COMBINING PAC AND HAOPs IN A MICROGRANULAR ADSORPTIVE FILTRATION PROCESS

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Abstract

Two pretreatment processes for NOM removal and fouling control of a low-pressure membrane were investigated – conventional batch adsorption, and microgranular adsorptive filtration (µGAF). In the latter process, feed water is passed through a thin layer of adsorbent pre-deposited on a support surface. Heated aluminum oxide particles (HAOPs) and powdered activated carbon (PAC), either alone or mixed, were used as adsorbents. In both processes, the mixed adsorbents enhanced NOM removal compared to an equal total mass of either adsorbent alone. In addition, µGAF outperformed batch adsorption with respect to both NOM removal and fouling mitigation. However, in conventional treatment, increasing the portion of the PAC in the adsorbent mixture improved the performance of the downstream membrane unit, while in the µGAF process, performance of the downstream membrane unit was improved by increasing the portion of the HAOPs in the adsorbent mixture.

Keywords: Membrane fouling; Natural organic matter; Pretreatment; HAOPs; PAC

Introduction

Despite the great potential of membranes as a reliable alternative to conventional drinking water treatment, their application is hindered by membrane fouling. The main membrane foulant in treatment of surface water is typically natural organic matter (NOM). In addition, NOM adds taste, odor and color to the water; increases the required doses of coagulants, adsorbents and disinfectants; enhances biological growth in water distribution networks; and reacts with oxidants to generate disinfection by-products (DBPs). NOM levels in Europe and North America are gradually increasing due to global climate change [Skjelkvaale (2003)], and stricter regulations are being enforced on drinking water treatment. Therefore, efficient and economical methods that remove NOM and mitigate membrane fouling are needed. This research investigated combinations of heated aluminum oxide particles (HAOPs) and powdered activated carbon (PAC) to enhance the performance of microgranular adsorptive filtration (µGAF), a process that has been reported to remove NOM and reduce membrane fouling. In µGAF, a layer of adsorbent is pre-deposited onto a support surface, and the raw water is passed through the adsorbent before being fed to a membrane.
Materials and Methods

Water used in this research was collected from Lake Union (LU), located in Seattle, WA. Water samples were stored at 4°C and were brought to room temperature prior to use. The water was at pH 7.4±0.3 and contained 2.0-2.3 mg/L DOC. The UV$_{254}$ of the water was 0.054–0.060 cm$^{-1}$, yielding a specific UV absorbance at 254 nm (SUVA$_{254}$) of 2.6-2.7 m$^{-1}$(mg/L)$^{-1}$. The pH of the water samples was adjusted to 7±0.05 with 1 M HCl, and the ionic strength was adjusted by adding 0.5 mM NaHCO$_3$ and 0.5 mM NaCl to all the water samples. With the added buffering capacity, the pH remained within ±0.2 throughout the experiments.

HAOPs were synthesized by neutralizing aluminum sulfate (Al$_2$(SO$_4$)$_3$·18 H$_2$O) solution with NaOH (4 M) to pH 7.0 to generate a suspension containing 10 g Al/L Al(OH)$_3$(s). This suspension was then oven-heated at 110ºC for 24 hours in a closed glass bottle and cooled to room temperature. HAOPs prepared in this way are reported to have a BET surface area of 116 m$^2$/g, mean volume-based diameter of 27.05 µm, and a point of zero charge at pH 7.7 [Kim et al. (2008)].

The activated carbon used in this study was Norit SA SUPER (Cabot Co. Boston, MA) with a BET surface area of 1150 m$^2$/g and a median diameter (D$_{50}$) of 15 µm. Excess water was removed by drying at 110ºC for 24 hours. Samples were then cooled to room temperature, and a 10 g/L slurry was made with Milli-Q water.

The experimental set-up consisted of a pretreatment unit followed by a membrane filtration unit. In the µGAF tests, a layer of adsorbent was deposited and supported on a paper filter (Whatman® quantitative filter paper, grade 40). LU water was passed through the layer, and the pretreated water was collected in a reservoir. In the conventional batch pretreatment tests, the desired dose of adsorbent was spiked into the solution, and the suspension was mixed for 2 hours before being filtered through paper to remove the adsorbent and collect the filtrate.

The water from each pretreatment process was fed to polyethersulfone (PES) membranes with a nominal pore size of 0.05 µm (PES, MP005, Microdyn Nadir). Each membrane was wetted, rinsed and fed deionized (DI) water for at least 2 hours prior to a filtration test. The flux to the µGAF unit was 150 LMH, and that to the membrane was 100 LMH. Control runs were conducted in which feed was filtered through the membrane without any pretreatment.

In the batch adsorption tests, the total adsorbent dose was always 20 mg/L, comprising various combinations of HAOPs and PAC. In the µGAF tests, the total adsorbent surface loading was 40 g/m$^2$, which yielded an effective adsorbent dose of 20 mg/L at the end of the test. The pressure required to maintain the desired flux was monitored throughout each test, and the quality of the water treated by each pretreatment was analyzed based on UV$_{254}$ and dissolved organic carbon (DOC) of the treated water.
Results and Discussion

Pretreatment by Conventional Batch Adsorption
The removal of DOC and UV$_{254}$ in the conventional batch adsorption tests are shown in Figure 1a, and fouling of the membrane, quantified by the increase in transmembrane (TMP), is shown in Figure 1b. NOM removal was maximized when a mixture of HAOPs and PAC was used, but fouling declined steadily as the contribution of PAC to the total adsorbent dose increased.

![Graph showing DOC and UV$_{254}$ removal and fouling](image-url)
Figure 1. System performance with different adsorbent mixtures in batch adsorption and membrane filtration tests. (a) Removal of DOC and UV$_{254}$; (b) Increase in TMP across the membrane.

Pretreatment by µGAF Process

The removals of DOC and UV$_{254}$ by µGAF pretreatment unit are shown in Figure 2a, and the increases in pressure loss across the µGAF unit and in TMP for the membrane unit are shown in Figures 2b and 2c, respectively. In all these tests, µGAF significantly mitigated fouling of the membrane, compared not only to the control run with no pretreatment, but also compared to the runs with conventional pretreatment. In these tests, membrane fouling control improved steadily as the contribution of HAOPs in the adsorbent layer was increased, opposite to the trend for conventional pretreatment. However, NOM removal was maximized when a mixture of adsorbents was used, as in the conventional pretreatment tests.
Pressure loss increase across the μGAF unit (psi)

Cumulative normalized volume filtered (L/m²)
Figure 2. System performance with different adsorbents or mixture of adsorbents in μGAF process. (a) Removal of DOC and UV$_{254}$; (b) Increase in pressure loss across the μGAF unit; (c) Increase in TMP across the membrane unit.

Conclusions

Contacting LU water with PAC Norit SA SUPER, HAOPs, or a combination of these adsorbents removed a substantial fraction of the NOM from LU water and also mitigated fouling of a UF membrane by the water. Both NOM removal and fouling mitigation occurred regardless of whether the pretreatment was carried out in a batch adsorption or a μGAF process, and with both processes, optimal NOM removal was achieved with a mixture of the two adsorbents (for a given total adsorbent dose). However, when pretreatment was accomplished by batch adsorption, mitigation of membrane fouling increased steadily with increasing amounts of PAC in the pretreatment step, whereas when μGAF was used, fouling mitigation increased steadily with increasing amounts of HAOPs. Overall, both NOM removal and fouling control were better with μGAF than with the conventional pretreatment process.

References