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Impact of Pressure and Gas Flow Rate on the Flow Pattern of Zeolite Suspension

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***Abstract*—The use of membrane processes is wide nowadays and the emphasis on the elimination of problems arising from the application of these processes is increasing. In membrane processes a fairly serious problem is concentration polarization and the associated membrane fouling. This effect can be suppressed or even removed by several methods. One of the methods used and studied is injection of air into the microfiltration device. In our experiments the influence of pressure, gas flow and suspension concentration on the flow patterns through membrane device with membrane replaced by transparent PVC tube was studied. Measurements were made with distilled water, suspensions of zeolite from Nižný Hrabovec (SK) at different concentrations. The pressure and gas flow were varied at each suspension concentration. The changes in the flow patterns were monitored. In experiments slug flow occurred under the most of the conditions though. Based on the experimental results it can be concluded that the injection of air into the suspension can be very important in reducing membrane fouling.**

***Index Terms*—flow pattern, fouling, microfiltration, zeolite.**

I. INTRODUCTION

Crossflow microfiltration is an effective and energy-efficient separation method. It allows separation of very fine particles from suspensions in the range of 0.1 -10 microns. Crossflow microfiltration has several advantages but in practice a fundamental problem - the membrane fouling often encounters. Membrane fouling is caused by a decrease in the flow and thereby the efficiency of separation is reduced. Several studies were devoted to membrane fouling reduction and improvement of the flux. These methods include increase of the filtration rate, injection of gas into the liquid, Dean or Taylor vortices, backwashing, obstacles in the channel of the membranes and other. The most promising are the injection of gas into the liquid and backwashing [1], [2].

Membrane fouling is caused by settling and slow accumulation of particles of larger size than the pores of the membrane on the surface. They form a highly concentrated layer – so called Stefan's layer. Due to the formation of the Stefan's layer, accumulation of suspension at the membrane surface occurs. In some cases it leads to irreversible fouling. The filter cake is composed of different mixtures of inorganic or organic substances (such as polysaccharides, proteins, etc.) or filtered microorganisms, depending on the filter material [3] – [5].

Concentration polarization resulting in high flow but low mass transfer coefficients has a significantly negative impact on microfiltration. These are caused by small diffusion coefficients of macromolecular substances, small particle sizes, emulsions and colloids. Several authors confirmed that the formation of a filter cake can be significantly reduced by shear stress generated by injecting gas into the filter circuit. Air (gas) injection improves the hydrodynamic conditions near the membrane surface and reduces concentration polarization layer (filtration cake). The results proved that the flux was improved by changing the conditions – use of multiphase microfiltration, low rate of liquid flow and medium rate of the air injected [6], [7].

Studies dealing with multi-phase flows are mainly experimental and aimed at improving conditions in microfiltration and ultrafiltration [8].

A study [9] showed that the reduction of the concentration polarization can be achieved in three different ways as follows:

- changes in the surface characteristics of the membrane,
- batch pre-treatment,
- fluid management methods.

The article is aimed on monitoring the flow patterns of three-phase solid-liquid-gas flow of suspensions of zeolite from Nižný Hrabovec (SK) at the concentrations of 10, 20, and 30 $g.l^{-1}$. The pressure (0, 100, 200 kPa) and gas flow (0.5, 1, 1.5 and 2 $m^3.h^{-1}$) were varied at each suspension concentration. The changes in the flow patterns were monitored.

II. MATERIALS AND METHODS

A. Zeolite

Zeolite used for the experiments is from the Nižný Hrabovec (SK) localization. The zeolite from the Nižný Hrabovec localization is a natural rock, which principal part is composed of crystalline hydrated aluminosilicate of alkaline metals and metals of alkaline soils (Ca, K, Na, Mg) so-called clinoptilolite. The structure of the clinoptilolite is based on the three dimensional skeleton consisting of $(SiO_4)^{4-}$ tetrahedrites interconnected via oxygen atoms, while a part of silicon atoms is replaced with $(AlO_4)^{5-}$ aluminium atoms. The mean chemical composition of zeolites is presented in Table 1.

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Table 1 - The mean chemical composition of zeolite

SiO_2	65.00 - 71.30 %	**MgO**	0.60 -1.20 %
Al_2O_3	11.50 - 13.10 %	**Na_2O**	0.20 - 1.30 %
CaO	2.70 - 5.20 %	**TiO_2**	0.10 - 0.30 %
K_2O	2.20 - 3.40 %		
Fe_2O_3	0.70 - 1.90 %	**Si/Al**	4.80 - 5.40 %

The particle size distribution of zeolite was estimated by a particle sizer Analysette 22 (Fritsch, D). The particle size distribution of the adsorbents used is presented in Fig. 1.

