

Experimental Study on Revolving Cross-flow Microfiltration of Highly Viscous Liquids*

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Abstract Experimental investigation of the microfiltration (MF) using a revolving cross-flow membrane filter was performed under the condition of constant pressure difference, and different flat membranes made of polyvinylidene fluoride (PVDF, 0.1 μm), cellulose acetate (CA, 0.22 μm), sulfonated polyethersulfone (SPES, 0.22 μm) and polyamide (PA, 0.45 μm), respectively, were used in filtration experiments. The dependence of the filtrate mass of the cross-flow MF on time was measured on-line. The experimental results showed that the effect of the cross-flow on high viscosity medium was more significant than that on the low viscosity one.

Keywords microfiltration membrane, viscous liquid, cross-flow

1 INTRODUCTION

The membrane separation technique becomes increasingly popular owing to the advantages of simple equipment, convenient operation, high efficiency, low energy consumption, and no phase transformation and chemical reaction. However, a major barrier to the large-scale application of the membrane separation technology in industry is the membrane fouling, which makes not only the permeate flux reduced, but also the quality of membrane deteriorated and the lifetime of the membrane shortened. Thus, it is very important to study the theory of membrane fouling and the method to improve the membrane flux and the lifetime. So far, many works have been done in eliminating or reducing the concentration polarization and membrane fouling, *e.g.*, the rotating disk dynamic filtration [1–3], vibrating dynamic filtration [3–5], cross-flow filtration [6–9], electromagnetic dynamic filtration [10, 11] and periodic back flushing technique and so on.

Rotating disk filter was invented in 1971 by Malinovskaya and Kobrinsky to increase the filtration rate of suspensions difficult to be filtrated [12]. With new membrane materials and membrane filters developed, the above-mentioned various kinds of the filtration methods are applied to improve the service lifetime of the membranes in filtration, and the membrane filtration becomes more popular for the suspensions with viscous liquids [13–18].

The most widely-used method is known to be filtration using the cross-flow of the feed liquid itself. However, the membrane separation of the highly viscous liquids by simple membrane cross-flow filtration is very difficult to be realized.

This paper aims to experimentally investigate the effects of the strong rotational flow caused by the mechanical action of a rotator on the rate of the membrane filtration for the liquids of the low and high viscosities so as to demonstrate the applicability of the

polymeric membrane in the filtration of the highly viscous liquids.

2 EXPERIMENTAL

The apparatus for the experiment of magnetic-stirred cross-flow membrane filtration (MF) is shown in Fig. 1.

The stirrer has a height of 10 mm, a width of 20 mm, and a thickness of 2 mm, respectively. Its rotating diameter is 48 mm.

The membrane module of the filter consists of the plate filtration membrane, and there exists the plate stirrer subjected to the magnetic field in the filtering space. The filter is placed on the magnetic stirring apparatus and the distance between the plate stirrer and the membrane is 3 mm.

The feeder of the feed solution is assigned on the top side of the filtering chamber, and the exits of the filtrated fluid and the concentrated suspension are designed in the cylindrical part of the filter, respectively.

The solid particles deposited on the membrane during filtration in this kind of filter are forced towards the centrifugal direction by the action of the stirrer rotating with the high speed, resulting in the limitation of the thickness of the cake-layer.

The feed solution is simultaneously subjected to both the filtration pressure and the centrifugal force during flowing through the filtration membrane so as to be filtered.

The magnetic stirring filter with membrane module of effective diameter of 5 cm (the effective area of the membrane being 19.6 cm^2) was employed in our experiment. The membrane module is a flat suction vacuum module. The membrane material is polyvinylidene fluoride (PVDF), cellulose acetate (CA), sulfonated polyethersulfone (SPES) and polyamide (PA).

The characteristic parameters of the membranes used are shown in Table 1.

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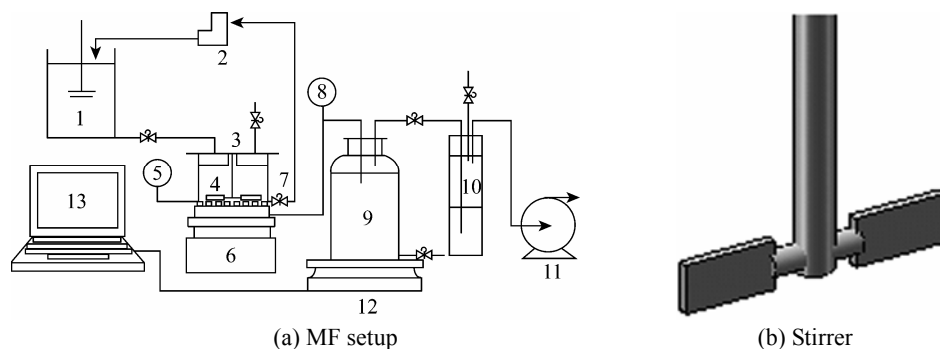


