

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 (TC) 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.

MATERIALS AND METHODS

Secondary effluent

The rendering plant wastewater (RPW) was treated in a SBR. The RPW was subjected to biological treatment in a SBR (2700 m^3) with:

- three consecutive cycles aeration (1.5 h) and stirring (0.5 h),
- 1.5 h of precipitation, and
- 0.5 h for discharge.

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) close to neutral,
- minimal content of coagulant (10, 25, 40, 55, 70, and 85 $\text{mg Fe}^{3+} \text{L}^{-1}$)
- minimal residual turbidity and total carbon (TC).

Jar testing was performed in 1 L beakers on a laboratory set-up with 6 pedal stirrers.

Jar test:

- addition of FeCl_3 solution while stirring at 220 rpm for 3 min,
- 20 min of slow stirring at 30 rpm, and
- 30 min of precipitation.

The optimal conditions were used to obtain 10 L of effluent, which was filtrated through a sand filter to remove the residual flocs.

Ultrafiltration

Ultrafiltration was performed with six membranes at 5 bar in a laboratory set-up with six parallel filtration cells. The membrane (characteristics are presented in Table 1) were washed and stabilized for 2 h at working pressure (5 bar). Ultrafiltration was carried out in batch circulation mode.

Table 1: Membrane characteristics.

	MWCO, kDa	θ_s , °	J_w , $\text{L m}^{-2} \text{h}^{-1}$
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

Water analysis included:

- total carbon (TC), inorganic carbon (IC), desolved organic carbon (DOC)
- turbidity, pH, conductivity
- cations (Ca^{2+} , Mg^{2+} , Na^+ , NH_4^+ , K^+) and anions (F^- , Cl^- , NO_2^- , NO_3^- , Br^- , PO_4^{3-} , SO_4^{2-})

