Investigation of Best Operating Conditions for Treatment of Oily Wastewters with Hollow Fiber Ultrafiltartion Membranes

Mohsen Abbasi[1,*] and Mohammad Reza Sebzari[2]

[1]*Department of Chemical Engineering, School of Chemical and Petrolium Engineering, Persian Gulf University, Bushehr, 75169, Iran*

[2]*Department of Chemical Engineering, Lamerd Branch, Islamic Azad University, Lamerd, Iran*

Abstract: This paper investigates the optimum operating conditions for treatment of oily wastewaters by application of UF process using the Taguchi method. The following operating conditions have been considered in this investigation: Back Wash time; Trans-membrane pressure (TMP); Flow rate and temperature. The optimum operating conditions of UF were found as follows: Backwash time of 5 s; TMP of 2 bar; Flow rate of 12 L min^{-1} and temperature of 30 °C.

Experimental results presents that the importance level of the percentage contributions of each item is: (1) TMP (98.80 %), (2) back wash time (7.85 %), (3) flow rate (1.11 %), and (4) the feed temperature (0.819 %).

Keywords: Taguchi method, ultrafiltration, Oily wastewater treatment.

1. INTRODUCTION

Recently, huge amount of oily wastewaters are discharged into environment by oil and gas industry. Oily wastewaters have salt, hydrocarbons and toxic matters that can be have a dangerous effect on human and animal health [1-3]. For solving this problem, several separation processes for treatment of theses wastewaters by separation of oil have been investigated. In this area, operation such as: advanced oxidation processes, sedimentation, coagulation, flocculation, membrane processes, etc have been investigated by different researchers in literature [1, 2].

Nowadays, one of the best methods for treatment of oily wastewaters is membrane technology that has been investigated greatly in the recent years and is becoming a favorable process. This technology has benefits such as: high efficiency for oil separation, low fixed and operating costs and low volume requirement. Also, membrane technology has several advantages including: no requirement of chemical addition, treated wastewater with stable effluent quality [2-7].

Membrane fouling is a major obstacle for commercialization of the membrane processes for treatment of oily wastewaters. This can be reduced by optimizing the operating condition and choosing the right membrane. Therefore, This study focuses on the investigating the effects of back wash time, trans-membrane pressure (TMP), temperature and volume flow rate (Q) on permeate flux of Hollow Fiber UF membranes for treatment of oily wastewaters.

The Taguchi method can significantly reduces the experimental costs by employing an orthogonal array that specially designed for the Taguchi method. Therefore, the best operating parameters can be achieved as presented by different researchers in literature for the area of wastewater treatment, ceramic preparation, solid fuel briquette, etc [7-14].

2. EXPERIMENTAL

2.1. Membrane Specifications

PAN-L1010 membrane module supplied by AMFOR Membrane Technology Company, was a kind of spiral wound membrane module has been employed in experiments. This commercial membrane has good performance (high permeability and high rejection rate of oil) during oily wastewater treatment. Table **1** lists the properties of this membrane.

Table 1: Properties of UF Membrane

	Ultrafiltration process
Membrane configuration	**Hollow Fiber**
Surface area (m^2)	0.7
Length (m)	0.5
MWCO (kDa)	100 kDa
TMP (bar)	1-2
Maximum allowable temperature (°C)	50
Suitable operating range of pH	3-10

*Address correspondence to this author at the Department of Chemical Engineering, School of Chemical and Petrolium Engineering, Persian Gulf University, Bushehr, 75169, Iran; Tel: +98 (917) 323-9077; Fax: +98 (771) 455-1838; E-mail: m.abbasi@mail.pgu.ac.ir

E-ISSN: 1929-6037/14

2.2. Oily Wastewater

The produced oily wastewater in Sand Filter unit of Tehran refinery has been employed in experiments. The feed was taken daily from the refinery. Specifications of the wastewater has been presented in Table **2**. The droplet size distribution of wastewater show that droplets diameter was below 20 µm (see Figure **1**). It must be noted that oil in water emulsion was stable during filtration experiments.

