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Precoagulation-microfiltration for wastewater reuse

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ABSTRACT

A range of coagulant chemicals and doses, up to 2 mg/L, were trialled on a microfiltration-based indirect potable reuse (IPR) pilot plant to evaluate their impact on membrane reversible and irreversible fouling. Jar tests revealed these doses to have negligible impact on organic matter removal, whilst scoping pilot trials showed them to have a positive impact on fouling rates. Initial trials carried out over a 6-h period suggested that ferric sulphate was the most promising of the coagulants tested with regards to irreversible fouling. Extended five-day trials using ferric sulphate at 0.5 mg/L were conducted at fluxes of 40–50 l/(m^2h) (LMH). Operation at 50 LMH without coagulant resulted in rapid fouling and a subsequent shortening of the chemical cleaning interval. The addition of the ferric coagulant resulted in a reduction in both reversible and irreversible fouling to those levels experienced at 40 LMH, enabling sustainable operation. The use of low levels of coagulant thus enables the pilot plant to operate at a 25% increased flux, equating to a 20% reduction in membrane area and overall savings of >0.1 p per m^3 for a seven year membrane life.

1. Introduction

A key problem encountered in the application of membrane filtration technology is fouling, which results in the loss of hydraulic performance and may reduce membrane life. Fouling can be characterised in terms of the method by which it is removed (reversible and irreversible for physical and chemical removal respectively), its chemical nature or origin (e.g. organic, inorganic, biological, etc), or its physical form (dissolved, colloidal, particulate, etc). Particulate fouling is considered to be reversible, since it is largely removed by physical cleaning. Other types of fouling may be irreversible, requiring chemical cleaning for their removal.

Much work has been aimed at elucidating fouling mechanisms to expedite its control and/or removal. Wiesner et al. (1989) concluded that particles greater than 3 μm should not contribute significantly to membrane fouling at normal operating fluxes, but that for many membrane configurations particles between 0.1 and 1 μm are more likely to. The proposed use of coagulants to aggregate foulants that would otherwise plug the membrane pores dates back many years (Mietton Peuchot and Ben Aim, 1992). Studies have subsequently been undertaken to further identify the size and nature of foulants, and the coagulant types and coagulation conditions most effective in fouling amelioration (Howe and Clark, 2006; Howe et al., 2006; Lee et al., 2007). Favourable results appear to be contingent on feed water quality, membrane characteristics (such as pore size), and membrane configuration.

Jar tests have been used to determine coagulant dose and type based on organic matter removal. Work initially by

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Edzwald and Benschoten. (1990) on surface waters revealed organic matter removal rates to be dependent on the its hydrophobicity as represented by the specific ultraviolet absorbance (SUVA), the ratio of the UV light absorbance at 254 nm to the dissolved organic content. Table 1 demonstrates how organic matter removal rates vary with SUVA and alkalinity. Where coagulant is used on those waters with a high SUVA value and low alkalinity (<30 mg/l as $CaCO_3$), high removal rates in the range 60–80% can be achieved. However, those waters with high alkalinity and low SUVA, as are likely to be encountered in the trials for this paper result in particularly low removal rates of 10–15% despite the use of coagulant (Fan et al., 2008; Pernitsky and Edzwald, 2006).

Fouling suppression, however, appears not to be contingent upon organic matter removal: work by Choi et al. (2004) and Konieczny et al., (2009) showed fouling to be suppressed at coagulant doses not significantly influencing organic matter removal. However, fouling is also affected by the plant operating and maintenance (O&M) regime, and in particular the flux or transmembrane pressure (TMP), backflush flux and frequency, and the chemical cleaning protocol. There is therefore obvious synergy between the coagulant dosing regime and the plant O&M, though few studies have focused on this synergy since many have been conducted on the bench-scale using non-backflushable flat sheet (FS) membranes (Lee et al., 2000; Schäfer et al., 2001; Shon et al., 2005). Moreover, results obtained from bench-scale studies cannot be considered representative of full-scale operation due to differences in membrane module geometry and configuration, which inherently yields differences in flux distribution and fouling rate (Carroll and Booker, 2000; Fane et al., 2002; Howe et al., 2007; Kim and DiGiano, 2006; Yeo et al., 2006).

