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Impact of ultrasonic pre-treatment on the microfiltration of a biologically treated municipal effluent

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A B S T R A C T

Biologically treated municipal effluent contains a wide range of organic components which play important roles in fouling filtration membranes. The effect of ultrasound (US) on feed pre-treatment for fouling mitigation in the microfiltration (MF) of an activated sludge–lagoon effluent was investigated at lab-scale. Two minutes sonication of the feed led to reduced irreversible membrane fouling, with an increase in flux recovery of 30%. However, considerable reduction in membrane permeability was observed. The coupling of US pre-treatment with Al^{3+}-based coagulation improved the permeate flux more than using coagulation alone. This was attributed to the fragmentation of the particles and altered physico-chemical properties of the effluent organic matter, particularly biopolymers, after sonication leading to enhanced coagulation and hence the formation of a cake layer with less hydraulic filtration resistance.

1. Introduction

Membrane fouling can be severe in the low pressure membrane filtration of municipal secondary effluent for wastewater reclamation due to a wide range of components present in the water being prone to fouling. Hydraulic and chemical membrane cleaning are common approaches to restore membrane performance; however, membranes exposed to repeated cleaning cycles face gradual reduction in flux recovery and degradation of membrane materials. As another means of mitigating membrane fouling, feed pre-treatment using chemical coagulants is typically applied to remove undesirable organic and particulate matter.

Various studies have been conducted using ultrasound (US) as a means of mitigating membrane fouling over the last decade; the US frequency applied was mainly in the range of 20–100 kHz, and power intensity was up to 1500 W. Cavitation and acoustic turbulence generated by US are generally regarded as the major mechanisms of detaching particles and other foulants from membrane surfaces. Kobayashi and co-workers conducted ultrasonic cleaning to restore the permeability of MF and ultrafiltration membranes fouled with dairy wastewater and concluded that US irradiation (28 kHz) increased the effectiveness of hydraulic cleaning [1]. An online US system was shown to reduce membrane fouling during the microfiltration (MF) of solutions containing natural organic matter [2].

US techniques have also been used for the dispersion of agglomerated particles in the liquid phase. Rapidly collapsing cavities generate shear forces that can break polymer chains [3,4]. For instance, polysaccharides (e.g., chitosan and starch) were degraded by US which led to a reduction in molecular weight [3]. Moreover, it was proved that the heat from cavity implosion decomposed water into hydroxyl radicals which are highly reactive toward organics [5]. Several researchers reported that US can alter the surface properties of organic molecules as well as degrade polymers by ultrasonic cavitation forces. The effect of high intensity US on the degradation of organic matter in wastewater treatment has been investigated [6]. US has also been examined as a feed pre-treatment for mitigating the fouling potential of the organic components present in a natural surface water [7]. It was found that short term sonication (60 s) diminished the flux decline for MF of the water, and membrane performance improved even more when the US treatment was followed by alum coagulation. However, there has been very little study on the application of the ultrasonic technique to municipal wastewater.

The aim of this study was to investigate the effect of US on feed pre-treatment for fouling mitigation in the MF of a biologically treated municipal effluent. In this lab-scale study, membrane performance was evaluated by measuring permeate flux, flux recovery after backwashing, and changes in water quality. Further analyses of membrane surfaces and organic composition in the solution were conducted to obtain a better insight into the effect of US on membrane performance.

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2. Materials and methods

2.1. Feed water

The treated effluent used in this study was from the Head of the Road Storage (HORS) pond at the Western Treatment Plant at Werribee, Victoria, Australia, where municipal wastewater is treated by an activated sludge–lagoon process. The samples were stored at 4 °C to minimise change in their properties.

2.2. Ultrasonic pre-treatment

Two litres of the wastewater was warmed to room temperature (20 ± 1 °C) before each test and treated in an ultrasonic bath (Sonica ETH3200, Soltec) at a frequency of 45 kHz. The power intensity was measured as 107 W output by calorimetry [8]. The temperature increased only slightly, up to 23 °C after 300 s sonication, hence the influence of temperature change on feed properties was negligible.

2.3. Coagulation methods

Two Al^{3+}-based coagulants, (poly) aluminium chlorohydrate (ACH, Megapac 23, Omega Chemicals) and aluminium sulphate hydrate (alum), were selected as they are commonly used in water treatment. The jar tests were conducted with a Phipps & Bird PB-700 JarTester and involved the addition of coagulant (5 mg as Al^{3+}) to 1 L of effluent. A rapid mix at 200 rpm for 1 min was followed by 20 min at 30 rpm, after which the coagulated water was filtered without settling.

