Original Article

Performance evaluation of tertiary treatment through ultrafiltration: Case study in Isfahan-industrial wastewater treatment plant

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ABSTRACT

Aims: The aim of this study was the performance evaluation of ultrafiltration (UF) membrane process as an advanced treatment to secondary effluent quality improvement in Isfahan - Morchekhort Industrial Estate wastewater treatment plant.

Materials and Methods: Membrane system used in this study included a flat sheet UF module of polysulfone with 0.1 μm pore size. The coagulation, flocculation and sedimentation (Coag, Floc, Sed) and rapid sand filtration in conjunction with granular activated carbon (GAC) filtration was used as pretreatment of secondary effluent. All test methods was obtained of standard method for the examination of water and wastewater.

Results: The membrane system could decrease turbidity, chemical oxygen demand (COD), total suspended solids (TSS), total hardness (TH), total coliform (TC), fecal coliform (FC), total nitrogen (TN) and Cl^-, 24.5, 19, 48, 10.5, 94.5, 85.1, 15.4 and 1.01%, respectively.

Conclusion: UF was able to improve chemical parameters of secondary effluent and meet national environmental standards. However, achievement to optimum operation of this system requires adequate pretreatments such as adding filter aid, sand filtration and GAC. The most part of suspended particles expressed by turbidity was removed within UF membrane, whereas only a little of organic substance expressed by COD or color and salt expressed by conductivity could be removed.

Key words: Coagulation and flocculation, granular activated carbon, industrial estate wastewater, sand filtration, ultrafiltration

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INTRODUCTION

Water is becoming an increasingly scarce resource in many populated areas and a major factor for industrial estates at all over the world.[1,2] Many industrial processes rely on the availability and reliability of their water supplies and usually

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compared with geographical and seasonal fluctuations associated with the use of water for agriculture and irrigation, fairly use a constant amount of water during a year. Therefore, such industries provide a special opportunity for use of reclaimed water. After 1990 industry becomes a necessity by observation strict environmental targets specifically for wastewater discharge.[3]

In these conditions UF, reverse osmosis (RO) and nano filtration (NF) have been widely used for the full-scale treatment and reuse. Karakulski *et al*.,[4] Koítuniewicz and Field,[5] Marchese *et al*.,[6] Salahi and Mohammadi,[7] Fateme *et al*.,[8] Mohammadi and Esmaeelifar[9,10] examined the feasibility of using polymer and ceramic membrane for municipal and industrial wastewater treatment. These processes have more benefits compared with conventional membrane processes. UF is a membrane separation process with low pressure used for selected compounds separation according to their size.[8]

UF membranes are capable to particular maintain with molecular weights 300-500000 Dalton and pore sizes 10-1000 Angstrom. This method usually used for separate macromolecules such as proteins from solvents with low molecular weight.[11] These membranes can't remove sugars and salts.[12]

UF membrane pore size and surface hydrophobicity is effective on the flux decline, fouling reversibility and fates of proteins.[13]

In evaluating the effectiveness of micro filtration (MF)/UF compared to conventional pretreatment, it is important to consider the cleaning level, back washing and maintenance required by the MF/UF system.[14]

MF and UF known as solid/liquid separation membranes that were able to remove suspended and colloidal particles including microorganisms.[15] These could remove high levels of bacteria, oocytes and protozoa cysts.[16]

MF and UF technologies both in effluent filtration as well as in membrane bioreactors are also suitable as pretreatment to NF or RO. Such physical barrier-processes are attractive in wastewater treatment because any technology employed must be able to produce reused water of uniform quality, regardless of the normally wide variation in the concentration or physicochemical properties of wastewater influent[17,18] and the absence of chemicals addition is of economic and ecological benefit.[19]

In an article in 2008, Goren *et al*., in southern occupied Palestine, with another review on coagulation and adsorption by powdered activated carbon and UF as tertiary treatment of sewage effluent, found a result of less than three for total organic carbon (TOC) that could be used for unrestricted irrigation. TOC reduction result in minimizing the membrane fouling.[20] Coagulation, sedimentation and filtration stages removed a large amount of suspended solids, colloidal particles and organic matter.[21]

Marcucci and Tognotti demonstrated ozonation with activated carbon filter is more effective in reducing COD while using UF and it is more effective in removing bacteria. However, yellowish color effluent removed by ozonation could not be removed by UF.[2]

Zheng *et al*., in 2009 worked on the effect of slow sand filter on treatment of municipal wastewater before treatment with UF. According to their observations, direct filtration of secondary effluent applied for UF result in rapid effects fouling, because of a lot of fouling in the secondary effluent. The foulants compounds in wastewater could be removed using slow sand filter, significantly improved UF performance.[22]

The purpose of this study was to investigate of the UF membrane process influence as an advanced treatment system to obtain high quality effluent for sustainable reclamation and reuse of industrial wastewater.