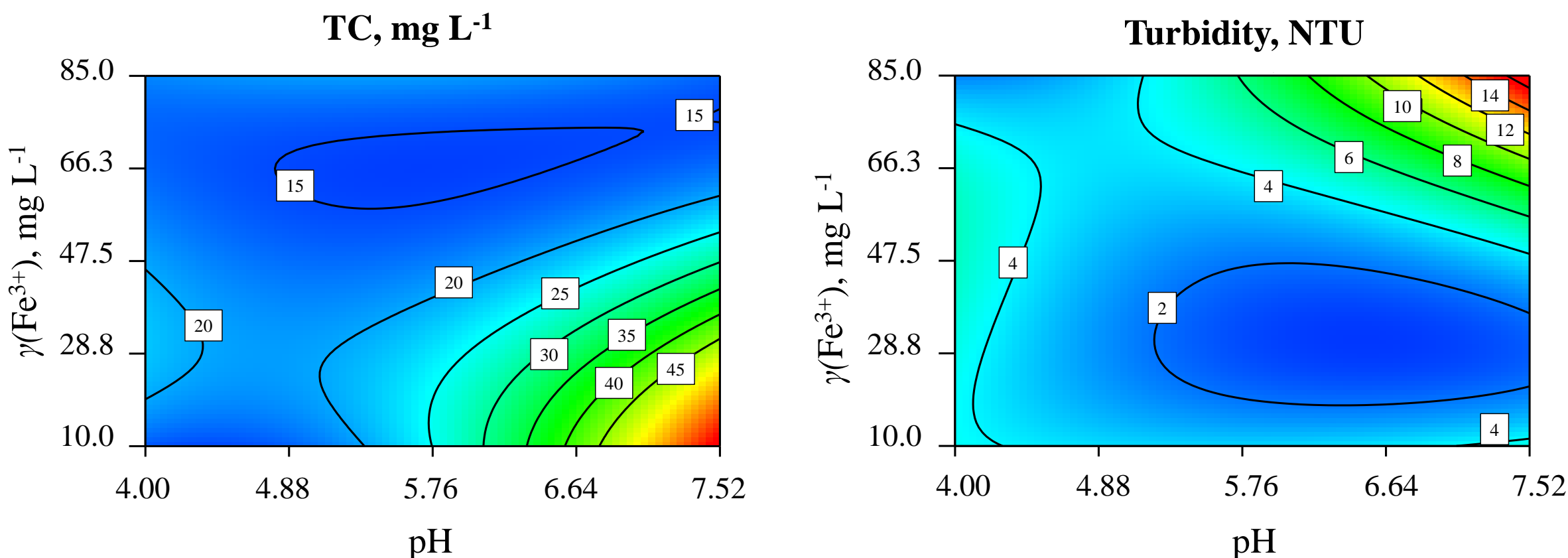
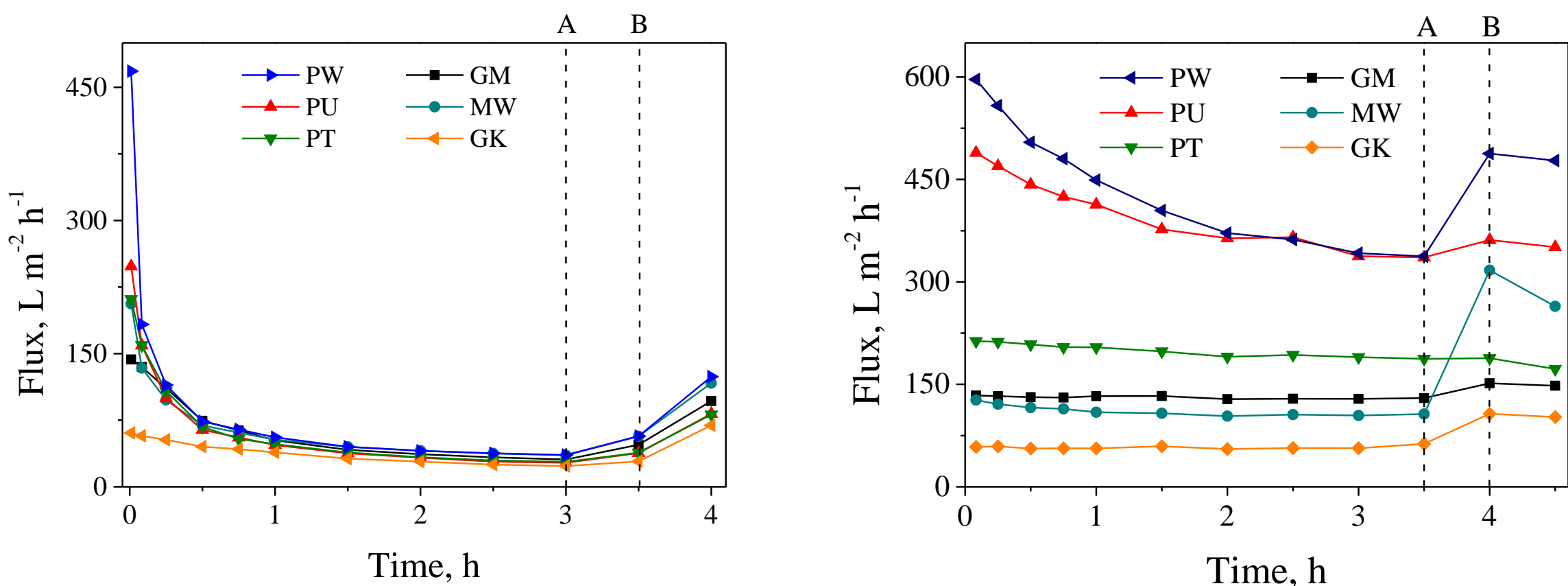


Fig. 1: Responce surface for total carbon and turbidity for the optimisation



The applied membranes showed similar separation efficiency (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. 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.

	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 , $\mu\text{S cm}^{-1}$	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	-	-

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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RESULTS AND DISCUSION

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 2: Membrane flux decline during UF of secondary effluent and secondary effluent after coagulation; A – after washing with PC 99, and B – after washing with water

Table 2: Water parameters measured after each stage of wastewater treatment and the limits according to US-EPA, Greek, and Spanish regulations .

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, sand filtration 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.