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STUDY OF THE INFLUENCE OF OPERATIONAL CONDITIONS AND HOLLOW-FIBER DIAMETER ON THE ULTRAFILTRATION PERFORMANCE OF A SECONDARY TREATMENT EFFLUENT.

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Abstract

Secondary treatment effluents from Municipal Wastewater Treatment Plants must achieve high water quality standards for their reuse in agriculture. To achieve these standards, ultrafiltration processes, which are easy to operate and economically feasible, are carried out. However, ultrafiltration has a drawback, membrane fouling, which causes operating difficulties and an increment of the operating cost. In order to minimize this phenomenon, it is important to determine the best operational conditions. For this purpose, a model wastewater feed solution was prepared due to the natural variability in secondary treatment effluents composition. In a previous work, it was concluded that the optimal model wastewater, capable of representing the secondary treatment effluent composition, consisted of 15 mg/L of bovine serum albumin and 5.5 mg/L of dextran. In this research, UF tests were performed with the optimal simulated wastewater using two membranes UFCM5 Norit X-flow® hollow-fiber: one of them with a fiber diameter of 1.5 mm and the other one with a fiber diameter of 0.8 mm. The operational conditions were varied in the range of 62-100 kPa for transmembrane pressure and in the range of 0.8-1.2 m/s for cross-flow velocity. The best operational conditions were selected in terms of higher permeate flux and lower energy consumption. The highest permeate flux was obtained for the membrane of 0.8 mm and the lower energy consumption was achieved at a cross-flow velocity of 1.2 m/s and a transmembrane pressure of 62 kPa.

1. Introduction

Nowadays, tertiary treatments are very important and necessary in order to improve the quality of the secondary treatment effluents. Many municipal wastewater treatment plants (MWWTP) use ultrafiltration (UF) as a tertiary treatment because it has been proved to be a reliable process.

There are many reasons to use UF as a tertiary treatment. For example, among the advantages of UF processes there can be found: the high quality of permeate, no by-product generation, the high efficiency achieved, the low energy consumed and the small footprint [1–5]. However, UF processes have an important drawback: membrane fouling [6].As a consequence of that, the permeate flux decreases [7] and it causes an increment of operating and maintenance costs [7, 8].Therefore, the main objective of this work is to carry out a study on the influence of operational conditions on permeate flux.

Membrane fouling is produced by extracellular polymeric substances (EPS), mainly composed of polysaccharides and proteins [9]. These compounds were previously reported to be used by other authors as Nataraj et al.[10] and Nguyen et al. [11] to simulate Secondary Treatment Effluent (STE) wastewaters .STEs UF performance is well reproduced by binary mixtures of protein/polysaccharides consisting of bovine serum albumin (BSA) and dextran [9, 12,13].

In this work, two operating parameters, transmembrane pressure (TMP) and cross-flow velocity (CFV), and two types of hollow fiber membranes of different fiber diameter were analyzed to evaluate their influence on membrane fouling. For this purpose, a model wastewater feed solution, capable of representing the STE performance, was used to ensure that the feed wastewater composition was the same for all the experiments. The best operational conditions to minimize membrane fouling during UF tests were selected.

2. Materials and Methods

2.1.Model wastewater composition

The model wastewater was prepared according to the STE composition from a Municipal Wastewater Treatment Plant located in Valencian Region (Spain).In a previous work, it was concluded that the optimal model wastewater to simulate the STE composition consisted of 15 mg/L of BSA and 5.5 mg/L of dextran [14].

The protein used to simulate STE composition was BSA from Sigma-Aldrich and the carbohydrate used was dextran (250000 Da from VWR International Ltd). Both of them were dissolved with tap water and with a gentle stirring. It is important to note that BSA may form aggregates, increasing its particle size [14].

Once the model wastewater was prepared, its composition was compared to that of the STE in terms of proteins, carbohydrates and chemical oxygen demand (COD). Protein concentration was determined by MicroBCA assay from Applichem, carbohydrate concentration was determined by the *anthrone* method from Panreac and COD was determined using kits from Merck.

The initial experiments were carried out both with STE and simulated wastewater in order to check that model solutions mimic properly STE.

