants

	DECO	DWP Sas van Gent	DWP Baanhoek	DWP Botlek	
Source	Municipal WWTP effluent	WWTP effluent from starch producing company	Surface water from the Biesbosch	Drinking water	Surface water from Lake Briel
Scheme	Microscreening (50 μm), CMF, RO 2x	Multi Media Filtration, UF, RO, Degassifier, RO	Strainer, UF, RO, Degassifier, Mixed bed	Softener, vertical RO/RO, mixed bed ion exchange	Combined flotation and filtration (DAFF); IX softener ; AiRO + RO, mixed bed IX
Reason for recycling	Cheaper compared to seawater and multi sources	Savings on drinkingwater	N.A.	N.A.	N.A.
RO membrane supplier	DOW-Filmtec	DOW-Filmtec & Hydranautics	DOW-Filmtec	DOW-Filmtec	DOW-Filmtec

to 7.5 with sulfuric acid (H_2SO_4) prior to feeding it to the CMF units, in order to control scaling of the RO (Fig. 1).

DWP Sas van Gent is located at Sas van Gent, in the delta area of the Netherlands. DWP Sas van Gent reclaims WWTP effluent from a starch-producing plant to produce demineralised water. The treatment consists of an inline flocculation with iron, dual media filtration with anthracite and sand (2.5–4 mm and 1.4–2.0 mm), ultrafiltration, antiscalant dosing, a first-stage RO system, degasifiers and a second-stage RO system (Fig. 2).

DWP Baanhoek treats surface water (Biesboschwater) with ultrafiltration, antiscalant dosing, reverse osmosis, a degasifier and mixed bed ion exchange to produce demineralised water (Fig. 3). The demineralised water is supplied to a plastics-producing industry.

The current source of DWP Botlek is drinking water. A train of softener, vertical RO/RO, mixed bed ion exchange is used to treat the drinking water (Fig. 4). The demineralised water is used as boiler feed water, smaller amounts as water for the production of chlorine and washing of pigments and various other purposes.

3. Result and discussion

3.1. Feed water quality fluctuation

Due to quality fluctuation of the water, the operation and control of the RO plant and its pretreatment may involve difficulties. From the four RO plants, feed water qualities are collected in Table 2.

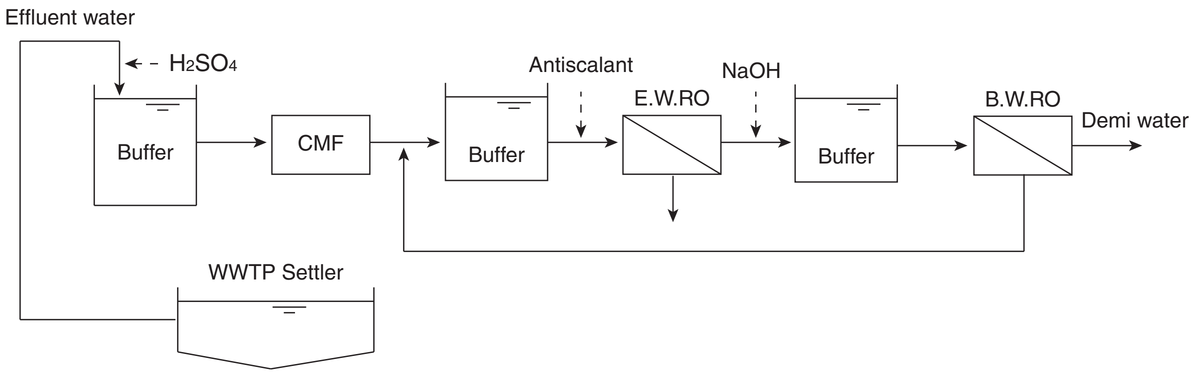

Fig. 1. Schematic process diagram of Plant DECO.

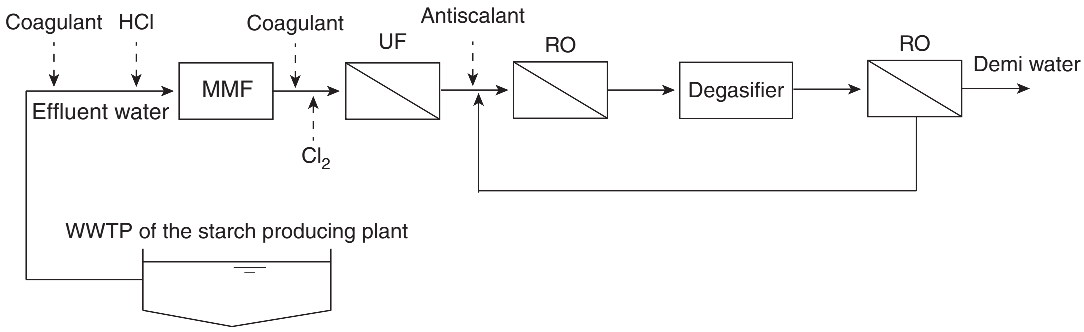

Fig. 2. Schematic process diagram of DWP Sas van Gent.

