Wastewater reuse for irrigation by coagulation and ultrafiltration

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Abstract

This study presents the application of coagulation and ultrafiltration as a combined treatment of rendering plant wastewater. The coagulation was optimized in a wide range of coagulant ($FeCl_3$) dosage (10-80 mg L^{-1}) and pH (4.5-7.5) according to the response surface methodology (RSM) to achieve a minimal turbidity and total carbon with a pH close to 7. The coagulation at optimal conditions was used as the pretreatment to ultrafiltration. The ultrafiltration was performed at 5 bar with 6 commercially available membranes (GK, PT, GM, PU, PW, and MW) that have a wide range of molecular weight cut-off (3-50 kDa). The main water parameters were measured after each treatment step (biological treatment, coagulation, and ultrafiltration) as well as the flux decline during ultrafiltration. The parameters were compared to the regulations and guidelines regarding water reuse for irrigation. After the ultrafiltration, the membranes were washed with an alkaline cleaning agent (Nalco PC 99) for recovering membrane flux. According to the obtained values of measured parameters and flux decline, the best ultrafiltration membrane for wastewater reuse was selected.

Keywords: wastewater, water reuse, irrigation, coagulation, ultrafiltration

1. Introduction

Wastewater reuse for irrigation has gained interest in the Mediterranean region as this region is subjected to an increase in drought frequency [Spinoni, *et al*. 2014] while tourism and irrigation, as economically important activity, have seasonal trends that do not coincide with the trends of water availability [Correia 1999]. Industries that are often placed near rural areas and have high water consumption, such as rendering plant, can be a reliable water source for agriculture, releasing the stress on water bodies and water supply systems.

Rendering plant consume large amount of water during the treatment of animal byproducts from local farms, slaughterhouses, etc. Their wastewater is loaded with organic matter (proteins, fats, carbohydrates) as well as increased chemical oxygen demand (COD), nitrogen, turbidity, and content of salts [Sindt 2006]. Thus, it must be treated prior to discharge to the communal wastewater treatment system. Typical treatments include sequential batch reactors (SBR) with biological treatment. Ultrafiltration (UF) could be used to achieve water quality suitable for the irrigation of local farms. The main issue with the application of UF is membrane fouling, which can be reduced by pretreating the secondary effluent (SE) with sand filtration (SF) [Zheng, *et al*. 2010], coagulation [Li, *et al*. 2010, Haberkamp, *et al*. 2007], adsorption [Haberkamp, Ruhl, Ernst and Jekel 2007, Gur-Reznik, *et al*. 2008], etc.

This paper presents the implementation of enhanced coagulation with ferric(III) chloride ($FeCl_3$) and UF for the treatment of the SE after biological treatment in an SBR. Coagulation was optimized according to response surface methodology (RSM) for the concentration of coagulant and pH. Six UF membranes were used for the treatment of the effluent obtained after enhanced coagulation at optimal conditions. The main water parameters were compared to water regulations from US-EPA [EPA 2012], Greece [A. Andreadakis, *et al*. 2003, Paranychianakis, *et al*. 2015], and Spain [Ortega and Iglesias 2009] to evaluate its suitability for reuse.

2. Material and methods

2.1 Secondary effluent

The rendering plant wastewater (RPW) was treated in a SBR as described in a previous publication [Racar, *et al*. 2017]. Briefly, the RPW was subjected to biological treatment in a SBR (2700 m^3) with three consecutive cycles of aeration (1.5 h) and stirring (0.5 h), followed by 1.5 h of precipitation, and 0.5 h for discharge. A sample (100 L) of SE was taken and used within two days.

2.2 Coagulation jar test and sand filtration

Coagulation was conducted with ferric(III) chloride, 40 w/v% $FeCl_3$ solution (Brenntag, Germany). The process was optimized for pH (4.50, 5.5, and 7.52) and content of coagulant (10, 25, 40, 55, 70, and 85 mg Fe^{3+} L^{-1}) to minimize the turbidity and total carbon (TC).

Jar testing was performed in a laboratory set-up with 6 pedal stirrers. Samples of SE with adjusted pH were fed into 1 L beakers. The jar test started after adding a defined volume of $FeCl_3$ solution while stirring at 220 rpm for 3 min to disperse the coagulant, followed by 20 min of slow stirring at 30 rpm, and 30 min of precipitation. Samples

(200 mL) were taken, analyzed, and when it was needed, they were filtered with 0.45 µm cellulose acetate filters.

The optimal conditions were used to obtain 10 L of effluent, which was filtrated through a column (55 cm high with a diameter of 5.5 cm) filled with sand (the particle radii ranged from 0.18 to 1.85 mm) to remove the residual flocs.

