Determination of the optimum permeate flow and total resistance to fouling by Minitab software during tangential microfiltration for the production of drinking water

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Abstract

The present work aims at minimizing the number of tangential microfiltration experiments to study the effects of the operating conditions (the pressure (P) and the filtration time (t)) and the characteristics of the raw water (the material in suspension (SM)) on the permeate flux and the total resistance to fouling and the interactions between them (the pressure on the filtration time (P, t)) (the pressure on the suspended material (P, SM)) (the filtration time on the suspended material (t, SM)) by the use of Minitab software (version 16) to determine the optimum of the permeate flow and the total resistance to fouling as well as the mathematical model Jp = f (P, t, SM), RT = f (P, t, SM) during the production of drinking water.

Key word: effect, interaction, optimal flow, Minitab, number of experiments and drinking water.

I. Introduction

Tangential microfiltration is one of the most important membrane processes in the treatment of water intended for human consumption [1]. The main difficulty encountered during this process is the determination of the flow and the optimum total resistance to the transfer of material to avoid fouling of the filter membrane [2]. This phenomenon may be linked non-linearly to the characteristics of the raw water to be treated (suspended matter turbidity, etc.) and the operating conditions of filtration time and pressure. There is currently no model of knowledge to express this phenomenon [3]. The only solution for establishing this model is to use behavioral modeling [4], in this case using the experimental design methodology with the Minitab software.

II. Estimation of the effects of the experimental parameters

The experimental domain defined for the three factors selected for this study (Table 1), makes it possible to establish the complete factorial experiment matrix of three factors (k = 3) at 2 levels each, denoted 2k = 2^3, forming eight combinations as described in Table 1 below.

Table 1. Codes and levels of the used independent variables

Variables	Factors	levels	
		-1	+1
X1	Filtration time (min)	10	60
X2	Pressure (Bar)	0.4	1.2
X3	Matter in Suspension (mg/L)	4.2	14.5

Table 2. Factor Experiment Matrix 2^3

Experiment	X1	X2	X3
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

The experimentally measured responses were the permeate flow (Jp) and the Total resistance to fouling (RT). They were calculated according to the following expressions:

$$J_p = \frac{V_p}{(A*t)} \qquad (1)$$

$$R_T = \frac{P}{\mu * J_p} \qquad (2)$$

with

J: Permeate flow ($L.m^{-2}.h^{-1}$)
R_T: Total resistance to fouling (m^{-1})
V: Permeate volume measured at time t (L)
A: Membrane surface (m^2)
t: Filtration time (h)
μ: Viscosity of Raw water (Pa.s)

III. Experimental design and results

The complete experimental design was obtained by replacing in the matrix of experiments, the extreme levels of the coded variables (-1 and +1) X1, X2 and X3, by the real values of the associated factors, noted P, t and MES, corresponding to the pressure, filtration time and matter in suspension, respectively

Table 3. Experimental Plan and Experimental Results

Run N°	coded variables			Real variables			Response Y1	Response Y2 x 10^{-12}
	X1	X2	X3	t (min)	P (Bar)	MES (mg/l)	Jp (L/h.m2	RT (m-1)
1	-1	-1	-1	10	0.4	4.2	123.32	1.16
2	+1	-1	-1	60	0.4	4.2	117.96	1.22
3	-1	+1	-1	10	1.2	4.2	268.09	1.61
4	+1	+1	-1	60	1.2	4.2	206.43	2.09
5	-1	-1	+1	10	0.4	14.5	69.7	2.06
6	+1	-1	+1	60	0.4	14.5	64.34	2.23
7	-1	+1	+1	10	1.2	14.5	154.6	2.79
8	+1	+1	+1	60	1.2	14.5	126	3.42

For the study of these three factors, we will adopt the following mathematical model:

$$Y = a0 + \sum_{i=1}^{3} a_i\, x_i + \sum_{\substack{i=1 \\ j=1 \\ i \neq j}}^{3} aij x_i\, x_j \qquad (3)$$

where Y is the response model, ai are the coefficients of the model and xi the model variables.

