Environmental Engineering and Management Journal November 2018, Vol. 17, No. 11, 2627-2633
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

TREATMENT OF FORGING INDUSTRY WASTEWATER USING NON-HYBRID AND HYBRID PROCESSES

Reza Aminzadeh[1,2], Seyed Mahmoud Mousavi[1*], Hamid Reza Nazari[1,2]

[1]*Department of Chemical Engineering, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran*
[2]*Research Center of Membrane Processes and Membrane, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran*

Abstract

In this study, five distinctive separation processes namely sand filtration (SF), adsorption, microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) were examined in two ways for the treatment of forging industry wastewater. At first, each process was examined separately, and then they were applied in association with each other as hybrid processes including pretreatment, main treatment, and post-treatment. The results related to non-hybrid experiments show that none of the mentioned methods are able to treat the forging wastewater satisfactorily while the results obtained from some of hybrid processes such as SF + MF + NF and combination of four or more processes indicate that they are able to reduce the pollution indices of chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), oil and grease, and three heavy metals to more than 77.9 %.

Key words: adsorption, forging industry, hybrid processes, membrane processes, wastewater treatment

Received: November, 2013; Revised final: January, 2015; Accepted: January, 2015; Published in final edited form: November 2018

1. Introduction

Resources of natural water in many regions of the world are finite and are becoming as a restrictive factor for further industrial growth. Nowadays, most countries, where the water availability is scarce, apply several wastewater technologies for regeneration and reuse. The reuse of treated wastewater presents the possibility of exploiting a new resource that can substitute the existing resources (Deniz et al., 2010).

Forging is the shaping of metal through the use of impact strikes or pressure to plastically deform the material. Forging and then wire drawing were the oldest of metalworking processes (Byers, 2006). The metalworking industry uses large quantities of coolants and water-based lubricants for cooling the work piece and machine tool, reducing the friction and wear of tool and die, and also improving the surface quality of work piece. Besides, the coolants and water-based lubricants are used to flush away the metal chips generated during the machining (Hu et al., 2002). This industry produces large amounts of wastewater. The wastewater come from many sources, not just "coolants" and washing "soaps". Additional sources include floor cleaners, phosphate wastes, vibratory deburring discharge, impregnation fluids, stamping and drawing compounds, lapping compounds, machine lubricants, test cell blow down, first fill oils, die casting lubricants, and so on. Because of this, the wastewater contains free oils, stable oil–water emulsions, water-soluble organic compounds, dissolved and undissolved metals, inorganic compounds such as nitrates, chlorides, sulfates, and suspended and settleable materials (Benito et al., 2010; Byers, 2006; Greeley and Rajagopalan, 2004). Thus, its treatment is necessary.

A variety of methods such as hydrothermal oxidation, biological treatment, membrane processes, filtration and adsorption have been studied for the treatment of metalworking wastewater (Belkacem et

*Author to whom all correspondence should be addressed: e-mail: mmousavi@um.ac.ir; Phone: +98 51 38816840

al., 1995; Busca et al., 2003; Cambiella et al., 2006; Cheng et al., 2005; Hilal et al., 2005; Muszyński and Łebkowska, 2005; Portela et al., 2001). However, more researches are needed in order to treat this wastewater containing various contaminants. Many researchers have not considered the real wastewater and hybrid processes for this purpose and also all the pollution indices of wastewater. Hence, this relatively comprehensive study presents different non-hybrid and hybrid processes for the treatment of wastewater of a forging unit, and then compares these processes to each other with respect to different pollution indices. Five separation processes namely adsorption, SF, MF, UF and NF were considered in different ways to provide some hybrid processes for the treatment of this wastewater.

2. Material and methods

2.1. Equipment

SF and adsorption tests were carried out in a fixed bed column covered by a jacket in order to keep the temperature constant. The fixed bed column was made of Perspex tube with 2.0 cm internal diameter and 90 cm height. The bed length used in the experiments was 60 cm.

An experimental set-up was used for membrane experiments. In this set-up, the feed tank was made from stainless steel. A centrifugal pump drew the feed from the feed tank through a steel pipe and delivered it to a flat sheet membrane module. The membrane module was made of stainless steel. The set-up had a heat exchange system in order to maintain the temperature constant.

