

Application of microfiltration membrane for treatment of car wash effluent by Taguchi method prediction

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Abstract

In this study conditions of refinement of car wash effluent from Paniz station in omidiyeh, Khuzestan by microfiltration polyvinylidene fluoride (PVDF- MFB) membrane with pore size 0.13 micrometer by taguchi method was investigated. Taguchi method has been applied to investigate the effect of various operating parameters such as feed pressure at 3 levels (0.4, 0.7 and 1.00 bars), feed Flow rate at 3 levels (30, 40 and 50 L/h) and feed temperature at 3 levels (25, 35 and 45°C) on the permeation flux of car wash effluent in the treatment process. In addition, the effect and contribution of each pertinent parameter on flux and the interaction among them was determined by Taguchi analysis. Results showed that the most influential factor was feed pressure. The second significant contribution was observed for the feed temperature. Feed Flow rate a low effect on permeation flux. At optimum conditions (i.e. 1.00 bar, 50 L/hr, and 45°C), the Taguchi model predicted the value of the response (the permeation flux) as 19.76 kg/m².h, which had a good agreement with the experimental results.

Key words: PVDF membrane, Permeation flux, Car wash effluent, Taguchi method

Highlights

- Treatment of car wash effluent by PVDF-MFB membrane.
- Effects of feed pressure, flow rate and temperature parameters on the permeation flux.
- Contribution of operating parameters and the interaction among them by taguchi method.

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Introduction

In recent years car washing has attained a great importance in human society in order to achieve better vehicle performance. Declining water resources across the globe is forcing the policy makers to impose stringent regulations on the usage of fresh water. A majority of countries have introduced a number of laws on waste water recycling associated with car washing (1 & 2). In Netherlands and Scandinavian countries 60- 70 L/car is the maximum allowable fresh water consumption (3). A recycle of 80% car wash effluent is compulsory in Germany and Austria. The Australian commission has established a maximum limit of 100 L fresh water per car. However, in current scenario car wash industries do not have efficient treatment methods to reclaim car wash water. Membranes have been previously reported in the literature to be useful in treating various kinds of industrial wastewater such as textile dyeing effluent (4 & 5), oily water (6 & 7), municipal wastewater (8), wastewater from pulp and paper industry (9) as well as poultry processing wastewater (10). However, little attention is paid to the car wash industry. The phenomena can be reflected by the limited number of articles and technical papers available in the open literature (11 & 12). The biggest limitation to implement car wash best management practices may be lack of knowledge regarding the impacts of polluted runoff. It is generally perceived by public that the wastewater from car washing is not severely contaminated compared with other industrial wastewaters. It is reported that many treatment methods such as coagulation, chemical oxidation, absorption and filtration, are available to be employed in

car wash industry, but only insignificant car wash stations are equipped with on-site wastewater treatment system. By taking into account the huge quantity of water consumed per car and the various chemical agents used in car wash industry, it is important to treat the effluents properly before discharging into the environment. From a viewpoint of environmental protection and effective utilization of water resources, initiative on water treatment should be emphasized to deal with the problem. The increase in car volume on the road together with the existing number of cars would definitely further boost the car wash industry, leading to increase in car wash service, particularly in high population of residential area located in urban areas. Depending on the type of car wash installation and the size of a car, it is reported that an average of 150- 600 l wastewater is produced from every car washing (13 & 14). These membrane processes are reverse osmosis (RO), microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), electro dialysis (ED) and gas separation, which have been developed for various applications (15- 17).

In this work, microfiltration polyvinylidene fluoride (PVDF- MFB) membrane was used for treatment of car wash effluent from Paniz car wash station in omidiyeh, Khuzestan by taguchi method prediction. A commercial hydrophobic polymeric membrane was used for the experiments. The effect of operating variables on the permeation flux was investigated. Taguchi optimization and sensitivity analysis were carried out for the studied factors. The main objective of this work is to investigate the feasibility of using MF membrane for the treatment of car wash effluent.

Material and Method

Materials: Feed samples (Car wash wastewater samples) from Paniz station in omidiyeh, Khuzestan were prepared.

A commercial hydrophobic membrane made of PVDF- MFB with 0.13 μm pore size was used for the experiments. The specifications of the applied membrane are presented in Table 1.

Table 1- Properties of microfiltration membrane used in this work.

