Pilot-scale Evaluation and Optimization of Pre-treatment Strategies for a Seawater Reverse Osmosis Desalination System

J. Liu,***, A. Heuzard*, R. Yin*, C. Shang*, W.L. Hui**, S. Chu**, A. Mok***, T. Lau***, Y. Kwok****

**Department of Civil and Environmental Engineering, the Hong Kong University of Science and Technology (HKUST), Hong Kong Special Administrative Region, the People's Republic of China*

Email: jliubj@connect.ust.hk; agheuzard@connect.ust.hk; ceryin@ust.hk; cechii@ust.hk

***Water Supplies Department, the Government of the Hong Kong Special Administrative Region of the People's Republic of China*

Email: wl_hui@wsd.gov.hk; yf_chu@wsd.gov.hk

****Binnies Hong Kong Limited, Hong Kong Special Administrative Region, the People's Republic of China*

Email: are25@bv13wsd17.com.hk; sre4@bv13wsd17.com.hk; LauW@binnies.com; KwokY@binnies.com;

Introduction

In response to the growing water demand and climate change, Hong Kong has formulated its water management strategies. Desalination using reverse osmosis (RO) technology has emerged as a viable solution to diversify water supplies. The Water Supplies Department (WSD) of the Government of the Hong Kong Special Administrative Region (HKSARG) of the People's Republic of China is constructing a seawater desalination plant (hereafter referred to the Plant) with a daily capacity of 135,000 m^3, meeting 5% of the city's freshwater demand. The plant's operation may face challenges like high level of total suspended solids (TSS) in the intake during typhoons and membrane fouling owing to algal blooms.

To prevent this, a pre-treatment unit is included in the Plant, processes including band screening, shock chlorination, coagulation, flocculation, dissolved air flotation (DAF) combined with dual media filtration, and cartridge filtration. This study aimed to 1) examine the effect of $FeCl_3$ dosing rates on the treated water quality and decide the optimal $FeCl_3$ dosing ranges during the daily routine operation and worst-case scenarios; and 2) evaluate the operation settings of the pilot pre-treatment unit to meet the targets on the water quality of the RO feed.

Methods

Source seawater of this study was collected from Hong Kong University of Science and Technology (22°20′16″N, 114°16′10″E). The water quality of the source seawater used is comparable to that in the intake of the Plant with a deviation of ±5%.

Jar tests were conducted using the integrated Platypus Jar Tester with DAF and a dual media filter consisting of sand (8 cm-bottom) and anthracite (8 cm-top) layers. The filtrates were collected and subjected to analyses of turbidity. Typhoon and algal bloom scenarios were respectively simulated by spiking seawater with TSS of up to 40 mg/L and using seawater containing >10^5 cells/mL of a marine diatom that was one of the culprits of bloom in Hong Kong[1], *Thalassiosira weissflogii*.

A pre-treatment unit in the pilot RO system was designed, installed and fine-tuned to simulate the pre-treatment processes in the Plant (Figure 1).

