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EFFECT OF PRESSURE GRADIENT ON THE MEMBRANE SEPARATION IN CERAMIC MICROFILTRATION MEMBRANE – FCCER

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ABSTRACT: *Manufacturing would be unthinkable without quality water. During production, the water contains various substances and impurities which can adversely affect final product quality. Therefore, due to their excellent ability to remove particles such as molecules, ions, macromolecular materials, colloidal particles and microparticles are membrane separation processes, such as microfiltration, ultrafiltration, nanofiltration and reverse osmosis widely used in various industries. Driving force in membrane processes is the pressure gradient. Industrial production has high demands not only on quality but also on quantity of purified water. This fact could in industrial application of membrane processes result in increased energy costs. Therefore the aim of this work was to assess the effect of transmembrane pressure on the membrane separation. Experiment was carried on ceramic microfiltration membrane – FCCER membrane. In experiment suspensions with concentrations of 1, 3, 5, 10, 12 and 15 % were used. Suspensions were created by mixing dry industrial sludge with distilled water. Experiment has shown that the pressure gradient has a significant effect on membrane separation.*
KEYWORDS: *microfiltration, pressure gradient, FCCER membrane, sludge*

INTRODUCTION

Membrane separation processes are giving us opportunity to divide products created at various stages of production. At present, the microfiltration separation is widely used in food and pharmaceutical industries. Microfiltration as well as ultrafiltration, nanofiltration and reverse osmosis are membrane separation processes, which are driven by pressure gradient force, ΔP_{TM}, which is a pressure difference applied in perpendicular direction toward the membrane surface. [4, 7]

Microfiltration is capable of removing particles whose size ranges from 0.1 to 10 um (colloidal particles, bacteria) from filtered media. The aim of this study was to assess the effect of pressure gradient on the membrane separation carried out on ceramic microfiltration membrane – FCCER membrane.

THEORETICAL

A characteristic feature of membrane separation process is a gradual decline in permeate flow through the membrane. This decrease is caused by phenomenon known as membrane fouling. [3]

The flow of permeate through the micro and ultrafiltration membrane is proportional to the used pressure and can be expressed using modified Darcy's equation [6]:

$$J = \frac{\Delta P_{TM}}{\mu(R_m + R_c)} \qquad (1)$$

where R_m is the resistance of the membrane and R_c is the resistance, which arises due to membrane fouling. Membrane resistance can be expressed as:

$$R_m = \frac{\Delta P_{TM}}{J\mu} \qquad (2)$$

where ΔP_{TM} is transmembrane pressure, J is density of the permeate flux and μ is dynamic viscosity. Additional resistance of the membrane, which arises from fouling, can be expressed as:

$$R_c = \frac{\Delta P_{TM}}{J\mu} \quad R_m \qquad (3)$$

where ΔP_{TM} is transmembrane pressure, J is density of the permeate flux, μ is dynamic viscosity and R_m is the resistance of the membrane.

For laminar flow in a porous system Hagen - Poiseuille and Kozeny - Carman equation can be applied [2]. If we consider that the membrane pores are cylindrical, it is possible to calculate the volume flow of permeate through the membrane (N_V):

$$N_v = \frac{\varepsilon d_p^{\,2}}{32\mu\eta\delta_M}\Delta P \qquad (4)$$

where ε is the porosity of the membrane, d_p is the diameter of cylindrical pores of the membrane, μ is the viscosity of the liquid phase, η is membrane tortuosity (η ≥ 1), δ_M is thickness of the membrane, and ΔP is the transmembrane pressure. For the transfer of substances through the membrane with a spongy or sintered particle structure Kozeny - Carman equation can be used:

$$N_v = \frac{\varepsilon^3}{K_K(1-\varepsilon)^2 a_s^{\,2}\delta_M}\Delta P \qquad (5)$$

where ε is the porosity of the membrane, μ is the viscosity of the liquid phase, δ_M is the thickness of the membrane, ΔP is transmembrane pressure, a_s is the specific internal membrane surface (a_s = 6/dP) and K_K is Kozeny-Carman constant (for ceramic membrane K_K = 13).