Membrane	Polymer	Water affinity	Pore Size (μm)
PVDF-MFB	Polyvinylidene difluoride	Hydrophobic	0.13

Experimental apparatus and procedure:

The setup consisted of a plate and frame module, a booster pump (Model: TYP-2500), a flow meter (Model: LIQUID-Sp.Gr.1.0/ZYIA) and pressure gauges. Fig. 1 shows the general scheme of the experimental apparatus applied for experiments.

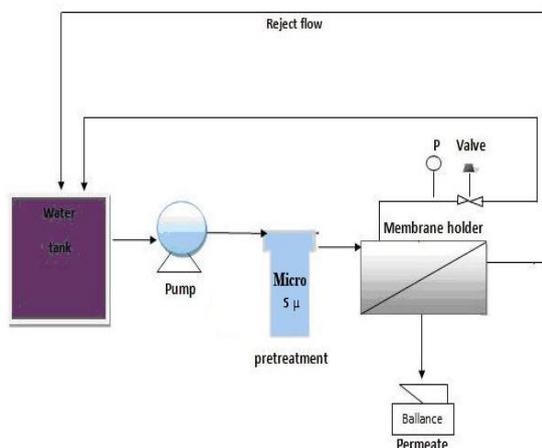


Fig. 1- The car wash wastewaters of reclamation systems.

In this study, a hydrophobic type PVDF membrane was used for the experiments. Prior to the permeation tests, all the membrane with effective area of 104 cm^2 each were compacted at pressure of 1.00 bar for at least 45 min to achieve steady

state flux. The permeate flux of membrane, J ($\text{kg}/\text{m}^2 \text{ h}$), at different pressures can be determined using the equation as follows. Where Q is quantity of permeate (kg), A is effective membrane area (m^2) and t is time to obtain the quantity of Q (h) (18).

$$J = \frac{Q}{At} \quad (1)$$

Taguchi method of experimental design:

In order to use the Taguchi method to investigate the effects of pressure, flow rate and temperature parameters on the permeation flux of car wash are effluent in the treatment process. Three levels for each parameter were selected. Experimental runs were conducted according to L_9 array in the Taguchi procedure. The Taguchi method is very useful for the optimization of process parameters, because it is insensitive to the variation of environmental conditions and other noise factors. With this method, analysis of a special design of orthogonal arrays was conducted to study the entire process parameter space in only a small number of experiments (19). In the present study, there are 6 degrees of freedom (DOF) due to three sets of three-level process parameters. The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. The process parameters and their levels are shown in Table 2.

Based on the Taguchi design methodology, an L_9 orthogonal array (three variables in three levels, Table 2) was investigated. This array has 26 degrees of freedom and can handle three level process parameters. Nine experiments were required to study the entire process parameter space when the L_9 orthogonal array was used. Nine experiments with the arrangement of Table 3 were performed and the permeation flux was calculated by Qualitek-4 Software. In this study, the target factor was permeation flux.

Table 2- Operating variables and their levels

Parameter	Unit	Level 1	Level 2	Level 3
P	bar	0.4	0.7	1.00
Q	L/h	30	40	50
T	°C	25	35	45

Table 3- Operating conditions of each experiment based on Taguchi L₉ orthogonal array

No.	P (bar)	Q (L/h)	T (°C)	Mean flux (kg/m ² h)
1	0.4	30	25	4.84
2	0.4	40	35	6.42
3	0.4	50	45	7.60
4	0.7	30	35	8.88
5	0.7	40	45	12.75
6	0.7	50	25	11.32
7	1.00	30	45	19.58
8	1.00	40	25	14.46
9	1.00	50	35	17.73

Results

In the previous works (15 & 18), different hydrophobic membranes were characterized and used for various membrane treatment purposes. Results indicated that the PVDF- MFB membrane with 0.13 μm pore size could be investigated as the best choice, due to its higher hydrophobicity, higher solute rejection, higher chemical and physical resistance, and better overall performance. Therefore, this membrane was investigated for experiments in this study. Based on the Taguchi experimental design in this work, nine experiments were required to study the permeation flux variation during the treatment of car wash effluent, when the L₉ orthogonal array was used. The experimental layout for the membrane process variables using the L₉ orthogonal array is shown in Table 3.

Nine experiments with the arrangement of Table 3 were performed. The permeation flux was measured after 45 min. Permeation flux has the higher the better performance characteristic. The result of experiments is shown in Table 3. The effect of each operating variable on the main

effect (permeation flux) at different levels could be separated because the experimental design is orthogonal. Fig. 2 shows the response value for each level.