Table 2: Characteristics of the Oily Wastewater

Item	Unit	Feed
TSS	mg/lit	92
Oil & grease content	mg/lit	26
TOC	mg/lit	141
Turbudity	mg/lit	21

2.3. Setup

To find the optimum operating parameters experiments were carried out in a pilot scale setup within 90 min operation. In setup, there were a heater and a coil of cooling water for adjusting the temperature. Also, each tank with a volume of 100 L and a thermostat in tank sets the temperature. Schematic of the setup has been shown in Figure **2**. During experiments, retentate and permeate were continuously recirculated into the feed tank because by application of total recycle mode of filtration, the wastewater concentration in the tank remains fixed. Finally, the membranes were back flashed during the experiments by using hot water. More details of pilot plant have been presented in refrence1.

2.4. Experimental Design

The Taguchi method has been generally adopted to optimize the design parameters [7–14] because this

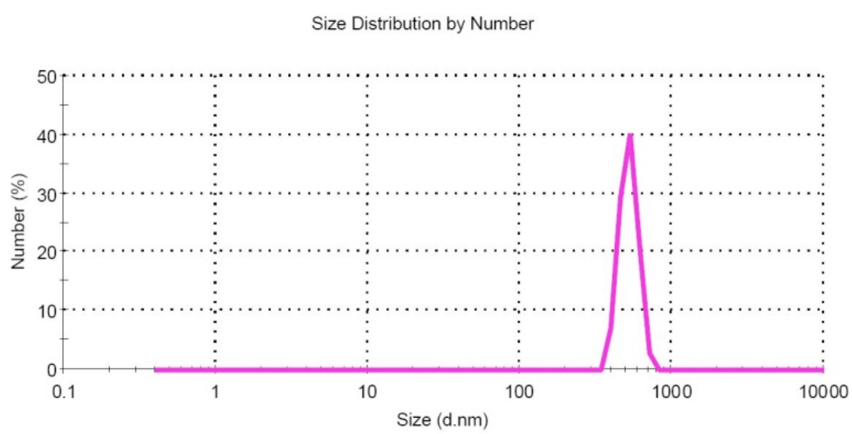

Figure 1: Droplet size distribution of oily wastewater.

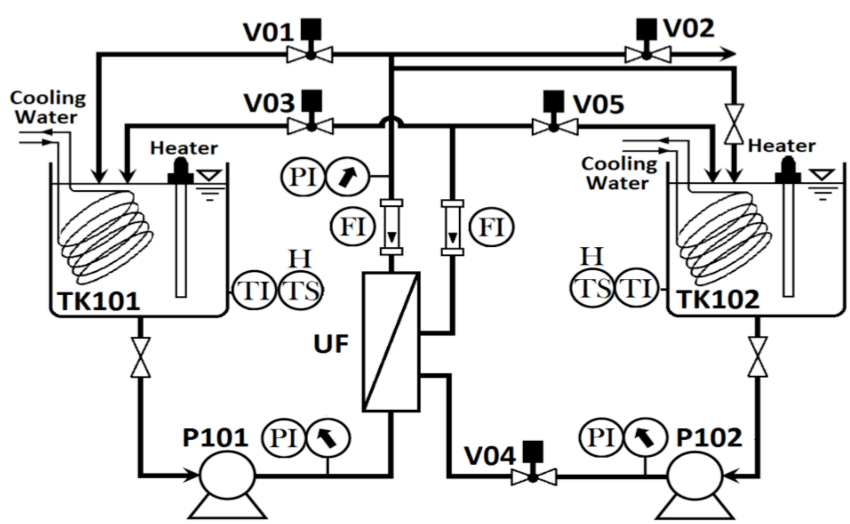

Figure 2: PFD of the experimental setup.

systematic approach can significantly minimize the overall testing time and the experimental costs. Using the orthogonal array specially designed for the Taguchi method, the optimum experimental conditions can be easily determined.