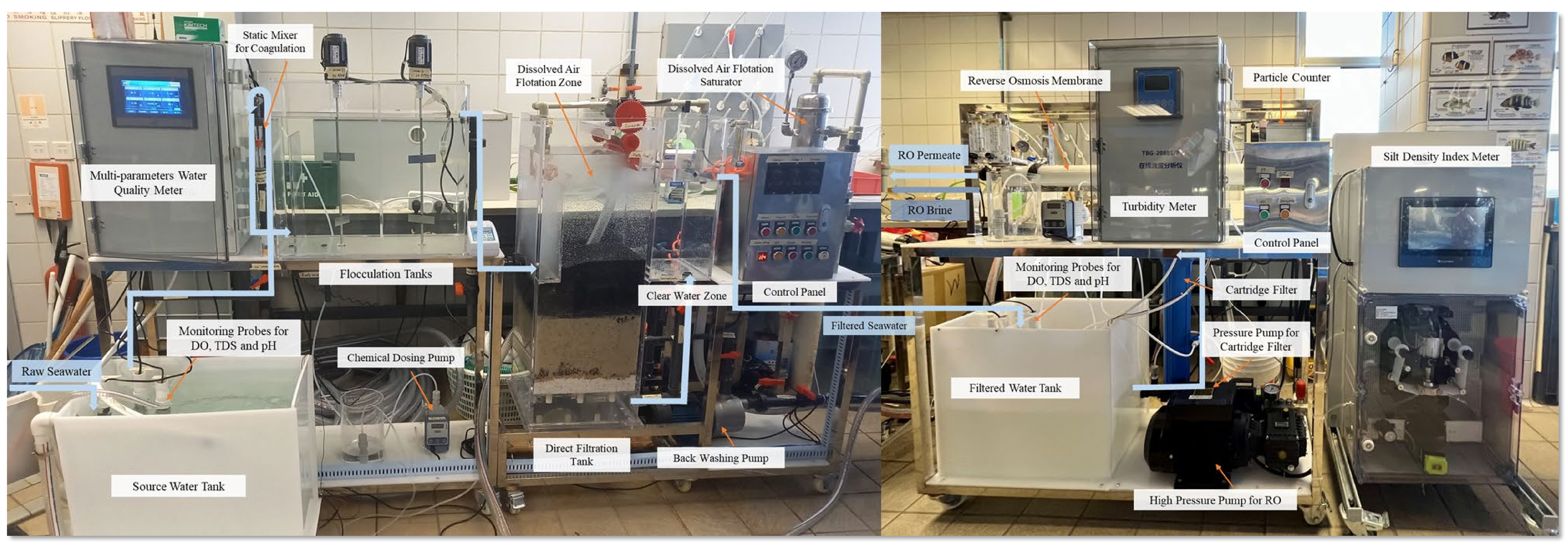

Figure 1 Pilot seawater RO desalination system.

Results and Discussion

From Figure 2a, despite different initial source seawater turbidity (0.18–3.25 NTU) and $FeCl_3$ dosages (0.25–5.5 mg/L), the filtrate turbidity were from 0.05 to 0.26 NTU, which already complied with the pre-treatment unit performance requirement even without cartridge filtration (i.e., < 0.30 NTU). From Figure 2b, with increasing initial turbidity, the total turbidity removal rates increased. With initial turbidity lower than 0.30 NTU, the removal rates varied from 40.5%–72.4%, and a lower $FeCl_3$ dosage (< 1.5 mg/L) led to a higher removal rate. When the initial turbidity was between 0.30 to 1.00 NTU, the removal rates varied from 64.5%–94.0%, and a medium $FeCl_3$ dosage (1.5–3 mg/L) gave a high total turbidity removal rate. On the other hand, all $FeCl_3$ dosages tested resulted in comparable removal rates (89.5%–98.1%) when the initial turbidity was higher than 1.00 NTU.

