Investigations on fouling reduction by air dispersion in spiral wound and submerged flat sheet microfiltration membranes

T.M. Qaisrani[*a] and W. M. Samhaber[a]

[a] Institute of Process Engineering, A-4060 Leonding, Welser Str. 42, Johannes Kepler University, Linz, Austria.

[*]Corresponding author. Tel:- +43-70-672509-12; fax:- +43-70-672509-5 e-mail: tahir.qaisrani@jku.at

Abstract

Application of air dispersion has been found to be effective for the reduction of fouling and enhancement of permeate flux for different membrane geometries and modules. Most of the work has been carried out on hollow fiber and tubular membrane but less attention has been paid to the submerged flat sheet membranes and open channel spiral wound modules. The present study focuses on the reduction of fouling with air dispersion in spiral wound module with open channel spacer as preliminary study for submerged flat sheet module. The effect of air to liquid ratio was studied on flux enhancement, specific cake layer resistance and pressure drop across the membrane module. The yeast suspension was prepared with commercial yeast with a dry mass concentration of 0,6 percent weight by volume. The air was injected in a continuous mode throughout the experiment. A flux enhancement of 170% was observed while the pressure drop due to air injection was found to be 10%. The permeate flux increased with increasing the air flow rate up to a certain value after which there was no further increase in the flux. It was observed that there was a very low pressure drop of 6-8 kPa across the module when air was injected in the system. The results of this study will help to characterize the air-liquid two-phase flow for control of fouling in the submerged flat sheet pilot-scale module.

Keywords: Two-phase flow; fouling control; cross flow microfiltration; yeast suspension; spiral wound module

1 Introduction

The application of cross flow MF process is increasing rapidly throughout the world for separation of fine solids from suspension which can not be separated by traditional separation techniques like settling, sedimentation, centrifugation and filtration. Concentration, clarification and purification processes in fruit juice, food, beverages & water processing industries involve suspensions with very fine particles. Cross flow microfiltration and ultrafiltration processes are most suitable for filtration of such suspensions.

Fouling of the membranes induced by particulate deposition, surface adsorption and pore blocking is the major limitation which hampers the performance of microfiltration membranes. The use of air/gas dispersion in microfiltration process is getting more attention in the present day research for its potential to control the fouling by increasing turbulences on the membrane surface. The use of air dispersion in hollow fiber [11] and tubular membranes [1, 10] has been found to be effective in reducing the fouling and enhancing the permeate flux. Two phase air-liquid flow generates a slug flow regime in these modules which has been found to be most effective in controlling the fouling. Cui and Wright [8] showed up to a 175% increase in permeate flux in yeast microfiltration. Mercier et al [9] applied slug flow to get a significant increase in the permeate flux. In another study, Mercier et al [10] showed 3 time increase in the permeate flux in ultrafiltration of bentonite and yeast suspension by air dispersion.

1.1 Control of fouling

The cake layer formed by particle fouling can be removed by chemical treatment. But the major drawback of chemical cleaning is that it requires stoppage of the process and membrane is to be isolated from the process fluid. This has stimulated an increased interest for use of hydrodynamic techniques for control of fouling. These techniques include back-flushing, pulsatile flow, air dispersion, etc. The pore blocking and the adsorption of solids can only be removed either by back-flushing or by application of suitable chemicals. While the external fouling, that is, cake layer on membrane surface is influenced by main flow characteristics like flow velocity and applied pressure. As found in the work of M. Mercier-Bonin, et al [13], high wall shear stresses and low and uniform transmembrane pressure (TMP) have been found to be good hydrodynamic conditions to improve the performances of microfiltration processes. There are many other proposed techniques like:

turbulence promoters [3], rotating membranes [4], Dean Vortices [7] along with unsteady flows, such as pulsating flows [3, 5] and intermittent jets [6]. Although the efficiency of the microfiltration process is improved by the above mentioned techniques, but the industrial application of such solutions is limited by technological aspects [13]. An other possibility is the continuous injection of air in order to generate two-phase air-liquid flow with unsteady characteristics to control the formation of cake layer on the membrane surface.

Fouling of the membrane can be controlled if the deposition of particles on the membrane surface is controlled. The deposition of particles on membrane surface is dependent upon the degree of adhesion forces between the particles and the membrane surface. The adhesion forces responsible for deposition of particles on membrane surface are in balance with the shear forces present on membrane surface due to cross flow. It means that by altering the flow regime from laminar to highly turbulent will be beneficial for preventing the deposition of particles on membrane surface. Dispersion of air causes high turbulences by generating bubbles along the membrane due to which deposition of particles on membrane surface decreases.

