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Microfiltration of the Sugar Refinery Wastewater Using Ceramic Membrane with Kenics Static Mixer

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***Abstract*—**New environmental regulations and the increasing market preference for companies that respect the ecosystem had encouraged the industry to look after new treatments for its effluents. The sugar industry, one of the largest emitter of environmental pollutants, follows this tendency. Membrane technology is convenient for separation of suspended solids, colloids and high molecular weight materials that are present in a wastewater from sugar industry. The idea is to microfilter the wastewater, where the permeate passes through the membrane and becomes available for recycle and re-use in the sugar manufacturing process. For microfiltration of this effluent a tubular ceramic membrane was used with a pore size of 200 nm at transmembrane pressure in range of 1–3 bars and in range of flow rate of 50–150 l/h. Kenics static mixer was used for permeate flux enhancement. Turbidity and suspended solids were removed and the permeate flux was continuously monitored during the microfiltration process. The flux achieved after 90 minutes of microfiltration was in a range of 50–70 l/m^2h. The obtained turbidity decrease was in the range of 50-99 % and total amount of suspended solids was removed.

***Keywords*—**Ceramic membrane, microfiltration, sugar industry, wastewater.

I. Introduction

THE commission of the European Communities introduced the Integral Pollution and Prevention Control Directive illustrating the current and future EU policy to encourage development of processes and standards in order to prevent negative effects on water and environment, using the Best Available Techniques (BAT) [1].

The Directive defines the Best Available Techniques as the most effective and advanced operation methods which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and reduce emissions and the impact on the environment [2], [3]. The methods of wastewater treatment proposed by BAT are numerous and one of the options recommended by these documents is the application of membrane separation techniques.

Membrane technology is convenient for separation of suspended solids, colloids and high molecular weight materials that are present. The size range depends upon the pore sizes of the used membrane. Fractionation of the feed stream occurs, with some molecules being concentrated on the upstream side of the membrane, which is known as the concentrate or retentate. The smaller molecules pass through the membrane into the permeate stream. The driving force is the pressure difference which enables a continuous separation process [4], [5].

The aim of this research is the possibility of applying a new generation of ceramic membranes with pore size of 200 nm to reduce the contamination of the wastewater, remove suspended solids and turbidity from sugar refinery wastewater. Previous investigations using the pore size of 200 nm and ceramic membrane showed promising results on a wheat starch wastewater [6].

Sugar refineries generate high amounts of wastewater and therefore represent a serious environmental problem, due to its high organic load, intense colouration and presence of phenolic compounds. The coloured nature of this effluent can lead to a reduction of sunlight penetration in rivers and streams which in turn decreases both photosynthetic activity and dissolved oxygen concentrations causing harm to aquatic life [7].

High organic load of the wastewater leads to lower chemical oxygen demand removal using hybrid biological reactor systems and therefore a pre-treatment is required [8]. In such cases, application of membrane technology proved to be successful pre-treatment technique for both wastewater and drinking water [9]. However, the major hurdle in the extensive use of membranes is the continuous reduction of permeation flux caused by concentration polarization and membrane fouling. Concentration polarization causes deposition of retained compounds on the membrane surface. The pure water flux of microfiltration membrane is usually high, but when separation starts through the membrane, the value of permeate flux declines very quickly, which is caused by the gel formation on the membrane surface. Membrane fouling could be attributed to the adsorption of suspended or colloidal particles on the membrane surface, as well as adhesion, precipitation of solute on the surface and/or in the pores of the membrane. Membrane fouling can't be avoided, but certain techniques can provide enhancement of membrane flux. Interesting technique is the use of static turbulence promoters. Static turbulence promoters increase wall shear rates and may produce secondary flows and instabilities, and the significant flux enhancements compared to a conventional cross-flow process [10], [11].

In this paper we will present the results obtained by the microfiltration of the sugar refinery wastewater using static turbulence promoter. The results regarding permeate flux

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values, suspended solids and turbidity removal will be presented and discussed.

II. Experimental

In this work microfiltration experiments were conducted on a wastewater from a medium size sugar refinery (5000 t of sugar beet per day). Characteristics of this type of wastewater are suspended solids in the range of 4.2–12.5 g/l, turbidity in the range of 500–1800 NTU.

In order to retain the large particles which could interfere with the microfiltration process, wastewater was filtered through the filter cloth. Laboratory plant for microfiltration, which was used in this paper, was designed at the Faculty of Technology in Novi Sad. For the purpose of this study, a tubular alumina ceramic membrane was used, manufacturer GEA Westfalia (Germany). Membrane length was 250 mm, with an outside diameter of 10 mm and an internal diameter of 6.8 mm with a pore size of 200 nm. Scheme of a microfiltration laboratory plant is presented in Fig. 1.