Main effects of operating variables: The first studied factor was feed pressure. Three levels for feed pressure (0.4, 0.7 and 1.00 bars) were tested. This result could be observed in Fig. 4a which shows the effect of feed pressure on the response, the permeation flux. As could be observed, the increase in the feed pressure increases the flux value up to 17.26 kg/m²h, and this increase was almost linear. This result was in good agreement with those obtained in literature (20- 21). The second studied factor was feed flow rate. Fig. 4b shows the main effect of feed flow rate (30, 40, and 50 L/h) on the response, the permeation flux. As could be observed, an increase in the feed flow rate led to a little increase in the permeation flux. With an increase in the feed flow rate from 40 to 50 L/h, the permeation flux increased from ~11.21 to ~12.21 kg /m²h; whilst it constant with an increase in the flow rate from 30 to 40 L/h which can be explained by the fact that its hydrophobic surface is very susceptible to

fouling attachment, which forms an additional resistance for water molecules to pass through. The fouling attachment on PVDF-MFB membrane can be strongly linked to the oil and grease in a car wash which could come from any of the petroleum products on the surface of vehicle or leaking from the engine. This behavior was in good agreement with published data in literature (22). The third studied factor was feed temperature. Three levels for feed temperature (25, 35 and 45°C) were tested. As could be observed,

an increase in the feed temperature led to an increase in the permeation flux due to providing more molecular mobility at higher temperatures. Fig. 4c shows the main effect of feed temperature on the response, the permeation flux. It could be observed that the flux increased with an increase in the feed temperature. Moreover, the increase in feed temperature from 35 to 45°C was more effective than those increases from 25 to 35°C. This result was in good agreement with those obtained in literature (22).