The spiral wound geometry with open channel spacers generates very high turbulence in the liquid stream and is considered to be effective for control of fouling. The spacers in spiral wound assembly create a feed-channel between facing membrane leaves & promote turbulent flow which reduces fouling phenomena. Osmonics produced first spiral wound element made form Polypropylene in early 80’s with open channel spacers with product code 52T-Y which are shown in figure 1. The effectiveness of air-liquid two-phase for control of fouling in spiral wound modules with different types of spacers needs to be studied in depth for finding whether this technique can reduce membrane fouling and if so then to find out an optimum air to liquid ratio for reduction of fouling and enhancement of permeate flux. Therefore the aim of present work is to investigate the effect of air-liquid two-phase flow on fouling control and flux enhancement in spiral wound module with open spacer in a closed system. The results attained from this study will be applied to experiments on submerged flat sheet module.

Fig-1 Two views of the first ever spiral wound element with open channel spacers by Osmonics (now GE Hydraulics and Water Technology, USA)

2 Experimental

2.1 Materials

Baker’s yeast suspension was used as test suspension. Yeast is composed of almost spherical particles with a mean diameter of 4.2 μm [12]. Yeast was chosen as a model suspension due to its well-defined granulometric properties. No previous washing of the yeast suspension was carried out in order to evaluate the fouling capacity of both the yeast cells and the extra cellular macromolecules (mainly proteins) which could cause more adhesive cake and severe fouling on the membrane surface. Yeast was used with a dry mass concentration of 0,6% weight/volume.

2.2 Membrane module

A bench-mounted spiral wound module was used for the experimentation. PVDF microfiltration elements of type JX 2540 COS from Desalination later named as Osmonics and now, GE Water Technology, USA, with an effective area of 1.01m^2 were used for these tests. The open channel spacer used was of diamond & ladder shape. The pore size of the membrane was 0.3 µm. The membrane was cleaned chemically with enzymatic membrane cleaner before start of each experiment.

2.3 Experimental apparatus

Fig-2 illustrates the experimental setup for testing of yeast. The temperature of the feed tank was kept constant by continuous tape water circulation in the water jacket of the tank. A positive displacement pump (an eccentric helical rotor pump from Bornemann, of type EL-236) was used to circulate the feed flow. The air was injected at the outlet of the pump in order to ensure complete dispersion of air in the liquid for generating two-phase flow in the membrane module. In order to monitor any pressure drop due to air dispersion, a differential pressure measuring pressure gauge was installed at the high pressure side of the module.

For turbidity measurements, WTW-Turb 550 turbidity meter was used. The concentration of solids was calculated as function of turbidity. The suspension system was passed through a 5 µm filter before processing through the membrane. Pure water flux was measured and recorded before starting the filtration of suspension. Pure water flux provides the reference to assess the effectiveness of the membrane cleaning. All experiments were conducted in recirculation mode. Both permeate and retentate were recirculated in the feed tank while the permeate flow was measure volumetrically.

.

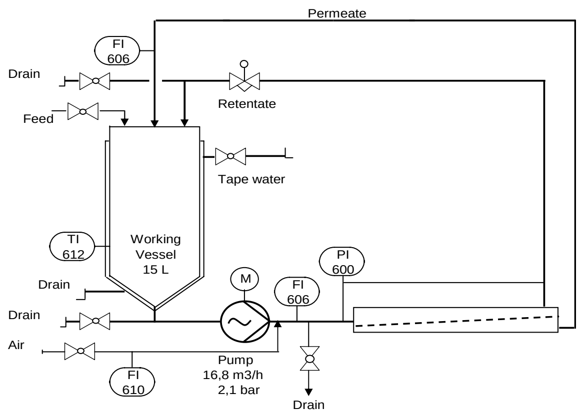

Fig-2 Schematic diagram of experimental set up for microfiltration

2.4 Membrane cleaning

For cleaning the membrane, standard procedure of chemical cleaning was adopted. The membrane was cleaned with commercially available alkaline enzymatic membrane cleaner, namely, Ultraperm-53 at 45°C. This was found to be effective for cleaning of yeast deposited on membrane surface. The membrane recovery was found to be between 90 to 100 percent during these experiments.