In this research, for treatment of oily wastewater, four operating parameters have been selected and each operating parameter has three levels as shown in Table **3**. Therefore, the test operating conditions can be arranged by using Table **3** and the L9 (3^4) orthogonal array as presented in Table **4**.

Table **4** presents the L9 (3^4) orthogonal array of operating condition for Taguchi method and there is not permeation fluxes in this table. Backwash operation is used to removing of filter cake on the membrane surface.

The analysis of mean (ANOM) statistical approach is adopted herein to construct the optimal conditions. Initially, the mean of the S/N ratio of each controllable factor at a certain level must be calculated. Therefore the optimal operating conditions were chosen as the highest average S/N ratios [14, 15].

For evaluation of experimental results plus obtaining best operation conditions for treatment of oily wastewater an analysis of the signal-to-noise (S/N) ratio is applied as follows [14, 15]:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right) \tag{1}$$

in the above equation, n is the number of repetitions under the similar experimental tests and Y presents the permeation flux of membranes. To finding best operating parameters for treatment of oily wastewater, the average of the S/N ratio of each operating parameter at a certain level is calculated as follows [14, 15]:

$$(M)_{Factor=I}^{Level=i} = \frac{1}{n_{Ii}}\sum_{j=1}^{n_{Ii}}\left[\left(\frac{S}{N}\right)_{Factor=I}^{Level=i}\right] \tag{2}$$

In Eq. (2), n_{Ii} shows the number of appearances of factor I in the level i. Also, the parameter in sigma term is the S/N ratio of factor I in level i, and its appearance sequence in Table **3** is the jth. In addition, the analysis of variance statistical method is also employed to investigate the effect of each operating parameter on the permeate flux. The percentage contribution of each factor (ρ_F), is calculated by the following formula [14, 15]:

Table 3: Operating Parameters and their Levels

Factor	Description	Level 1	Level 2	Level 3
A	Back Wash time (t) s	3	5	7
B	Trans-membrane pressure (TMP) bar	1	2	3
C	Flow rate (Q) $Lmin^{-1}$	8	12	16
D	Temperature (T) °C	25	30	35

Table 4: Test Conditions

	t (s)	TMP bar	Q ($Lmin^{-1}$)	T (°C)
Test 1	3	1	8	25
Test 2		2	12	30
Test 3		3	16	35
Test 4	5	1	12	35
Test 5		2	16	25
Test 6		3	8	30
Test 7	7	1	16	30
Test 8		2	8	35
Test 9		3	12	25

$$\rho_F = \frac{SSF - (DOF_F V_{Er})}{SS_T} \times 100 \quad (3)$$

In above formula, DOF_F presents the degree of freedom for each factor. SS_T is the total sum of squares and is calculated by this equation [14, 15]:

$$SS_T = \sum_{j=1}^{m} \left(\sum_{i=1}^{n} Y_i^2 \right)_j - mn(\bar{Y}_T)^2 \quad (4)$$

where

$$\bar{Y}_T = \sum_{j=1}^{m} \left(\sum_{i=1}^{n} Y_i \right)_j / (mn) \quad (5)$$

m shows the experiments number and n is the number of repetitions under the similar experimental conditions. The factorial sum of squares, SS_F, is given by:

$$SS_F = \frac{mn}{L} \sum_{k-1}^{L} (\bar{Y}_k^F - \bar{Y}_T)^2 \quad (6)$$

where Y^F_k is the mean value of the measurement results of a certain factor in the k_{th} level. In addition, the variance of error (V_{Er}) can be calculated by the following equation [14, 15]:

$$V_{Er} = \frac{SS_T - \sum_{F=A}^{D} SS_F}{m(n-1)} \quad (7)$$

Table 5: The S/N Ratio of each Experiment Condition

	Y (%)		S/N
	Y_1	Y_2	
Test 1	167.4545	165.2474	44.44106
Test 2	191.2782	190.2345	45.61049
Test 3	190.4762	192.1652	45.57389
Test 4	171.4286	171.7624	44.65618
Test 5	190.2857	190.2978	45.56518
Test 6	187.1815	186.4532	45.42193
Test 7	174.9451	173.8766	44.83307
Test 8	185.5573	184.1223	45.34603
Test 9	194.8052	193.5411	45.7696