EXPERIMENTAL

Flux density of distilled water is directly proportional to the used transmembrane pressure. For suspensions with given concentration is this dependence non-linear. During all experiments suspensions (crushed dry sludge mixed with distilled water) with concentrations of 1, 3, 5, 10, 12 and 15 % were used. Industrial sludge used had the following chemical composition (see Table 1).

Table 1: Chemical composition of sludge

SIO_2	3,4 %
Al_2O_3	0,84 %
Fe_2O_3	49,87 %
CaO	19,35 %
MgO	1,81 %

Chemical analysis of sludge also included a determination of annealing loss. Resulting value was 21.36 %. Physical analysis of the sludge was carried out using sieve analysis. The most frequently occurring size of grains was 85 μm (see Figure 1).

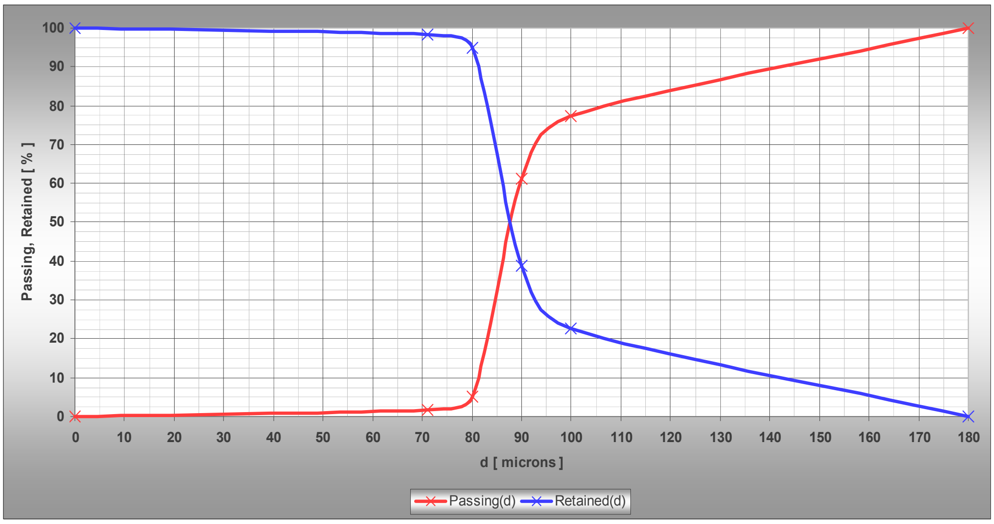

Figure 1: Grain size (distribution) curve

Experiments to determine the characteristics of different sludge concentrations were carried out in the microfiltration module using ceramic microfiltration membranes FCCER, which is capable of capturing 99.8% of particles with size above 0.3 μm. [8] MF module was then set up according to below schematic.

In experiment the 10 liter storage tank with diameter of 250 mm was used. It was then filled up with 5 liters of prepared sludge

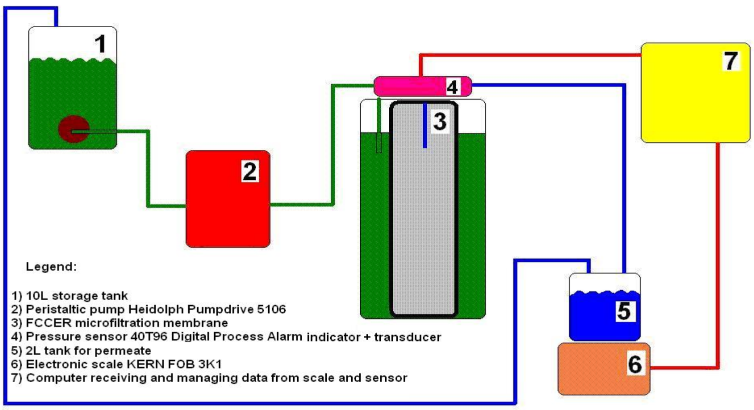

Figure 2: Microfiltration schematic

suspension with concentration of 1, 3, 5, 10, 12 and 15 %. Pressure in MF module was controlled by variable speed peristaltic pump Heidolph Pumpdrive 5106 and measured with digital pressure sensor 40T96 Digital Process Alarm Indicator + transducer. Retentate from microfiltration was returned to the storage tank.

