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Influence of suspension concentration and transmembrane pressure on microfiltration of montmorillonite based suspension

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ABSTRACT

The effects of various operating conditions including transmembrane pressure, suspension concentration and crossflow velocities for the microfiltration of micro-sized suspensions were experimentally investigated. The experiments were carried out with suspensions of bentonite particles with particle diameters of 0.5–100 μm using 0.1 μm tubular ceramic membranes. The step by step technique was used to determine the values of the critical flux and influence of the high frequency backflushing was analysed. It was found that the permeate flux is significantly depend on the suspension concentration and crossflow velocity. High permeate fluxes were obtained at low concentration 1 g.l^{-1} and/or at high velocity 2.2 ms^{-1}.

Keywords: Microfiltration; Montmorillonite; Crossflow; Backflush; Bentonite; Critical flux

1. Introduction

Crossflow microfiltration is a pressure driven process widely used in many applications for particulate separation, purifying or concentrating the suspended particles from solution.

The decline of permeate flux with time depends on forming a cake layer on the membrane surface and/or by blocking the membrane pores (membrane fouling). Field et. al. [1] defined concept of the critical flux as a flux value below which there is no particle deposition on the membrane surface and above which the deposition is significant during the filtration of suspensions. In practical application, the value of the critical flux is often determined by monitoring the transmembrane pressure in a flux stepping test [2].

The efficiency of crossflow microfiltration is primarily a function of the operating parameters such as pore size of the membrane, transmembrane pressure, crossflow velocity, temperature and concentration of suspended solids in the feed [3,4]. The influence of a variety of operating parameters on the permeate flux has been intensively investigated. It was found that with an increasing crossflow velocity the thickness of the cake layer is decreasing and the permeate flux is increasing [5]. Backflusing also has been successfully used in many membrane filtration processes to reduce fouling and maintain flux [6,7]. The membrane backflushing process is carried out by periodically reversing the direction of the permeate flow and backflush duration 5–20 s and pulses 3–10 times per hour are recommended [8].

The objectives of this study were to experimentally investigate the influence of different operating conditions on microfiltration of bentonite suspension.

2. Experimental

2.1. Materials and chemicals

Tests were carried out using Bentonite−a sorbent of generally impure clay consisting mostly of montmorillonite (a minimum of 75% weight). The size distribution

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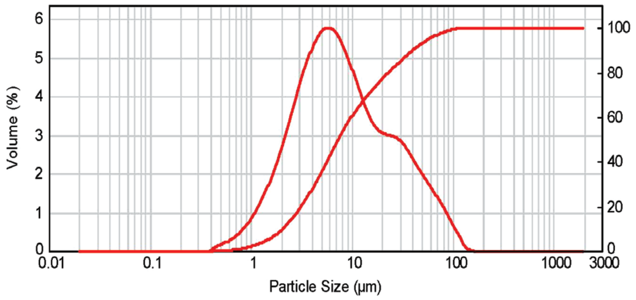


Fig. 1. Bentonite particle size distribution.

of grinded particles swollen in water was measured by the MasterSizer (Malvern Instruments, UK) and is presented in Fig. 1. The suspensions were prepared by adding the appropriate amount of Bentonite particles to deionised water and then mixing by the magnetic mixer for 10 min. The zeta potential of the suspensions measured by the ZetaSizer instrument (Malvern Instrument Ltd., UK) was on average–29.83 mV at a pH 9.12.

The membrane used in the experiments was asymmetric ceramic membrane Membralox (Pall) with an inner diameter of 0.7 mm, outer diameter 10 mm and a length of 0.25 m.

The mean pore size of the membrane active layer was 0.1 μm and the effective area of the membrane 48.38 cm^2. The active membrane layer was made of thin zirconia layer deposited on a durable porous α-Al_2O_3 support.

2.2. Equipment and methods

The membrane experimental unit used in this study was with a circulating loop and is shown in Fig. 2. The suspensions were pumped from the feed tank into the stainless steel microfiltration module with a tubular

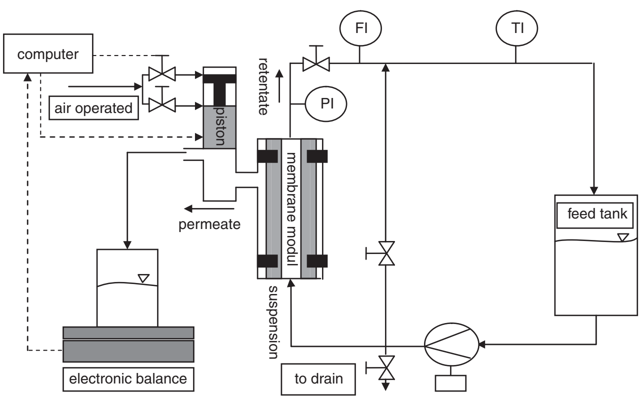


Fig. 2. Scheme of filtration unit.

