Acta Mechanica Slovaca **24 (2): 38 - 41,** June **2020**
https://doi.org/10.21496/ams.2020.027

Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

A new Correlation for Predicting the Filtration Flux Development in a Membrane Tube

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Abstract: In the present study, the mass transfer characteristics in a tubular membrane are analysed. Based on the available experimental data, a new reliable correlation is elaborated to predict the mass transfer as the term of the permeate flux inside membrane tubes. Analysing of available results shows that the filtration time (t_F), and the concentration of suspensions (C) are directly affecting the permeate flux (P_f). Therefore, the present analytical study was conducted to propose a new correlation. This correlation is compared with other experimental data; a very satisfactory agreement has been achieved.

Keywords: *correlation, mass transfer, membrane tube, permeate flux, filtration flux.*

1. Introduction

The classical membrane tube is a primordial device which is largely used in membrane systems such as water treatment processes, biotechnological and other industrial applications. In recent years, several techniques are realized in the classical membrane tube to improving it efficiency, where any development of performance is based on the comparison by the classical membrane tube. For example, the location of the turbulence promoters inside the membrane tubes can considerably improve the mass transfer phenomenon in these systems, and its need to compared with the classical membrane tube [1–8]. In this context, the comparison founded on the results of available researches of literature, while correlations to predict the permeate flux inside the membrane tubes are almost absent. In order to enhance mass transfer inside a membrane tube, Cao et al. [9] determined the fluid flow characteristic by using spacer-filled tube. They visualized the flow pattern inside the membrane tube by using CFD package. Comparing with smooth membrane, they showed that the peak shear stress and velocity fluctuation are repeated after each spacer cylinder, and as result, mass transfer rate was enhanced. Abbasi Monfared et al. [10] numerically investigated steady-state permeation flux versus filtration time of a gelatine-water in a tubular membrane. They reported that rise in cross flow velocity (CFV) and trans-membrane pressure (TMP) leads to increase in permeate flux. Likewise, Taha et al. [11] simulated the gas-liquid tow-phase cross flow ultra-filtration phenomenon inside horizontal and inclined tubular membranes. They confirmed that the CFD modeling of the permeate flux can be used as successful tool compared with experiments. Also, they showed that inclined systems produce different shear patterns than the horizontal systems. Where, the wall shear rates are higher when the membrane was disposed by 45° from the horizontal. In order to enhance wall shear stress (WSS) and to generate eddy mixing, thus reducing wall concentration and fouling, Schwinge et al. [12] numerically analysed the characteristics of spiral-wound membrane modules. They showed that the

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Reynolds number (Re) increased above 300, the flow becomes super-critical viewing time-depended movements for a filament situated in the centre of narrow tube. Also, when Re is augmented above 500, the flow becomes super-critical for a filament near to the membrane wall. Yeh [13] reported that the prediction of the permeate flux for ultrafiltration (UF) inside tubular membranes was typically based on the estimation of mass and momentum balances, transmembrane pressure (TMP) along the membrane tubes. In addition, they concluded that the increase of the concentration polarization along the tubes can decline in the permeate flux. In light of above works and motivated by their observations, we proposed in this paper a reliable correlation to predict the mass transfer as a term of permeate flux towards the membrane tube. An analytical study is conducted in the present article based on available and important researches in literature.

2. Material and method

The separation membrane technique is known for a certain time but its development remains recent. These techniques can be found mainly in several engineering systems such as the milk and drinks industry, the fruit juices or the water treatment. These processes consume relatively little energy due to generated pressure trans-membrane (TMP) in the sides of the tube (inlet and outlet).

As shown in Fig. 1, when one carries out a filtration on membrane, one obtains: the permeate (molecules and/or particles retained by the membrane) and the waste or filtrates (molecules which pass through the membrane). Tubular membrane can be of single-channel type or multi-channel and are often of mineral nature. In the case of tubular membranes multi-channel, the tubes are gathered in parallel in a module. The permeate is recovered outside the tubes, in the envelope of the module. These systems are less sensitive to filling but are expensive and can be cumbersome.

A typical membrane tube of 200 mm of tube length and 15 mm of diameter is used in this paper to analyse the available results. Titanium dioxide [2, 5] and carbonate calcium [3, 6, and 8] are the particles suspensions which are usually used to test the performance of mass transfer in the membrane systems. Some physical conditions are also considered in this work: Concentration of suspension (C) changing from 1 to 10 g/L,

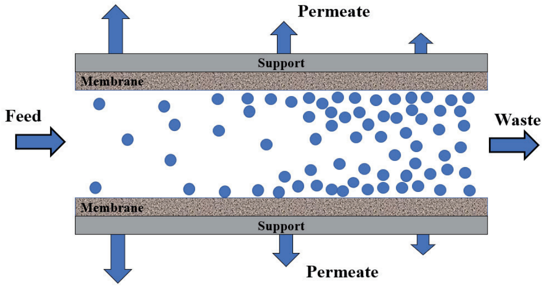

Figure 1: A descriptive scheme of membrane tube operation.

Re=7500, trans-membrane pressure (TMP=50 kPa), and filtration time (t_F) varying from 1 to 90 min.

