Desalination 385 (2016) 83–92

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Advanced organic and biological analysis of dual media filtration used as a pretreatment in a full-scale seawater desalination plant

Sanghyun Jeong [a,b], Robert Vollprecht [c], Kyungjin Cho [d], TorOve Leiknes [a], Saravanamuthu Vigneswaran [b,*], Hyokwan Bae [d], Seockheon Lee [d]

[a] Water Desalination and Reuse Center (WDRC), King Abdullah University of Science and Technology (KAUST) Thuwal, 23955-6900, Saudi Arabia
[b] Faculty of Engineering and IT, University of Technology, Sydney (UTS), PO Box 123, Broadway, NSW 2007, Australia
[c] Degremont Pty Ltd, Perth Seawater Desalination Plant/Lot 3003, Barter Road, Naval Base, WA 6165, Australia
[d] Center for Water Resource Cycle Research, Korea Institute of Science and Technology, 39-1 Hawolgok-Dong, Seongbuk-Gu, Seoul 136-791, Republic of Korea

HIGHLIGHTS

- This paper focuses on the monitoring of organic and biological foulants using advanced techniques.
- Optimization of dual media filter (DMF) to maximize the reduction of foulants was made.
- Microbial community analysis of DMF filtered seawater and medium, and cartridge filter was conducted.
- Semi-pilot scale DMF columns were operated on-site at the biofiltration mode.

ARTICLE INFO

Article history:
Received 10 December 2015
Received in revised form 1 February 2016
Accepted 9 February 2016
Available online xxxx

Keywords:
Biofouling
Dual media filter
Microbial community
Organic fouling
Seawater desalination

ABSTRACT

Dual media filter (DMF) is being used as a primary pretreatment to remove particulate foulants at seawater desalination plants. However, many plants experience organic and biological fouling. The first part of this paper focuses on the monitoring of organic and biological foulants using advanced analytical techniques to optimize functioning of DMF at Perth Seawater Desalination Plant (PSDP) in Western Australia. In addition, microbial community analysis in DMF filtered seawater, and on DMF media (DMF-M) and cartridge filter (CF) was conducted using terminal restriction fragment length polymorphism (T-RFLP) and 454-pyrosequencing. In the full-scale DMF system, the bacterial community structure was clustered along with the filtration time and sampling positions. For the DMF effluent samples, the bacterial community structure significantly shifted after 4 h of filtration time, which corresponded with the permeability reduction trend. The dominant bacterial communities in the DMF effluent were OTU 13 (Phaeobacter) and OTU 19 (Oceaniserpentilla). The different biofilm-forming bacteria communities were found in the biofilm samples on DMF-M and CF. In the second part of the study, semi-pilot scale DMF columns were operated on-site under same operating conditions used in PSDP. It demonstrated the advantage of operating DMF at the biofiltration mode for improving the reduction of biofoulants.

1. Introduction

Many seawater desalination plants (either thermal or reverse osmosis (RO) based) use granular media (conventional) filtration or dual media filtration (DMF) as a primary pretreatment strategy prior to the main desalting processes [1–3]. After screening trash from the intake seawater, which constitutes the initial pretreatment, coagulation/flocculation, media filtration (typically single-stage DMF; anthracite and sand), and cartridge filter (CF) steps are usually used as pretreatment to improve the feed water quality for the RO-based desalination plant [4]. Ferric salts are often used to coagulate and flocculate colloidal particles and dissolved organics in feed water (seawater). Sulfuric acid (H_2SO_4) is dosed to provide optimal pH for improving the coagulation performance. DMF coupled with coagulation/flocculation works well reduces the particulate fouling on RO membranes (especially during summer or when algal bloom occurs). The filter media is backwashed on a regular basis (once in 24–36 h) with air scour followed by the DMF to remove captured SS from the filters. CF is usually used to

Abbreviations: AOC, assimilable organic carbon; ATP, adenosine tri-phosphate; BP, biopolymers; BB, building blocks; CA, correspondence analysis; CF, cartridge filter; CIP, chemical cleaning in place; DMF, dual media filter; DOC, dissolved organic carbon; HS, humic substances; LC-OCD, liquid chromatography with organic carbon detection; LMW-A, low molecular weight acids; LMW-N, low molecular weight neutrals; NMDS, non-metric multidimensional scaling; PSDP, Perth Seawater Desalination Plant; RO, reverse osmosis; SDI, silt density index; TEP, transparent exopolymeric particles; T-RFLP, terminal restriction fragment length polymorphism.

* Corresponding author.
E-mail address: Saravanamuth.Vigneswaran@uts.edu.au (S. Vigneswaran).

http://dx.doi.org/10.1016/j.desal.2016.02.017

prevent the sudden occurrence of particulate matter after DMFs. DMF and CF consume less energy compared to membrane-based pretreatment [5]. However, conventional DMF is not effective in inhibiting the organic and biofouling [6]. As a result, a number of desalination plants face the problem of biofouling both on CF and RO membranes downstream of the DMF system [7]. In addition, DMF filtered seawater still has high fouling potential that results in fouling of CFs and these have to be replaced once every 2–8 weeks [8]. Furthermore, non-optimized DMF may lead to frequent chemical cleaning of RO membranes. Although currently the cost of chemical cleaning is relatively low, the non-production of water during chemical cleaning in place (CIP) results in a loss of production and a significant increase in workload. The optimization of DMF, in turn, can reduce the operational and energy costs of RO plants and increases the lifetime of the CFs (usually used as a security barrier after DMF). It is therefore important to establish the proper design and operational guidelines for DMF through a detailed study on organic and biofouling.