Table 2 summarises studies of coagulation impacts on reversible and irreversible fouling of microfiltration/ultrafiltration (MF/UF) membranes at laboratory and pilot plant scale. Whereas reversible fouling pertains to fouling between backwashing, irreversible fouling relates to the rise in the TMP post-backwash. Results show the use of coagulant to enhance backwash efficiency, providing greater flux recovery or TMP reduction and so a reduction in irreversible fouling rate. Alum is the most widely used coagulant and can reduce the irreversible fouling rate of hollow fibre (HF) membranes by 75–100%. The dose used varies from 0.2 to 0.5 mg/l as Al when dosed via an aerated mixing tank to 1.3–2.5 mg/l when added inline, with no obvious correlation between dose and water quality or membrane pore size. Laboratory scale results showed much smaller reductions in the irreversible fouling rate which could be attributable to higher feedwater turbidities, differing coagulants and/or differing hydrodynamics between FS and HF membranes. Ferric chloride has given mixed results with regards to the reduction of the irreversible fouling rate. Citulski et al. (2009, 2008) found that it gave rapid and irreversible fouling rate at low doses (10–40 mg/l as Ferric Chloride), an observation corroborated by Judd and Hillis (2001) who found that at low doses the floc growth rate was insufficient to avoid pore plugging. However, at doses of 3.1 mg/l as Fe^{3+} the same authors, found that the irreversible fouling rate to be reduced by 30%, corroborating previous reports elsewhere (Fan et al., 2008). Pilot scale results indicated low doses of alum ($\leq$0.5 mg/l as Al) to increase reversible fouling rate, whereas doses of 1.3–2.5 mg/l reduce reversible fouling.

However, such papers have not considered the effect of coagulant on the relationship between turbidity and reversible fouling (Raffin et al., 2011 In progress). Citulski et al., (2008) investigated the statistical significance of turbidity on TMP stability and, contrary to that for total suspended solids, found it to be insignificant. However, little detail was provided, other than average and standard deviation turbidity values recorded during the trials (4.37 and 3.69 respectively). It is unclear from the report whether turbidity measurements used in the statistical analysis were daily spot samples or averages, such that the effect of turbidity spikes on fouling rates – known to be significant from operational practice – would have been overlooked.

This paper reports on the evaluation of a range of coagulants on permeability decline (manifested as the TMP increase at constant flux) on a pilot-scale MF plant treating secondary wastewater. The study concentrates on the use of coagulant at doses similar to those previously reported (Table 1, 0.5–2 mg/l) whereby coagulated organic matter removal is through charge neutralisation rather than sweep flocculation. Charge neutralisation has been shown to provide enhanced removal rates

Table 1 – Summary of papers on organic matter removal values.

Lead Author, Pub. Year	Water Source	Feedwater Quality					Coagulant	Dose (mg Me^{3+}/l)	% TOC Removal
		TOC (mg/l)	UV (cm^{-1})	Alkalinity (mg $CaCO_3$/l)	pH	SUVA l/(mg. m)			
Pernitsky and Edzwald, (2006)	Surface	3.3	0.05	120	7.9	1.6	$Al_2(SO_4)_3$ & PACl	1.5	10–15
Pernitsky and Edzwald, (2006)	Surface	2.8	0.04	<30	6.7	2.2	$Al_2(SO_4)_3$ & PACl	1.2	35–65
Fan et al., (2008)	2ndary effluent	9.83[a]	0.26	190	7.1	2.6	$Fe_2(SO_4)_3$, $Al_2(SO_4)_3$	2 & 5	10–15[a]
Best et al., (2001)	Surface	2.6	0.07	11	6.8	2.8[b]	$Al_2(SO_4)_3$	1	45
Pernitsky and Edzwald, (2006)	Surface	3.1	0.09	<30	7.2	3.0	$Al_2(SO_4)_3$ & PACl	1.6	60–80
Bagga et al., (2008)	Surface	5.3[a]	0.18	57	7.5	3.4	$FeCl_3$	15	18–32[a]
Walsh et al., (2009)	Surface	1.72[a]	0.08	3.6	5.8	4.5	$Al_2(SO_4)_3$	0.4–0.6	65–77[a]

a Value is DOC not TOC.
b SUVA value is an estimate based on TOC and DOC.