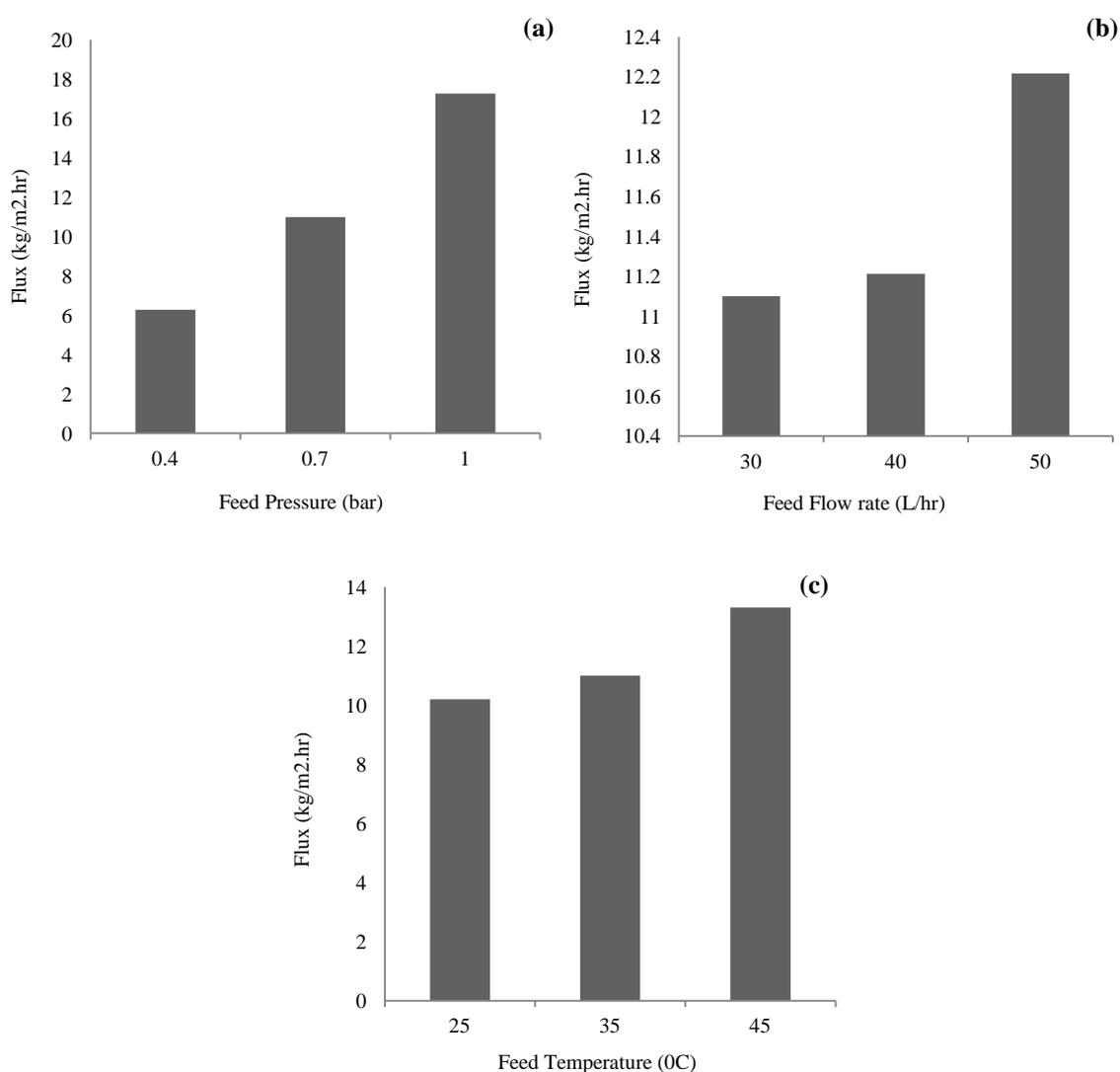


Fig. 2- Main effects of operating parameters on the permeation flux: (a) feed pressure, (b) feed flow rate, (c) feed temperature.

Interactive study of operating variables: Table 5 presents the results for the response of each level. These results indicated that there are some interactions between the operating variables. To find the interactions between investigated variables, the response of each parameter against others shall be constructed (23). The results are shown in Fig. 3a–c. This figure shows the regions in which there are interactions. In each region in which the lines cross each other there is interaction and the slope of the lines at the cross point is a criterion for the interaction percentage. The operating variables' interactions could be evaluated based on the severity index (SI%). The term SI is defined such that it is 100%

when the angle between the lines is 90° and 0 when the angle is zero. After all interactions are calculated, the Taguchi method uses the SI values to order them (see Table 4). Among three interactions tested, the SI values range between 41.01% (as the highest) and 7.76% (as the lowest). The higher SI value was between the feed temperature and flow rate. This is due to the effect of molecular mobility at higher temperatures on the recirculation rate of the feed stream. The lowest SI value was between the feed pressure and flow rate. This is due to low liquids compressibility, the interaction feed pressure is lower than other variables.