The main analyzed pollution indices in this work were COD, TDS, TSS, and oil and grease along with three heavy metals, i.e. Fe, Ni, and Cr (VI) which were more likely present in the wastewater. The amounts of heavy metals were determined via an atomic absorption spectrophotometer (Varian spectra AA-220). The values of TSS, COD, and oil and grease were measured with a spectrophotometer (DR3000, Hach, USA). Metler Toledo conductivity meter was used for the determination of TDS of the samples.

2.2. Materials

The wastewater, as the feed, was the outflow of the equalization tank of a local forging unit. It had relatively high pollution load. The materials employed for the SF and adsorption processes were sand (mostly) and anthracite, respectively, provided from a local municipal water treatment plant. The sand filter consisted of two layers: gravel (grain size 7–10 mm) and sand (grain size 0.6–1 mm). The way that the column was filled by the sand was as follows: The first 5 cm of the column from the bottom was filled by the gravel. This 5-cm layer acted as a support layer for the subsequent sand. Afterwards, each 5 cm of the column was filled by the sand followed by a 1 cm separator layer of the gravel. The wastewater was mainly filtered by the sand while 1 cm separator layer of the gravel inhibited the clogging of the fluid paths within the column, so that better distribution of the fluid inside the column was provided.

Size of the adsorbent grains (1.1–3.2 mm) was larger than that of the sand, thus no separator layer was needed for the adsorption column. However, the first 5 cm of the column from the bottom was filled by the gravel as a support layer. The characteristics of anthracite adsorbent are presented in Table 1.

Three different flat sheet-type membranes were used for MF, UF, and NF processes. The membrane used as microfilter was polytetrafluoroethylene(PTFE) on a polypropylene (PP) substrate; with pore size of 0.45 µm. Ultrafilter and nanofilter were polyacrylonitrile (PAN) and polyamide (PA), respectively.

Table 1. Properties of the adsorbent

Parameter	***Value***
Bulk density (g mL^{-1})	0.425
Solid density (g mL^{-1})	4.04
Moisture capacity (%)	0.52
Ash capacity (%)	6.5
Particle size (mm)	1.1-3.2
Porosity (dimensionless)	0.67
(m^2 g^{-1})BET surface area	413.3

2.3. Experimental procedure

Exploring the effectiveness of the hybrid processes from combination of SF, adsorption, MF, UF and NF to treat the wastewater of forging industry, was the aim of the present study. However, knowing the abilities of each process in removing the contaminants from the wastewater as a separate process could be helpful to find the effectiveness of each process and the accurate sequence of processes in hybrid experiments. Hence, two kinds of experiments were performed: at first, each of processes was examined separately as non-hybrid processes, and later they were applied in association with each other as hybrid processes. The temperature was kept at 30 ˚C in all experiments.

2.3.1. Non-hybrid processes

The comparative study was carried out among the separation processes to evaluate ability of each process in removing the contaminants of wastewater. SF was the first process which was accomplished as the independent process. The SF experiments were performed in the fixed-bed column under atmospheric pressure. The process wastewater was pumped from the feed tank at a rate of 2 mL/min through the column. The effluent from the column during the experiment was recycled to the column as the influent. This recycling was accomplished for 5 times and the final effluent from the column was sampled and analyzed. Adsorption was the second process which was performed similar to SF.

After SF and adsorption, membrane experiments were carried out. Before being used as a separation step for the wastewater treatment, all membranes were soaked in deionized water for 24 h. Thereafter, the membranes were preprocessed for 30 min with pure water to obtain stable membrane structures. Besides, in order to evaluate the membrane fouling, the pure water fluxes were measured by using the membranes in the membrane setup. Afterwards, the treatment was carried out with the forging wastewater as the feed stream. The transmembrane pressure for MF, UF, and NF was 3.5, 7, and 20 bars, respectively.

The experiments were carried out under total recirculation mode, i.e. both permeate and retentate streams were recycled into the feed tank to keep the feed composition approximately constant. The feed volume was kept constant on 20 L for all experiments.

In the membrane experiments, the fluxes were calculated using Eq. (1):

$$J = \frac{V}{At} \tag{1}$$

where J is the permeate flux (l/m^{2}h), V is the permeate volume (l), A is the effective membrane area (m^2), and t is the sampling time (h). Also, the rejection (%) was calculated using Eq. (2):

$$R = \left(1 - \frac{C_p}{C_f}\right) \times 100 \tag{2}$$

where C_p and C_f are the concentration of contaminant (mg/L) in the permeate and feed, respectively.