ceramic membrane via a diaphragm pump with an adjustable flow rate. The values of the volumetric flow of suspension and output trans-membrane pressures (TMP) were measured by a flow meter and sensor, respectively. The velocity and pressure in the retentate loop were varied independently by means of pump controller and an appropriate needle valve.

The permeate was collected in a reservoir on the electronic balance and in regular time intervals the actual weight accumulated volume, the temperature, the pressure and the flow rate of suspension were logged into a computer. The retentate velocities was measured by flow meter and maintained constant. In the present study all retentate velocities suggestive a turbulent flow where Reynolds number (Re) was in the range of 5480<Re<17225. The permeate product was periodically returned to the feed tank to prevent change in the feed concentration. After each run the system was cleaned by circulating deionised water and membrane was mechanically cleaned. All experiments were carried out at ambient temperature.

Before filtration experiments the clean membrane flux J_w was experimentally determined with low-conductivity deionised water. From this value the membrane resistance R_m (1.53×10^{12} m^{-1}) was calculated using the Eq. (1)

$$R_m = \frac{\Delta P}{\mu_p \bullet J_w} \tag{1}$$

where μ_p is the dynamic viscosity of the permeate, J_w is the permeate flux for deionised water and ΔP is the transmembrane pressure (TMP).

The critical flux J_{crit} determinations were carried out using the step by step technique. For each velocity (u = 0.7, 1.1, 1.4, 1.8 and 2.2 ms^{-1}) and concentration (2, 5 and 10 gl^{-1}), the permeate flux was measured by changing the transmembrane pressure.

The backflushing was provided by using permeate water stored in the piston of the backflushing system using an air driven piston mechanism. The backflushing process for crossflow filtration is cyclic operation in which a period of forward filtration of duration t_F is followed by period of backflushing of duration t_B. The reverse flow removes particles reversibly deposited on or in the membrane and the foulants are swept away by the crossflow.

The net permeate flux during one period can be expressed by Eq. (2) [8,9]

$$J = \frac{\int_0^{t_F} J_F dt - \int_{t_F}^{t_F+t_R} J_R dt}{t_F + t_R} \tag{2}$$

where J_F and J_B are the forward and reverse fluxes respectively and t_F and t_R are periods of filtration and backflushing processes, respectively.

3. Results and discussion

Fig. 3 depicts the effect of changing transmembrane pressure on the flux. The transmembrane pressure was first increased at fixed intervals (25 kPa) and then decreased in time steps of 10 min. It can be seen that the flux measured after an increase followed by a decrease of the pressure (50 kPa) is below the flux recorded at the same TMP before the increase. The decrease of the flux at the same TMP is caused by the membrane fouling which occurred at higher transmembrane pressures and cannot be removed by a change of the hydrodynamic conditions.

The velocity and concentration of suspension influenced the value of the critical flux. Fig. 4 a) and b) shows the critical flux J_{crit} as a function of different concentrations and retentate velocity, respectively. With increasing velocity, the critical flux increased for all concentration. The increase of the concentration from 1 to 10 g.l^{-1} was significant and negative depending on the value of the critical flux. The results are consistent with other studies presenting that the value of critical flux decreases with increasing concentration [10,11].

The limiting flux was measured by changing the values of the transmembrane pressure and dependence of pressure on flux is shown in Fig. 5. Measurements were carried out for three different concentration (2, 5, 10 g.l^{-1}) and velocity 1.8 m.s^{-1}. The limiting flux for all concentrations was defined as the flux value which does not change with increasing transmembrane pressure. The transmembrane pressure was changed in steps of 10 kPa. Lower transmembrane pressure than 30 kPa could not be set up at given retentate velocity for technical limits of the filtration unit. The suspensions reached limiting fluxes at pressure of 40 kPa and as expected the higher concentrations of bentonite suspension gave lower values.