2.3 Ultrafiltration

Ultrafiltration was performed with six membranes: GK, PT, GM, PU, PW, and MW (GE, USA) at 5 bar in a laboratory set-up with six parallel filtration cells as described in a previous publication [Dolar, *et al*. 2011]. The membrane characteristics are presented in Table 1. The membranes were washed with demineralized water (20 L) to remove the conserving agent and stabilized for 2 h at working pressure (5 bar). Ultrafiltration was carried out in batch circulation mode, i.e. permeate and retentate were returned into the feed solution.

2.4 Water analysis

The TC, IC, and DOC were determinate on Carbon Analyzer Shimadzu TOC-V_{WS} (Japan) after filtering the sample with a 0.45 µm filter. Turbidity was measured with WTW Turb 430 (Germany) turbidimeter, conductivity with Schott Lab 960 (Germany), COD and Fe^{3+} with Hach DR 100 (USA) colorimeter, and pH with Schott pH-meter CG 842 (Germany). Anions (F^-, Cl^-, NO_2^-, NO_3^-, Br^-, PO_4^{3-}, SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+, NH_4^+, K^+) were determinate on DIONEX ICS – 3000 (Thermo Fisher Scientific, USA) ion chromatograph.

Table 1. The molecular weight cut-off (MWCO), contact angle of water (θ), and measured pure water flux (J_w) of tested membranes.

	MWCO, kDa	θ, °	J_w, L m^{-2} h^{-1}
GK	3	65.5±1.1	67.52
PT	5	38.1±1.2	225.63
GM	8	71.9±3.3	141.59
PU	10	41.9±6.5	529.32
PW	20	33.1±5.2	656.38
MW	50	14.8±0.6	159.25

3. Results and discussion

3.1 Coagulation

Fig. 1 shows the response surface for TC and turbidity. The models that describe the response are significant (R^2 for TC is 0.93 and for turbidity is 0.87). The optimization of process parameters (pH and content of coagulant) was conducted to achieve a minimum turbidity and TC with a minimum concentration of coagulant at a pH close to neutral. The optimal conditions were determinate with Design Expert 7 and correspond to the pH of 5.56 and 10 mg L^{-1} of Fe^{3+} with predicted responses of 3.43 NTU and 22.99 mg L^{-1} of TC. Optimal conditions, when applied, removed the TC similarly to the predicted value (22.14 mg L^{-1}), while the turbidity was even lower than expected (0.52 NTU) (Table 2).

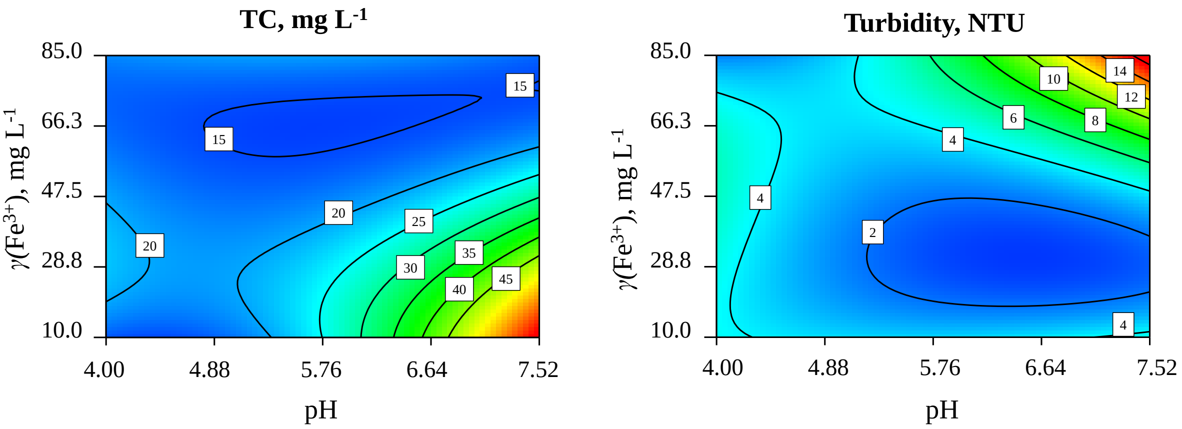

Fig. 1. Response surface of TC and turbidity for the optimization of coagulation parameters: content of coagulant ($\gamma(Fe^{3+})$) and pH.

3.2 Ultrafiltration

The applied membranes showed similar separation efficiency as the parameters of the resulting permeate were similar (Table 2). The main difference among membranes was their flux. PW and PU membranes have the highest flux, but also they flux decline was high. Thus, there were two options when choosing the optimal membrane. One option was the membrane with the highest flux, i.e. PW, which had a substantial flux recovery after the membrane cleaning. The second option was to use PT membrane as it did not exhibit a flux decline, i.e. no fouling occurred.

The unexpected high flux recovery for MW membrane (Fig. 2) can be explained by the decompression of the membrane. As MW has a noticeable flux decline during the recompression and stabilization phase. During the cleaning the solution of PC99 was not applied with pressure, and during that phase the membrane decompressed, and its permeability increased.