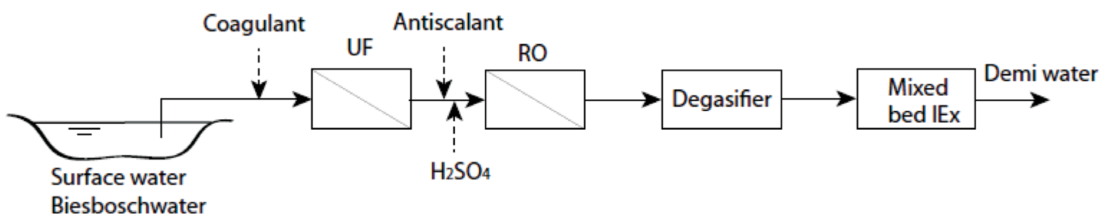

Fig. 3. Schematic process diagram of DWP Baanhoek.

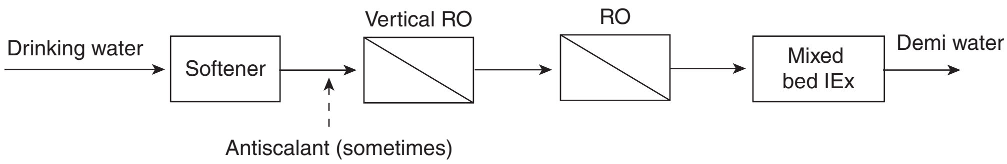

Fig. 4. Schematic process diagram of DWP Botlek.

Surface water from the Biesbosch has large fluctuations in temperature, from 2.3°C to 21.5°C, and surface water from Lake Briel has large variations in salt (sodium chloride) concentration. Chlorophyll (1.8 μg/l to 60 μg/l) and phaeophytin (1.1 μg/l to 56 μg/l) are detected in the surface water at Lake Briel which is the future source water of DWP Botlek.

Turbidity, bicarbonate and TOC fluctuations are found in the feed water of DWP Sas van Gent. The feed water is WWTP effluent water from a starch-producing company. The turbidity varies from 32 NTU to 300 NTU. The bicarbonate varies from 800 mg/l to 2000 mg/l. The TOC is tested from 15 mg/l to 25 mg/l. However, effluent water in DECO and DWP Sas van Gent has higher temperatures, which can contribute to bio-fouling. Furthermore, the effluent water contains more organic matter, ammonium and phosphate than the surface water, which enlarges the potential of bio-fouling in the MF or UF and RO system. The higher concentrations of phosphate and calcium in the effluent water can also lead to scaling of the RO membrane.

3.2. Prevention of fouling on the MF/UF

3.2.1. Plant DECO

In the case of DECO, before the effluent is delivered to the plant, sodium hypochlorite (NaOCl) and ammonium salt (NH_4Cl) is dosed to reduce the bio-fouling risk in the membrane system, and then effluent water is transported to a storage tank. Backwash with air and water is carried out on the CMF every 25 min or when the pressure drop reaches 120 kPa. CEB (Chemical enhanced backwash) is carried out every day. The CEB is performed with sodium hydroxide dosed in distilled water, aiming to kill the microbes and to remove organic contaminants from the membrane. A cleaning with chlorine is not adopted because the membranes are not resistant to free chlorine. Every 4 times of CEB, sodium hydroxide is replaced by Divos 109 (composed of bisphosphonates and KOH). Acid cleaning is also performed once a week by Divos 25 (composed of citric, phosphoric and glycolic acid), aiming to remove lime and other mineral deposits.

Nonetheless, due to the fouling and aging of CMF, a low production of CMF allows only one RO unit to run at one time, and the units are alternated on a daily basis (one day off/one day on) [16,17]. The flux of the CMF is only 50 l/m^2/h (Table 3).