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{123}x_1x_2x_3 \qquad (4)$$

The coefficients of the three permeate flow factors and the total fouling resistance calculated by Minitab software is shown in Tables (4) and (5), respectively.

Table 4. Permeate flow factors coefficients

Intercept coefficient	Linear coefficient	Interactive Coefficient
$\boldsymbol{a_0} = 141.31$	$a_1 = -12.62$	$a_{12} = -9.94$
	$a_2 = 47.47$	$a_{13} = 4.13$
	$a_3 = -37.65$	$a_{23} = -10.83$
		$a_{123} = 4.13$

Table 5. Total resistance to fouling factors coefficients

Intercept coefficient	Linear coefficient	Interactive Coefficient
$\boldsymbol{a_0}$ =2,0725* $\mathbf{10^{12}}$	$a_1 = 1{,}675 * 10^{11}$	$a_{12} = 1{,}1 * 10^{11}$
	$a_2 = 4{,}05 * 10^{11}$	$a_{13} = 3{,}25 * 10^{10}$
	$a_3 = 5{,}525 * 10^{11}$	$a_{23} = 7{,}5 * 10^{10}$
		$a_{123} = 5 * 10^{9}$

The mathematical models of permeate flow and total resistance to fouling expressed in the Real variables are as follows.

$$J_p = 141{,}31 - 12{,}62t + 47{,}47P - 37{,}65\ SM - 9{,}94tP4{,}13\ t\ SM - 10{,}83P\ SM + 4{,}13tp\ SM \qquad (5)$$

$$R_T = 2{,}072510^{12} + 1{,}675\ 10^{11}t + 4{,}05\ 10^{11}P + 5{,}525\ 10^{11}SM + 1{,}1\ 10^{11}tP + 3{,}25\ 10^{10}t\ SM + 7{,}5\ 10^{10}\ P\ SM + 5\ 10^{9}\ t\ p\ SM \qquad (6)$$

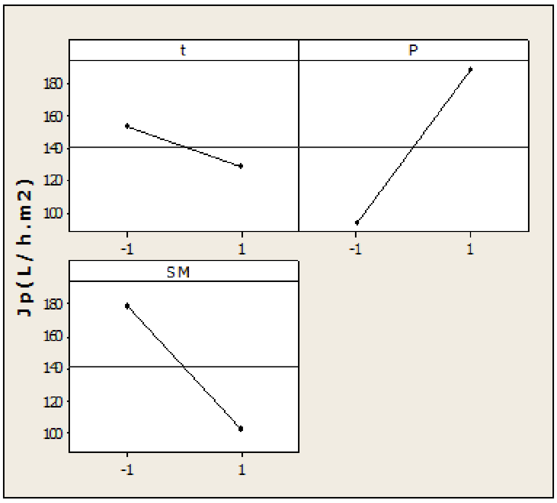

Figure 1: Effects Diagram of Permeate Flow

The diagram of the permeate flow effects (Figure 1) shows that there is a very important effect of the pressure on the increase of permeate flow (a rising right) as well as a significant effect of suspended matter on the decrease of permeate flux. Moreover, another moderately important effect of the filtration time on the decrease of permeate flux (decreasing lines) is also evident. These effects demonstrate immediately that one can obtain an optimal (maximum) flow of permeate by combining maximum pressure and a short filtration time regardless of the increase in suspended matter (the variable characteristic of raw water that we cannot control).

