Chemical Engineering Journal 228 (2013) 976–983

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Journal

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

Assessment of biological activity in contact flocculation filtration used as a pretreatment in seawater desalination

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HIGHLIGHTS

- The biological activity in contact flocculation filtration (CFF) was investigated.
- Sand and anthracite filter media were evaluated in terms of biological activity.
- Significant removal of LMW organics with an active microbial population was achieved.
- Biofouling potential was reduced by CFF through biological activity and bio-stabilization.

ARTICLE INFO

Article history:
Received 23 November 2012
Received in revised form 21 May 2013
Accepted 22 May 2013
Available online 4 June 2013

Keywords:
Anthracite
Biofilter
Biofouling
Flocculation
Sand
Seawater

ABSTRACT

Contact flocculation filtration (CFF) is a promising pretreatment method to improve feed water quality prior to seawater reverse osmosis (SWRO). CFF is the combination of deep bed filtration and in-line flocculation. To date, CFF has been used mainly as a barrier for particle removal in the filter bed itself with hydrophobic organic compounds removal by flocculation. In this study, the potential of CFF was investigated as a biofilter in addition to its major function of flocculation and particle/floc separation. Two different media (sand; S-CFF and anthracite; A-CFF) were tested on CFF. Bacterial activity in the filter bed was assessed in terms of cell number and adenosine tri-phosphate (ATP) measurement. The microbial community test in the filtration bed was carried out over 50 d in case of sand filter (S-CFF) and 90 d for anthracite filter (A-CFF) filtration periods. With the growth of an active microbial population on the filter bed medium, significant removal of organic compounds, especially low molecular weight (LMW) organics, from the seawater was achieved. The results indicated that CFF functions both as flocculation and separation unit and also as biofilter with moderate efficiency in reducing biofouling potential. The results also showed that A-CFF needed longer time to achieve bio-stabilization but it showed more effective biofiltration potential than S-CFF.

1. Introduction

Currently, about 50% of desalination plants use reverse osmosis (RO). RO requires effective pretreatment to reduce fouling, save cleaning agent and energy, maintain stable flux and extend the lifetime of membrane element [1].

The main foulants of RO membranes include particulate/colloidal fouling, inorganic fouling (including scaling), organic fouling and biofouling. The particulate/colloidal fouling is mainly caused by suspended solids and metal-based hydroxides which can accumulate on the surface on the RO membrane. Microorganisms such as bacteria, fungus or algae can produce biopolymers to aggregate themselves to the surfaces of membrane and to promote biofilm. This leads to serious problem to the RO operation since it accelerates the chemical decomposition of RO membranes. Organic compounds do not only cause adsorptive fouling but also can act as energy source of microorganisms. Therefore, the control of colloidal, organic and biofouling need an intensive pretreatment [2].

Deep bed filtration (DBF) is the most common pretreatment presently used in large-scale RO plants due to its relatively low energy consumption, and low operational and installation costs [3]. DBF is a robust technology to remove suspended solids from sea water by size exclusion and adsorption onto media [4]. However, conventional DBF cannot remove dissolved organic matter effectively. Thus, flocculation is used prior to the DBF

Abbreviations: ATP, adenosine tri-phosphate; BOM, biodegradable organic matter; CFF, contact flocculation filtration; CFU, colony forming unit; DBF, deep bed filtration; DO, dissolved oxygen; DOC, dissolved organic carbon; EBCT, empty bed contact time; HRT, hydraulic retention time; LC–OCD–OND, liquid chromatography–organic carbon detection with organic nitrogen detector; LMW, low molecular weight; NOM, natural organic matter; PBS, phosphorus buffer solution; PCR, polymerase chain reactions; RO, reverse osmosis; SW, seawater; TEP, transparent exopolymer particles; UF-MFI, ultrafiltration-modified fouling index.

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http://dx.doi.org/10.1016/j.cej.2013.05.085

to form particulate aggregates to enhance the particle removal. Recently, hybrid materials, which are composed of two or more different types of components in onepolymeric matrix, have been receiving increased attention by researchers in recent years due to their unique properties and superior performance compared to that of conventional inorganic coagulants and organic polymeric flocculants [5]. However, metal (Al or Fe) coagulants are still used at different doses and pH conditions in water treatment plant. They are precipitated as aluminum or ferric hydroxides. When particles in the water are incorporated into flocs by the coagulation, it is called sweep-floc coagulation. Coagulation can also remove natural organic matter (NOM) by phase change. Dissolved NOM gets into particles directly by precipitation or by adsorption onto aggregated particles produced by the coagulant [6].

Contact flocculation–filtration (CFF), which is DBF coupled with in-line flocculation, is initially used in water treatment as well as in pretreatment for RO desalination. In CFF, flocculation of particles and the filtration of flocs occur within the filter bed itself. When flocculant is used in-line in the filter (direct filtration and contact flocculation–filtration) the chemical (i.e. $FeCl_3$) dose is usually reduced by 30–40% as compared to separate flocculation–filtration [7]. In the previous short-term CFF study by Jeong et al. [8], it was found out that CFF could remove both hydrophobic and hydrophilic organic compounds with low $FeCl_3$ concentration of 0.5 mg of Fe^{3+} L^{-1}. The lower use of $FeCl_3$ can minimize the risk on disposal of flocculated sludge. However in the previous study, only short-term experiments of 6 h was conducted to study on the removal of particulate and organic matters. On the other hand, this study concentrates on a long-term on-site filtration experiment mainly to study the biological activity on the deep bed filter in a detailed manner.