3 Results and Discussion

3.1 Flux decline

Fig-3 illustrates the permeate flux decline in microfiltration of yeast suspension at different air-liquid ratios. As shown in the figure, the permeate flux decreased sharply in first 20 minutes of operation and then this decline became slow. It was observed that after two hours of operation, no steady state flux condition was achieved. This was due to the reason that the yeast used was not washed and contained certain extra cellular macromolecules which kept depositing on membrane surface and therefore the permeate flux continued to decline with the passage of time.

It can also be seen in the figure that the flux decline rate is low at higher air flow rates. This is due to the reason that bigger sized bubbles are formed at higher air flow rate which cause a wiping action on the membrane surface thus reducing the cake layer deposition on membrane surface. The air flow rate can be expressed in terms of volume of air passing through the membrane in unit time as

$$Q_{gas} = \text{Volume/Time}$$

While the air flow rate was measured in liter/minute with the help of a gas flow meter. Minimum flux decline was observed at an air flow rate of 2,88m^3/h and when air flow was further increased, flux decline was increased due to increase in density of cake by high air flow rate.

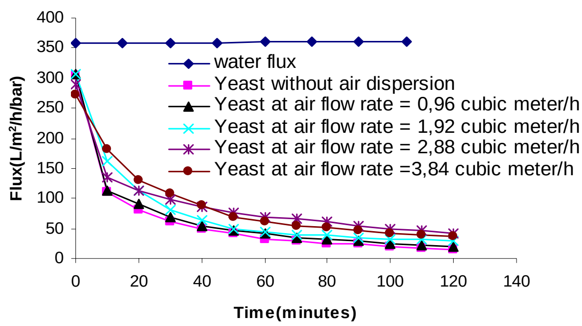

Fig-3 Effect of two-phase air-liquid flow on the permeate flux. TMP =0,7bar; Feed flow rate = 2m^3/h; Yeast concentration = 6,1g/L (dry-mass); pH=5,5

3.2 Effect of air-liquid ratio on flux enhancement

Fig-4 shows the enhancement of permeate flux with air dispersion with same experimental conditions as those of fig-3. The flux enhancement is shown in terms of the relative increase in the permeate flux, defined as

$$\% \text{ Flux enhancement} = (J_{ad}/J_{wa}-1) \times 100$$

Where J_{ad} is the permeate flux with air dispersion and J_{wa} is permeate flux without air dispersion. As the air-liquid ratio was increased, the flux enhancement also increased. The maximum flux enhancement of 170% was observed at an air-liquid ratio of 1,44. Beyond this ratio, no flux enhancement was observed. This effect can be attributed to the reason that the cake became denser and compact due to high rate of air when air liquid ratio was increased from 1,44 to 1,92.

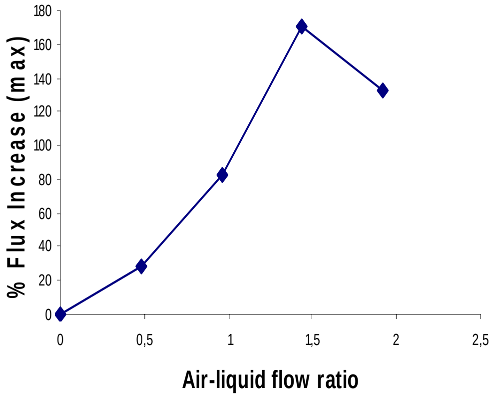

Fig-4 Effect of air-liquid ratio on percent permeate flux enhancement. TMP =0,7bar; Feed flow rate = 2m^3/h; Yeast concentration = 6,1g/L (dry-mass); pH=5,5

Therefore no further enhancement in the permeate flux was observed. These results prove that increasing air-liquid ratio leads to the formation of particle deposits which offer less resistance to flow as compared to the case when no air is dispersed in the system.

3.3 Effect of feed flow rate on permeate flux

Fig-5 shows the effect of feed flow rate on the permeate flux with and without air dispersion. The air was dispersed at a flow rate of 2,88 m3/h where maximum flux enhancement was observed. When no air was dispersed, the permeate flux kept increasing with increase in feed flow rate. This is due to the fact that as the feed flow rate was increased, the turbulence along the membrane surface also kept increasing due to high Reynolds's number which did not allow the settling of the solid particles on the membrane surface due to high turbidity. Therefore the permeate flux kept increasing with increase in the feed flow rate. This fact was proved as the feed concentration kept increasing as the feed flow rate was increased.