2.2.Hollow-fiber membranes

To carry out UF tests, hollow-fiber membranes were selected because they are the best membranes for STE [15,16] due to their high active surface/volume ratio [17]. Two hollow-fiber membranes were used; both from *Norit X-flow*. The main characteristics of these membranes are shown in **¡Error! No se encuentra el origen de la referencia.**:

Table 1.Main Characteristics of the hollow-fiber membranes

MOLECULAR WEIGHT CUT-OFF (MWCO)	200000 Da
MATERIAL	polyethersulfone/polyvinylpyrrolidone (PES/PVP)
CONFIGURATION	Inside-out
DIAMETER	0.8/1.5 mm
ACTIVE AREA	0.07/0.04 m^2

2.3.Lab-scale plant and operational conditions

The lab-scale plant used to perform the UF tests was *Norit X-flow T/RX-300.* During the UF tests the feed solution was stirred and a temperature regulator was used to keep the temperature constant. Data were logged in a programmable logic controller (PLC). Besides, the retentate and the permeate were both returned to the feed tank (Figure 1) and the permeate flux was monitored.

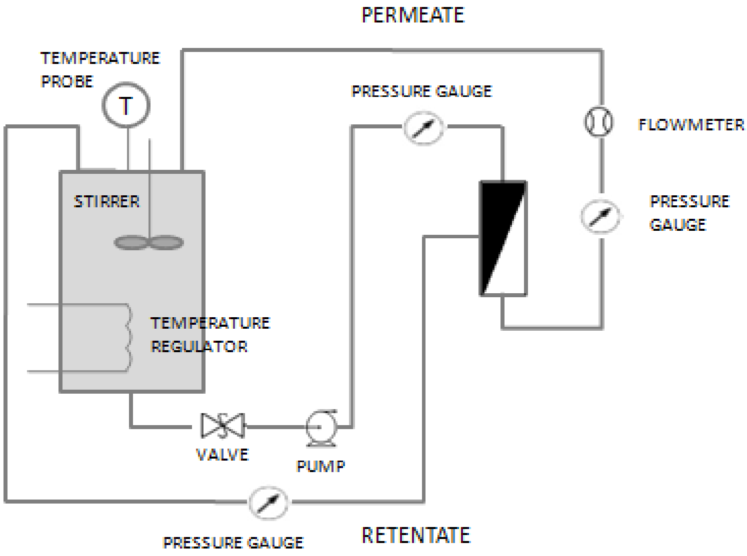

Figure 1. UF Lab-scale plant scheme

The experimental conditions were selected according to previous literature: low TMPs between 62 and 100 kPa [18] and CFVs between 0.8 and 1.2 m/s [19,20].

2.4.Cleaning protocol

The cleaning protocol, three steps, was performed at the lowest TMP and the highest CFV achieved in the lab-scale plant. The first step consisted of a rinse with deionized water during 30 minutes at 25ºC. The second step was a chemical cleaning performed at 40ºC using 154 ppm of NaClO and 0.5 mol/L of NaOH in deionized water. The third step was rinsing at the same experimental conditions of the first step. The hydraulic permeability was evaluated after each cleaning protocol to ensure that initial membrane permeability was restored.

2.5. Flux normalization

As the permeabilities after each UF test were not completely restored, permeate flux was normalized according to Eq.1:

$$J_N = J \cdot \frac{R_0}{R_m} \qquad \text{Eq.1}$$

In the Eq.1 "J" is the permeate flux obtained during the test, "J_N" is the normalized permeate flux, "R_0" is the resistance of the membrane before its first use and "R_m" is the membrane resistance before each test.

3. Results and discussion

In Figures 2 and 3 the permeate flux decline with time for the STE and the simulated wastewater (SW) at the same experimental conditions are compared for the two membranes used. It can be observed that the SW represents well the STE UF performance for both membranes.

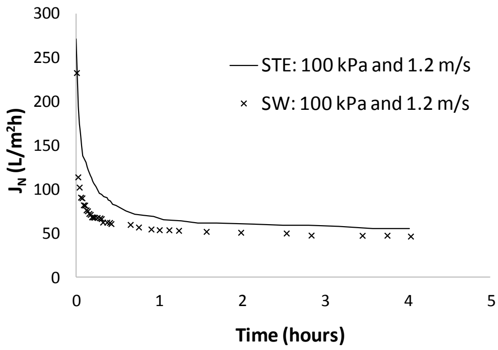

Figure 2. Permeate flux decline versus time with a hollow-fiber diameter of 1.5 mm.