MATERIALS AND METHODS

Wastewater source and properties

The wastewater used in this work was collected from an industrial wastewater treatment plant located in the Mourchekhort Industrial Estate, on 50 km-North West of Isfahan, center of Iran. The capacity of the available treatment plant was about 2000 m^3/d. The wastewater treatment process in this treatment plant was an anaerobic contact reactor followed by an aerobic sequencing batch reactor.

The influent westwater quality was extremely variable and its main characteristics are given in Table 1.

Membrane module and properties

Direct injection of wastewater into the membrane filters is not recommended. In this study in order to improve the effluent quality, we used coagulation, flocculation, sedimentation, sand filtration and activated carbon as pertreatment.

The UF module was purchased of Woongjin Chemical Co., Ltd. (South Korea) and other process equipment's were provided by Mirab Co. (Iran). The characteristics of UF module are summarized in Tables 2-4.

Experiments

The influent wastewater was obtained of treatment plant effluent storage tank and filtrated via 5 μm filter, before pumping to the UF. Poly aluminum chloride (PACl) solution considered as a suitable coagulant. The jar test was performed to determine the optimum PACl dosage.

Table 1: The properties of coagulation, SF, AC and water reuse quality treated by UF membrane

Parameter	Sample size	Feed water	Coagulation, flocculation, sedimentation	SF	AC	UF
		Mean ± SD (maximum, minimum)	Mean ± SD (maximum, minimum)	Mean ± SD (maximum, minimum)	Mean ± SD (maximum, minimum)	Mean ± SD (maximum, minimum)
Turbidity (NTU)	60	31.8±26.4 (146, 5.3)	5.8±4.8 (30, 1.3)	3.3±2.5 (15.4, 0.95)	1.99±1.8 (8.1, 0.43)	1.4±1.5 (9.3, 0.28)
pH	60	8.05±0.27 (8.8, 7.45)	7.4±0.23 (8.01, 6.9)	7.51±0.23 (8.13, 7)	7.56±0.23 (8.19, 7.01)	7.64±0.22 (8.2, 7.14)
Temperature (°C)	60	19.4±3.95 (26, 10.3)	18.6±4.4 (26.1, 8)	18.6±4.6 (26.3, 7.3)	18.6±4.7 (26.3, 7)	19.6±43.4 (26.9, 7.3)
EC (μS/cm)	60	3893±460.5 (4690, 2890)	3855±484 (4690, 3040)	3839±493 (4730, 3010)	3819±505 (4750, 2970)	3839±533 (4790, 2840)
TDS (mg/L)	20	2512.33±365 (3396, 1894)	2508.7±299.17 (2903, 1920)	2448.3±250.8 (2888, 1905)	2445.5±264.1 (2852, 1991)	2476.5±313 (2910, 1827)
TSS (mg/L)	20	117.3±20.38 (152, 78)	66±14.7 (98, 46)	45.8±14.3 (63, 21)	25.4±8.94 (46, 11)	13.2±3.5 (19, 7)
COD (mg/L)	20	142.9±130.9 (554, 47.4)	54.5±69.8 (246, 10.7)	38.9±31 (124, 12.4)	28±25.4 (100, 2.3)	14.15±11 (44, 2)
TH (mg/L)	20	683.3±87.4 (832, 520)	654.2±111.9 (820, 436)	615.6±106.2 (756, 410)	594.2±114.7 (757, 394)	530.3±106.7 (698, 344)
TN (mg/L)	10	22.9±7.3 (32, 13.6)	16.6±6.2 (24, 5.8)	15.7±6.2 (24, 5.8)	14±6.9 (23, 5.3)	12.1±7.3 (23, 4.2)
Cl^- (mg/L)	20	134±8.83 (150, 115)	141.6±9.7 (155, 125)	140.6±9.1 (155, 125)	139.5±8.6 (150, 125)	138.1±9.1 (150, 125)
TC	20	$4.6\times10^6\pm4.4\times10^6$ $(1.2\times10^7, 2.1\times10^5)$	$8.9\times10^5\pm1.3\times10^6$ $(4\times10^7, 2.4\times10^4)$	$2.7\times10^5\pm3.9\times10^5$ $(1.5\times10^6, 1.7\times10^4)$	$1.6\times10^5\pm2.7\times10^5$ $(9.3\times10^5, 4.3\times10^3)$	6344±4514 (15000, 900)
FC	20	$2.4\times10^6\pm3\times10^6$ $(1.1\times10^7, 4\times10^4)$	$3.8\times10^5\pm4.4\times10^5$ $(1.5\times10^6, 1.5\times10^4)$	$1\times10^5\pm1.4\times10^5$ $(1.5\times10^5, 4\times10^3)$	$4.6\times10^4\pm1.09\times10^4$ $(1.5\times10^4, 1.5\times10^3)$	1469±96 (3600, 700)