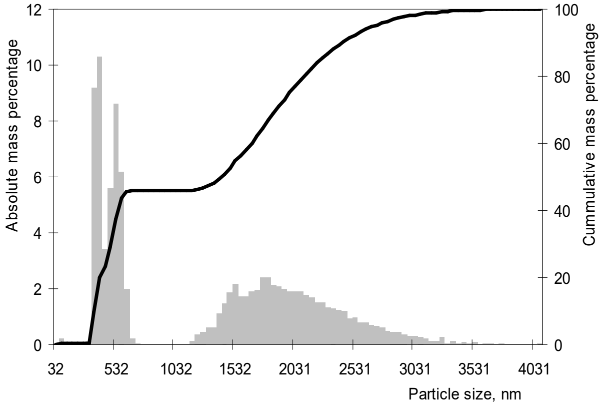

Fig. 1 – *Particle size distribution of zeolite particles.*

B. *Microfiltration*

The experimental measurements were carried out using the device schematically shown in Fig. 2.

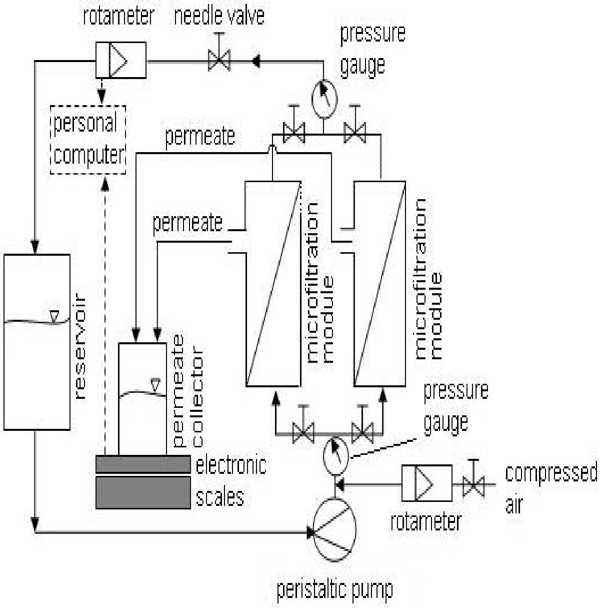

Fig. 2 – *Scheme of microfiltration device.*

In the microfiltration equipment the suspension of different concentrations was drawn from a reservoir of 4 litres volume by diaphragm plunger pump with frequency converter. The feed flowed into the membrane module vertically positioned with a tubular ceramic membrane microfilter. The gas was injected into the feed prior to the microfilter through a pipe of 1.3 cm in diameter direct. The device was equipped with two membrane modules for single-channel and multi-channel membranes arranged in parallel due to their different parameters. Each segment was used separately. Permeate flowing from the module was collected in a glass container placed on electronic scales that have been linked with a communication port. The retentate flowed back into the storage container. After the membrane module a pressure sensor which measured the pressure of flowing suspension above the membrane was placed. This pressure was set by the control valve. Feed flow rate in the membrane was measured by a flow metre in the retentate part.

III. EXPERIMENTAL

A blank experiment using demineralised water (DW) for the microfiltration was carried out before each experiment.

In these experiments the suspensions of zeolite was used for experiments while the experiments were carried out under the conditions in Table 2. The process parameters were selected in accordance with the construction characteristics of the microfilter so that it was possible to compare the impact of two-phase flow onto the microfiltration. Measurements were carried out with a liquid-gas two-phase and solid-liquid-gas three-phase flow with selected parameters.

IV. RESULTS AND DISCUSSION

From the experiments it appears that not all modes observed under given conditions correspond to the theoretical flow regimes estimated based on the calculated injection factor ε. The patterns presented in Figs. 3-8 are contradictory to the theoretical findings presented in Table 1. For this reason they were selected and described in more details.

Fig. 3 – *The observed flow patterns in water without addition of zeolite at 100 kPa.*

6). Also at a flow rate of 2.0 $m^3.h^{-1}$ churn flow was observed.

Table 2 – An overview of injection factors ε and flow patterns for the measurements.

Pressure [kPa]	**Gas flow [$m^3.h^{-1}$]**	**DW**		**DW+ 36g of zeolite**		**DW + 72 g of zeolite**		**DW +108 g of zeolite**	
		ε	**flow**	ε	**flow**	ε	**flow**	ε	**flow**
0	**0.5**	0.45	slug	0.74	slug	0.51	slug	0.51	slug
	1.0	0.63	slug	0.85	slug	0.68	slug	0.67	slug
	1.5	0.71	slug	0.90	churn	0.76	slug	0.75	slug
	2.0	0.77	slug	0.92	churn	0.81	slug	0.80	slug
100	**0.5**	0.50	slug	0.23	bubble	0.62	slug	0.60	slug
	1.0	0.67	slug	0.37	plug	0.76	slug	0.75	slug
	1.5	0.75	slug	0.47	slug	0.83	slug	0.82	slug
	2.0	0.80	slug	0.54	slug	0.87	churn	0.86	churn
200	**0.5**	0.56	slug	0.17	bubble	0.63	slug	0.49	slug
	1.0	0.71	slug	0.28	plug	0.78	slug	0.66	slug
	1.5	0.79	slug	0.37	plug	0.84	slug	0.74	slug
	2.0	0.83	slug	0.44	slug	0.87	churn	0.79	slug

In experiments with DW without addition of zeolite at pressure of 100 kPa these are particularly the cases of 0.5 $m^3.h^{-1}$ and 1.0 $m^3.h^{-1}$. According to the theoretical presumption both are slug flow but there were bubble flow observed (Table 2 and Fig. 3).