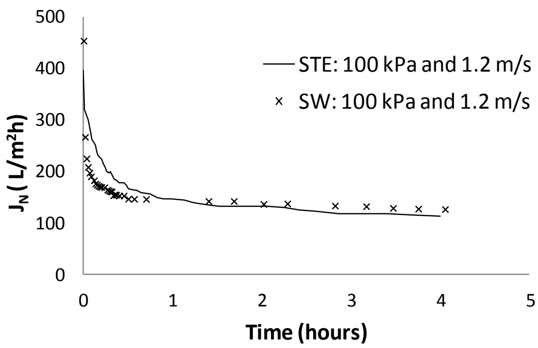

Figure 3. Permeate flux decline versus time with a hollow-fiber diameter of 0.8 mm.

The permeate flux decline with time for the two hollow-fiber membranes with different fiber diameter is compared for four different experimental conditions (figures 4, 5, 6 and 7).The results showed that the membrane with a fiber diameter of 0.8 mm was the one that achieved the highest permeate fluxes (lowest membrane fouling) for all the experimental conditions tested.

The highest percentage differences in long term permeate flux between both membranes were 67%. The highest steady-state permeate flux achieved for the membrane with a fiber diameter of 1.5 mm is approximately 50 L/m^2h, whereas in the case of the membrane with a fiber diameter of 0.8 mm it is around 150 L/m^2h.These results are in accordance with those obtained by Mondor et.al. [21]. They worked with three different fiber diameters and they concluded that the membrane with the smallest diameter achieved the highest permeate flux. As well, Chang et al. [22] studied the effect of fiber diameter on flux decline and they concluded that the fiber with the highest diameter tested produced more flux decline. This fact is also satisfied in the present work, in which the membrane with a fiber diameter of 1.5 mm produced a 71.2% of flux decline and the membrane with a fiber diameter of 0.8 mm declined the flux in a 64.4 %.

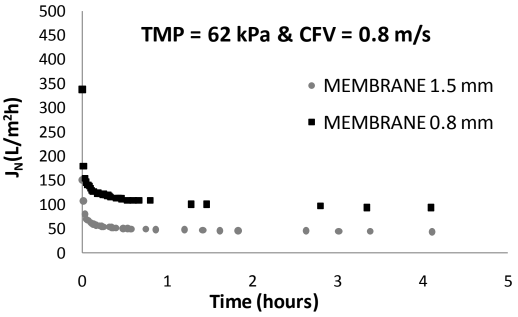

Figure 4. Permeate flux decline versus time with simulated wastewater at 62 kPa and 0.8 m/s.

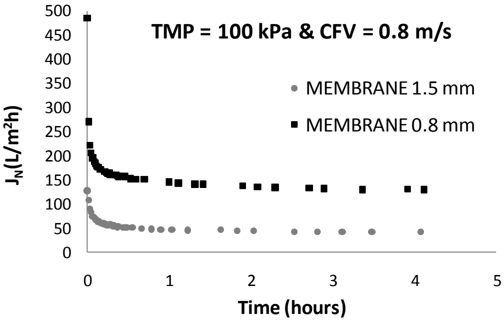

Figure 5. Permeate flux decline versus time with simulated wastewater at 100 kPa and 0.8 m/s.

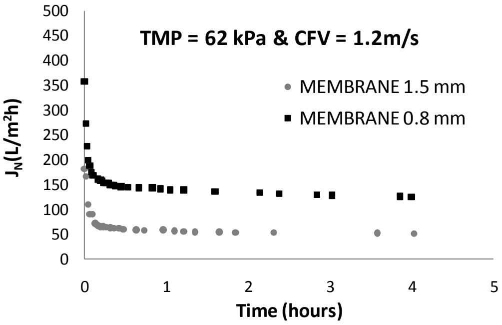

Figure 6. Permeate flux decline versus time with simulated wastewater at 62 kPa and 1.2 m/s.

