FLUX ENHANCEMENT BY USING HELICAL BAFFLES IN ULTRAFILTRATION OF SUSPENDED SOLIDS

Noreddine Ghaffour[1,*], Rahim Jassim[2] and Tahir khir[2]

[1] Middle East Desalination Research Center (MEDRC), Oman
[2] Jeddah College of Technology, KSA

Corresponding author: PO Box 21, Al-Khuwair, PC. 133, Muscat, Sultanate of Oman
Fax: +968 697107, **Email**: nghaffour@medrc.org.om

ABSTRACT

The main reason for the flux decline during the initial period of all filtration processes is the usual phenomena of concentration polarization and fouling. After this stage follows the cake filtration process that allows to obtain the steady state flux. The solute accumulated on the membrane surface forms a high concentration gel layer, which increases the effective membrane thickness and so reduces its hydraulic permeability. Different techniques are used to reduce this formation and use of helical baffles inside the membrane element is one of such techniques. The selection of appropriate helical baffle is vital to get improved permeation flux with minimum pressure drop for cross-flow feed. The number of helices per unit length has a considerable influence on the selected helical baffle. All experiments have been conducted with an inorganic tubular ultrafiltration membrane for filtering a supernatant from activated sludge plant consisting of suspended and biological solids. The influence of the operational parameters is studied in this paper. Nevertheless, the feed temperature and the concentration were kept constant at the industrial values. We found 1 bar as an optimal pressure, above this pressure the permeation flux decreases, contrarily to several works, which observe a plateau after certain value of pressure. Progressive fouling can be limited by use of helical baffles in the filtration element operated at low pressures and the flocculation of particles is reduced. On the other hand, we have found that the influence of Reynolds number inside the membrane tube and the feed flow-rate are similar to other studies that used different helical baffles.

Keywords: Ultrafiltration, Helical baffles, Tubular membrane, Suspended solids, Deposited layer

1. INTRODUCTION

One of the most important problems in applying membrane technology is the usual concentration polarization and membrane fouling, which has very serious operational, economic and environmental implications. The deposit formed on the membrane surface, which causes blockage of flow passages, can be removed with different techniques, mainly the using of helical baffles inside the membrane tube. The permeation flux limitation is often due to the high concentration of solute on the membrane surface due to concentration polarization.

Several authors used different techniques to reduce the concentration polarization and membrane fouling such as use of baffles [3, 12, 17, 20] and spacers [23], increasing the cross-flow velocity or backflushing [15] and air or gas sparging during filtration [4, 6, 7, 22].

Gupta et al. [12] reported that the permeate flux increased with increase in number of helices by unit length. Moreover, visualizing by video camera revealed that flow was rotational around the baffle axis that was responsible for enhanced mixing leading to migration of suspended solids away from the membrane surface. Metal grate type of helical baffles (crimped lozenges meshes type) are also used by Sebbane [20]. He found that the permeate flow-rate decreases when the thickness of the fluid vein increases. Other researchers, Bennasar [3], Maubois and Mocqout [17], using similar helical baffles, found that the ultrafiltration of milk gave better results when the hydraulic diameter was reduced. The latter thinks that D_h plays an essential role on the formed layer on the membrane surface and on his internal fouling.

Sebbane showed that the gel resistance decreases with the hydraulic diameter. The shear stress can influence on internal fouling while acting on the gel layer, which lead an increase of the permeate flux more important than foreseen. We can think also that the gel concentration vary with the hydraulic diameter.

After preliminary screening, we selected the helical baffle since it gave higher permeate flux. The number of helices per unit length has a big influence on the selected helical baffle. All experiments have been conducted with an inorganic tubular membrane manufactured by TechSep. The second step was the study of the influence of the pressure and flow rate on the flux performance.

2. EXPERIMENTAL

2.1. HELICAL BAFFLE

The helical baffles in this study come from suggestions of several authors [12]. These are wound stems in circular helices, which can consist a variable number of helices per unit length. To the difference of the systems proposed by Gupta et al. [12], their installation in the filtration element implies the existence of contact points between the helix and the membrane wall as shown in Figure 1.

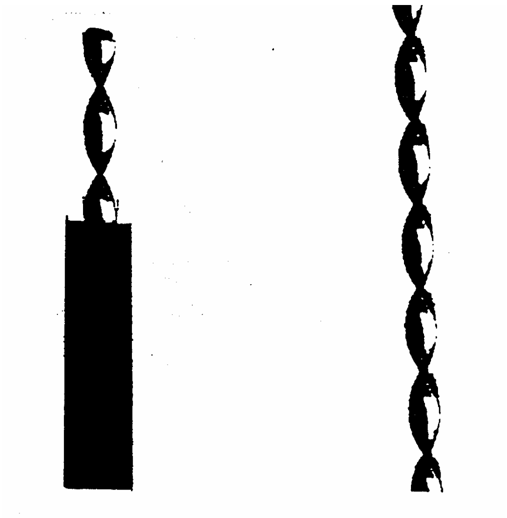

Figure 1. Schematic of the used helical baffle.