Permeate was drained into a beaker placed on an electronic weight KERN FOB 3K1 where its weight was noted in given time intervals. Control experiments were conducted on distilled water and effect of pressure on membrane separation was observed (see Figure 3).

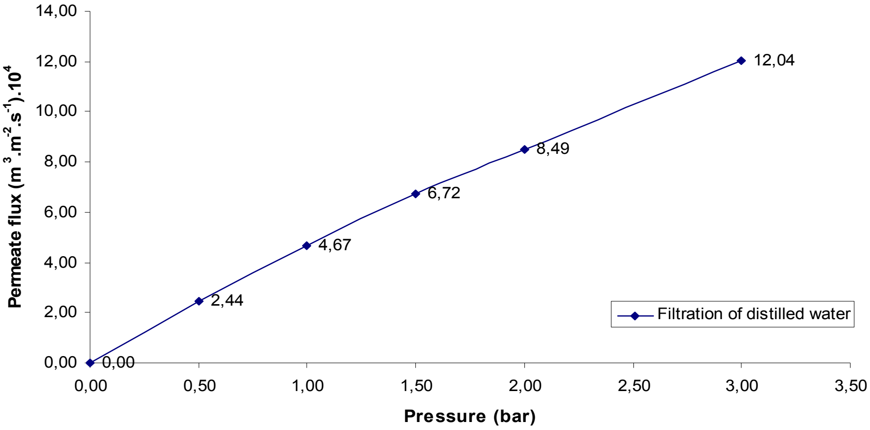

Figure 3: Control experiments with distilled water

Distilled water contains zero physical contaminants therefore the resulting permeate flux is proportional to the applied transmembrane pressure. All other measurements were conducted on prepared suspension with concentration of 1, 3, 5, 10, 12 and 15 % at pressures 0.5, 1, 1.5, 2 and 3 bar.

RESULTS AND DISCUSSION

Conducted experiments showed that increase of suspension concentration results in decrease of permeate flow rate and additional pressure is needed for its restoration. Experiments also demonstrated that the pressure gradient has a significant effect on membrane separation.

In filtration of 1% suspension (Figure 4), significant decline in permeate flux is recorded when compared with control experiments with distilled water. It can be observed that the permeate flow was linearly increasing when pressure was up to 1 bar. At the pressure of 2 bar, the permeate flux of suspension was constant and when pressure was increased to 3 bar no notable change happened.

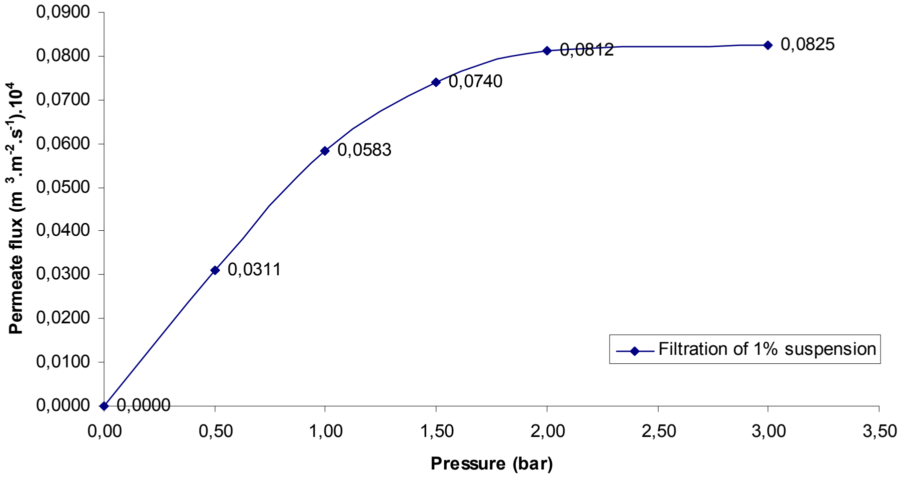

Figure 4: Filtration of 1% suspension

After increasing the concentration of the suspension to 3 % (Figure 5), at filtration pressure of 0.5 bar linear flow of permeate is observed. Figure 5 also shows that beyond this point further increase in pressure caused the permeate flow to rise non-linearly.