Flow of DW without addition of zeolite at pressure of 200 kPa and flow rate of 0.5 $m^3.h^{-1}$ almost no bubbles were observed (Fig. 4) though according to calculations it is also slug flow. At a flow rate of 2.0 $m^3.h^{-1}$ the flow regime resembled rather churn flow than slug flow, since ε was 0.83 which is close to the limit between the churn and slug flows.

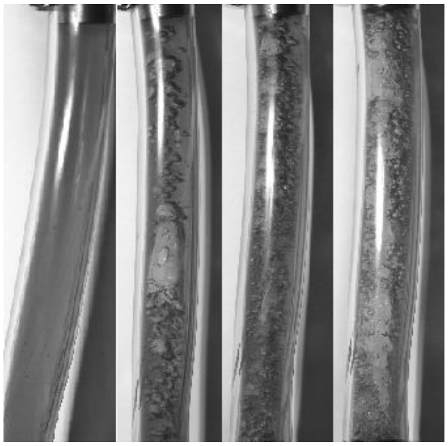

Fig. 4 – *The observed flow patterns in water without addition of zeolite at 200 kPa.*

Series of experiments at the concentration of zeolite 10 $g.l^{-1}$ were in accordance to the theoretical flow regimes (Table 2) except those at the pressure of 100 kPa (Fig. 5). At the flow rate of 0.5 $m^3.h^{-1}$ no pattern was observed, while at flow rates of 1.5 and 2.0 $m^3.h^{-1}$ churn and annular flows were observed instead slug flow (ε = 0.47 and 0.54, respectively).

In the series of experiments with suspension of zeolite with concentration of 20 $g.l^{-1}$ it was more difficult to observe the flow regimes. Irregularities at pressure of 0 kPa were especially at flow rates of 0.5 and 1.0 m^3h^{-1}. It should be slug flow theoretically; however, bubble flow was observed (Fig. 6).

Fig. 5 – *The observed flow patterns in suspension with addition of 10 $g.l^{-1}$ of zeolite at 100 kPa.*

Also at pressure of 200 kPa mismatches were observed with the calculated values in Table 2. At flow rates of 0.5 and 1.0 $m^3.h^{-1}$ bubble flow was observed. At a flow rate of 2.0 $m^3.h^{-1}$ slug flow was observed (Fig. 7).

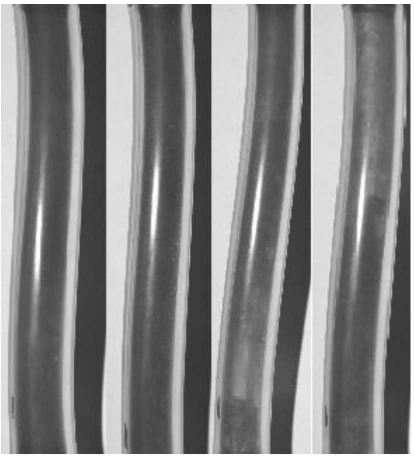

Fig. 6 – *The observed flow patterns in suspension with addition of 20 $g.l^{-1}$ of zeolite at 0 kPa.*

In a series of experiments with the suspension of concentration of 30 g.l^{-1} the flow patterns were corresponding with the calculated values despite the poor visibility. The only exception was at experiment with pressure of 0 kPa and flow rate of 0.5 m^3.h^{-1} (Fig. 8), where bubble flux was observed.

Fig. 7 – *The observed flow patterns in suspension with addition of 20 g.l^{-1} of zeolite at 200 kPa.*

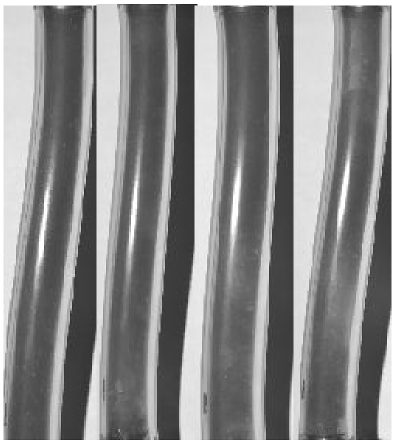

Fig. 8 – *The observed flow patterns in suspension with addition of 30 g.l^{-1} of zeolite at 0 kPa.*

V. CONCLUSION

The changes to the flow in microfiltration are a very important factor affecting membrane fouling and the efficiency of membrane processes. In experiments slug flow occurred under the most of the conditions though in some cases described above the theoretical flow found by calculating the injection factor ε was not consistent with the experimental results. This fact was probably caused by poor visibility, imperfection of the device, etc. Based on the experimental results it can be concluded that the injection of air into the suspension can be very important in reducing membrane fouling. But it is necessary to further examine the factors that materially affect the flow regimes in microfiltration systems.

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