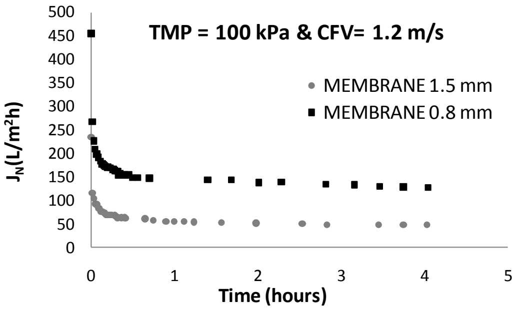

Figure 7. Permeate flux decline versus time with simulated wastewater at 100 kPa and 1.2 m/s.

Once the membrane was selected, the influence of TMP and CFV on permeate flux for this membrane was studied (Figure 8). The worst result in terms of permeate flux is obtained for 62 kPa and 0.8 m/s. There were not significant differences in permeate flux for the rest of experimental conditions tested. Therefore, the optimal experimental conditions were selected on the basis of the lowest energy consumption. This fact is achieved in the case of lowest transmembrane pressure (62 kPa) and at a cross-flow velocity of 1.2 m/s.

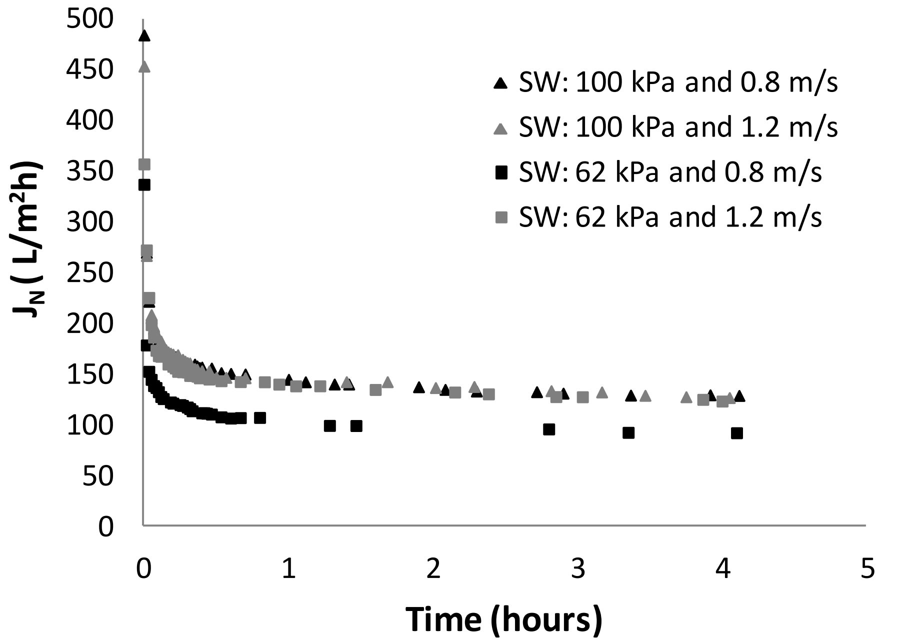

Figure 8. Permeate flux decline versus time with the membrane of 0.8 mm of diameter

Figure 9 shows the values of permeate flux decline for each experimental condition tested in terms of percentage of steady-state permeate flux with respect to the initial permeate flux. It can be seen that the test performed at 62 kPa and 1.2 m/s was the test that presented the lowest permeate flux decline. This fact indicated that the fouling produced for these operational conditions was the lowest.