At the end of the experiments, the samples of both permeate and feed streams were taken and analyzed.

2.3.2. Hybrid processes

The next stage of experiments was related to the treatment of wastewater by using hybrid processes. It was specified by doing some primary experiments that SF could be more effective as a pretreatment process prior to the other processes while NF and adsorption should be used after a proper pretreatment process. However, the wastewater treatment was rather considerable with MF and UF. Hence, in hybrid processes, SF was applied as a pretreatment process, membrane processes of MF and UF were used as the main treatment stages while NF and adsorption were used as post-treatment stages. The operational conditions of processes were the same as the previous section.

The hybrid processes began with SF. The wastewater was pumped from the feed tank and passed through the fixed bed column. The effluent from the column during the experiment was recycled to the column as the influent for 5 times. The final effluent from the column was used as a feed for MF process. The permeate and feed were analyzed at the end of MF experiment. Also, the flux of MF membrane was measured during the experiment. After passing SF and MF, the permeate was conducted separately to UF and NF membranes for further treatment. At the end of the experiments, the permeate and feed of both processes of UF and NF were analyzed. Also, the flux of UF and NF membranes were measured during the experiments. Similar to the non-hybrid processes, the transmembrane pressure for MF, UF, and NF was controlled at 3.5, 7, and 20 bars, respectively. In another hybrid process, the permeate coming from NF membrane was used as the feed for another NF stage in order to reach a further treatment.

The permeate stream of UF in the previous steps was used as the feed for NF experiment. Sampling and analyzing the permeate and feed were carried out at the end of NF experiment. Afterwards, as a post-treatment, the permeate streams of NF experiment were conducted to the adsorption column. The permeate stream of NF membrane were pumped through the adsorption column. The effluent from the column during the experiment was recycled to the column as the influent for 5 times. The final effluent from the column was sampled and analyzed. As the finishing stage of the hybrid experiments, the final effluent from adsorption column was collected and then used as the feed stream for NF membrane.

In summary, to find an effective hybrid process for the wastewater treatment of forging industry, the various combinations of the separation processes were performed in this work. These combinations are summarized as follows:

- SF + MF
- SF + MF + UF
- SF + MF + NF
- SF + MF + NF + NF
- SF + MF + UF + NF
- SF + MF + UF + NF + adsorption
- SF + MF + UF + NF + adsorption + NF

3. Results and discussion

As mentioned before, the general process of the experiments was based on two stages. In the first stage, the separation ability was examined for each separation method individually. Fixed bed SF, fixed bed adsorption, MF, UF, and NF were conducted independently. In the second stage, the separation ability was investigated via the combination of separation methods which was the main aim and goal of the present research.

3.1. Non-hybrid experiments

The removal ability of pollution indices of COD, TSS, TDS, oil and grease, and heavy metals from the wastewater was examined separately for each separation method. Table 2 illustrates the removal or rejection results for each possible separation process in non-hybrid experiments.

Table 2. Values of removal or rejection in non-hybrid experiments

Process	***Removal or rejection of pollution indices (%)***						
	TSS	***TDS***	***COD***	***Oil and grease***	***Ni***	***Fe***	***Cr (VI)***
SF	25.0	6.3	30.6	54.3	23.4	30.0	2.4
Adsorption	27.8	11.8	44.5	20.0	27.7	28.9	17.2
MF	90.3	44.7	70.4	85.9	59.0	48.3	13.4
UF	93.6	51.3	83.0	96.0	77.1	62.5	41.8
NF	-	-	-	-	-	-	-