In filtration of 5 % suspension, at a pressure of 0.5 bar permeate flux rose linearly. Beyond this point further increase in pressure caused the permeate flow to rise non-linearly. Between the pressure of 2-3 bar the permeate flow was constant and no further grow in permeate flux was registered (see Figure 6).

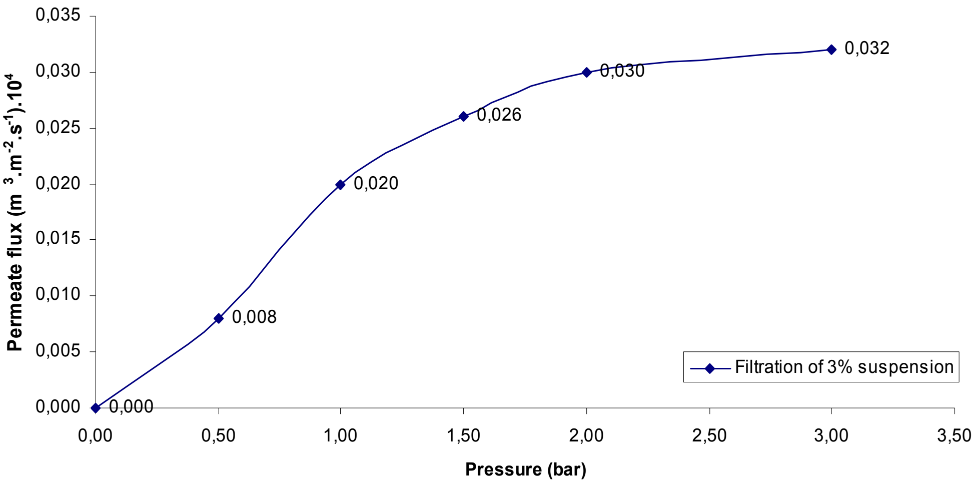

Figure 5: Filtration of 3% suspension

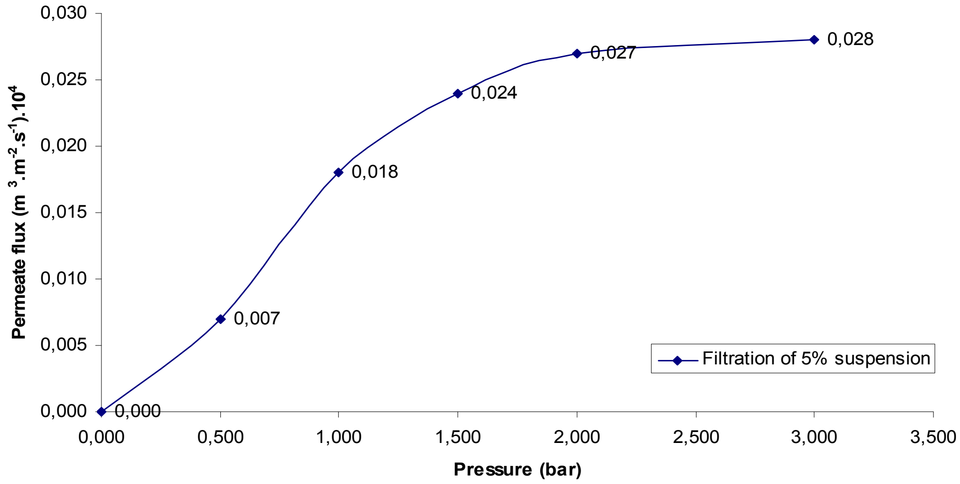

Figure 6: Filtration of 5% suspension

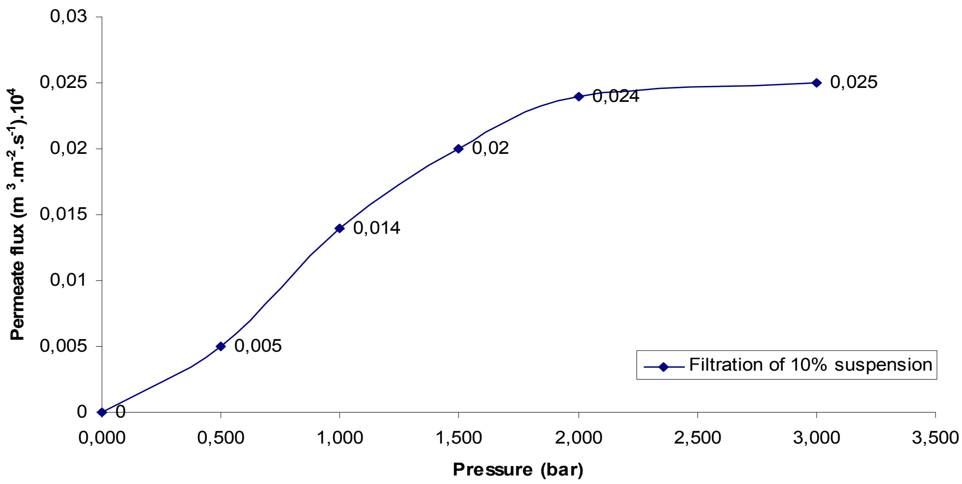

Figure 7: Filtration of 10% suspension

After further increase in concentration of suspension up to 10 % (Figure 7) again at a pressure of 0.5 bar permeate flux rose linearly. Beyond this point further increase in pressure caused the permeate flow to rise non-linearly. Same behavior of permeate flux was observed when concentration of suspension was increased to 12 % (Figure 8). Between the pressure of 2-3 bar the permeate flow was constant.

In the last experiment (Figure 9). Suspension concentration was increased to 15 %. Here again at a pressure of 0.5 bar permeate flux rose linearly. Beyond this point further increase in pressure caused the permeate flow to rise non-linearly. Between the pressure of 2-3 bar the slight rise in permeate flow was observed.