At present, six large seawater desalination plants are operating in Australia [9]. Four desalination plants use the DMF as a primary pretreatment and one of these full-scale plants is Perth Seawater Desalination Plant (PSDP), which is located in Western Australia. This plant was commissioned in November 2006 with a capacity of 144 MLD that produces up to 17% of Perth's drinking water [10].

This study focuses on the following: i) monitoring of DMF by using organic and biological parameters, and ii) facilitating DMF to operate in the biofiltration mode. The performance of DMF at PSDP was monitored in terms of organic foulants using liquid chromatography with organic carbon detector (LC-OCD), and biological foulants (assimilable organic carbon; AOC, standard blocking index by ultrafiltration; Ks-UF and adenosine tri-phosphate; ATP).

Molecular level analyses on the DMF and CF systems can help to optimize the DMF operation. For this reason a detailed analysis of the microbial community in DMF filtered seawater and on DMF and CF media was conducted. The above samples were analyzed using terminal restriction fragment length polymorphism (T-RFLP) and 454-pyrosequencing. A pilot-scale DMF study was also conducted with same filter media and coagulant used in PSDP together with the same operating conditions such as filtration velocity. The effects of filter run-time (or backwashing frequency) and backwashing duration on biofouling reduction were assessed in terms of biological activity to operate the DMF in biofiltration mode.

2. Materials and methods

2.1. Processes and samples description

2.1.1. Dual media filter (DMF) operation

At the PSDP, DMF is operated under pressure as opposed to gravity to ensure long runs. Each DMF consists of a 300 mm layer of sand with an effective size of 0.3 mm and an 800 mm layer of anthracite with an effective size of 1.6 mm. A 100 mm gravel bed is provided so that the nozzles are protected against clogging by the sand. After operation, flocculated suspended solids, dissolved solids and organics and biofilms together with ferric hydroxide (oxidized ferric coagulant) are present on the DMF media.

Ferric sulfate solution (Orica Chemicals, Australia) serves as a primary coagulant in the pretreatment system of the PSDP. This assisted in the precipitation of dissolved solids and ions and flocculation of suspended solids in the feeding seawater. Ferric sulfate was dosed into a dilute sulfuric acid stream flowing into the seawater pipeline to the DMFs. pH was adjusted using sulfuric acid to 6.8 (between 6.7 and 7.0) for optimum coagulation. Floquat FL 4526 PWG (Polydiallyldimethylammonium Chloride (PolyDADMAC)) was added as a cationic polymeric coagulant aid. It should be noted that ferric sulfate and Floquat FL 4526 PWG are referred to as coagulant and coagulant aid (or flocculant and flocculant aid).

The DMFs require regular backwashing to maintain the filter bed in a good filtration condition and to remove the solids retained in the filter media. Backwashing interval is determined by the monitoring of pressure drop using differential pressure transmitters and the hydraulic permeability measured using a flow meter. The condition of the backwashing process is summarized in Table 1.

2.1.2. DMF samples

DMF filtered seawater samples collected at different filtration times were analyzed in this study (DMF-0 h, 1 h, 4 h, 8 h, 12 h, 18 h, 24 h and 30 h). They were also used in a study of the microbial community. DMF media (DMF-M) samples were taken from DMF number 9 (DMF 9) at PSDP in March 2013 for the analysis. They were washed twice with 1× phosphorus buffer solution (PBS) followed by mild sonication for extraction of biofilm on DMF-M. The mild sonication was carried out with the DMF-M in a beaker containing 1× PBS using an ultrasonic bath (Powersonic 420, Thermoline Scientific, 300 W) for a short time (10 min).

2.1.3. Cartridge filters (CFs)

DMF filtered seawater was then passed through CFs. In PSDP, 5 μm CFs (1251-10C, Pall Corporation, USA) are used as security filters. It is made of high consistency polypropylene melt blown cartridge. In this study, the fouled CFs were taken from CF number 14 (CF-14) at PSDP in March 2013 for microbial analyses. The CFs were frozen immediately after their removal from the housing. Several segments were then cut from the fouled CF for analysis. Biofilm on CF was extracted using the same method used for DMF-M extraction (see Section 2.1.1). A detailed description of samples used in this study is given in Table 2.

2.2. Monitoring methods

2.2.1. Silt density index (SDI)

SDI is being used as a main fouling index or water quality-monitoring indicator at desalination plants [11]. In the SDI test, the time required to filter a fixed volume (500 mL) of feed water through a standard 0.45 μm pore size microfiltration (MF) membrane with a diameter of 47 mm under constant-pressure (207 ± 3 kPa) is measured. The initial time (t_i) and the time of a second measurement taken to filter 500 mL water (t_f) (after silt built-up) is noted and SDI value is calculated using Eq. (1).

$$SDI = \frac{(1 - t_i/t_f)}{T} \times 100 \tag{1}$$

where, t_i and t_f are the initial and final time in seconds required to collect the 500 mL permeate respectively, and T is the total elapsed flow time (in this study, flow time of 5 min was used, thus is called SDI_5).

2.2.2. Liquid chromatography with organic carbon detector (LC-OCD)

Dissolved organic carbon (DOC) concentrations in DMF effluent and organic foulant on CF were measured using DOC-LABOR Liquid Chromatography — Organic Carbon Detector (LC-OCD). The LC-OCD system separates and measures hydrophilic DOC compounds according to their molecular size using both an OCD detector (after inorganic carbon

Table 1
Main backwashing procedure of DMF in PSDP.

Operation	DMF
Normal flow	800 m^3/h
Rinse drain	3 min
Water scour	800 m^3/h for 2 min
Air scour	55 m/h for 7 min
Backwash	1400 m^3/h for 13 min
Maturation	12 m/h for 18 min