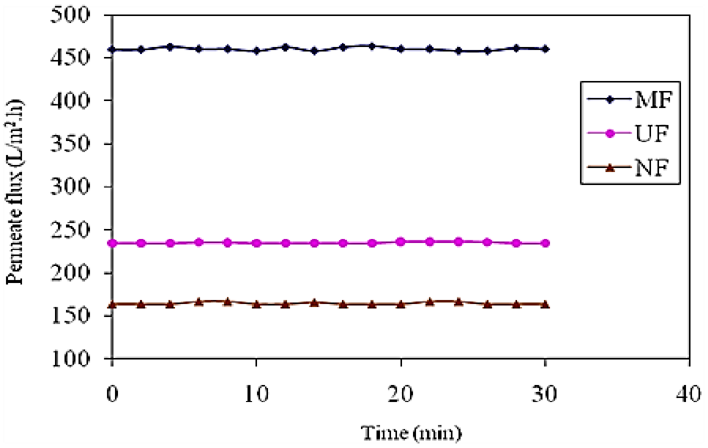

Fig. 1. Permeate flux versus time for distilled water in MF, UF and NF processes

3.1.1. Effect of SF on wastewater treatment

With regard to the obtained results of SF in Table 2 which show removal or rejection percent of the pollution indices, it is obvious that the high amount of disposal is for oil and grease. The removal of oil and grease can be helpful for other separation processes, e.g. membrane separation because it can decrease the membrane fouling. Thus, SF as a pretreatment process before other processes can result in more favorable results for the wastewater treatment. Unlike oil and grease, the removal of Cr (VI) and TDS has partially been accomplished.

3.1.2. Effect of adsorption on wastewater treatment

As it can be seen in Table 2, COD can be removed by adsorption process better and more among the other pollution indices. Moreover, the amount of removed TSS by this process is close to the amount eliminated by SF. However, the removal of heavy metals by adsorption process has been totally better than that by SF. Ismail and Beddri (2009) and Ismail et al. (2013) investigated the importance of removing heavy metals.

Generally, it seems that adsorption process has not been able to remove the pollution indices properly due to relatively high pollution load of the wastewater. Therefore, pretreatment before the adsorption process seems to be necessary. In other words, the direct use of the adsorption process is not correct, and it should be applied in post-treatment stages. The use of adsorption as a post-treatment method was reported by other researchers (Al-Malah et al., 2000).

3.1.3. Effect of each membrane process on wastewater treatment

Prior to examination of the effects of MF, UF, and NF processes on the amount of pollutants removal, the permeate flux for distilled water for each of three mentioned processes was measured in order to estimate the formation and amount of membrane fouling. The transmembrane pressure for MF, UF, and NF was 3.5, 7, and 20 bars, respectively. Fig. 1 shows the permeate flux in terms of time for distilled water. For doing this, from the beginning of the experiment, the permeate flux was measured every 2 minutes. As it is seen in the figure, there was practically no change in the amounts of permeates flux with time during the experiments. The reason is that the distilled water was relatively pure. The amount of permeate flux for distilled water in MF, UF, and NF processes was 463.26 L/m^2h (132.36 $L/m^2h.bar$), 236.21 L/m^2h (33.74 $L/m^2h.bar$), and 166.47 L/m^2h (8.32 $L/m^2h.bar$), respectively.

a. Effect of MF on wastewater treatment

As can be seen in Table 2, MF process could, somehow, treat the wastewater. MF process could decrease TSS by 90.3%. The process could just eliminate TDS 44.7%. The lowest percentage of removal was for Cr (VI). However, among metals, Ni was eliminated much better.

Furthermore, Fig. 2 shows the permeate flux in terms of time in the MF process when it was used individually. In order to measure the permeate flux in this stage, the amount of flux was measured from the beginning in every 4 minutes. In comparison with Fig. 1, it becomes apparent that there is a considerable decrease in the permeate flux when the wastewater passes through MF membrane. As it is illustrated in Fig. 2, the rate of this descent in permeate flux is more in the initial moments of the operation, gradually it is getting less intensity, and eventually after almost 40 minutes from the beginning, it becomes stable. The reason for this decline is the effect of concentration polarization and membrane fouling. The cause of this fouling can be the high amount of suspended materials and oil and grease of the wastewater.

b. Effect of UF on wastewater treatment

With regard to Table 2, UF process has provided more favorable results, but it can't diminish the amount of some pollution indices effectively. It seems that the proper pretreatment before UF can enhance the efficiency of this process to treat the wastewater as much as possible.

Additionally, Fig. 2 shows the permeate flux in terms of time in the UF process when it was used individually. With regard to this figure, it can be concluded that the trend of flux variation for both processes of MF and UF is almost similar.

c. Effect of NF on wastewater treatment

As it can be observed in Table 2, no data is presented for NF process. The reason is the fouling of membrane pores. These pores are so minute, and as a result, there was no permeate in this process. With regard to this issue, it can be said that the utilization of NF as an independent treatment process with no pretreatment for the pollutants removal of this wastewater is incorrect. Therefore, before applying this process, it is better to remove the oil and grease and also suspended particles, which disrupt the NF membrane function, with using pretreatment methods.