Figure 1 Magnetically-stirred cross-flow MF setup

1—feed tank; 2—pump; 3—membrane module; 4—stirrer; 5—pressure gauge; 6—magnetic stirrer driver; 7—valve; 8—vacuum gauge; 9—filter tank; 10—buffer slot; 11—vacuum pump; 12—electric balance; 13—PC

Table 1 Membrane parameters

Membrane	Maximum pore diameter/ μm	Mean thickness/ μm	Porosity
PVDF	0.1	121	0.811
CA	0.22	118	0.737
SPES	0.22	117	0.682
PA	0.45	145	0.865

The concentrated suspension is recycled with a constant flow pump (BT00-600M, Changzhou Kejian Peristaltic Pump Co.). The variation of the filtrate mass with time under constant pressure was determined on line by weighing the permeate using electric balance 12.

The maximum vacuum obtained by water-circulated multi-functional vacuum pump 11 (SHB-IIIT, Suzhou Dalong Measuring Apparatus Co.) is 0.098 MPa and the filtration pressure can be controlled by the valve atop buffer cylinder 10.

The flat polymeric membrane used in this experiment can withstand the maximum vacuum pressure, and the height of the feed solution over the filtration membrane is fixed to 5 cm in the filtering chamber.

The stirring rotating speed of the magnetic stirrer was determined using a non-contact digital speedometer (SZG-441G, Shanghai Automatic Rotating Speedometer Electric Co.), which can measure rotating speed, linear velocity and frequency in the ranges of 10 to 50000 $\text{r}\cdot\text{min}^{-1}$ and 0.5 to 999 $\text{m}\cdot\text{min}^{-1}$, respectively.

The tested suspension is a mixture of aqueous CMC solution and clay. The rheological parameters of carboxymethylcellulose (CMC, China Medico-Chemical Reagent Co.) solution were measured using the viscometer Haake-K10 (Germany), and the characteristic indices measured are given in Table 2.

Table 2 Suspension parameters

Liquid	Rheological parameter (20°C)		Solid (clay) maximum particle diameter/ μm	Solid-liquid ratio $\times 10^4$
	$k/\text{Pa}\cdot\text{s}^n$	n		
0.5%CMC	0.0876	0.891	20	0.883
1.0%CMC	0.1305	0.728	20	0.883

3 RESULTS AND DISCUSSION

CMC solution with different concentrations was filtrated through the cross-flow MF experiment under constant pressure. The total filtrate volume per unit filtration area q was determined after operating the membrane for a period Δt under a constant rotating rate.

Under the filtration pressure of the constant pressure, firstly, 0.5% CMC solutions were filtrated in dead end mode using the CA membrane of 0.22 μm pores. The magnetic stirring system was started until filtration continued for 140 min. Under the condition of a same membrane and a same feed, dynamic MF was carried out and the effect of revolving cross-flow was compared. The variation of q value with time is shown in Fig. 2.

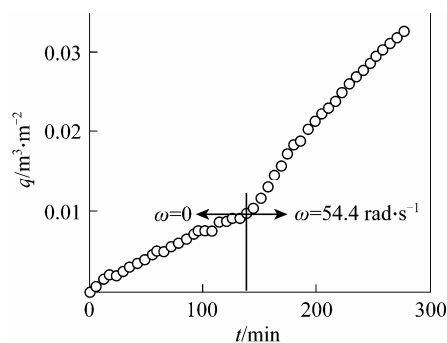


Figure 2 The effect of cross-flow on the MF of 0.5% CMC solution using the CA membrane (the membrane pore is 0.22 μm)

As seen in Fig. 2, the slope for the dynamic MF curve is obviously higher than that for the static one, which indicates that the velocity of MF for high viscosity fluid can be increased by magnetic stirring revolving cross-flow MF.

The effect of the stirring revolutions on the MF velocity was investigated by MF experiments for CMC solution of 0.5% under different revolutions and Δp of 0.095 MPa with the PA membrane of 0.45 μm pores. The experimental results are shown in Fig. 3.