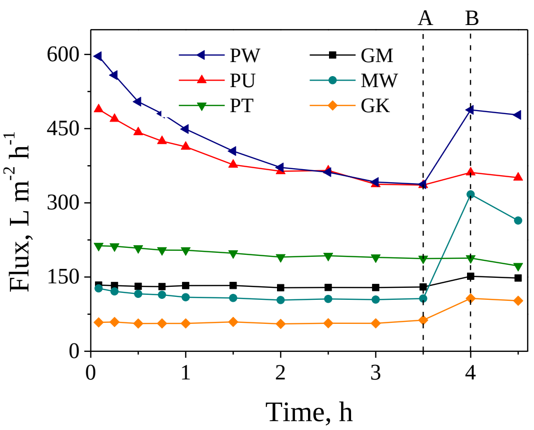

Fig. 2. Flux decline during UF and flux recovery after membrane cleaning with demineralized water (A) and PC 99 (B).

Table 2. Water parameters measured after each stage of wastewater treatment and the limits according to US-EPA[EPA 2012], Greek [A. Andreadakis, E. Gavalaki, D. Mamais and A. Tzimas 2003, Paranychianakis, Salgot, Snyder and Angelakis 2015], and Spanish [Ortega and Iglesias 2009] regulations.

	SE	SE-C	SE-C-SF	GK	PT	GM	PU	PW	MW	US-EPA	Greece	Spain
TC, mg L^{-1}	88.73	22.17	10.22	3.004	3.165	3.117	3.662	3.377	3.545	-	-	-
IC, mg L^{-1}	55.63	17.71	7.895	1.508	1.864	1.586	2.061	2.191	1.802	-	-	-
DOC, mg L^{-1}	33.10	4.46	2.325	1.496	1.301	1.531	1.601	1.186	1.743	-	-	-
Turbidity, NTU	13.92	0.52	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2	- (2)	10
pH	7.42	4.94	5.25	6.33	6.1	6.14	5.99	5.99	6.11	6,5 – 8,4	-	-
***κ*, µS cm^{-1}**	373	642	635	632	630	632	632	634	627	700 (3000)	-	-
COD, mg L^{-1}	19.3	4.7	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-	10(25)*	10*
Na^+, mg L^{-1}	13.6	11.5	11.5	11.3	11.3	11.3	11.3	11.3	11.1	69 (207)	-	-
NH_4^+, mg L^{-1}	2.0	1.8	1.8	1.7	1.8	1.7	1.8	1.7	1.7	75	-	-
K^+, mg L^{-1}	4.1	3.5	3.3	3.3	3.3	3.1	3.3	3.3	3.2	-	-	-
Mg^{2+}, mg L^{-1}	19.0	19.3	19.2	19.4	19.3	19.0	19.2	19.2	19.1	50	-	-
Ca^{2+}, mg L^{-1}	73.9	72.1	72.0	74.8	75.2	74.0	75.1	75.0	73.9	100	-	-
Fe^{3+}, mg L^{-1}	0.121	0.753	0.071	0.000	0.016	0.016	0.016	0.014	0.021	1	3	-
Cl^-, mg L^{-1}	200.7	238.9	237.9	236.7	234.9	235.5	237.1	237.0	234.9	142 (355)	-	-
NO_2^-, mg L^{-1}	11.8	0.8	0.9	0.9	0.5	0.9	1.2	0.9	0.5	-	-	-
NO_3^-, mg L^{-1}	45.9	4.4	4.7	4.8	4.8	4.1	4.7	4.4	4.8	5 (30)	-	-
PO_4^{3-}, mg L^{-1}	22.4	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	5	-	-
SO_4^{2-}, mg L^{-1}	289.5	25.7	25.0	23.4	21.7	23.5	25.3	25.1	21.7	10	-	-

*biological oxygen demand (BOD_5)

3.3 Water reuse for irrigation

Coagulation resulted in an effluent that can be reused in Greece and Spain, but as $FeCl_3$ is used there is a possibility of overdose which would exceed the limits for Fe^{3+} concentration. Thus, by adding UF most of the iron is removed as the residual iron is mostly in colloidal form (the iron not removed during the sedimentation phase). The final treatment with optimized coagulation, SF, and UF resulted in permeates that can be reused according to the regulations in Greece and Spain, but a few parameters exceed the limits of US-EPA: pH and content of Cl^- and SO_4^{2-} ions. The pH can be corrected with the addition of NaOH, as Na^+ is below the limits while the concentration of Cl^- and SO_4^{2-} can be lowered by mixing the permeate streams with fresh water.

4. Conclusion

Enhanced coagulation was optimized for pH and coagulant ($FeCl_3$). The effluent after coagulation at optimal conditions resulted in a low fouling for 4 (PT, GM, MW and GK) of the 6 tested membranes. Permeates of all tested membranes were adequate for reuse for irrigation.

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