2.4. Membrane filtration

The filtration unit comprised a feed tank and a cell with a membrane area of 13.4 cm^2 (Amicon 8050, Millipore) which was pressurised by nitrogen gas at 70 kPa and stirred at 430 rpm. For the filtration of coagulated effluent, the stirring speed was set at 100 rpm to avoid breakage of flocs. The permeate volume was monitored every minute using an electronic balance and logged by a computer.

MF membranes (hydrophilic polyvinylidene fluoride, VVLP Durapore) of 0.1 µm pore size were soaked in Milli-Q water for 2 h, after which approximately 300 mL of Milli-Q water was passed through the membrane. The pure water flux (J_0) was determined after the permeate flux stabilised. Membranes were selected for use when J_0 was in the range of 1770 ± 60 L m^{-2} h^{-1}. Filtration was stopped when the permeate volume reached 500 mL. Each filtration test was conducted in duplicate to ensure the reproducibility of the results (less than 3% variation was observed) and average values are reported.

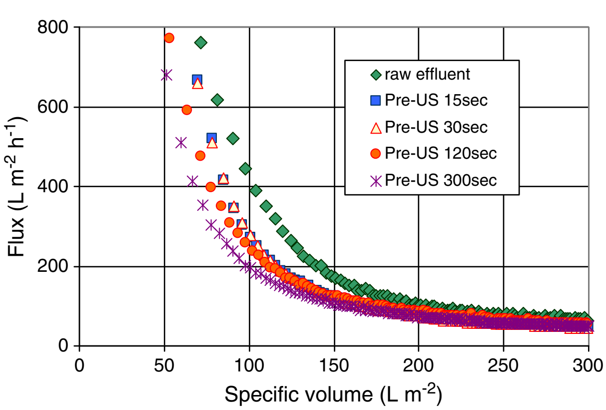

Fig. 1. Comparison of permeate flux for MF of raw and US pre-treated effluent.

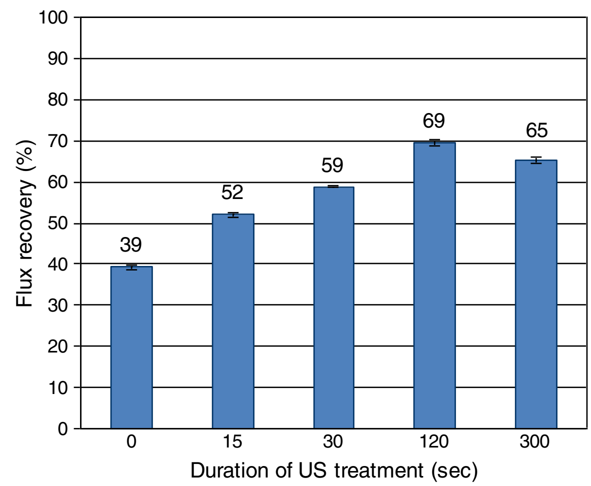

Fig. 2. Flux recovery after backwashing of membranes fouled with raw and ultrasonically treated feed.

2.5. Membrane cleaning methods

The fouled membrane was rinsed gently with Milli-Q water to remove particles on the surface, then turned over and backwashed by passing 150 mL of Milli-Q water through it at 70 kPa and stirring speed of 430 rpm. The cleaned membrane was then returned to the initial orientation and the flux recovery, $(J_w/J_0) \times 100$, was determined after measuring the pure water flux (J_w) for the cleaned membrane. The flux recovery tests were conducted in duplicate, the observed variation was less than 3%, and average values are reported.

2.6. Analytical methods

Samples were filtered (0.45 µm, cellulose acetate) before the following analyses. Dissolved organic carbon (DOC) was measured using a TOC analyser (Sievers 5310 C Laboratory, GE). Measurements of UV absorbance at 254 nm (UV_{254}) were conducted with a UV/vis spectrophotometer (UV2, Unicam). Fluorescence excitation emission matrix (EEM) spectra were determined using a PerkinElmer Fluorescence spectrometer (LS55).

Membrane fouling was evaluated by analysing the membrane surface using attenuated total reflection–Fourier transform infrared spectroscopy (ATR–FTIR) (Spectrum 100, PerkinElmer).

3. Results and discussion

Two effluent samples collected on different dates were used for each experiment. Although these two samples showed different characteristics in terms of DOC (10.1 cf. 10.5 ppm), UV absorbance (0.164 cf. 0.245 cm^{-1}), turbidity (4.8 cf. 3.1 NTU) and MF filterability

Table 1
Characteristics of raw effluent and the effluent treated ultrasonically for various durations.

	DOC (mg L^{-1})	UV_{254} (cm^{-1})	Turbidity (NTU)
Raw	10.1	0.164	4.8
After US pre-treatment			
15 s sonication	9.9	0.160	5.2
30 s	10.1	0.162	4.6
120 s	10.7	0.170	6.1
300 s	10.5	0.167	7.0