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Microbial activity in biofilter used as a pretreatment for seawater desalination

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HIGHLIGHTS

- GAC biofilters as a pretreatment process in seawater desalination
- Microbial activities measured in terms of active biomass (ATP) and total cell count
- Biofouling potential assessed by transparent exopolymer particles (TEP) and AOC concentration
- GAC biofilter is an effective pretreatment in reducing biofouling potential.

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ABSTRACT

Biofilters as a pretreatment process in seawater desalination can reduce biofoulants through adsorption and biodegradation. In this study, the performance of granular activated carbon (GAC) biofilter with three different filtration velocities was studied in terms of dissolved organic carbon (DOC) removal. This apart, the microbial activities in the biofilters were measured in terms of concentration of active biomass (adenosine tri-phosphate; ATP) and total cell count. Biofouling potential in biofilter effluents were assessed in terms of transparent exopolymer particles (TEP) and assimilable organic carbon (AOC) concentration. AOC was carried out using a new rapid bioluminescence method. Upon reaching mature stage, the GAC biofilters achieved high DOC removal efficiency of more than 60%, especially the low molecular weight organics. This organic removal was mostly attributed to active biomass on the GAC media. In addition, GAC biofilters led to significant reduction of the AOC and TEP concentration amounting to only 0.6 ± 0.2 μg-C glucose/L and 5.3 ± 1.1 μg-C/L, respectively in effluents. Thus, GAC biofilter is an effective pretreatment in reducing biofouling potential.

1. Introduction

Seawater desalination provides sustainable long term solution for the growing water demand pressures across the globe. Seawater reverse osmosis (SWRO) has been a widely applied technology for producing fresh water. One of the challenges for successful operation in SWRO desalination is membrane fouling [1]. In particular, biofouling is a serious problem since it is difficult to control and eliminate, resulting in flux decline and overall productivity loss.

Biofouling is due to absorption or adhesion of microbes on membrane surface that forms a sticky polymer substance — biofilm [1]. Current findings have established that one of the sources of biofilm formation is transparent exopolymer particles (TEP). Hence, the presence of TEP in source (feed) water can potentially lead to membrane fouling [2]. In comparison to other fouling types which can be identified and controlled through suitable chemical or physical operation, biofouling is uncertain and the most challenging to control as it depends on various factors. These factors include the presence of microorganisms and organics in the water, oxygen availability and water temperature [3]. Specifically, the easily biodegradable compounds of the organics in the feed water are highly influential to the development of membrane biofouling. The biodegradable compound is utilized for microbial growth that causes biofilm on the membrane surface.

Generally, deep-bed biofilter with media depths between 40 and 120 cm and flow rates ranging between 5 and 15 m/h has been used as a conventional pretreatment method [4]. In a deep bed biofilter, organic matter is removed by adsorption and biodegradation [5]. Microbes attach to either the external surface or pores of media particles. These microbes utilize the biodegradable fraction of organic matter as a carbon source for their growth, metabolism, and reproduction, yielding effective organic removal [6,7]. Thus, deep-bed biofilter is a suitable pre-treatment as it is expected to effectively minimize biofouling in seawater [8].

Abbreviations: AOC, Assimilable organic carbon; ATP, Adenosine tri-phosphate; BP, biopolymer; BB, building blocks (BB); DOC, Dissolved organic carbon; EBCT, Empty bed contact time; EPS, Extracellular polymeric substances; GAC, Granular activated carbon; HS, humic substances; LC-OCD, Liquid chromatography with organic carbon detection; LMW, Low molecular weight; MFI, Modified fouling index; NOM, Natural organic matter; OND, Organic nitrogen detector; SDI, Silt density index; SWRO, Seawater reverse osmosis; TEP, Transparent exopolymer particles; UF, Ultrafilter; UF-MFI, Ultrafiltration-modified fouling index.

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As the dominant part of organic removal during biofiltration is attributed to biological processes, it is necessary to measure and analyze the microbial biomass in the filters to better understand the organic removal performance of biofilters. In recent times, a number of studies have assessed the microbial activity focusing on drinking water treatment [6,7,9]. However, relatively few had explored the interphase between microbial biomass and organic removal in biofilters to treat seawater [8,10].

Generally, indicators such as modified fouling index (MFI) or silt density index (SDI), turbidity and particle counts have been used to assess the fouling potential of pretreated seawater. These measurements only provide information on particulate fouling, but are not able to assess the organic and biological elements that contribute to biofouling [2]. Hence, more advanced indicators are required for assessment of biofouling potential.

Upon feedwater pretreatment, one of the significant factors that contribute to biofouling is bacteria regrowth. Disinfectant such as chlorination has been used to kill all microorganisms. However, using disinfectant has led to massive biofouling occurrence on the later membrane process. This phenomenon is due to the increase in the production of organic matter by dead microorganism that leads to rapid bacteria regrowth. This shows that proliferation and regrowth of bacteria on the membrane is mainly caused by the presence of the biodegradable fraction of organic matter of seawater [11,12]. These labile organic matters can be assimilated by bacteria known as the assimilable organic carbon (AOC). The AOC bioassay method was developed to represent this fraction effectively. It is indicated that biological stable water should have less than 20 μg-C acetate/L AOC concentration [13].