The geometric parameters of the used helical baffle are given in the table 1, knowing that the hydraulic diameter is defined by:

$$D_h = \frac{4\Omega'}{P_h} \quad (1)$$

Table 1. Geometric parameters linked to the used helical baffle.

D (mm)	Membrane tube diameter	6
Ω (mm^2)	Membrane cross section	28,3
Ω' (mm^2)	Cross section with helical baffle	23,3
P_h (mm)	Wetted perimeter	30,8
D_h (mm)	Hydraulic diameter	3

2.2. UNIT AND MEMBRANE

The experimental unit used is shown schematically in Fig. 2. Temperature and feed concentration were maintained at 35 ^{o}C and 5 g/l respectively. Temperature is maintained homogenous using a helical coil heat exchanger immersed in a 10 liter feed tank. The selected M9 Carbosep membrane, manufactured by TechSep, was an inorganic composite membrane whose zirconia-active layer was deposited on a carbon support. This tubular membrane has an internal 6 mm diameter and a length of 40 cm. The membrane cut-off as given by the manufacturer is 300 000

Daltons, which corresponds to a pore diameter of 0.02 µm [2]. All experiments have been carried out at the optimum values of the operational parameters obtained without helical baffles.

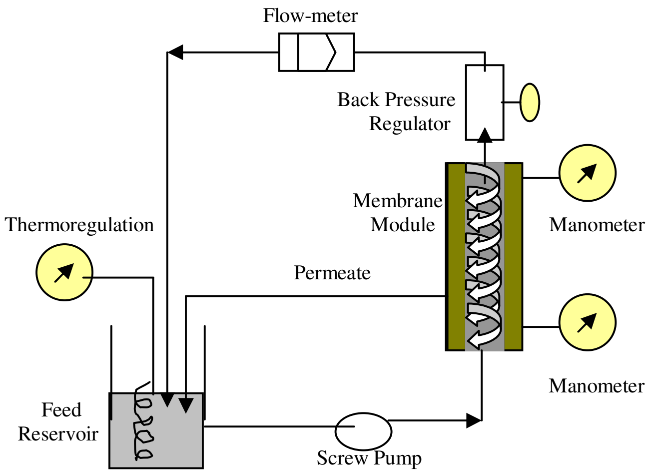

Figure 2. Experimental unit.

2.3. SUSPENSIONS AND DETERMINATIONS

The suspensions are made with suspended solids collected from the settler of an activated sludge plant. The unstable solution was continuously stirred and thermo-regulated in a storage tank to keep the feed temperature and concentration homogeneous. Filtration flow-rate and flux were determined by measuring the time required to collect a given filtrate volume. The membrane was cleaned chemically with a 30% sodium hydroxide and 30% nitric acid solutions after each experiment until the permeability was regained.

3. RESULTS AND DISCUSSION

3.1. INFLUENCE OF THE HELICES PITCH

The general form of the curves, permeate flux against time, is not changed by changing the pitch but it effected the time necessary to reach the steady state and its value.

The highest flux is obtained when the baffle has 3 helices every 4 cm (Fig. 3); no additional pressure drop is observed but the flux decreased when the driving pressure is higher than 1 bar (Fig. 8). This result is not same as Gupta et al. They observed that the increase in number of helices per unit length has no effect after reaching a plateau.

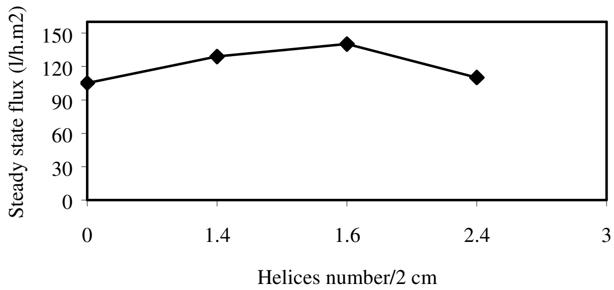

Figure 3. Effect of the number of helices per unit length on the steady flux, 1.32 l/min, 1 bar.

The steady state is improved by about 30%, but the pressure drop due to helical baffle is negligible. In the subsequent experiments, the helical baffle with 3 helices every 4 cm that gave maximum permeation flux was used.

3.2. INFLUENCE OF THE PRESSURE

The permeate flux decreases with time before reaching the steady state after about 50 minutes except for 0.5 bar where the flux remains noticeably constant (Fig. 4). Therefore, at 0.5 bar, the fouling is almost avoided and it therefore could be convenient to operate an industrial membrane at such low pressure. It is probably the critical flux similar to that defined by Howell et al.. It is remarkable to know that the critical flux is close to the steady values at high pressures.