3.2. Hybrid experiments

As it can be observed in Table 2, the removal or rejection of pollution indices by non-hybrid processes is not totally very suitable. With regard to the results obtained from non-hybrid experiments, it was decided that in hybrid experiments, SF should be used as pre-treatment process, membrane processes of MF and UF are proper for the main stages of treatment, and adsorption as well as NF process should be used as post or final treatment.

The best was done to conduct different combinations of these processes. The obtained results with respect to the final step outflow of each hybrid process are shown in Table 3.

3.2.1. Effect of consecutive processes of SF and MF on wastewater treatment

As it can be observed in Table 3, the combination of SF and MF processes could increase the removal or rejection percentage of pollutants in comparison with when they were used separately. According to this table, the process did not act well for removing Cr(VI). The effect of using the SF process before initiating MF process on the permeate flux is shown in Fig. 3. As it can be seen in this figure, in comparison with Fig. 2, SF could increase the permeate flux produced by MF process. The reason can be the relative removal of solid suspended particles as well as oil and grease by SF process. So, the SF pretreatment causes lower fouling.

This finding is in a close agreement with the results of Zheng et al. (2009), who used SF as pretreatments UF. Furthermore, it takes the MF permeate flux 48 minutes to reach the stable level after using the SF as the pretreatment process.

3.2.2. Effect of consecutive processes of SF, MF, and UF on wastewater treatment

Table 3 indicates that the hybrid process of SF, MF, and UF has not acted very well in eliminating the TDS and heavy metals. Fig. 3 illustrates the permeate flux in terms of time for UF process after using SF and MF. Comparing with Fig. 2 in which the permeate flux in terms of time for UF process had been shown in non-hybrid experiment, it can be stated that SF and MF processes have effectively prevented the fouling in UF process which leads to an increase in the flux in UF process in this hybrid experiment. Also, as it is found in Fig. 3, it takes the UF permeate flux 52 minutes to reach the stable level.

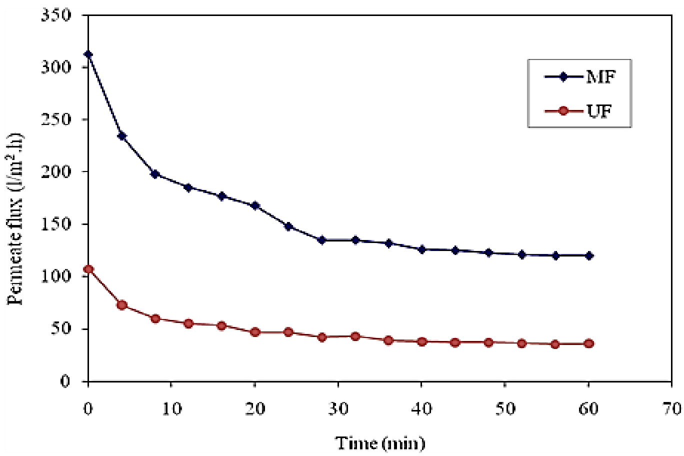

Fig. 2. Permeate flux versus time for MF and UF processes in non-hybrid experiments

Table 3. Values of removal or rejection in hybrid experiments (each value obtained with respect to the final step outflow of each hybrid process)

Processes	***Removal or rejection of pollution indices (%)***						
	TSS	***TDS***	***COD***	***Oil and grease***	***Ni***	***Fe***	***Cr (VI)***
SF+MF	91.3	44.7	72.9	89.2	59.6	48.6	13.9
SF+MF+UF	95.5	73.7	94.4	98.4	80.9	74.2	57.5
SF+MF+NF	98.5	78.2	99.2	98.8	87.8	82.6	78.0
SF+MF+UF+NF	98.8	84.6	99.6	99.7	94.8	94.5	86.6
SF+MF+NF+NF	99.0	86.5	99.7	99.8	94.6	95.4	87.5
SF+MF+UF+NF+Ads	99.0	88.9	99.8	99.9	96.8	95.8	100
SF+MF+UF+NF+Ads+NF	99.6	94.4	100	100	99.5	98.5	100