3. Results accumulation and elaboration of correlation

In order to elaborate a reliable correlation to evaluate the permeate flux; we accumulated several results from literature. The accumulation of these results is based on the same conditions that allow us to propose a corrected formula. The appreciated conditions in this analysis are: the trans-membrane pressure (TMP), Reynolds number (Re), where, the tow lasts parameters are largely fixed in literature at 50 kPa and 7500, respectively. Analysing of the results presented in Tab 1, and Fig. 2 shows that the filtration time (t_F), and the concentration of different suspensions (C) are straight affecting the permeate flux (P_f).

Table 1: Summarized of different conditions affecting the permeate flux.

Authors	*Suspensions*	*Concentration g/L*	*TMP*	*Re*
Ahmad et al [2]	Titanium dioxide	1	50kPa	7500
Ahmed et al [5]				
Jafarkhani et al [3]	Calcium carbonate	5		
Liu et al [6]		5 and 10		
Ameur and Sahel [8]				

The analytical analyse is approved by tow part, the first is conducted to present correlation in order to evaluate the effect of the time on the permeate flux (t_F), and the second is shared to evaluate the effect of the concentration of suspensions (C). The normalization method is used to combine between the two relationships. For example, in the first step, we fix the value of the concentration (C) and we plot $P_f = f(t_F)$. In the second step, we divide the data of the graph $P_f = f(t_F)$ on a fixed value of time (t_F). At the end, we find the function $P_f = f(C, t_F)$. Therefore, a new correlation is proposed (eq.1) to estimate the permeate flux which is considered the effect of the concentration of suspensions (C). and the time of permeate flux (t_F).

$$P_f = \left(-56{,}48 \times C^2 + 791{,}62 \times C\right) t_F^{-0{,}22} \qquad (1)$$

where, (eq. 1) is valuable for the following conditions:

- *Trans-membrane pressure, TMP=50 kPa*
- *Reynolds number, Re= 7500*
- *Concentration of suspension: $1 \le C \le 10$ g/L*
- *Time of filtration flux: $1 \le t_F \le 90$ min*

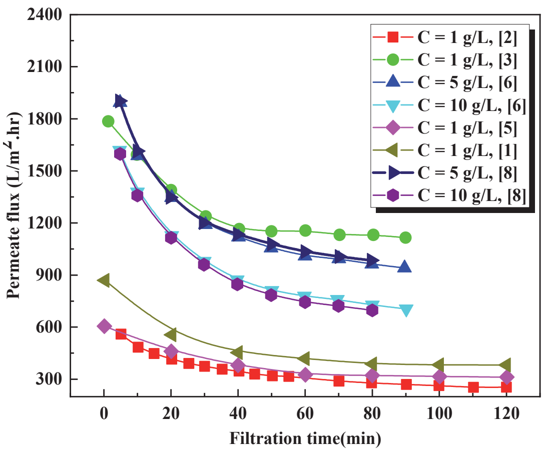

Figure 2: Variation of permeate flux (P_f) versus time (t_F), for different values of concentrations (C)

4. Validation of new correlation

In the present work, validity is a very important step to ensure that our results can be used effectively. After elaborating of the correlation, it is necessary to test it validity. Fig. 3 displays the variation of the predicted results using the new correlation versus the experimental results from literature [1-3, 5-8].

This figure illustrates a satisfactory agreement of the new correlation compared with experiments, where we used the medium line ($y = b*x$) for testing the reliability of the correlation. The last displays a coefficient of determination (R-square) of 0.946. Consequently, the maximum error between the predicted and experiment results is 5.4 %. Therefore, researchers can use this correlation without supplementary efforts to estimate the mass transfer inside the membrane tubes.

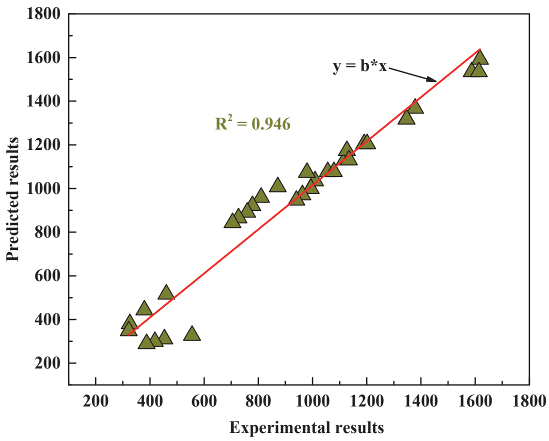

Figure 3: Variation of predicted results versus experiments.

5. Conclusion

A report of the mass transfer characteristics in a membrane tube has been presented. In order to take into account, the mass transfer development with variation in the filtration time (t_F), and the concentration of suspensions (C), an analytical work has been conducted on the foundation of the available experimental results. Therefore, a new correlation was proposed for predicting the permeate flux (P_f) in a classical membrane tube. The new correlation has been validated with experimental data from literature and a good accuracy is found. For more reliability of correlation, it is advised to into account in future works, the effects of trans-membrane pressure (TMP) and Reynolds numbers (Re).

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