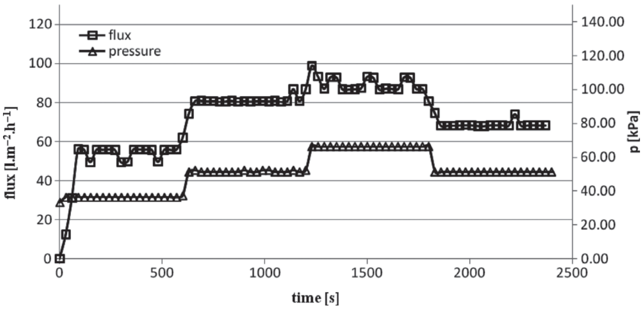
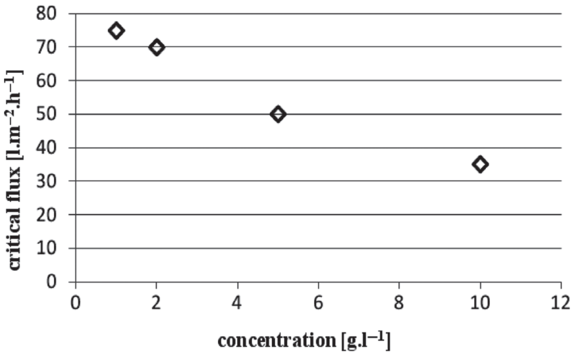


Fig. 3. Permeate flux as a function of time (u=2.2 ms^{-1}, c=2 g.l^{-1}).



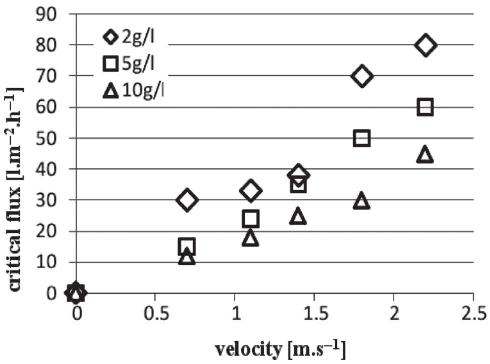


Fig. 4. Critical flux as a function of a) concentration and b) retentate velocity.

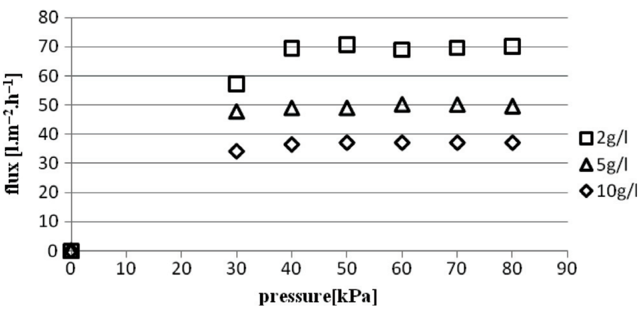


Fig. 5. Permeate flux as a function of pressure.

The steady-state permeate flux through the membrane as a function of the time is shown in the Fig. 6. The long term experiment was carried out with the suspension kept at 3 g.l^{-1}. The crossflow velocity was fixed at 1.8 ms^{-1} and transmembrane pressure at 50 kPa. In this test, the permeate product has not been periodically returned to the feed tank as the deionised water was continuously added there to prevent changes in the feed concentration. A quick flux decline has been observed after addition of a suspension into deionised water. This implies that no additional membrane fouling occurred

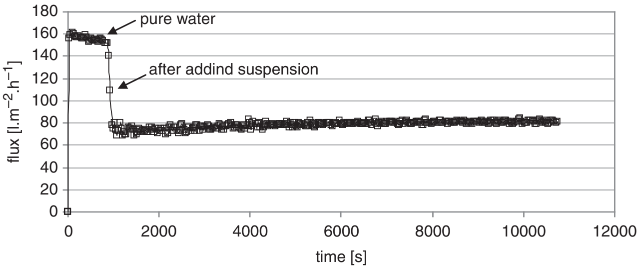


Fig. 6. Permeate flux as a function of time (c= 3 g.l^{-1}, u=1.8 ms^{-1}, Δp=50 kPa).

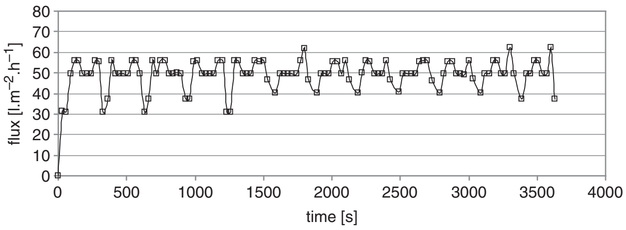


Fig. 7. Backflush of bentonite suspension (c= 5 g.l^{-1}, u=1.8 ms^{-1}, Δp=50 kPa).

after a short filtration time. This result is in contrast to that reported by Xu et. al. [12] with microfiltration of alumina particles where the steady-state was achieved after 2 h, but on the other hand is similar as observed by Hwang et al. [13] during microfiltration of dextran.