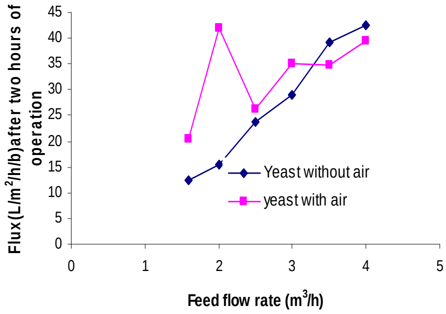

Fig-5 Effect of feed flow rate on the permeate flux. TMP =0,7bar; Air flow rate = 2.88 m^3/h; Yeast concentration = 6,1g/L (dry-mass); pH=5,5

Similar behavior was observed in flux increase when feed flow rate was increased in the presence of air with exception at feed flow rate of 2 m^3/h and air flow rate of 2,88 m^3/h. It was found that this combination was optimum for flux enhancement with air dispersion. As compared to flux enhancement with increase in feed flow rate without air dispersion, it can be seen that the enhancement of flux was low when feed flow rate was increased in the presence of air. This can be attributed to the reason that air caused a compression of cake on the membrane surface when feed flow rate was increased. Due to this compression of cake, the resistance to permeate flow increased. Therefore the enhancement of flux remained relatively low when feed flow rate was increased in the presence of air.

3.4 Effect of air-liquid ratio on cake layer resistance

The cake layer resistance can be measured by applying Darcy's law for known values of the permeate flux as under:

$$J = \frac{\Delta P}{\mu \cdot (R_m + R_c)}$$

where J is the permeate flux, R_m & R_c are specific membrane and cake layer resistances respectively while ΔP is transmembrane pressure and μ is the dynamic viscosity. Figure 6 below gives variation of cake layer resistance at different air-liquid ratios.

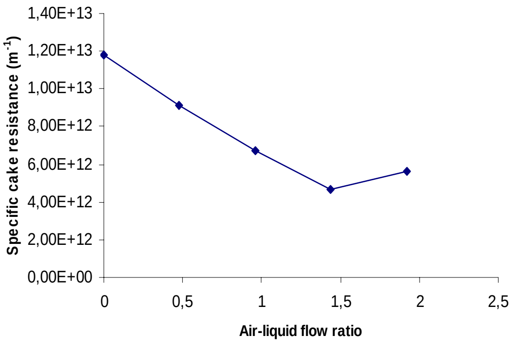

Fig-6 Effect of air-liquid ratio on specific cake layer resistance; TMP =0,7bar; Feed flow rate = 2m^3/h; Yeast concentration = 6,1g/L (dry-mass); pH=5,5

The specific cake layer resistance decreased by increasing the air-liquid ratio. This is due to generation of larger size bubble at high air flow rate which cause a wiping action on the membrane surface due to increased wall shear forces thus reducing the resistance to permeate flow through the membrane. It was observed that the cake layer resistance started to rise from the minimum value when air to liquid ratio was increased to a value of 1,92.

3.5 Effect of air dispersion on pressure drop

The pressure drop increases when liquid flow rate is increased. This fact is illustrated in the fig-7 below.

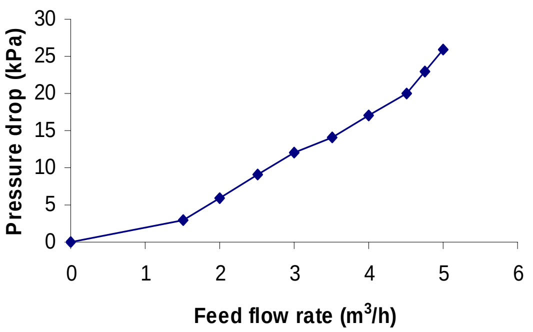

Fig-7 Effect of feed flow rate on pressure drop

This drop in pressure is major draw back of running a microfiltration process at high liquid velocity for control of fouling as it increases the cost of energy. Experiments were carried out to see whether injection of air to generate two-phase air liquid flow causes any pressure drop in the system. Figure 8 shows the effect of air dispersion on pressure drop.

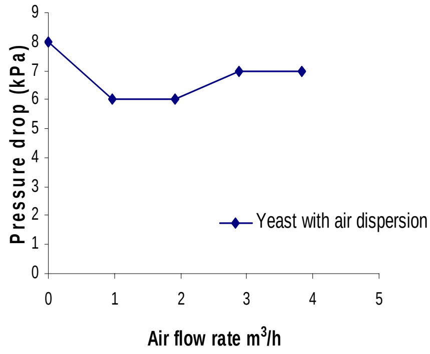

Fig-8 Effect of air dispersion on pressure drop; feed flow rate=2m^3/h; Inlet pressure= 0,7bar

The figure shows that pressure drop decreased 25% as compared to that of without air dispersion when low air to liquid ratio was applied and this decrease became 13,5% when air to liquid ratio was set to maximum of 1,92. The results show that by injecting air for generation of two phase flow, there is a low pressure drop of around 10% only.