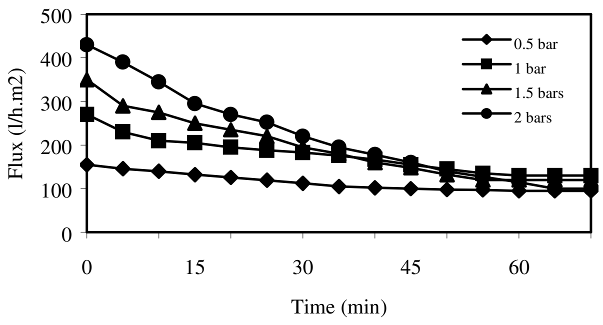

Figure 4. Permeation flux against time for different pressure, 1.32 l/min.

3.3. TRANSIENT FILTRATION

The helical baffle has a beneficial effect on the flux density without changing the pressure drop. The adequate model, which takes into account both the transient filtration and the steady state, is the cake deposition with retroflux. The equation of this model is given by [8,16]:

$$\frac{\frac{Q_o}{Q}-1}{V}=k_d-k_d k_p \frac{t}{V} \qquad (2)$$

With:

$$k_d=\frac{\alpha x_o}{AR_m} \quad \text{and} \quad k_p=\frac{Q_r}{x_o} \qquad (3)$$

Where Q and Q_o are respectively the filtrate flow-rate and the initial flow-rate, V the filtred volume, k_d and k_p are respectively linked to the deposition and the retroflux and t the time. Q_r is the retroflux flow-rate and x_o the volume fraction occupied by particles in the bulk of the suspension, A is the filtering surface area, R_m the initial membrane resistance and α the specific resistance per unit length of deposit.

The linear relation between $[(Q_o/Q)-1]/V$ and t/V shown in figure 5 confirms the validity of the model. The Adjustments are also satisfactory for the feed concentration. The deposition and retroflux coefficients can be calculated from the obtained lines.

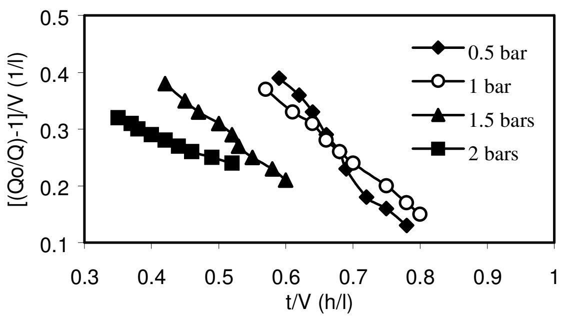

Figure 5. Cake deposition with retroflux model for different pressure, 1.2 l/min.

The specific cake resistance against pressure takes the same trend as the cake coefficient k_d, i.e. inversely proportional (Fig. 6). The specific resistance is also inversely proportional to the feed flow rate (Fig. 7), this phenomenon is not observed without helical baffle, which explain that using this type of baffles eliminates the flocculation and the agglomeration of the deposited particles.

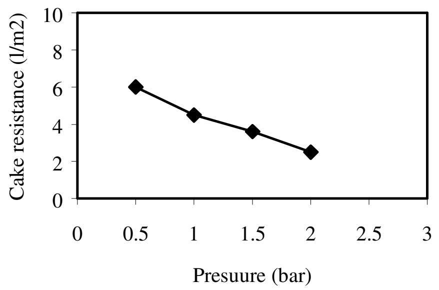

Figure 6. Variation of the specific resistance with the pressure, 1.32 l/min.

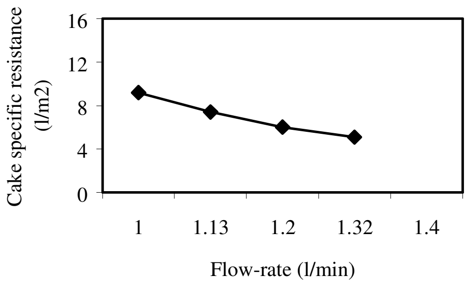

Figure 7. Variation of the specific resistance with the flow rate, 1 bar.

3.4. LIMITING FLUX

We noted that the permeate flux reaches a maximum value at 1 bar and then decrease very slowly before reaching a plateau (Fig. 8). This is essentially due to the type of baffle used, which brushes against the internal surface of the membrane, helping the disruption of the deposit layer at high pressures. The helical baffle does not do his work. It occupies an important volume of the membrane tube and creates an obstruction to flow. In presence of another type of helical baffle, Sebbane [20] showed that the linear part of the curve is more spread.