The backflushing test was performed at constant operating parameters, Δp=50 kPa; u=1.8 ms^{-1} with the suspension 5 g.l^{-1}, t_R=1 s with frequency equal to 5 min and the negative transmembrane pressure difference during the reverse flow was set to 400 kPa. The effect of backflushing on flux restoration is shown in Fig. 7. It can be seen that the flux has not been restored by backflushing under these filtration conditions, in addition it was decreased by backflush of permeate. The result is in contrast to that observed by Zhao et al. during microfiltration of fine TiO_2 particles with 1 μm pore-size membrane, where backpulsing pressure was found to have significant influence on the extent of flux restoration [14].

4. Conclusions

In this study, the critical fluxes for Bentonite particle suspensions of different concentration were determined by changing the transmembrane pressure in defined time steps. Significant increases in critical flux were recorded during filtration with high retentate velocity for all concentrations. The increase of concentration on the other hand caused a decrease of the critical fluxes. The steady-state values were reached very quickly after adding of suspension to the deionised water. The influences of backflushing duration and its frequency were not significant thus backflushing is not a suitable method to the flux restoration for grinded particles of bentonite.

Acknowledgements

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References

[1] R.W. Field, D. Wu, J.A. Howell and B.B. Gupta, Critical flux concept for microfiltration fouling, J. Membr. Sci., 100 (1995) 259–272.
[2] H. Li, A.G. Fane, H.G.L. Coster and S. Vigneswaran, Direct observation of particle deposition on the membrane science during crossflow microfiltration, J. Membr. Sci., 149 (1998) 83–97.
[3] H.K. Vyas, R.J. Bennett and A.D. Marshall, Influence of feed properties on membrane fouling in crossflow microfiltration of particulate suspensions, Int. Dairy J., 10 (12) (2000) 855.
[4] H.K. Vyas, R.J. Bennett and A.D. Marshall, Performance of crossflow microfiltration during constant transmembrane pressure and constant flux operations, Int. Dairy J., 12 (5) (2002) 473.
[5] M.Y. Lee and M. Clark, Modeling of flux decline during crossflow ultrafiltration of colloidal suspensions, J. Membr. Sci., 149 (1998) 181–202.
[6] A.S.C. Chen, J.T. Flynn, R.G. Cook and A.L. Casaday, Removal of oil, grease and suspended solids from produced water with ceramic crossflow microfiltration, SPE Prod. Eng., (1991) 131–136.
[7] N. Mugnier, J.A. Howell and M. Ruf, Optimisation of a backflush sequence for zeolite microfiltration, J. Membr. Sci., 175 (2000) 149–161.
[8] J. Cakl, I. Bauer, P. Doleček and P. Mikulášek, Effects of backflushing conditions on permeate flux in membrane crossflow microfiltration of oil emulsion, Desalination, 127 (2000) 189–198.
[9] M. Héran and S. Elmalech, Prediction of cross-flow microfiltration through an inorganic tubular membrane with high-frequency retrofiltration, Chem. Eng. Sci., 56 (2001) 3075–3082.
[10] H. Li, A.G. Fane, H.G.L. Coster and S. Vigneswaran, Assesment of depolarization models of crossflow microfiltration by direct observation through the membrane, J. Membr. Sci., 172 (2000) 135–147.
[11] D.Y. Kwon, S. Vigneswaran, A.G. Fane and R. Ben Aim, Experimental determination of critical flux in cross-flow microfiltration, Separation and Purification Technology, 19 (2000) 169–181.
[12] N. Xu, Y. Zhao, J. Zhong and J. Shi, Crossflow microfiltration of micro-sized mineral suspensions using ceramic membranes, Institution of Chemical Engineers, Trans IchemE, vol 80, Part A, March 2002.
[13] K.J. Hwang and P.S. Hung, Cross-flow microfiltration of dilute macromolecular suspension, Sep. Purif. Technol., 68 (2009) 328–334.
[14] Y. Zhao, J. Zhong, H. Li, N. Xu and J. Shi, Fouling and regeneration of ceramic microfiltration membranes in processing acid wastewater containing fine TiO_2 particles, J. Membr. Sci., 208 (2002) 331–341.