The main goal of this study was to assess the performance of seawater deep-bed biofilters in controlling biofouling. Biofilter with granular activated carbon (GAC) media was compared at three different velocities of 5.0 m/h, 7.5 m/h and 10.0 m/h. In order to better understand the organic removal capacity of the biofilters, microbial activity in the biofilters were measured during the operation. The particle and colloidal removal performances of the biofilters were monitored to ensure stable and feasible operating condition using turbidity and ultrafilter-modified fouling index (UF-MFI). The organic removal by the biofilters was measured by Liquid Chromatography with Organic Carbon Detection (LC-OCD). The biological activities in the biofilter were measured in terms of colony forming unit (CFU) using marine agar plate for cell counting and adenosine tri-phosphate (ATP) for live biomass counting. The biological fouling potential in biofilter effluent was determined by measuring the values of AOC and TEP.

2. Material and methods

2.1. Seawater

The experiment was conducted at Sydney Institute of Marine Science, Chowder Bay, Australia for continuous seawater feeding. The seawater used in this study was withdrawn 1 m below the sea surface level and filtered through centrifuge filtration system to remove the large particles. The characteristics of seawater (as average values over the operation time) are given in Table 1.

2.2. Experimental

The experimental set-up is shown in Fig. 1. Three transparent acrylic filter columns with an internal diameter of 20 mm were operated in parallel (at a down-flow mode). The columns were packed with GAC as a media. The nominal size (d_{50}) of GAC used in this study was 0.41 mm. The same size of GAC was packed in all the columns.

A batch isotherm test was conducted prior to the biofilter experiment. It was carried out at different GAC amounts with seawater at 25 °C for 24 h. Organic adsorption capacity (q_{max}) estimated by the Langmuir isotherm model was up to 0.81 mg of DOC/g of GAC with a good fit ($R^2 = 0.99$) of the observed data. In kinetic test with 5 g/L of GAC, after 6 h operation, the equilibrium was reached. Even within 30 min, 85% of adsorption reaction was achieved.

Table 1
The characteristics of seawater used in this study.

Seawater characteristics	Measured values
pH	8.03 ± 0.14
Turbidity (NTU)	0.68 ± 0.13
Conductivity (mS/cm)	39.9 ± 0.71
Dissolved organic carbon (DOC) (mg/L)	1.85 ± 0.42

The three biofilters were operated with different filtration velocities of 5.0 m/h (GAC (1)), 7.5 m/h (GAC (2)) and 10.0 m/h (GAC (3)). These filtration velocities were selected based on the standard filtration velocity values used in deep-bed water filters [4,14]. In order to maintain the stable biological activity in the biofilter, relatively low velocities were used in this study. Based on the filtration velocities, the corresponding empty bed contact time (EBCT) of GAC (1), GAC (2) and GAC (3) biofilters were 7.8 min, 5.4 min and 3.9 min, respectively. Media were packed to a depth of 65 cm from the bottom. Sampling ports were placed at 60 cm, 30 cm and 10 cm for media collection. The specifications of the media used in this study are present in Table 2.

2.3. Analytical methods

2.3.1. Solids assessment

Particulate fouling potential of seawater and effluent through biofilters was measured in terms of turbidity and UF-MFI. In UF-MFI test, UF (NTR 7410, Nitto Denko Corp., Japan) with a molecular weight cut off of 17.5 kDa and a diameter of 47.0 mm was used. The water samples were pressurized to the flat sheet UF membrane at 2.0 bar by N_2 gas. The filtrate volume by UF was then measured over the time. The methodology is explained elsewhere in more detail [5]. UF-MFI value represents the specific resistance of the cake formed and deposited on the membrane by the fouling component in the water sample during the filtration time. The UF will also retain macromolecules (>17.5 kDa) in addition to the particles and colloids.

2.3.2. Organic assessment

In this study, LC-OCD analysis was used to characterize the dissolved organic carbon (DOC) present in the seawater and effluents. The LC-OCD consist of a Toyopearl TSK HW50S column (TOSOH Bioscience

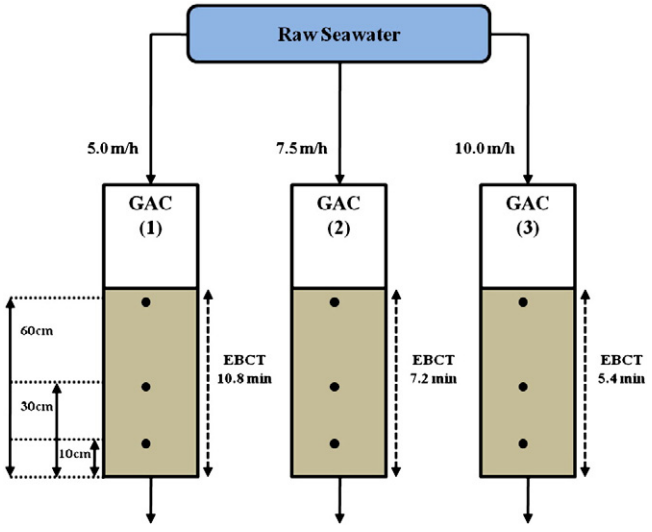

Fig. 1. Experimental set-up of GAC biofilters operated at three different filtration velocities.