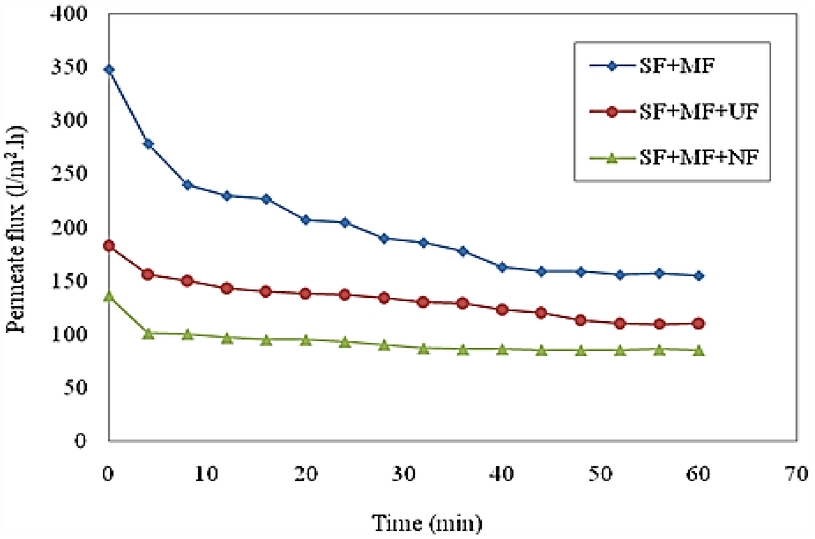

Fig. 3. Permeate flux versus time in different hybrid processes

3.2.3. Effect of consecutive processes of SF, MF, and NF on wastewater treatment

Unlike non-hybrid tests in which there was no permeate obtained from NF process, it is possible to have the permeate from NF process subsequent to SF and MF. Because SF and MF processes could not eliminate the suspended solids and oil and grease of the wastewater completely, as illustrated in Fig. 3, there is a sudden drop in flux at the first stages of NF process. The permeate flux of this hybrid process is for NF process after applying SF and MF processes.

With respect to Table 3, the general result obtained from this process is relatively better than the results of hybrid process of SF, MF, and UF.

3.2.4. Effect of consecutive processes of SF, MF, UF, and NF on wastewater treatment

Considering the results presented in Table 3, it can be concluded that the hybrid process of SF, MF, UF, and NF only could not considerably decrease TDS and Cr (VI). Therefore, it can be concluded that NF plays a crucial role, as a complementary process, in separating and removing the pollutants of wastewater.

Moreover, as it can be observed from Figs. 3 and 4, the final permeate flux in terms of time for NF in the hybrid process of SF, MF, UF and NF is relatively better than that in the hybrid process of SF, MF and NF. It is due to presence of UF, which can considerably remove fouling elements prior to NF process.

3.2.5. Effect of consecutive processes of SF, MF, NF, and NF on wastewater treatment

As it is seen in Table 3, the hybrid process of SF, MF, NF and NF could decrease the amount of pollution indices almost slightly better than the hybrid process of SF, MF, UF and NF. Furthermore, NF process, in the first stage, could considerably purify the permeate from any fouling elements; thus, there is no considerable drop in the flux through the NF membrane in the second NF stage (see Fig. 4). With regard to the amount of flux as well as its little amount of drop during the process, it can be concluded that the value and variation of flux in this state is close to those of pure water for NF process in Fig. 1.

3.2.6. Effect of consecutive processes of SF, MF, UF, NF, and Adsorption on wastewater treatment

With respect to Table 3, the utilization of adsorption process after SF and membrane processes of MF, UF, and NF results in the considerable removal of majority of pollution indices. Only the removal or rejection of TDS is below 90 %.

3.2.7. Effect of consecutive processes of SF, MF, UF, NF, adsorption, and NF on wastewater treatment

As it can be observed from Table 3, the removal or rejection of pollution indices, even TDS, by the hybrid process of SF, MF, UF, NF, adsorption, and NF is very high.