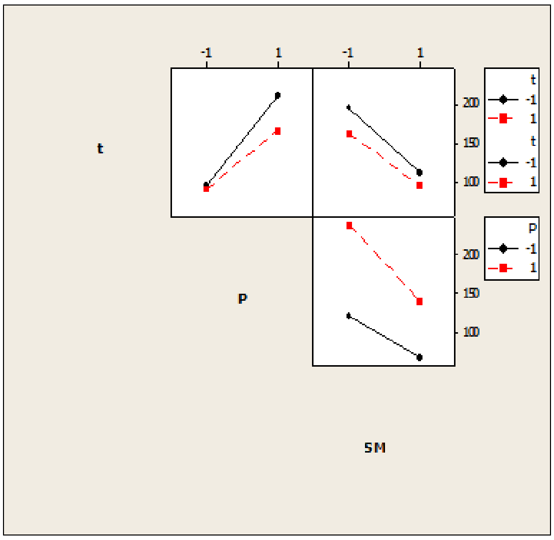

Figure 2: Interactions Diagram of Permeate Flow

According to the permeate flux interaction diagram (Figure 2), there is a large interaction of the pressure on the material in suspension (the two lines are not parallel with a large margin). A weak interaction of the filtration time on the matter in suspension (the two lines are almost parallel) is noted whilst a large interaction of the filtration time is also obtained but with a small difference.

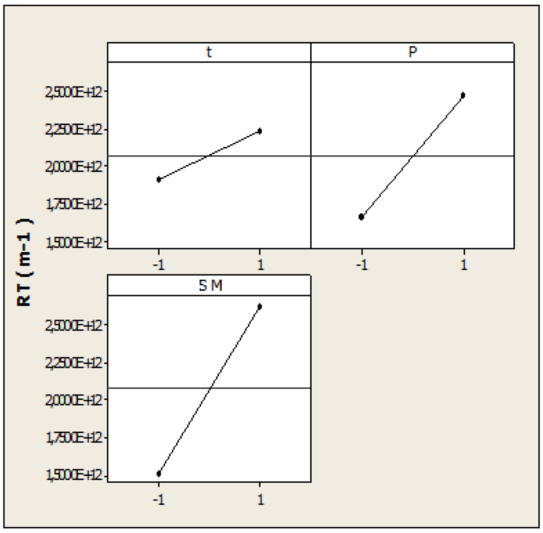

Figure 3: Effects Diagram of the Total Resistance to Fouling

The diagram of the effects of the total resistance to fouling (Figure 3) shows that there is an optimal effect of the suspended matter and the pressure on the total resistance (increasing lines with a steep slope) contrary to the time of filtration which gives us an increasing right with a low slope (a medium effect). These effects clearly validate that if we choose a long filtration time with a low pressure accompanied by an increase in the concentration of the suspended matter, optimum (minimum) total resistance to fouling is then achieved.

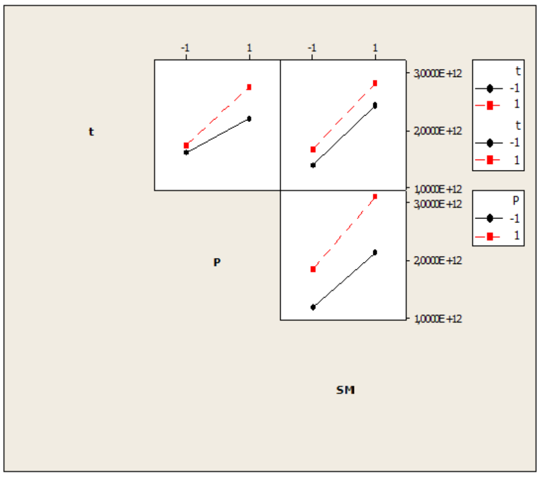

Figure 4: Interactions Diagram of Total Resistance to Fouling

From the diagram of the interactions of total resistance to fouling (Figure 4), we notice that there is a relationship between the filtration time and the pressure (the two lines are not parallel) and we also notice a correlation between the two levels of the pressure and the suspended matter (the lines are not parallel). The third graph puts in evidence two lines that are almost not parallel and thus indicating the very weak interaction of the filtering time on the matter in suspension.

III. Conclusion

The optimization of the number of tangential microfiltration experiments by the application of the experimental design methodology (complete factorial design (2k) made it possible to visualize the effect and the combinatorial interactions of three factors (filtration time, pressure and suspended matter of raw water) considered very influential on the determination of the permeate flow and the total resistance to fouling during the production of drinking water.

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