When relatively slow flow rates are used, DBF functions as a biofiltration. Here, biofilm is developed on the medium and it helps in decomposing biodegradable organic material [9]. Following the adsorption of organic matters onto the filter media, the initial degradation is accomplished by extracellular enzymatic hydrolysis of macromolecules to smaller substrates, which can then be transported into the biofilm. Further degradation takes place by a diverse microbial biofilm community developed in the filter media [10]. However, so far, only little is known on the biological activity in the CFF systems used in seawater desalination as a pretreatment. Due to the frequent backwashing and relatively rapid flow of water through these filters, the impact of biological activity in CFF is assumed to be minimal. However, this study shows that there is a significant biological activity in CFF. The specific aim of this paper is to investigate the biological activity in the CFF through a long-term experiment. Organic removal by flocculation and biological activity in filter media were investigated using two different commonly used filter media (sand and anthracite).

The water quality of CFF effluent is usually determined by parameters related to particulates fouling such as turbidity and headloss. However, this work highlighted the need for monitoring biological water quality characteristics such as dissolved organic carbon (DOC), biopolymers, especially transparent exopolymer particles (TEP) which affect significantly the RO biofouling [11]. Microbial activity on the CFF was measured in terms of heterotrophic bacterial count (or colony forming unit, CFU) and adenosine tri-phosphate (ATP as an active biomass). During a 50 d operation of CFF packed with Sand (S-CFF) and 90 d operation of CFF packed with anthracite (A-CFF), the development of the microbial community on the media was also investigated using the 16S rRNA sequencing of cultural colonies. The biological activity of the CFF at different depths of filter media (top, middle and bottom layers) was also studied.

2. Materials and methods

2.1. Materials

2.1.1. Seawater

The filtration experiments were conducted at Sydney Institute of Marine Science (SIMS), Chowder Bay, Australia. The seawater pumped from 1 m below seawater surface level was first filtered through a 140 μm pore filtration system (to remove the large particles). During the experimental period of 90d duration, the average pH, dissolved oxygen (DO), turbidity and DOC values of seawater used in experiments were 7.97 (±0.15), 4.9 (±0.3) mg L^{-1}, 0.61 (±0.24) NTU and 2.33 (±0.51) mg L^{-1}, respectively.

2.1.2. Ferric chloride ($FeCl_3$)

Ferric chloride is highly recommended as a flocculant for seawater since it generates the amorphous ferric hydroxide in seawater over a wide range of pH and temperature conditions [12]. Ferric chloride is highly insoluble leaving residual dissolved Fe in the water after pretreatment and this avoids precipitation problems on RO membrane. Further, ferric flocs formed are easy to be removed. Also, organic matter forms complex with positively charged Fe and gets absorbed onto flocs. At natural ranges of pH (7.5–8.0) and temperature (20–35 °C), there would be high fractions of positively charged Fe as $Fe(OH)_2^+$ available for charge neutralization during coagulation. Due to these reasons, ferric chloride was selected as a flocculant in this study. A stock solution (Fe^{3+} = 10 mg L^{-1}) was prepared and was injected into rapid mixing unit of the CFF with seawater at a ratio of 1:20 (ferric chloride:seawater) by a dosing pump (Cole Parmer Masterflex Pump). The dose was calculated as 0.5 mg of Fe^{3+} L^{-1} to DBF.

2.1.3. Filter media

Long-term filtration experiments were carried out with in-line flocculant addition in the filtration columns packed with two different media; sand and anthracite. Sand and anthracite were washed with 1N-HCl, 1N-NaOH and Milli-Q water several times prior to their use. The physical properties of sand and anthracite used in this study are shown in Table 1.

2.2. Contact flocculation filtration set-up

The CFF experimental set-up is shown in Fig. 1. The internal diameter of the filtration column was 3.8 cm. It was packed with sand (S-CFF) and anthracite (A-CFF) to a depth of 60 cm from the bottom. Thus, the packing volume was 680 cm^3. The filtration velocity and flocculant ($FeCl_3$) dose were set at 7.5 m h^{-1} and 0.5 mg of Fe^{3+} L^{-1} respectively. These values were determined as optimal condition from the previous study [8]. The rapid mixing was performed in a spiral flocculator unit which contained a PVC tube. The length of spiral tube used as rapid mixing zone was 50 cm and its diameter was 0.16 cm. Rapid mixing time was calculated from length and diameter of the tube, as well as flow rate of the feed water. The rapid mixing time and velocity gradient (*G* va-

Table 1
Physical properties of filter media.

Parameter	Sand (S) Estimated value	Anthracite (A) Estimated value
Effective size (mm)	0.6	1.0–1.1
Bulk density (kg/m^3)	1500	660–720
Uniformity coefficient	<1.50	1.30
Specific gravity	2.65	1.45
Zeta potential (mV) at pH 7.0	−7.5 (±0.6)	−36.1 (±1.1)
Surface isoelectric pH	0.7–2.2	4–5