Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Chemical cleaning of potable water membranes: The cost benefit of optimisation

*Nicandro Porcelli, Simon Judd**

Centre for Water Science, Cranfield University, Cranfield, Bedfordshire MK43 0AL, United Kingdom

ARTICLE INFO

Article history:
Received 15 September 2009
Received in revised form
9 November 2009
Accepted 11 November 2009
Available online 26 November 2009

Keywords:
Membrane cleaning
Factorial analysis
Hollow fibre
Potable water
Cost benefit

ABSTRACT

A study of the variability in chemical cleaning factors on permeability recovery for potable water microfiltration (MF) and ultrafiltration (UF) systems has been carried out employing a cost model simulating plant fouling and cleaning regimes. The impact of a range of operating and cleaning factors on operating cost variation was computed using algorithms describing operational and cleaning factor relationships with permeability recovery data measured from bench scale tests on fibres sampled from full-scale operational plants. The model proceeded through sequencing of the cleaning and backwashing operations to generate transmembrane pressure (TMP), and so head loss, transients. A number of cleaning scenarios were considered for each plant, based on employing either a threshold TMP or fixed chemical cleaning intervals. The resulting TMP profiles were then converted to operational costs. The effect of the variability in permeability recovery on annual operating costs was calculated for each of the simulations. It was evident that significant operating cost reductions were possible from optimisation of the cleaning protocol. Cost benefit varied according to facets of plant design and operation; the innate variability in permeability recovery precluded the correlation of cleaning efficacy with fouling characteristics.

1. Introduction

Studies into cleaning sequencing and its impact on operating costs require experimental fouling data to provide head loss information. Whilst abundant fouling data is available, as well studies of the impact and/or optimisation of physical cleaning for fouling amelioration (Lodge et al., 2004; Katsoufidou et al., 2005; Smith et al., 2006; van de Ven et al., 2008), studies of chemical cleaning of membranes in the municipal water sector are much less common.

Early studies into optimisation of membrane cleaning qualitatively modelled the relationship between cleaning regime and recovery for single foulants (Bartlett et al., 1995). These studies were developed from Hermia's blocking model, where foulants form resistance layers (Belfort et al., 1994). Further studies into quantifying the effects of chemical cleanants have been used predominantly in food and industrial applications (Shorrock and Bird, 1998; Blanpain-Avet et al., 2004). Observations of cleaning effects with surrogate foulants in laboratory experiments show differences in cleaning effects and efficiencies for different solutions (Field et al., 2008). Dead end hollow fibre (HF) membrane cleaning studies on fibres from a single field source showed the impact of cleaning reagents to be dependent on foulant character (Strugholtz et al., 2005). Recently models have been developed investigating dynamic cleanant performance on membranes fouled with surface waters at high organic loads (Zondervan and Roffel, 2007). Economic simulations based on ultrafiltration (UF) have suggested that optimising the number of cleaning cycles does not reduce operating costs, and that cleaning should instead be optimised to control fouling (Lodge et al., 2004; Zondervan and Roffel, 2008).

* *Corresponding author.*
E-mail address: s.j.judd@cranfield.ac.uk (S. Judd).