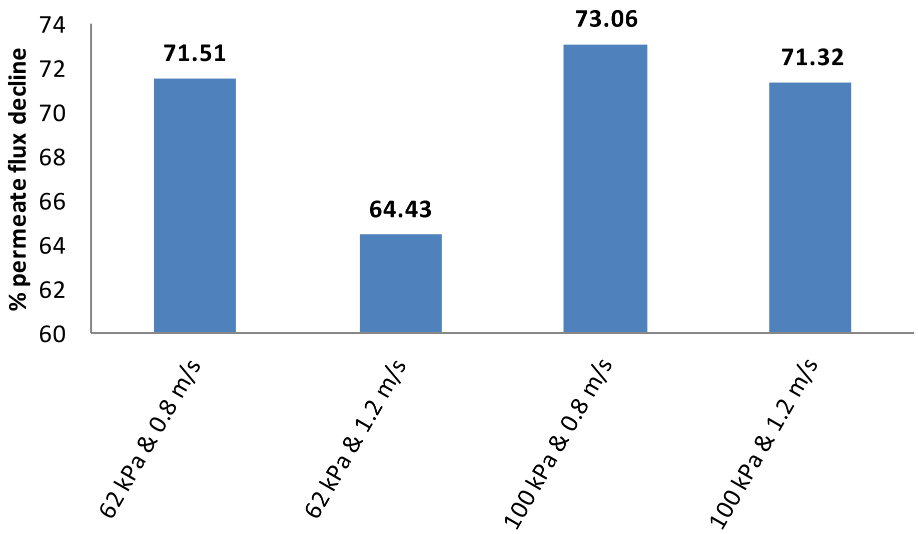

Figure 9. Percentage of permeate flux decline for each operating condition.

Table 2 shows the proteins and carbohydrates rejection for the UF tests carried out with both membranes for all the experimental conditions considered in this study. These results were analyzed to evaluate the permeate quality. In terms of carbohydrates rejection, the UF test performed with the membrane of 0.8 mm, at 62 kPa and 1.2 m/s, achieved the highest value (46.16%). For proteins rejection, the test with the highest rejection value (93.15%) was that performed with the membrane of 0.8 mm of fiber diameter at 100 kPa and 1.2 m/s. However, the test carried out at 62 kPa and 1.2 m/s, for the same membrane, achieved a protein rejection of 88.35%, only 4.81% far from the maximum, what can be considered as negligible. On the other hand, the COD rejection was also evaluated and its values were in the range of 56.5-70.9%. In general terms, it can be stated that the highest rejection values corresponded with the membrane of 0.8 mm, what can be explained since its permeate flux was higher than that measured for the 1.5 mm membrane.

Table 2. Proteins and carbohydrates rejection

MEMBRANE	EXPERIMENTAL CONDITIONS	PROTEINS (%)	CARBOHYDRATES (%)
1.5 mm	62 kPa and 1.2 m/s	89.8	38.0
1.5 mm	62 kPa and 0.8 m/s	78.8	33.0
1.5 mm	100 kPa and 1.2 m/s	69.1	34.5
1.5 mm	100 kPa and 0.8 m/s	68.9	42.0
0.8 mm	62 kPa and 1.2 m/s	88.3	46.2
0.8 mm	62 kPa and 0.8 m/s	81.6	40.8
0.8 mm	100 kPa and 1.2 m/s	93.1	40.5
0.8 mm	100 kPa and 0.8 m/s	92.3	44.7

Considering the highest permeate flux, the lowest energy consumption and the high permeate quality, it can be concluded that the optimal operating conditions were achieved for the 0.8 mm membrane at a TMP of 62 kPa and a CFV 1.2 m/s.

4. Conclusions

The main objective of this research was to select the best operating conditions (TMP, CFV and hollow fiber diameter) to reduce the membrane fouling and energy consumption during STE ultrafiltration. At the same time, it was necessary to achieve a high permeate quality. The analysis of all these factors allowed the selection of the optimal operating conditions: a membrane of 0.8 mm of fiber diameter, a TMP of 62 kPa and a CFV 1.2 m/s

5. Acknowledgements

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6. Nomenclature

Symbols

J	Permeate flux (L/m^2h)
J_N	Normalized permeate flux (L/m^2h)
R_0	Resistance of the membrane before the first use (m^{-1})
R_m	Resistance of the membrane before each test (m^{-1})
μ	Dynamic viscosity of the water (Pa·s)
TMP	Transmembrane pressure (kPa)
CFV	Cross-flow velocity (m/s)
STE	Secondary treatment effluent
SW	Simulated wastewater
MWWTP	Municipal wastewater treatment plant
UF	Ultrafiltration
EPS	Extracellular polymeric substances
BSA	Bovine serum albumin
COD	Chemical oxygen demand (mg/L)
MWCO	Molecular weight cut-off

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