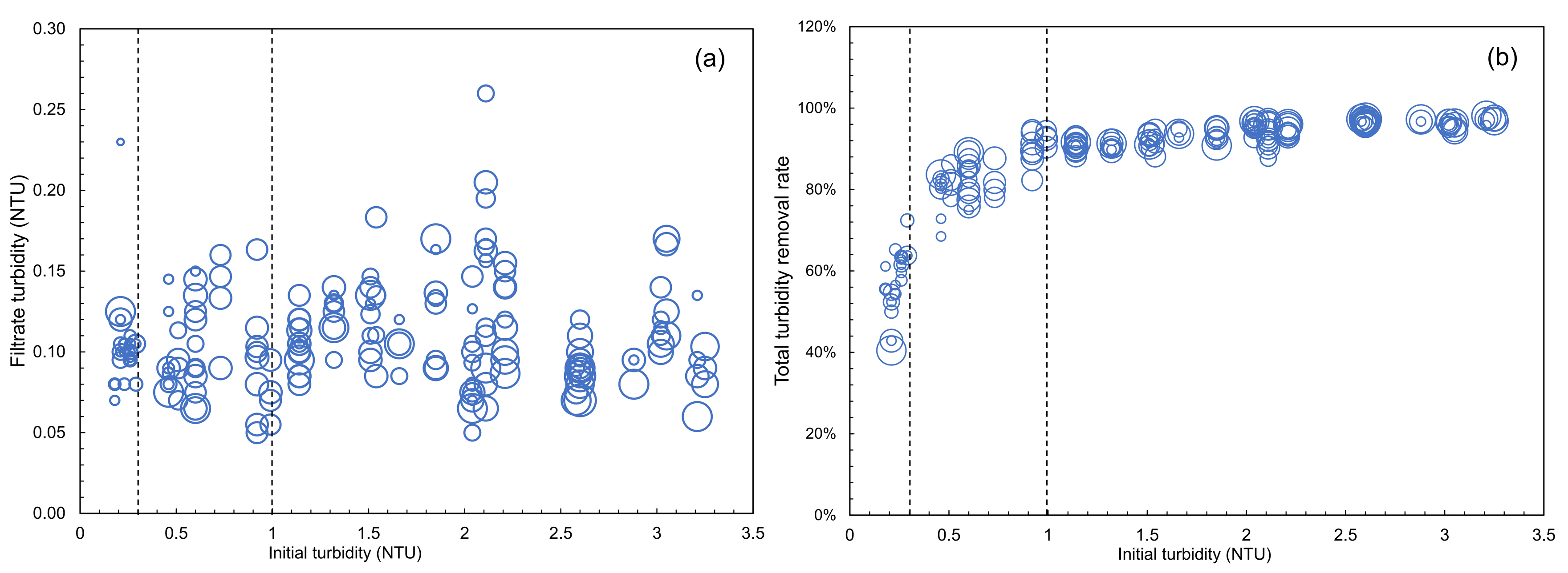

Figure 2 (a) Filtrate turbidity after dual media filtration; and (b) total turbidity removal rate in jar testing. Note that the sizes of bubbles reflect the $FeCl_3$ dosages. The bigger the bubbles, the higher the $FeCl_3$ dosages ($FeCl_3$ dosages = 0.25–5.5 mg/L).