0043-1354/$ – see front matter
doi:10.1016/j.watres.2009.11.020

Symbols and abbreviations

(C_{min}), C	(minimum) concentration
(P_{max}), P	(maximum) soak period (min)
(T_{min}), T	(minimum) temperature (°C)
£$_{op}$	overall operational cost (GBP)
£$_p$, £$_h$, £$_c$, £$_w$	cost of pumping, heating, chemicals, and waste (GBP)
£$_{unit}$	unit operational cost per volume produced (pence m^{-3})
Δh	head difference for a column of water (m)
μ	viscosity (kg m^{-1} s^{-1})
$a-f$	factors in two-factorial expression for permeability recovery in Eq. (2)
A_m	membrane area (m^2)
BBD	Box Behnken determination
CEB	chemically enhanced backwash/backflush
Cf_c	unit chemicals cost (GBP/tonne)
Cf_e	unit electricity cost (GBP/kWh)
Cf_w	unit waste cost (GBP/kWh)
CIP	clean in place
CT	capillary tubes
C_v	specific heat capacity (kJ kg^{-1} K^{-1})
g	gravitational constant (9.81 m s^{-2})
GAC	granular activated carbon
HF	hollow fibres
J	flux (L m^{-2} h^{-1})
K_f, K_i	final, initial membrane permeability from cleaning test (L m^{-2} h^{-1} bar^{-1})
K_v	virgin membrane permeability (L m^{-2} h^{-1} bar^{-1})
M	factor in two-factorial expression for permeability recovery (Eq. (2))
MF	microfiltration
N_b	number of backflushes per year
N_c	number of chemical cleans per year
PACL	poly aluminium chloride
PES	polyethersulphone
PP	polypropylene
PP	polypropylene
PVDF	polyvinylidene difluoride
Q_b	backwash flow rate (L s^{-1})
Q_m	filtration flow rate (L s^{-1})
r	ratio of chemical cleanant volume to membrane area
R_M, R_f	membrane, fouling resistance (m^{-1})
R_v	percentage permeability recovery from cleaning
$R_{v,max}$	optimal cleaning recovery (%)
sHF	submerged hollow fibres
T	average feed temperature (°C)
t_b	period between backflushes, i.e. backflush frequency (min)
t_{bb}	backflush duration (s)
t_c	period between chemical cleans, i.e. chemical cleaning frequency (days)
t_{cc}	clean period (min)
UF	ultrafiltration
V_m, V_b, V_c	annual volumes: design throughput, backwashing, cleaning (m^3)
V_p	net production of permeate per annum (m^3)
X_a, X_b, X_c	proportion of fouling removed by backwashing, chemical cleaning and unremoved in Eq. (4) (m min^{-1})
α	specific cake resistance (m kg^{-1})
ΔP or TMP	transmembrane pressure (m H_2O, bar g or kPa)
ΔT	difference between ambient temperature and reagent temperature (°C)
η	conversion efficiency (%)
ρ	density (kg m^{-3})

Factorial analysis using analysis of variance has been shown to identify and optimise cleaning with proprietary reagents, specifically on spiral wound ultrafiltration and reverse osmosis membranes fouled from wastewater recovery duties (Chen et al., 2003). Recent chemical cleaning optimisation studies based on hollow fibre UF and MF (microfiltration) membranes sampled from full scale potable water treatment plants have quantified optimum permeability recovery from chemical cleaning of hollow fibre (HF) and capillary tube (CT), respectively representing shell-side to lumen-side and lumen-side to shell-side flow, submerged and pumped membranes (Porcelli et al., 2009; Porcelli and Judd, in press). The method for these latter studies was based on three factorial analyses using a response surface methodology, Box Behnken Determination (BBD), and has yielded algorithms quantifying the variation in permeability recovery from cleaning as a function of the key cleaning parameters of concentration (C), temperature (T) and soak period (P). The experimental method (Porcelli et al., 2009) has allowed optimum values of C, P and T to be identified for membranes pertaining to a range of plants, cleaning protocols, operating conditions and feed qualities (Porcelli and Judd, in press).

In the following paper the results from a cost model based on the simplest representation of fouling, as resistances in series (Belfort et al., 1994; Zondervan et al., 2008), are presented based on previously published data (Porcelli and Judd, in press). The model has been applied to four full-scale, established MF/UF potable plants selected to provide a range of membrane material types and configurations, water sources, pre-treatment, fouling conditions and corresponding operation and maintenance conditions, with the latter particularly relating to the chemical cleaning regimes.

2. Methodology

2.1. *Sampled membrane plants*

Cost models for a number of cleaning operational scenarios were built from cleaning factor relationships generated from permeability recovery data from laboratory cleaning optimisation tests (Porcelli et al., 2009; Porcelli and Judd, in press). Fig. 1 shows the information flows to a transient headloss (ΔP) or Trans Membrane Pressure (TMP) model built from site and