Seawater Pre-treatment for Reverse Osmosis System

By

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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ABSTRACT

Membrane based desalination technology such as reverse osmosis (RO) has rapidly become a viable alternative to conventional treatment for drinking water production from seawater. However, membrane fouling is a major concern in reverse osmosis (RO) based seawater desalination. The fouling on RO membrane deteriorates the performance of RO membranes and increases the energy consumption and even requires more frequent replacement of the membranes. The objective of the study was to assess the different pre-treatment systems to reduce membrane fouling reduction, and remove organic matter in terms of dissolved organic carbon in RO desalination projects. Silt density index (SDI), modified fouling index (MF/UF-MFI) and cross-flow sampler modified fouling index (CFMF-MFI) were used to study the pre-treatment efficiency of different process such as flocculation, deep bed filtration, microfiltration, ultrafiltration and biofiltration.

A long term on site biofilter experiment was investigated in terms of removal of particulate matter, different fouling indices and dissolved organic carbon (DOC) from sea water by the use of biofiltration. In this study, three biofilter columns were operated packed with granular activated carbon (GAC), anthracite and sand as a filter media. The experimental results indicated that biofiltration pre-treatment systems reduced organic matter and particulate matter. It was expected that biofilter can lower fouling to a subsequent RO process in desalination plant. In terms of DOC removal efficiency, GAC biofilter showed higher and stable removal efficiency (41-88%), than sand biofilter (7-76%) and anthracite

biofilter (3-71%). All biofilters used in this study removed most of hydrophobic organic compounds (around 94%). On the other hand, hydrophilic organic removal varied depending on the media filter. GAC biofilter removed more organic bio-polymers (51%), humic substances (75%) and building blocks (50%) compared with sand and anthracite biofilters. Thus GAC filter was the best medium to provide the lowest fouling potential as it showed the highest removal efficiency of DOC, including hydrophilic, humic, building blocks and biopolymer. The fouling potential of treated seawater (filtrate) was evaluated using three different fouling MF-MFI, UF-MFI, and CFMF-MFI. GAC biofilter had lower fouling potential compared to sand and anthracite biofilters.

The in-line flocculation and spiral-flocculation followed by media filtration (sand or anthracite) have been investigated as a pre-treatment of seawater to reverse osmosis (SWRO). In the case of in-line flocculation filtration system, the seawater was passed through the media filter just after rapid mixing of raw seawater with flocculants for 10 seconds. In the case of spiral-flocculation filtration, after the rapid mixing of seawater with flocculants, it was then passed through the spiral-flocculation. Both filtrations showed good turbidity removal efficiency (up to 71%). In-line flocculation filtration showed 2-3 times higher headloss than the spiral-flocculation filtration. The UF-MFI reduction was 63-70% for sand as medium in the presence of the flocculant whereas it was 65-76% for anthracite. Both filtration systems in the presence of flocculant (3 mg/L Fe^{3+}) led to 50-65% removal of hydrophobic organics. The hydrophilic organic removal was around 30-38%. The predominant portion of hydrophilic was humic substances which had a poor removal. In general sand filter gave a higher removal than anthracite filter.

The performance of $TiCl_4$ and $Ti(SO_4)_2$ was compared to $FeCl_3$ at different coagulant concentrations (1-30 mg/l) of Ti salts and $FeCl_3$ and at different pH of 5 to 9. Coagulation was conducted using conventional jar test. For each jar test, six 1 litre beakers were filled with raw seawater. The pH was adjusted with 0.1 N solution of hydrochloride acid and sodium hydroxide prior to coagulant addition. The solution was subjected to rapid mixing (100 rpm) for 2 min followed by slow mixing (20 rpm) for 30 min. It was then stopped to allow the aggregated flocs to settle down for 30 min. The supernatant samples were drawn for the measurements of turbidity, UV-254 absorbance and DOC, zeta potential and particle size distribution. The results showed that at pH of 8.0 (similar to seawater pH), $TiCl_4$ had advantages over $FeCl_3$ and $Ti(SO_4)_2$ at the same coagulant dose of 20 mg/L. Under this condition, $TiCl_4$ achieved ~70% DOC and UV-254 removal. This was approximately two times higher than $FeCl_3$ and $Ti(SO_4)_2$. Nevertheless, $FeCl_3$ and $Ti(SO_4)_2$ showed better turbidity removal. At higher coagulant dose (30 mg/L), the turbidity removal of $TiCl_4$, was especially compromised. The differences in the performance of the coagulants were associated with the coagulant mechanisms based on the floc zeta potential evaluation. The coagulant mechanisms of Ti-salts could be associated to charge neutralization while $FeCl_3$was inclined towards adsorption mechanism.