Table 6: S/N Ratio Response Table

Factor/Level	$\left(\frac{S}{N}\right)_{Factor=I}^{Level=i}$		$(M)_{Factor}^{Level}$
	j=1	j=2	
A/1	45.1872	45.13947	45.16327
A/2	45.29453	45.24743	45.27092
A/3	45.19311	45.14545	45.16922
B/1	44.62429	44.57344	44.59879
B/2	45.56575	45.52014	45.54289
B/3	45.4848	45.43877	45.46172
C/1	45.04891	45.00044	45.0246
C/2	45.32363	45.27666	45.30008
C/3	45.30231	45.25526	45.27872
D/1	45.26689	45.21965	45.24321
D/2	45.23716	45.18969	45.21336
D/3	45.1708	45.12302	45.14684

Table 7: S/N Ratios in Test 9 and at the Best Operating Condition

	A	B	C	D	Y_1	Y_2	S/N
Test 9	7	3	12	25	194.8052	193.5411	45.7696
Optimization condition	5	2	12	25	199.1230	199.5432	45.98243

Table 8: Y_k for each Factor with Different Level

	Y_k^A	Y_k^B	Y_k^C	Y_k^D
Level 1	182.5006	170.707	179.4954	183.6128
Level 2	182.4653	188.5404	185.3373	183.9682
Level 3	184.6025	190.321	184.7357	181.9874

3. RESULTS AND DISCUSSION

Table **4** presents the L9 (3^4) orthogonal array of operating condition for Taguchi method. The S/N ratio of each test condition is determined by applying Eq. (1) has been presented in Table **5** in this table, the boldface is the maximum value of S/N ratio in all experiment tests. Also, Table **6** presents the mean of the S/N ratios of a certain factor in the i_{th} level. It must be noted that in Table **6**, the boldface is the maximum value of all data and thus it presents the best operating conditions for treatment of wastewater by hollow fiber UF membranes.

Based on results of Table **6**, the optimum operating conditions of UF are as follows. (1) Backwash time of 5 s; (2) TMP of 2 bar; (3) Flow rate of 12 L min^{-1} and (4) temperature of 30 °C.

Table **7** illustrates the S/N ratio of registered permeate flux by using confirmed experiments at the best operating conditions.

The difference of the S/N ratio between the best operating conditions and Test 9 is very small but the TMP decreases from 3 bar (in Test 9) to 2 bar (at the best operating conditions) and the duration of back wash decreases from 7 s (in Test 9) to 5 s (at the best operating conditions). It is obvious that employing filtration process with lower TMP, reduces operating costs for treatment of wastewater and also shorter back wash time have a positive effect on the total permeation flux of membrane.

Table **8** presents the Y_k by employing results of Table **5**. By replacing Y_k and Y_T = 183.1895 into Eq. (6), the SS_F is calculated individually and these results have been listed in Table **9**. Using Eq. (4), the SS_T, can be determined. By substituting SS_F and SS_T = 1571.575 in the Eq. (7), V_{Er} was obtained. In final, by the replacement of SS_F, SS_T = 1571.575, V_{Er} = 0.25, and DOF_F = 2 in the Eq. (3), the ρ_F was determined sequentially; and these results have been illustrated in Table **9**.

Table 9: SS_F and ρ_F

	SS_F	ρ_F
A	123.90127	0.078521
B	1411.814717	0.898026
C	17.97448867	0.011119
D	13.3844607	0.008198

Based on the order of magnitudes of the operating conditions, the rank order of the percentage contributions of each factor is as follows: (1) TMP (98.80 %), (2) back wash time (7.85 %), (3) flow rate (1.11 %), and (4) the feed temperature (0.819 %). Therefore, it can be concluded that TMP is the most important parameter on permeation flux of membranes.