3.2.2. DWP Sas van Gent

In DWP Sas van Gent, the turbidity varies from 32 NTU to 300 NTU. The multimedia filter is the first barrier against the fluctuating turbidity. The filter consists of anthracite and (2.5–4 mm and 1.4–2.0 mm). Prior to the multimedia filter, 2.5 mg/l iron is dosed to capture particulate matter and decrease phosphate content. The saturation index for calcium carbonate is very high for the effluent (about +0.9), so even the multimedia filter and UF are under the risk of scaling. Since 25 January 2010 an HCl dosing (towards pH 7.3) has been implemented in front of the multimedia filter for preventing $CaCO_3$ scaling on the multimedia filter and UF.

The ultrafiltration (pore size 25 nm) is operated with a flux of 60 l/m^2/h. A dose of 1.1 mg/l iron is also added before the ultrafiltration step. With this dose, the last small sludge particles gather into larger flocculation. In addition, there is a constant chlorine dose of 0.5 mg/l applied to remove ammonium and avoid bio-fouling of ultrafiltration. The remaining ammonium and organic matters ensure that hardly any free chlorine is present in the water after the ultrafiltration. However, recently the chlorine dosage stoped because of too little ammonium existing in the raw water. Backwash of the UF is carried out every 20 min or the pressure drop reaching 100 kPa. CEB with chlorine is performed every 6 h and the chlorine dosage is 150 mg/l. Acid cleaning is operated twice per week with 1% oxalic acid and 0.014% HCl. CEB with Divos 109 is carried out once per week.

3.2.3. DWP Baanhoek

In DWP Baanhoek, the same ultrafiltration membranes with DWP Sas van Gent are installed (pore size 25 nm). However, these UF membranes are operated with a flux of 80 l/m^2/h, instead of 60 l/m^2/h in DWP

Table 2
Overview of feed water quality

RO plants		DECO			DWP SvG			DWP Baanhoek			DWP Botlek						
Type of feed water		Municipal WWTP effluent			WWTP effluent from starch producing company			Surface water from the Biesbosch			Surface water from Lake Briel			Drinking water for DWP Botlek			
		min	average	max	min	average	max	min	average	max	min	average	max	1st quarter 2009	2nd quarter 2009	3rd quarter 2009	4th quarter 2009
Temperature	°C	8	15	22	22	32	36	2.3	12.1	21.5				6.4	14.3	20.4	11.8
Conductivity	μS/cm	500	1500	2500	5400	6400	7700	390	412	438				440	430	437	471
Suspended Solids	mg/l	1	6	>30		12					4.1	14	32				
Turbidity	NTU	2	4	>50	32	55	300	0.1	0.9	3.2				0.07	0.06	0.05	0.02
pH	–	7	7.5	8.2	7.8	8.3	8.5				7.7	8.2	8.7	8.11	8.15	8.06	7.99
Sodium	mg/l		300					25	29	37	30	40	214	33	35	36	40
Calcium	mg/l		80		30	34	60				57	68	79	50	45	45	48
Magnesium	mg/l		30								8.8	11	13	6.9	7.0	6.9	7.1
Bicarbonate	mg/l		325		800	1700	2000	94	121	136	130	157	196	117	122	134	125
Iron	mg/l		0.3					<0.005	0.01	0.070				<0.005	<0.005	<0.005	<0.005
Sulphate	mg/l		100					42	49	58	46	58	70	53	45	44	55
Chloride	mg/l		480					37	41	48	56	85	380	50	55	49	58
Total Phosphate	mg/l	<0.1	1	2				0.04	0.07	0.10			0.12				
Ortho-phosphate	mg/l				0.1	0.7	2.0	0.02	0.05	0.09							
TOC	mg/l		9.8		15	20	25	3.0	3.6	4.4	2.3	3.2 DOC	5.8				
Ammonium as N	mg/l		3.5					0.02	0.04	0.07	0.03	0.24	1.2	<0.023	<0.023	<0.023	<0.023
Nitrate as N	mg/l							2.4	2.8	3.3			2.2	3.03	3.03	2.62	2.55
Oxygen	mg/l													10.9	8.8	7.9	13.6
Chlorophyll	μg/l										1.8	15	60				
Phaeophytin	μg/l										1.1	13	56				

Table 3
Characteristics of UF/MF membranes in the plants

	DECO	DWP Sas van Gent		DWP Baanhoek
		Skid 1	Skid 2	
Membrane type	MF	UF	UF	UF
Membrane material	PP	PES/PVP	PES/PVP	PES/PVP
Pore size/nm	200	25	25	25
Last replacement	Dec-2004	06-Apr-2006	30-Oct-2007	04-Feb-2009
Flux/l/m^2·h	50	50	60	80

Sas van Gent, because Biesbosch water is cleaner than the effluent water in DWP Sas van Gent in terms of all parameters listed in Table 2. Nevertheless, 1.1 mg/l iron chloride is dosed prior to UF, in order to protect the UF from fouling. Backwash is also operated every 51 m^3 filtration, while CEB with chlorine is carried out every 36 backwashes. CEB with Divos 2 acid is performed every 4 CEBs with chlorine.