The study found that biofiltration, in-line flocculation and spiral-flocculation followed by media filtration, coagulation and flocculation are appropriate pre-treatment before RO. In particular, Biofilter showed to a consistent removal of organic matter over a long period of time.

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LIST OF PUBLICATIONS BASED ON THIS RESEARCH

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2. Shrestha, A., Jeong, S., Vigneswaran, S., Kandasamy, J. (2013), "Seawater biofiltration pre-treatment system: comparison of filter media performance", Desalination and Water Treatment, in press, Vol. 52 , Iss. 34-36,2014.

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LIST OF NOTATIONS

RO	=	Reverse osmosis
SWRO	=	Seawater reverse osmosis
SDI	=	Silt density index
MFI	=	Modified fouling index
MF/UF-MFI	=	Micro filtration / Ultra filtration modified fouling index
CFS-MFI	=	Cross-flow sampler modified fouling index
GAC	=	Granular activated carbon
DOC	=	Dissolved organic carbon
MF-MFI	=	Micro filter - modified fouling index
CFMF-MFI	=	Cross flow micro filter -modified fouling index
UF-MFI	=	Ultra filter - modified fouling index
NF-MFI	=	Nano filter - modified fouling index
UNEP	=	United Nations Environment Program
IWMI	=	International Water Management Institute
CSIRO	=	Commonwealth Scientific and Industrial Research Organisation
NOM	=	Natural organic matter

MF	=	Microfiltration
UF	=	Ultrafiltration
NF	=	Nanofiltration
LC-OCD	=	Liquid chromatography-organic carbon detection
DOM	=	Dissolved organic matter
Da	=	Dalton
Ppm	=	Parts per million
EPS	=	Extracellular polymeric substances
NTU	=	Nephelometric Turbidity Unit
TOC	=	Total organic carbon
COD	=	Chemical oxygen demand
BOD	=	Biochemical oxygen demand
EfOM	=	Effluent organic matter
BTSE	=	Biologically treated secondary effluent
IE	=	Ion exchangers
ZVI	=	Zero-valent iron
TDS	=	Total dissolved solid
PAC	=	Powdered activated carbon

DMF = Dual media filters

DAF = Dissolved air flotation

TSS = Total suspended solids

ASTM = American standard testing and method

UV = Ultra violet

t_i = Initial filtration time (to filter a fixed volume)

t_f = Final filtration time (to filter the same fixed volume)

T_f = Elapsed time

Spb = Pore blocking slope by critical time – pore blocking index (1/L)

V = Total permeate volume (l)

R_m = Membrane resistance (m^{-1})

t = Filtration time (s)

ΔP = Applied trans-membrane pressure (Pa)

η = Water viscosity at 20^{o}C (N s/m^2)

α = The specific resistance of the cake deposited

C_b = The concentration of particles in a feed water (mg/l)

A = The membrane surface area (m^2).

SAC = Spectral absorption coefficient

SEC	=	Size exclusion chromatography
BDOC	=	Biodegradable organic carbon
AOC	=	Assimilable organic carbon
G	=	Velocity gradient, 1/s
g	=	Gravitional acceleration, cm^2/s
ν	=	Kinematic viscosity,cm^2/s
Q	=	Flow rate, cm^3/s
V	=	Volume of the flocculator (in this case, tube volume), cm^3
ΔH	=	Headloss through the flocculator, cm
LMW	=	Low molecular weight