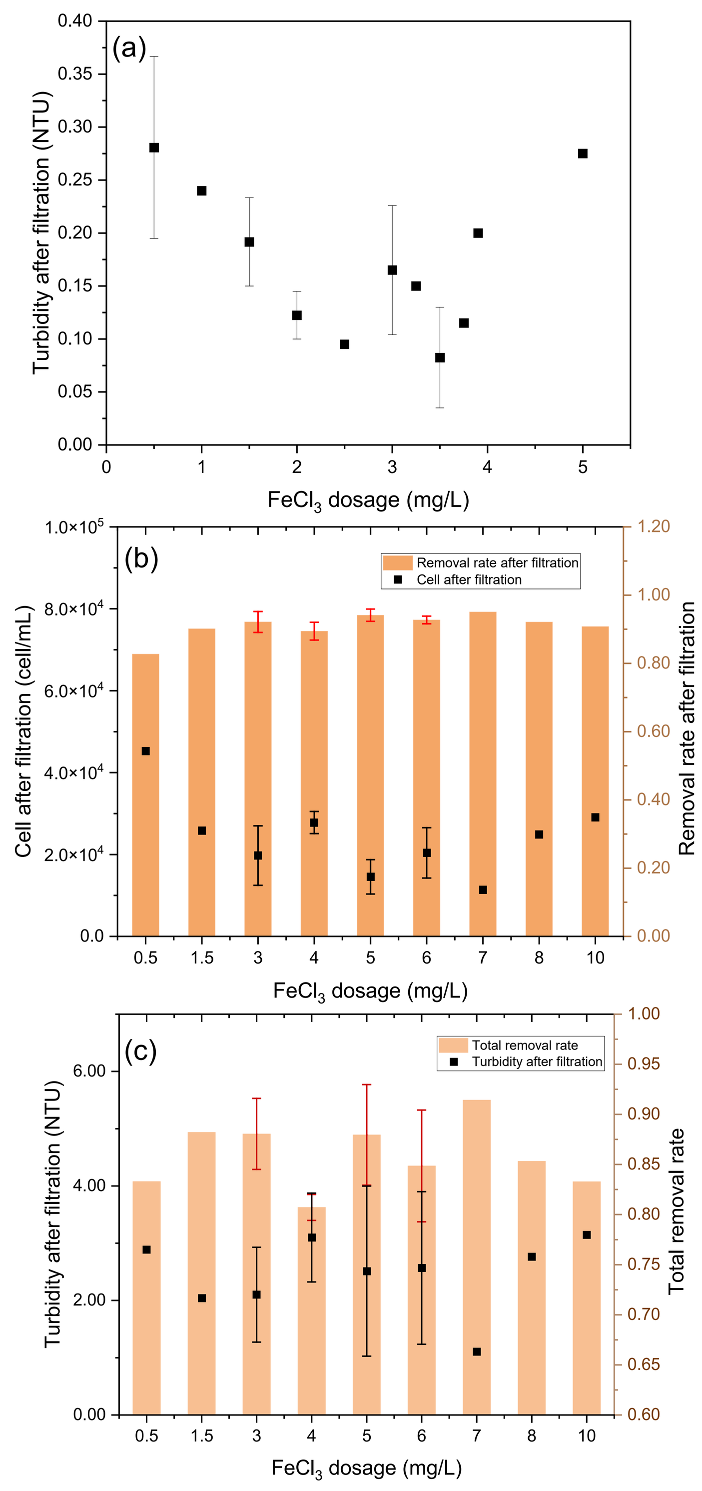

Figure 3 (a) Turbidity after filtration of SST; (b) residual algal cell counts after filtration of SSA; and (c) Turbidity after filtration of SSA.

The average initial turbidity of the simulated seawater during typhoon (SST) in this study was 9.31 NTU (equivalent to 40 mg/L TSS). From Figure 3a, most of the filtrate turbidity were below 0.30 NTU. The filtrate turbidity decreased with $FeCl_3$ dosages to the levels of 0.10 NTU, after which the turbidity increased. The optimal $FeCl_3$ dosage was 2–3.5 mg/L and the corresponding turbidity removal rate was 99.1%. In another worst-case scenario, the simulated seawater during algal bloom (SSA) contained 2.24×10^5 to 3.16×10^5 cells/mL of algal cells, resulting in an average initial turbidity of 17.44 NTU. From Figure 3b, the removal rates of algal cells after filtration were between 82.7% to 95.1%, and the residual algal cell counts varied from 1.14×10^4 to 4.53×10^4 cells/mL. Besides, from Figure 3c, the total removal rates of turbidity were in the range of 80.7% to 91.4%, while the treated water turbidity were between 1.11 to 3.15 NTU, which are far beyond the requirements. The results suggested that although the pre-treatment reduced the algal cell counts and turbidity significantly, it still posed pose heavy particle loading and fouling potential to the following cartridge filter.

During the operating period of the pilot system from June to August 2023, the initial turbidity of source seawater varied from 0.27 to 15.12 NTU. After dual media filtration, most treated seawater turbidity were reduced to < 0.30 NTU and it would be further polished by the cartridge filter. The silt density index (SDI), a key fouling potential indicator, exceeded 6.67 in source seawater sample and in over 80% of samples after dual media filtration. From Figure 4, the SDI of filtrate from 1-μm filter varied from 3.10 to 5.09, which was approximately 30% lower than that from 5-μm filter (4.20 to >6.67). After each replacement, the SDI reached a peak, then decreased gradually over time and stabilized thereafter, indicating the pores of the filter were blocked by particles during the initial lag time, effectively reducing the filter pore size and hence increasing the removal of particles in the submicron range. Since the RO feed water require SDI < 5 for 100% of the time and < 4 for 95% of the time, only filtrate from 1-μm filter after stabilization could fulfil the requirement in the data recording period.