4 Conclusions

4.1 Two-Phase air-liquid flow proved a high efficiency to improve flux and reduce fouling for spiral wound module with open channel spacers. Air dispersion allowed to remove or prevent external fouling and minimized the effects of concentration polarization. The flux increased has been found linked with increase in air to liquid flow ratio. The permeate flux increased even at very low values of air to liquid ratio.

4.2 The injection of air did not cause any significant pressure drop across the membrane. A pressure drop of 8-10% was found when air to liquid ratio was varied from minimum to maximum for this study.

4.3 The specific cake layer resistance of the deposited mass was reduced by increasing the air to liquid ratio which is due to the turbulences generated by air dispersion on the membrane surface.

4.4 The flux increased by increasing the feed flow rate without injection air into the system. The flux enhancement attained at highest speed of pump was found to be lower than the flux enhancement attained with two-phase air liquid flow at lowest feed flow rate.

4.5 The air dispersion was found to be most effective when the conditions were more favorable to fouling, that is, at low feed flow rate and less turbulence on membrane surface.

5 Future prospective

As it has been proved that air dispersion can enhance the permeate flux and reduce the fouling on membrane surface in a geometry which generates high turbulence like spiral wound membrane with open channel spacers, it is highly expected to attain better results in a flat sheet membrane geometry. On the basis of the results attained in this study for controlling membrane fouling and enhancing permeate flux, further work is planned to be carried out in near future for characterizing the effect of air dispersion in submerged flat sheet microfiltration pilot-scale module with various systems of suspensions.

References

[1] L.Vera, R. Villarreal, S. Delgado & S. Elmaleh, Enhancing microfiltration through an inorganic tubular membrane by gas sparging, J. Membr. Sci. 165 (2000) 47

[2] Z. F. Cui, S. Chang, & A. G. Fane, The use of gas bubbling to enhance membrane processes, J. Membr. Sci. 221 (2003) 1-35

[3] S. M Finnigan, J. A. Howel, The effect of pulsatile flow on UF fluxes in a baffled tubular membrane system, Desalination 79 (1990) 181.

[4] K. H. Kronev, V. Nissinen, H. Ziegler, Improved dynamic filtration of microbial suspension, Biotechnology 5 (1987), 921

[5] B. B. Gubta, P. Blanpin, M. Y. Jaffrin, Permeate flux enhancement by pressure & flow pulsations in microfiltration with mineral membrane, J. Membr. Sci. 70 (1992), 257

[6] G. Arroyo, C. Fonade, Use of intermittent jets to enhance flux in cross flow filtration, J. Membr. Sci. 80 (1993) 117

[7] H. R. Millward, B. J. Bellhonse, I. J. Sobey & R. W. H Lewis, Enhancement of plasma filtration using the concept of the vortex wave, J. Membr. Sci. 100 (1995) 121-129

[8] Z. F. Cui & K. I. T. Wright, Air sparging to enhance microfiltration in waste water treatment, Engineering in Membrane processes II-Environmental Applications II, Ciocco, Italy, (1994) April 26-28.

[9] M. Mercier, C. Maranges & C. Fonade, Yeast suspension filtration, flux enhancement using an upward gas/liquid slug flow-application to continuous alcoholic fermentation with cell recycle, Biotech & Bioengg, 58 (1998) 47-57

[10] M. Mercier, C. Fonade, C. Lafforgue-Delorme, How slug flow can enhance the ultrafiltration flux in mineral tubular membranes, J. Membr. Sci. 128 (1997), 103-113

[11] C. Cabassud, S. Laborie & J. M. Laine, How slug flow can improve ultrafiltration in organic hollow fibers, J. Membr. Sci. 128 (1997), 93-101

[12] J. Herron, Open-channeled spiral wound membrane module, United States Patent, Patent No: US 6,902,672 B2, June 7, 2005

[13] M. Mercier-Bonin, C. Lagane, C. Fonde,' Influence of a gas/liquid two-phase flow on ultrafiltration and microfiltration performances: case of a ceramic flat sheet membrane, J. Membr. Sci. 180 (2000), 93-102