As seen in Fig. 3, the effect of the revolutions on MF flux was higher. When MF of high viscosity fluid was in static mode, the increment of q values with time

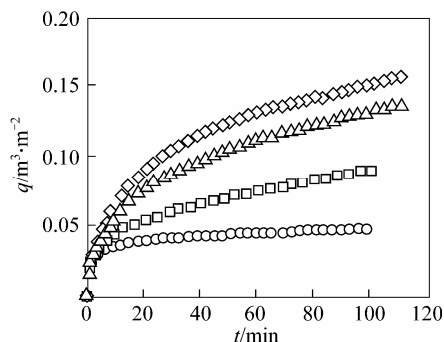


Figure 3 The effect of stirring revolutions on the MF of 0.5% CMC solution using the PA membrane (the membrane pore is 0.45 μm)

$\omega/\text{rad}\cdot\text{s}^{-1}$: $\circ$ 0; $\square$ 35.2; $\triangle$ 54.4; $\diamond$ 78.5

was lower, and the MF process was complete in a short time. While the q values increased obviously for the dynamic MF under a certain revolution, the q values in the same time increased with the increase of revolution.

The reason is that if the rotating speed of the agitator is increased, the fluid cut rate produced on the membrane wall surface is also increased and simultaneously, the main migratory rate of the particles being retained to the suspension is also high.

To sum up, the cut velocity of fluid near the membrane increased with an increment of the stirring rotating speed of the revolving cross-flow filter, and thus, effectively restrained the deposition of the solutes on the membrane surface, decreased the total resistance, and increased the velocity of MF. On the other hand, the appended pressure resulting from the stirring revolution was beneficial to the increment of MF velocity.

From the data of Fig. 3, under different revolutions, after the filtration for 100 min, the filtrate mass was compared as given below in Table 3.

Table 3 Comparison of the filtrate mass after filtration for 100 min

Rotating rate/ $\text{rad}\cdot\text{s}^{-1}$	Filtrate mass/ g	Ratio of cross-flow MF flux over dead-end MF flux
0	84	—
35.2	127	1.51
54.4	190	2.26
78.5	227	2.70

As seen in Table 3, when the cut velocity of the stirring was $78.5 \text{ rad}\cdot\text{s}^{-1}$, after MF of 100 min, the filtrate mass was 2.7 times that of the static MF. Namely, the flux of cross-flow MF was higher by a few times than that of dead end MF.

Microfiltration was carried out for tap water using PVDF membrane of 0.1 μm under the different revolutions to analyze the difference of the cross-flow effect on the MF of low and high viscosity fluid under the pressure of 0.095 MPa. The experimental results are shown in Fig. 4.

As seen in Fig. 4, the revolving cross-flow effi-

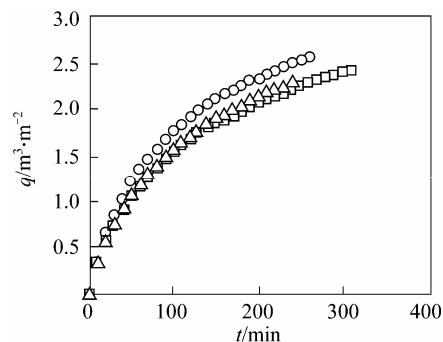


Figure 4 The effect of stirring revolutions on the MF of tap water using the PVDF membrane (the membrane pore is 0.1 μm)

$\omega/\text{rad}\cdot\text{s}^{-1}$: $\circ$ 77.45; $\triangle$ 32.3; $\square$ 0

ciency of low viscosity fluid such as tap water was not higher than that of high viscosity fluid, and the effect of the stirring revolutions on the MF velocity was not obvious.

Figure 5 shows the different influences of the cross-flow on the membrane filtration under the condition of the different rotational velocities for 1.0% CMC solutions with the high velocity.

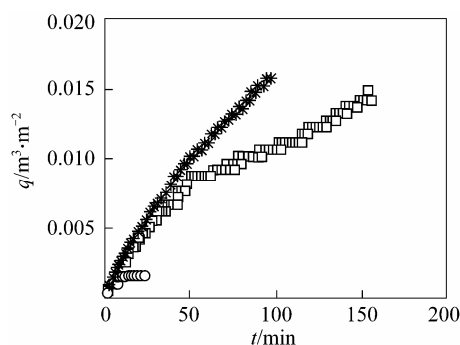


Figure 5 The effect of stirring revolutions on the MF of 1% CMC solution using the PA membrane (the membrane pore is 0.45 μm)

$\omega/\text{rad}\cdot\text{s}^{-1}$: $\circ$ 0; $\square$ 54.4; $*$ 78.5

To sum up, as seen in Figs. 4 and 5, the revolving cross-flow efficiencies for low viscosity fluid and high viscosity fluid were significantly different; the higher the viscosity of fluid, the more obvious was the revolving cross-flow efficiency. During the filtration of high viscosity feed, dead-end MF could not attain the aim of the separation and even the sustainable filtration could not be carried out; the action of the enhanced flux must be adopted.

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