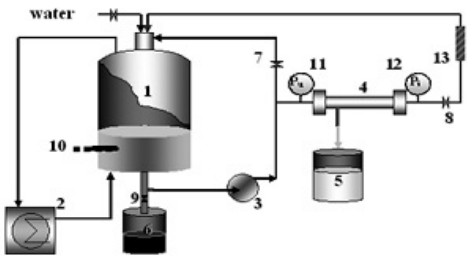

Fig. 1 Laboratory apparatus for cross-flow microfiltration 1 – tank, 2 – thermostat, 3 – pump, 4 – membrane module, 5 –permeate tank, 6 – retentate tank , 7 – flow rate correction valve, 8 –pressure correction valve, 9 – retentate valve, 10 – thermometer, 11 – manometer, 12 – manometer, 13 – rotameter

The conducted experiments were designed based on a full 3^2 factorial designed experiment. In this experiment, the input factors were the transmembrane pressure (TMP) and feed flow rate (Q). The values of input factors which varied during the microfiltration process are presented in Table I.

TABLE I
Varied Values of Input Factors and Dependent Responses

Input factors	Factor levels		
	-1	0	1
Transmembrane pressure (bar)	1	2	3
Feed flow rate (l/h)	50	100	150
Dependent responses			
Permeate Flux (l/m^{2}h)			
Turbidity (NTU)			
Suspended solids (g/l)			

During the process of microfiltration permeate flux was constantly monitored and calculated using (1):

$$J = \frac{V_p}{A_m \cdot t} \quad (1)$$

where J represents permeate flux (l/m^{2}h), V_p volume of permeate (l), A_m membrane surface (m^2) and t time of microfiltration (h).

Turbidity and suspended solids were determined at the beginning and at the end of the experiment in feed mixture, peremeate and retentate by the titrimetric method SRPS ISO 6060 [12]. Turbidity is determined by the device Turb 550 IR. The measurements are performed automatically. Before each experiment membrane was cleaned with a solution of hydrochloric acid (HCl). The effectiveness in membrane cleaning was assessed by examining the water flux recovery. The cleaning procedure was repeated until the 95 % of original water flux was restored.

III. Results And Discussion

In order to examine the conditions of microfiltration of wastewater, dependence of the permeate flux from transmembrane pressure for both wastewater and distilled water had to be deteremined. Permeate flux of distilled water is the basis for comparison, since it represents the solvent in wastewater. Dependence of the permeate flux of distilled water and the permeate flux of wastewater, at 20°C and feed flow rate (Q) of 100 l/h, on transmembrane pressure is presented in Fig. 2.

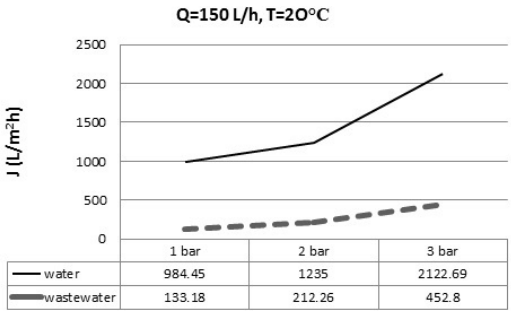

Fig. 2 Dependence of the permeate flux of distilled water and the permeate flux of wastewater on the transmembrane pressure

The additional resistance to the flow through membrane pores is evident during microfiltration of wastewater. The value of distilled water permeate flux is 5–7 times greater than the flux of the wastewater permeate. As the previous investigations of the permeate flux decline showed, the main reason for resistance formation on the membrane surface during microfiltration of the wastewater is membrane fouling and concentration polarisation, caused by the compounds present in the wastewater [13].

The obtained values of the permeate flux at the beginning and at the end of microfiltration of the sugar refinery wastewater are given in Table II. The results showed that the highest permeate flux are obtained at the medium transmembrane pressure.

On the basis of experimental values graph of the two dependencies is drawn and presented in Fig. 3. Within the first minute of the microfiltration, initial rapid permeate flux decline is observed. Such an effect can be ascribed to an

increased adsorption and adhesion of particles and solutes on the membrane, which leads to an effective decrease in the diameter of the pores and a decline in the permeate flux [11].