3.3. RO operation and fouling control

Scaling and bio-fouling are found in these RO systems as the main problem of both surface water and effluent water desalination.

In these RO plants, scaling is controlled by pH adjustment and antiscalant dosing. In Plant DECO, the pH of effluent is adjusted to 7.5 with sulfuric acid (H_2SO_4) prior to feeding it to the CMF units; after CMF units, 3.5 mg/l antiscalant (Genesys LF) is dosed to further prevent the RO from scaling. The other plants are using a similar approach; see Table 4. Because of the high phosphate concentration in the feed water of DWP Sas van Gent, 2.5 mg/l iron chloride is dosed prior to the multimedia filter, and thus, phosphate content is reduced to prevent calcium phosphate scaling in the RO step.

Bio-fouling is found at Plant DECO, DWP Sas van Gent and DWP Baanhoek. At DWP Sas van Gent, PAA has been dosed at the 1st array of the RO system since December 2006, when the membrane had already been fouled. One month later, the NPD of the 1st array was decreased by 0.4 bar, while the NPD of the parallel 2nd array without PAA dosing was increased by 0.5 bar [18]. In DWP Baanhoek, the NPD (Normalized Pressure Drop) increases more rapidly with a higher temperature of feed water. However, at another parallel RO train with oxidant PAA dosage (peracetic acid and hydrogen peroxide), the NPD remained low [18]. At the DECO plant, the fouling also becomes serious with increasing water temperatures. The NPD varies with water temperature fluctuations (Fig. 5). The chemical CIP (Cleaning in Place) frequency thus becomes intensive in summer (Fig. 6).

CIP at pH 12 dosing NaOH (1.5–2%) and CIP at pH 2 dosing HCl are operated at plant DECO and DWP Sas van Gent. In DWP Baanhoek, a dosage of Divos 2 is applied instead of HCl.

3.4. Water sources backup and effluent water quantity fluctuation

At the DECO Plant, a buffer tank (1500 m^3) is sited prior to the plant, in order to adjust effluent flow fluctuation during the day and night from the MWWTP. Industrial water (of surface water origin) can also be supplied as a backup in case of insufficient or off-spec effluent water. This surface water can also be supplied to the effluent water during the night time regime, to operate both membrane lines [16]. When the conductivity is higher than 2500 µS/cm or turbidity higher than 15 NTU, the effluent water is not used anymore and backup water sources will take over the effluent water.

At DWP Sas van Gent, the effluent water varies considerably in terms of turbidity, conductivity, TOC and

Table 4
Scaling prevention of RO in the plants

	DECO	DWP Sas van Gent	DWP Baanhoek	DWP Botlek
pH correction	H_2SO_4, pH 7.5	7.2	H_2SO_4, pH 7.5	9.5–10.5
Antiscalant	Genesys LF	Genesys LF	Permatreat 191	Permatreat 191 (temporarily)
Dosage	3.5mg/l	3.68 mg/l	3.5 mg/l	