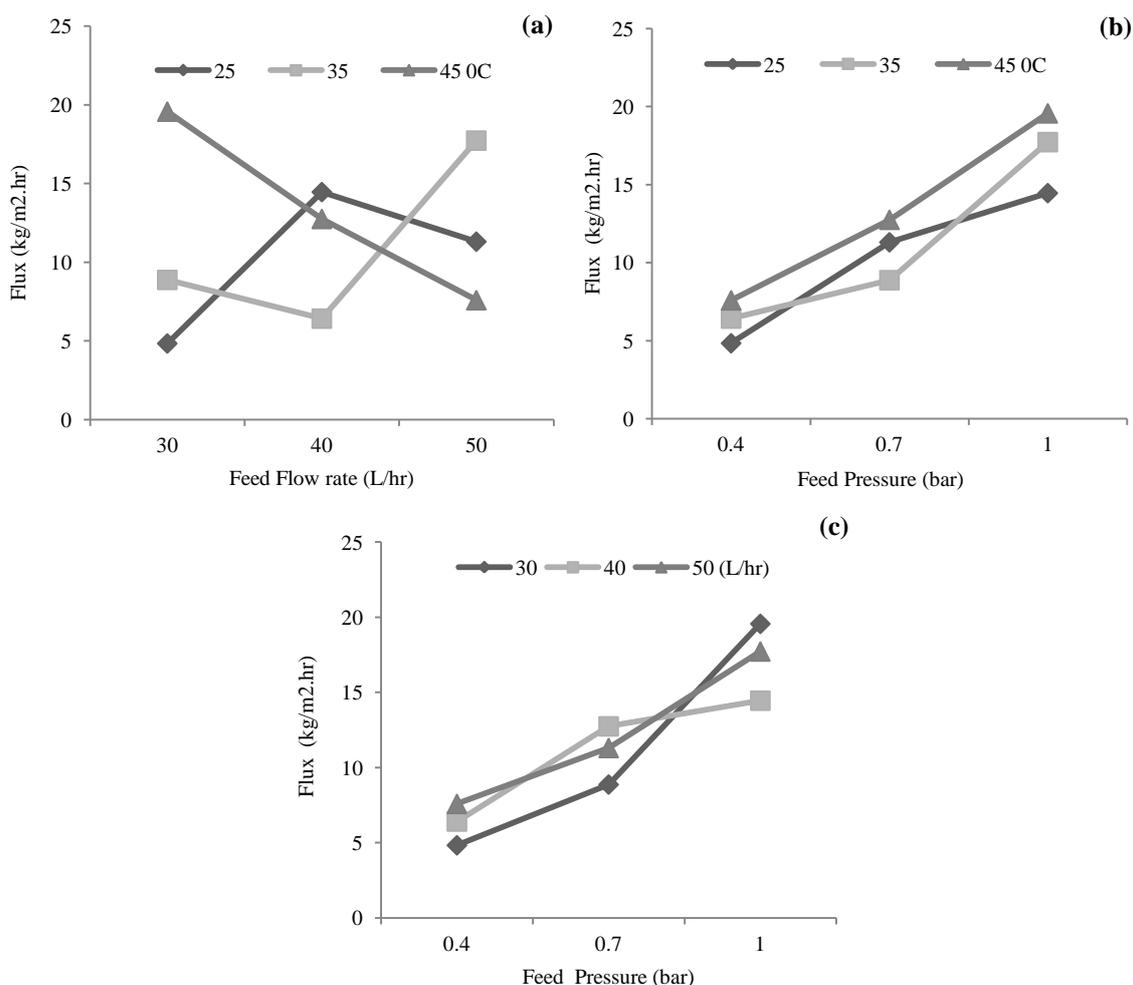


Fig. 3- Plotted interaction lines of operating parameters, (a) Q × T, (b) P × T, (c) P × Q.

Optimum conditions and responses based on Taguchi method: A new Taguchi design was done and the permeation flux was introduced as the target parameter and the permeation flux was introduced again as “bigger is better”. Considering the data presented in Table 6, it was found that the best combination of the operating variables for treatment of car wash effluent using microfiltration membrane was $P_3Q_3T_3$. In other words, using this combination of the factors which were predicted by Taguchi, the best response (higher permeation flux) with minimum required operational conditions will be attainable. Based on this prediction, $19.766 \text{ Kg/m}^2\text{h}$ permeation flux should be reached. In order to verify the validity of Taguchi model’s prediction, this combination is within the runs in Table 3 (Run#7) and the measured permeation flux for this run was obtained as $19.58 \text{ kg/m}^2\text{.h}$ which is reasonably close to the predicted value. Basically, the larger the response, the better the performance characteristic. As could be observed in Fig. 4, good validity was achieved between the excess experiments and the Taguchi prediction for the response.

Analysis of variance (ANOVA) : To determine those process parameters having significant effects on the performance characteristics, an analysis of variance (ANOVA) was carried out. This was accomplished by separating the total variability of each level, which is measured by the sum of the squared deviations from the total mean of the responses, into the contribution by each process parameter and the error (24). The percentage contribution from each of the process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the permeation flux.

Table 4- The percent of interactions between the process parameters (Interaction Severity Index).

Intraction	Columns	SI (%)
1. Q×T	2×3	41.01
2. P×T	1×3	13.62
3. P×Q	1×2	7.76

Table 5- Responses for the Taguchi analysis of the permeation flux.

Response	Operating parameter		
	P (bar)	Q (L/h)	T ($^{\circ}\text{C}$)
L1	6.286	11.101	10.208
L2	10.985	11.213	11.012
L3	17.26	12.217	13.311
L2-L1	4.698	0.111	0.804

Table 6- Optimum conditions based on Taguchi analysis.