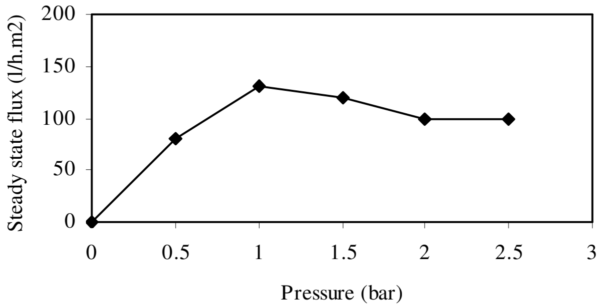

Figure 8. Influence of the pressure on the permeate flux, 1.32 l/min.

The increase of the feed flow-rate has also a beneficial effect on the permeate flux (Fig. 9). Beyond 1.2 l/min the flow-rate has no influence on the flux. The cake already formed could not be pulled out.

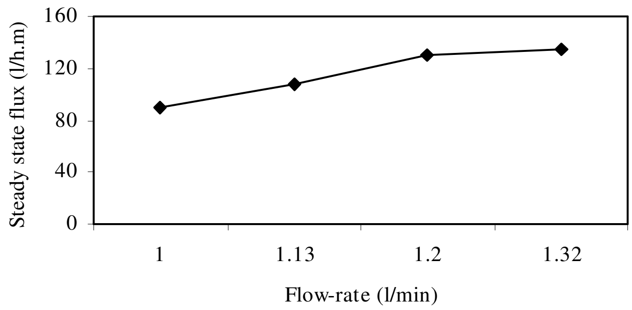

Figure 9. Influence of the feed flow-rate on the permeate flux, 1 bar.

Sebbane [20] noted that the turbulence rate at the canal center does not depend on the Reynolds number, and it is maximal at the neighborhood of the membrane wall and decreases towards the center at a ratio of the order of 3.

The variations of the steady state flux against the cross-flow velocity in the studied conditions are linear with a slope equal to 0,68 corresponding to the system of the flow (Fig. 10). The cross-flow velocity is calculated using free cross sectional area. The increase of the cross-flow velocity with the influence of helical baffles leads an increase of turbulence in the membrane tube and mass transfer coefficient, reduce the effect of concentration polarization and increase the permeation flux.

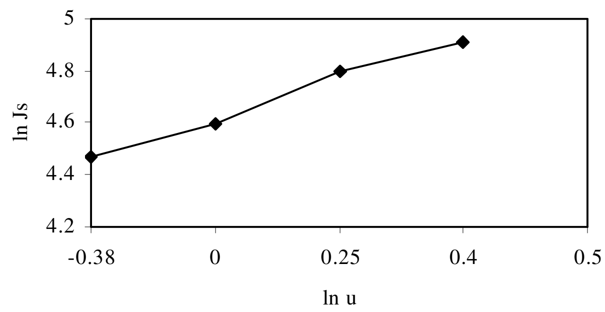

Figure 10. Variation of $\ln J_s$ with $\ln U_c$, 1 bar.

Several authors, using different helical baffles, found similar results. Sebbane found slope values, close to that of Harriot and Hamilton ones [20], in the order of 0,9 with the helical baffle; in addition they are less sensitive to the evolution of the fluid vein thickness. On the other hand, without helical baffle they become more than 1. Quemeneur and Schlumpf [19], Goldsmith [11], Cadanel and Bartoldi [5] also found, with different devices, slope values of the same order (a=1.1 to 1.5). Poyen et al. [18] found, with or without helical baffle, in utltrafiltration of an engine oil additive, slope values equal to 0.6; this is independent of the used membranes and the hydraulic diameter.

Gekas and Hallstrom [10], Aimar et al. [1] explained the difference in slope values since the diffusion coefficient, the viscosity and the density (D, μ and ρ) depend on the gel concentration and not on the bulk concentration. Indeed, it is necessary to know as Jaffrin et al. [14] found that the D and μ affect the friction at the membrane wall or the velocity. The oily emulsion could have, as milk, a pseudo-plastic behavior. In addition, the influence of the shear should be as much stronger than the layer is thick.

4. CONCLUSION

The helical baffles allow to increase significantly, by elimination of the formed layer, the permeate flux without changing the process limiting the transfer flux. At the optimal conditions, 1 bar and 1.32 l/min, the flux is improved of 30%. The cake deposition with retroflux model is very satisfactory.

The permeate flux depends, also, on the number of helices per unit length. The maximum is found for stems behaving 3 helices for every 4 cm and a pressure of 1 bar. At 0.5 bar, the permeate flux remains noticeably constant, it is then the critical flux as defined by Howell et al.

When a helical baffle is introduced in the filtration element, the progressive fouling is almost avoided if the driving pressure is maintained at 0.5 bar.

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