Table 2: Basic characteristics of UF membrane

Membrane (material)	Membrane type	Permeate flow rate (m^3/day)	Molecular weight cut off (Dalton)	Effective membrane area (m^2)	Element configuration	Maximum operating pressure (psi)
Polysulfone (PSF)	Homgenous asymmetric flat sheet	13.2	50-100 K	7	Spiral-wound, taping	400

Table 3: Characteristics SF and AC used in the study

Filter type	SF	AC
	Rapid SF with two layers of bed	Rapid filter
Body material	Three-layer polyethylene	Three-layer polyethylene
Mode of operation	Alternative	Alternative
Type of streaming	Gravitational	Gravitational
How cleaning	Backwashed with water	Backwashed with water
The total volume (L)	80	80
Total height (cm)	123	123
Diameter (cm)	31	31
Cross section (m^2)	0.071	0.071
Altitude gallery (cm)	20	20
Hydraulic loading rate (L/m^2/min)	111	111

Table 4: Characteristics used in SF and AC media

Filtration	Type substrate	Characteristic	Size (cm)	Depth (cm)	Geometric shape	Density (g/cm^3)
SF	Silica	Granule	0.1-0.3	35	Fragmental	2.6
	Silica	Granule	0.5-0.8	35	Fragmental	2.6
AC	Carbon	Granule	0.1-0.3	70	Granule	2.6

All of the coagulation, flocculation and sedimentation processes were performed in a single package reactor. Then, effluent wastewater passed via a sand filter, caused to carbon activation and finally arrived in the UF membrane. In this study, all analyses done base of the standard method for the examination of water and waste water [Table 5].[23]

RESULTS

The effluent quality of the coagulation system, sand filter, activated carbon and UF are shown in Table 1.

Table 6 shows mean ± standard deviation concentration of heavy metals included Pb, Cd, Cr, Ni and Zn. The comparisons of means percent removal of chemical and microbial parameters are present in Figures 1 and 2. Figure 3 shows the efficiency of removal variable at the whole study. Change of pressure during of 1 h operation shown in Figure 4. The flux, temperature and pressure changes during operation also are present in Figures 5-7.

DISCUSSION

The obtained results showed that the reduction of turbidity, COD, TSS, TH, TN, EC, total dissolved solids (TDS), fecal coliform (FC), total coliform (TC), Pb, Ni, Cr, Cd and Zn at a rate of 94, 84, 88.96, 22.61, 47.77, 1.35, 1.15, 99.73, 99.9, 50.72, 25.12, 39, 59.83 and 66.18%, respectively [Figure 3].

In this study, the coagulation showed removal efficiency of 65-80% for turbidity, TC, FC and COD and approximately 25-50% reduction in TSS and TN parameters.

The final effluent quality of UF processes highly dependent on influent wastewater properties, permeated water might be suitable for unrestricted irrigation purpose, as it is high in nutrients (N and P practically insensitive to filtration), low micro pollutant and micro organics content and exhibits favorable inorganic ratios [Table 1].[19]

In this study, sand filtration removed suspended solid with 50 micron diameter. Contaminants were adsorbed onto the activated carbon particles, which were then separated from water by UF.

Coagulation and flocculation had a slight increase in the chloride ion, which could be because of the using PACl as a coagulant. Furthermore, due to PACl had a low pH (3.5), coagulation system output pH had been declined.