Parameter	Level description	Level	Contribution
P (Bar)	1.00	3	5.749
Q (L/h)	50	3	0.707
T ($^{\circ}\text{C}$)	45	3	1.8
Total contribution from all parameters	8.256		
Current grand average of performance	11.51		
Expected result at optimum conditions	19.766		

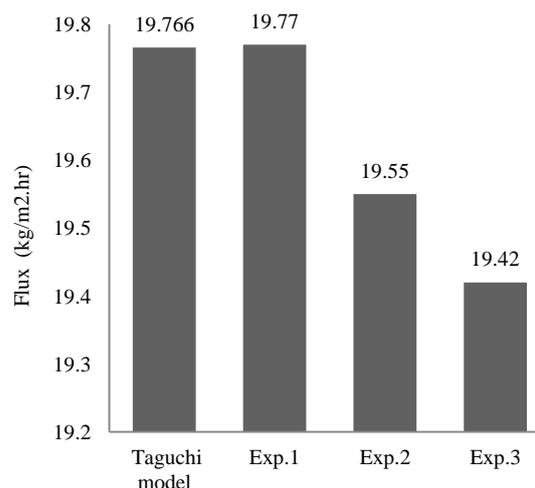


Fig. 4- Response values (permeation flux) based on the Taguchi model’s prediction and the excess experiments.

Results of ANOVA which are shown in Table 7 indicate that feed pressure is the significant operating variable to affect the performance characteristics (target parameter, the permeation flux). Based on the above discussion, the optimal operating variables are feed pressure level 3, feed flow rate level 3 and feed temperature level 3 (Fig. 2). Moreover, the contribution of the error is 4.54%, which may be assumed to be reasonable.

Table 7- Results of the ANOVA

Process parameters	DOF	Sum of squares	Variance	Percent (%)
P (bar)	2	545.587	272.793	87.542
Q (L/h)	2	6.805	3.402	0.746
T (°C)	2	46.662	23.331	7.167
Error	20	21.689	1.084	4.545
Total	26	620.744		100.00

Discussion and Conclusion

In this work, the effect of various operating variables on treatment of car wash effluent by microfiltration polyvinylidene fluoride (PVDF- MFB) membrane was studied. Results indicated that maximum permeation flux was achieved when feed pressure of 1.00 bar and feed temperature of 45°C were used. Moreover, this concluded that feed flow rate has a low role permeation flux. The Taguchi analysis of the data shows that there are some interactions between the operating variables and the best experimental conditions, which were predicted based on the Taguchi model are (P₃Q₃T₃). The contribution of feed pressure on the process response, the permeation flux, are greater compared with other factors. The features demonstrated by PVDF-MFB membrane in treatment from car wash effluent from Paniz station in omidiyeh, Khuzestan are at a relatively low operating pressure (1.00 bar) coupled with

stable water production can offer an environmentally sustainable option to car wash industry, i.e. meeting regulatory requirements for discharge and reducing fresh water consumption from water reclamation.

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کاربرد غشای میکروفیلتراسیون برای تصفیه پساب کارواش با استفاده از پیشگویی روش تاگوچی

آناهیتا دانشیار *

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چکیده

در پژوهش حاضر، شرایط تصفیه پساب کارواش ایستگاه پانیز در امیدیه، خوزستان به وسیله غشای میکروفیلتراسیون پلی وینیلیدین دی فلوراید (PVDF- MFB) با اندازه منافذ ۰/۱۳ میکرومتر با روش تاگوچی بررسی شد. روش تاگوچی به بررسی اثر شاخص‌های عملیاتی مختلف از جمله فشار خوراک در سه سطح (۰/۴، ۰/۷ و ۱ بار)، سرعت جریان خوراک در سه سطح (۳۰، ۴۰ و ۵۰ لیتر بر ساعت) و دمای خوراک در سه سطح (۲۵، ۳۵ و ۴۵ درجه سانتی گراد) بر روی شار نفوذی پساب کارواش در فرآیند تصفیه به کار برده شد. افزون بر این، اثر و سهم هر شاخص مربوطه بر روی شار و تداخل بین آن‌ها با تحلیل تاگوچی تعیین شده بود. نتایج نشان داد که مؤثرترین شاخص فشار خوراک بوده است. دومین سهم قابل توجه برای دمای خوراک مشاهده شد. سرعت جریان خوراک اثر کمی بر روی شار نفوذی دارد. در شرایط بهینه (۰/۱ بار، سرعت جریان ۵۰ لیتر بر ساعت و دمای ۴۵ درجه سانتی گراد)، میزان پاسخگویی مدل تاگوچی (شار نفوذی) $19/76 \text{ kg/m}^2\text{h}$ پیشگویی شده است که با نتایج تجربی مطابقت داشت.

واژه‌های کلیدی: غشای پلی وینیلیدین دی فلوراید، شار نفوذی، پساب کارواش، روش تاگوچی

* نویسنده مسؤول مکاتبات