4. CONCLUSIONS

In this work, by employing the Taguchi method, the best operating conditions for treatment of oily wastewater in Sand Filter unit of Tehran refinery have been investigated. In addition, the percentage contribution of each operating parameter on the permeation flux of membranes was determined by the analysis of variance in a pilot scale plant.

Results showed that the beast operating conditions of UF are as follows:

(1) Backwash time of 5 s;

(2) TMP of 2 bar;

(3) Flow rate of 12 $Lmin^{-1}$ and

(4) temperature of 30 °C.

It was also found out that the shorter backwash time is more effective.

REFERENCES

[1] Hosein Abadi SR, Sebzari MR, Hemati M, Rekabdar F, Mohammadi T. Ceramic membrane performance. Desalination 2011; 265: 222-8. http://dx.doi.org/10.1016/j.desal.2010.07.055

[2] Cui J, Zhang X, Liu H, Liu S, Yeung KL. Preparation. J Membr Sci 2008; 325: 420-6. http://dx.doi.org/10.1016/j.memsci.2008.08.015

[3] Hua FL, Tsang YF, Wang YJ, Chan SY, Chua H, Sin SN. Performance. Chem Eng J 2007; 128: 169-5. http://dx.doi.org/10.1016/j.cej.2006.10.017

[4] Ebrahimi M, Willershausen D, Ashaghi KS, Engel L, Placido L, Mund P, Bolduan P, Czermak P. Investigations. Desalination 2010, 250: 991-6. http://dx.doi.org/10.1016/j.desal.2009.09.088

[5] Mohamed YT, Hussin LMS, Gad HMH, Daifullah AAM, Abo-El-Enein SA. Membrane Stabilitiy. J Membr Sep Tecnol 2013; 2: 102-8.

[6] Jie Y, Dandan Z, Chao C, Hongxia G, Bangjun H, Yahong H, Zhenao G, Shuren Y, Hong Y, Ziwei D, van Agtmaal S, Chunhui F. Pilot Scale. J Membr Sep Tecnol 2014; 3: 44-49.

[7] Tong G, Song J, Wang P, Zhao H, Tan X. Preparation. J Membr Sep Tecnol 2014; 3: 146-53.

[8] Wang SB, Pan C, Two-phase. Exp Thermal Fluid Sci 1998; 17: 189-201. http://dx.doi.org/10.1016/S0894-1777(98)00005-3

[9] Wu DH, Chang MS. Use. Materials Science and Engineering 2004; 379: 366-71. http://dx.doi.org/10.1016/j.msea.2004.03.006

[10] Chiang, KT. Optimization. Int Commun Heat Mass Transfer 2005; 32: 1193-201. http://dx.doi.org/10.1016/j.icheatmasstransfer.2005.05.015

[11] Erzurumlu T, Ozcelik B. Minimization. Mate Design 2006; 27: 853-61. http://dx.doi.org/10.1016/j.matdes.2005.03.017

[12] Wang TY, Huang CY. Improving. European J Operational Res 2007, 176: 1052-65. http://dx.doi.org/10.1016/j.ejor.2005.08.020

[13] Chou CS, Ho CY, Huang CI. The optimum conditions. Adv Powder Technol 2009; 20: 55-61. http://dx.doi.org/10.1016/j.apt.2008.02.002

[14] Chou CS, Lin SH, Peng CC, Lu WC. The optimum conditions. Fuel Process Technol 2009; 90: 1041-46. http://dx.doi.org/10.1016/j.fuproc.2009.04.007

[15] Chou CS, Yang RY, Chen JH, Chou SW, The optimum conditions for preparing. Powder Technol 2010; 199: 264-71. http://dx.doi.org/10.1016/j.powtec.2010.01.015

Received on 29-10-2014 Accepted on 27-11-2014 Published on 03-12-2014

DOI: http://dx.doi.org/10.6000/1929-6037.2014.03.04.9