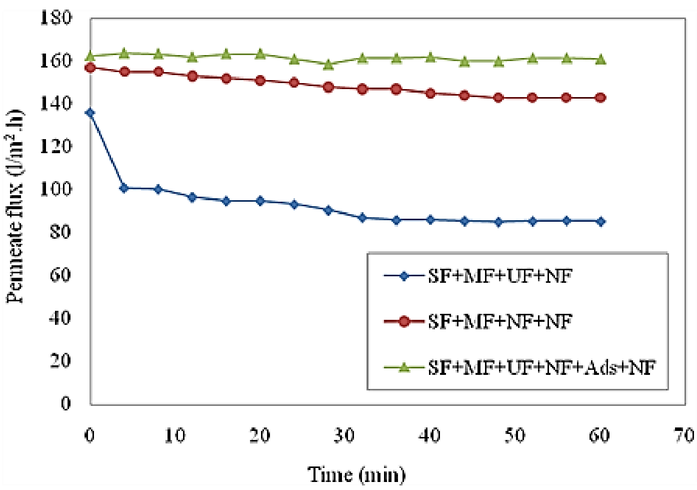

Fig. 4. Permeate flux versus time in some other hybrid processes

Because the permeate characteristics is the same as that of pure water, practically the changes of permeate flux in terms of time in this hybrid process is very similar to those for NF process of distilled water as shown in Figs. 1 and 4. As it can be seen, there is no considerable change in the permeate flux during the process.

4. Conclusions

Five distinctive separation processes namely SF, adsorption, MF, UF and NF were examined in two non-hybrid and hybrid ways for treatment of forging industry wastewater. The results of non-hybrid experiments showed that none of the mentioned methods were able to give the suitable removal or rejection for most of the pollution indices.

The results obtained from hybrid processes showed that the pretreatment using SF before membrane processes would cause the flux increase as well as quality improvement of these processes. The reduction of membrane fouling and increase of treatment operation efficiency were the general results of the hybrid processes.

References

Al-Malah K., Azzam M. O.J., Abu-Lail N.I., (2000), Olive mills effluent (OME) wastewater post-treatment using activated clay, *Separation and Purification Technology*, **20**, 225-234.

Belkacem M., Matamoros H., Cabassud C., Aurelle Y., Cotteret J., (1995), New results in metal working wastewater treatment using membrane technology, *Journal of Membrane Science*, **106**, 195-205.

Benito J.M., Cambiella A., Lobo A., Gutierrez G., Coca J., Pazos C., (2010), Formulation, characterization and treatment of metalworking oil-in-water emulsions, *Clean Technologies and Environmental Policy*, **12**, 31-41.

Busca G., Hilal N., Atkin B.P., (2003), Optimization of washing cycle on ultrafiltration membranes used in treatment of metalworking fluids, *Desalination*, **156**, 199-207.

Byers J.P., (2006), *Metalworking Fluids*, Second Edition, Taylor & Francis Group, USA.

Cambiella Á., Ortea E., Ríos G., Benito J.M., Pazos C., Coca J., (2006), Treatment of oil-in-water emulsions: Performance of a sawdust bed filter, *Journal of Hazardous Materials*, **B131**, 195-199.

Cheng C., Phipps D., Alkhaddar R.M., (2005), Treatment of spent metalworking fluids, *Water Res*earch, **39**, 4051-4063.

Deniz F., Sadhwani J.J., Veza J. M., (2010), New quality criteria in wastewater reuse, the case of Gran Canaria, *Desalination*, **250**, 716-722.

Greeley M., Rajagopalan N., (2004), Impact of environmental contaminants on machining properties of metalworking fluids, *Tribology International*, **37**, 327-332.

Hilal N., Busca G., Rozada F., Hankins N., (2005), Use of activated carbon to polish effluent from metalworking treatment plant: comparison of different streams, *Desalination*, **185**, 297-306.

Hu X., Bekassy-Molnar E., Vatai G., (2002), Study of ultrafiltration behaviour of emulsified metalworking fluids, *Desalination*, **149**, 191-197.

Ismail Z., Beddri A.M., (2009), Potential of water hyacinth as a removal agent for heavy metals from petroleum refinery effluents, *Water, Air and Soil Pollution*, **199**, 57-65.

Ismail Z., Salim K., Othman S.Z., RamLi A.H., Shirazi S.M., Karim R., Khoo S.Y., (2013), Determining and comparing the levels of heavy metal concentrations in two selected urban river water, *Measurement*, **46**, 4135-4144.

Muszyński A., Łebkowska M., (2005), Biodegradation of used metalworking fluids in wastewater treatment, *Polish Journal of Environmental Studies*, **14**, 73-79.

Portela J.R., López J., Nebot E., Martínez de la Ossa E., (2001), Elimination of cutting oil wastes by promoted hydrothermal oxidation, *Journal of Hazardous Materials*, **B88**, 95-106.

Zheng X., Mehrez R., Jekel M., Ernst M., (2009) Effect of slow sand filtration of treated wastewater as pre-treatment to UF, *Desalination*, **249**, 591-595.