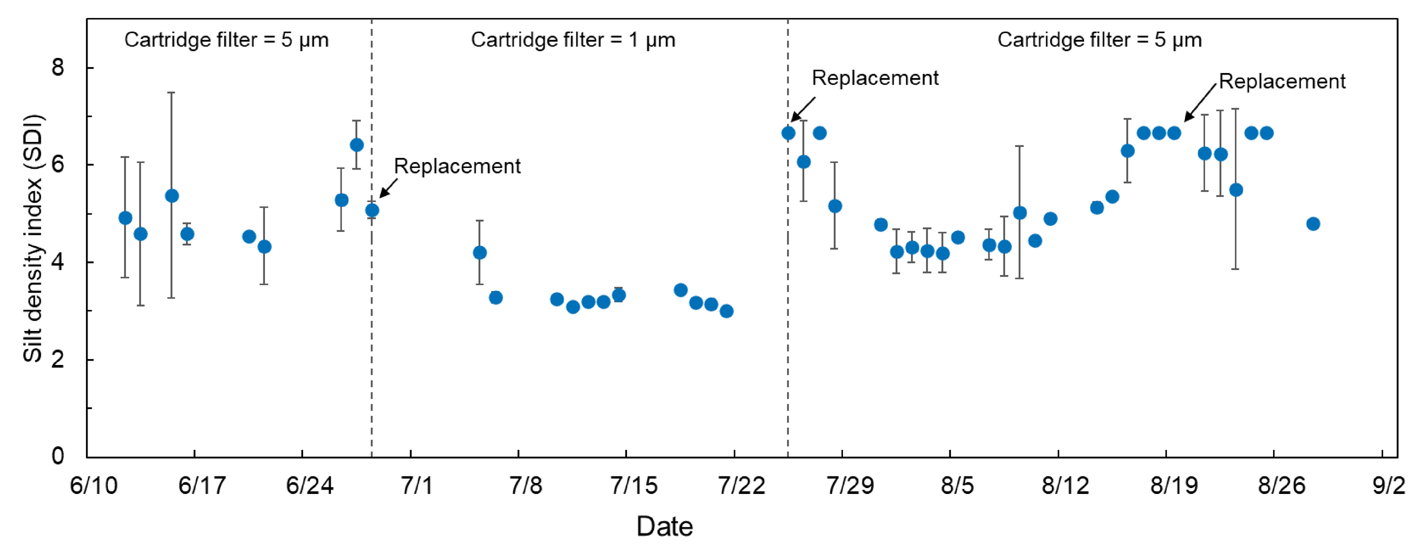

Figure 4 SDI of filtrate from cartridge filter. Note that the maximum detection limit of SDI is 6.67. Data recording period: 12 June to 28 August 2023.

Conclusions

During daily routine operation, different $FeCl_3$ dosages (0.25–5.5 mg/L) can be dosed for different initial source seawater turbidity (0.18–3.25 NTU) to have an optimal performance. Under the simulated typhoon conditions seawater with high turbidity (9 NTU), most of the filtrate turbidity complied with the requirements and a $FeCl_3$ dosage of 2–3.5 mg/L was the optimal condition out of the testing dosage range. However, in the presence of algal bloom, neither the algal cells nor the seawater turbidity was sufficiently removed, which can pose fouling potential to the following cartridge filters as well as the RO membranes. In the pilot system, although filtrate turbidity after dual media filtration fulfilled the pre-treatment requirements despite high initial turbidity, the SDI of that failed to meet the RO feed water target. Cartridge filters of 1 μm and 5 μm contributed significantly to the reduction of the fouling potential by removing particles in the submicron range. The pilot system will be kept testing, providing data and optimising the operating settings for the Plant.

REFERENCE

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Water Supplies Department