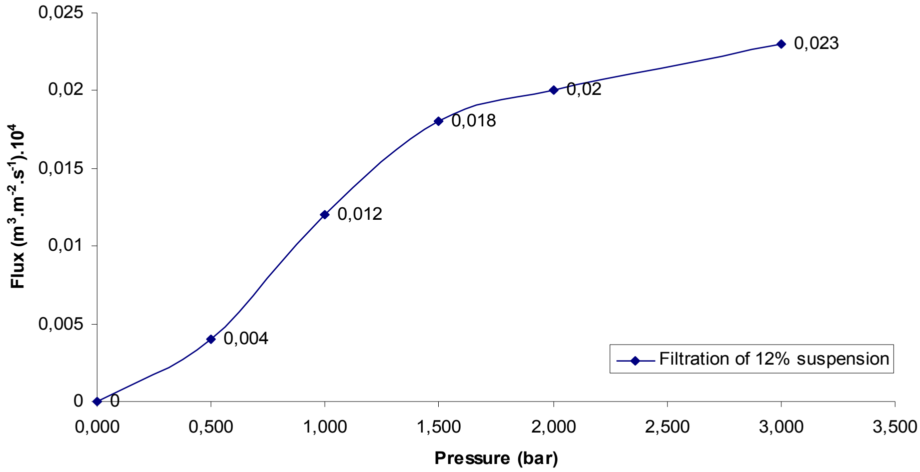

Figure 8: Filtration of 12% suspension

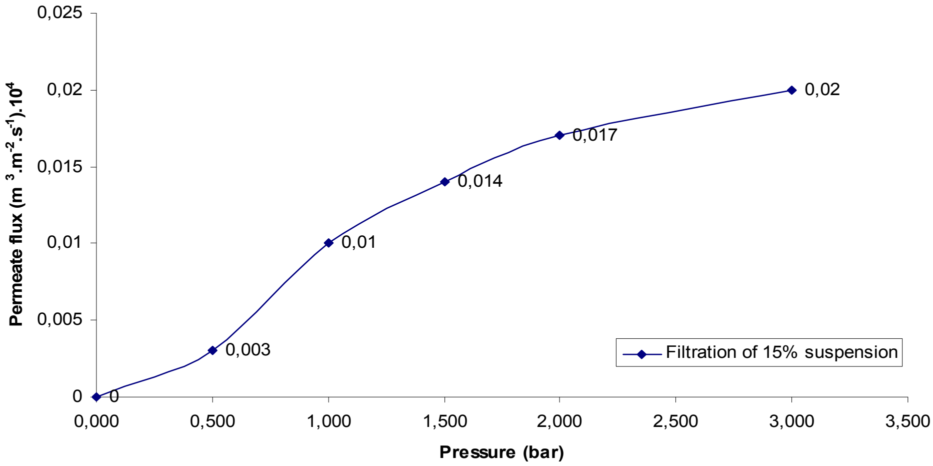

Figure 9: Filtration of 15% suspension

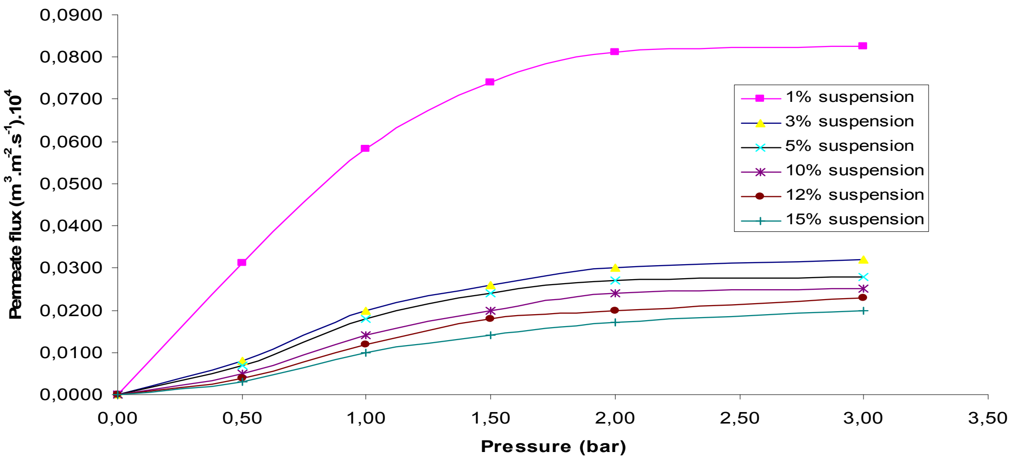

Figure 10: Summary filtration graph

Figure 10 shows summary graph of all monitored suspension concentrations and their effect on permeate flux. It is noticeable that permeate flow is greatly influenced by concentration of suspension and the pressure used in a microfiltration module. Increasing pressure of suspension in a microfiltration module results in increases of the permeate flux.

CONCLUSIONS

The aim of this work was to assess the effect of pressure gradient on the membrane separation - microfiltration. Experiments with suspensions of sludge with concentrations of 1, 3, 5, 10, 12 and 15% were carried out on ceramic membrane FCCER. Measurements were conducted at given suspension pressures 0.5, 1, 1.5, 2 and 3 bar.

Experiments have shown that the transmembrane pressure has a significant effect on the membrane separation. Increasing transmembrane pressure results in increase of the volume of *permeate flow. In control experiments with distilled water permeate flow depended on applied pressure. This dependence was linear. In experiments conducted on suspensions the linear dependence was only observable up to a certain "critical" point. In our case, this critical point was at pressure of 0.5 bar. Beyond this point dependence was non-linear. This means that with increasing concentration of the suspension the permeate flow rate decreases.*

Industrial production has high demand on quantity of purified water. In this case the loss of permeate flow is an undesirable condition which must be corrected by pressure increase. This operation increases the industry energy costs. Therefore the aim of the current research teams and individuals is to achieve the best separation using the lowest possible pressure. [1, 5, 9]

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