TABLE II
RESULTS OF THE PERMEATE FLUX, AT THE BEGINNING AND AFTER 90 MINUTES OF ULTRAFILTRATION

Run	Permeate flux at the beginning of microfiltration J_0	Permeate flux after 90 minutes of microfiltration J_{end}
(P=1bar,Q=50l/h)	125.78	37.73
(P=1bar,Q=100l/h)	102.91	60.11
(P=1bar,Q=150l/h)	133.18	65.31
(P=1bar,Q=50l/h)	295.32	90.56
(P=1bar,Q=100l/h)	399.56	91.79
(P=1bar,Q=150l/h)	452.83	91.78
(P=1bar,Q=50l/h)	100.88	35.75
(P=1bar,Q=100l/h)	150.94	54.33
(P=1bar,Q=150l/h)	212.24	71.50

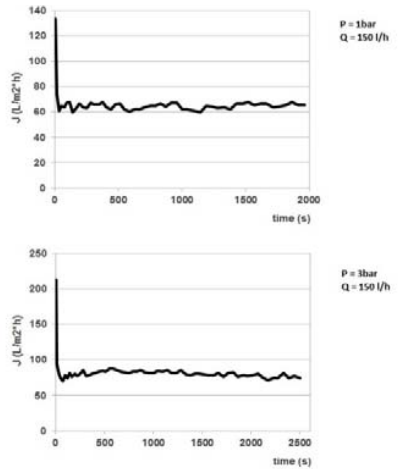

Fig. 3 Permeate flux (J) vs time curve during the ceramic membrane microfiltration using static mixer

After the initial decrease permeate flux values, steady state permeate flux occurred and the value of the permeate flux maintained above 60 l/h for applied conditions. This enhancement of the flux values pronounces a highly positive effect caused by the static mixer which eliminates the occurrence of the concentration polarization, i.e. the layer of compounds that normally forms on the membrane surface.

Removal of the suspended solids and turbidity from wastewater after the microfiltration is presented in Fig. 4. Total amount of suspended solids are removed using ceramic membrane with 200 nm pore size. Since permeate is clear of suspended solids, it could be expected that total amount of suspended solids from wastewater move to retentate. However, certain amount of particles from wastewater form a cake layer on the membrane surface and represent a membrane fouling effect. Moreover, the results regarding turbidity removal are presented in Table III. The obtained turbidity decrease was in the range of 50-99%. However, it is clear to notice that the lowest turbidity removal was achieved at the medium transmembrane pressure where the highest values of permeate flux were obtained. This can be attributed to the effect of the static mixer inside of the membrane tube, which prevents consistent cake layer to be formed on the membrane surface. The cake layer represents additional porous filter which decreases original pore diameter of the membrane and enchases the microfiltration effect [14].

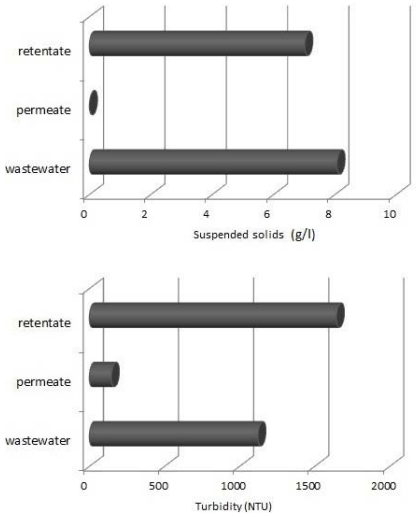

Fig. 4 Suspended solids and turbidity before microfiltration in wastewater and after microfiltration in permeate–purified wastewater and retentate

TABLE III
RESULTS OF TURBIDITY VALUES, AT THE BEGINNING AND AFTER 90 MINUTES OF ULTRAFILTRATION

Run	Turbidity(NTU)		
	Wastewater	Permeate	Retentate
(P=1bar,Q=50l/h)	644	7	765
(P=1bar,Q=100l/h)	1106	3.5	1396
(P=1bar,Q=150l/h)	1122	11	1650
(P=1bar,Q=50l/h)	530	360	780
(P=1bar,Q=100l/h)	940	450	1050
(P=1bar,Q=150l/h)	1030	218	1996
(P=1bar,Q=50l/h)	1206	75	2006
(P=1bar,Q=100l/h)	1760	82	3240
(P=1bar,Q=150l/h)	1780	8	1914

IV. CONCLUSION

Based on the effects of microfiltration of wastewater at transmembrane pressure in the range of 1–3 bar and feed flow rate from 50 to 150 l/h, it can be concluded that microfiltration can reduce contamination of wastewater, suspended solids content and turbidity of wastewater.

Using membranes with pore diameter of 200 nm turbidity removal reached 99%.

The lowest turbidity removal was achieved at the medium transmembrane pressure where the highest values of permeate flux were obtained.

Total amount of suspended solids are removed from the wastewater for all applied conditions.

The value of distilled water permeate flux is 5–7 times greater than the flux of the wastewater permeate. After steady state permeate flux occurred the value of the permeate flux maintained above 60 l/h for applied conditions.

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