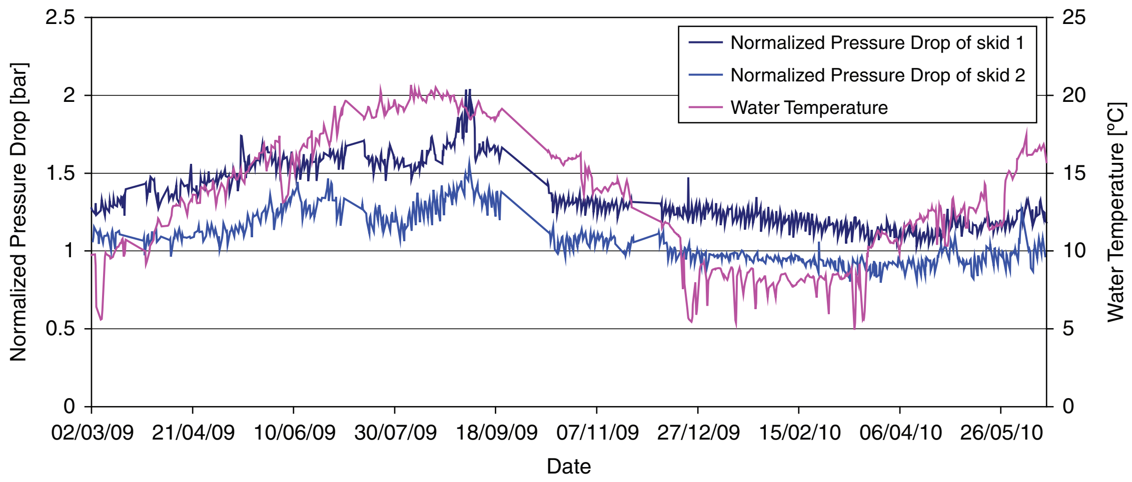

Fig. 5. Normalized pressure drop of the EWRO (Effluent Water RO) at Plant DECO.

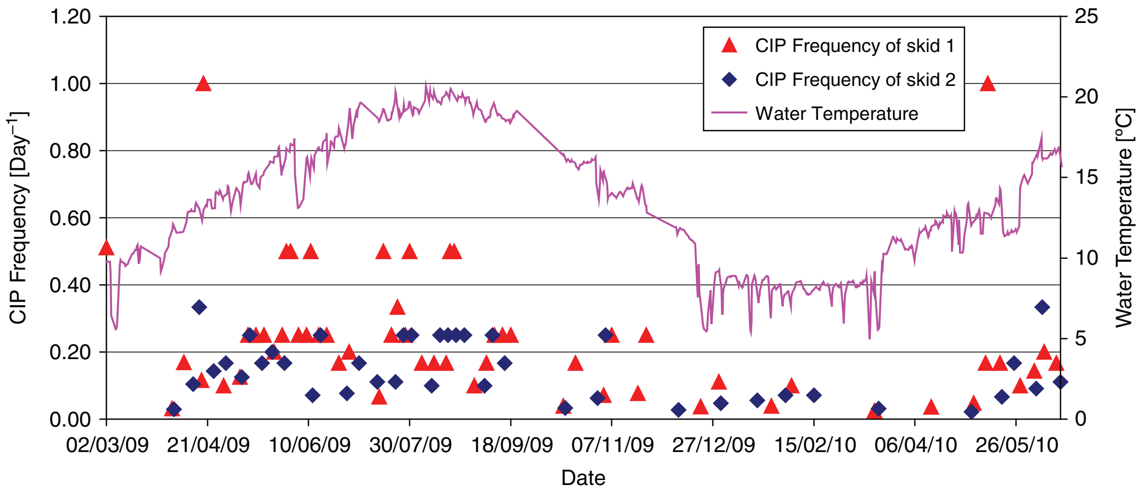

Fig. 6. CIP frequency of EWRO (Effluent Water RO) at Plant DECO.

ortho-phosphate, as shown in Table 2. Drinking water is used as RO feed when effluent water cannot be used. The main specifications of effluent water of DWP SvG are regulated as turbidity <290 NTU, conductivity<7500 >µS/cm, O_2 after MMF>0.1 mg/l, redox after MMF>150 mV and 22°C<Temperature<36°C.

4. Conclusions

Four selected RO plants producing industrial water are studied. Baanhoek and DWP Botlek are producing industrial water from surface water; WWTP effluent is successfully reclaimed and reused by Plant DECO and DWP Sas van Gent for industrial utilities.

The effluent water quality is compared with surface water. Higher temperature and more organic matter, bicarbonate and phosphorus than surface water are the main characteristics of effluent water. However, surface water has high temperature fluctuation and possible algae blooming.

Bio-fouling is found in the membranes at all plants fed by both effluent and surface water. At DWP Sas van Gent and Baanhoek, the bio-fouling of MF/UF is well controlled by coagulation, backwash and chemical enhanced cleaning. Multimedia filter is adopted at DWP Sas van Gent as a barrier to the fluctuation of turbidity in effluent. In the RO steps, bio-fouling is more obvious, and intensive CIP has to be performed to maintain the RO operation, especially in the warm seasons.

Water quality failure and water quantity fluctuations of the effluent water will happen in water reclamation plants. Reasonable back-up water volumes must be applied to guarantee a water supply in good quality and quantity.

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