In this experiment, the elimination mean of microbial parameters - total and FC was 94.5% and 85%, respectively. Bourgeous *et al*., reported coliform bacteria in the effluent of UF. They used to be from membrane with size 0.01 microns that expected removed all coliform (coliform measures approximately are 0.1 microns). It was attributed to several factors such as:

1. The membrane surface damage,
2. precipitation of iron salts at high pH thereby protecting the bacteria even at high concentrations of disinfectants during backwashing,
3. lowering the quality of the membrane due to the effect of bacterial enzymes or other substances and

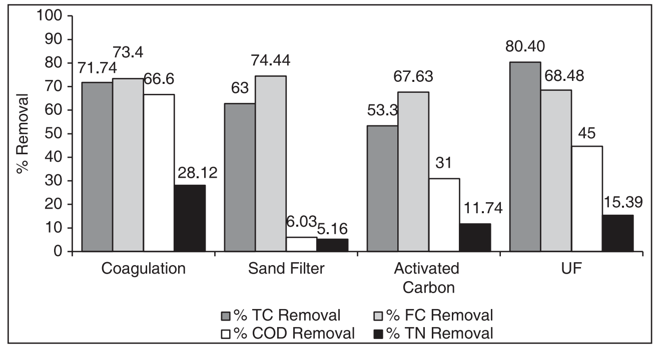

Figure 1: Average percent removal total coliform, fecal coliform, chemical oxygen demand, and total nitrogen in treatment system

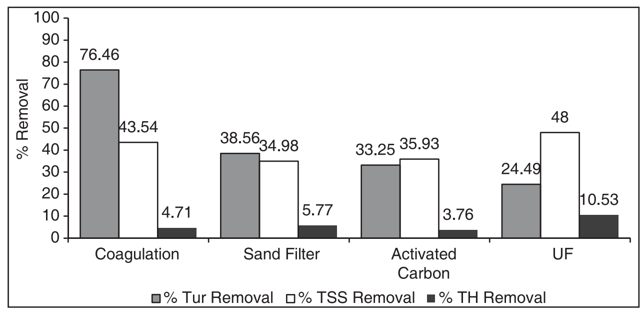

Figure 2: Average percent removal total suspended solids, Turbidity, and total hardness in treatment system

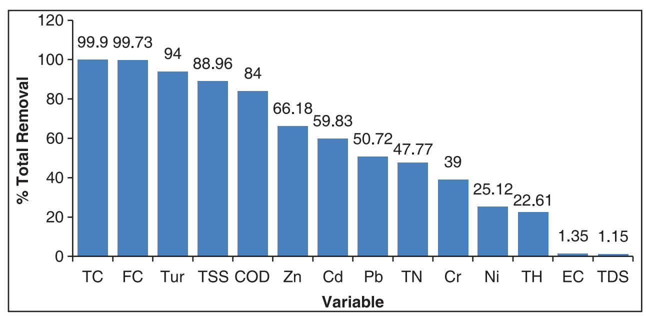

Figure 3: Efficiency of removal variable in the whole system

Table 5: Physical, chemical, and microbial experiments method

Parameter	Code	Method
Turbidity	2130 B	Nephelometric method/turbidimeter TN-100 Eutech
Conductivity	2510 B	Laboratory method
TDS	2540 C	Total dissolved solids dried at 180°C
TSS	2540 D	Total suspended solids dried at 103-105°C
Temperature	2550 B	Laboratory and field methods
pH	4500 H⁺ B	Electrometric method
COD	5220 D	Closed reflux, colorimetric method
TH	2340 C	EDTA titrimetric method
N	4500-N C	Per sulfate method
Heavy metal	3120 B	ICP
TC	9221 B	Standard TC fermentation technique
FC	9221 E	FC procedure

ICP: Inductively coupled plasma, EDTA: Ethylenediaminetetraacetic acid

Table 6: Concentration of heavy metals

Heavy metal (μg/L)	Mean ± SD				
	Feed water	Coagulation	SF	AC	UF
Cr	1.9 ± 0.5	1.7 ± 0.46	1.3 ± 0.44	1.3 ± 0.3	1.1 ± 0.13
Cd	1.96 ± 1.5	1.3 ± 1.43	1 ± 0.86	0.8 ± 0.6	0.6 ± 0.36
Zn	62.5 ± 113.65	27.7 ± 39.2	20.8 ± 26.76	14.2 ± 21.6	9.9 ± 17.8
pb	7.2 ± 8.74	4.3 ± 3.89	3.2 ± 3.06	2.6 ± 2.86	2.2 ± 2.37
Ni	140.1 ± 182.2	117 ± 148.1	96.7 ± 118.3	89 ± 109	86.3 ± 105.9

SD: Standard deviation, UF: Ultrafiltration, SF: Sand filter, AC: Activated carbon

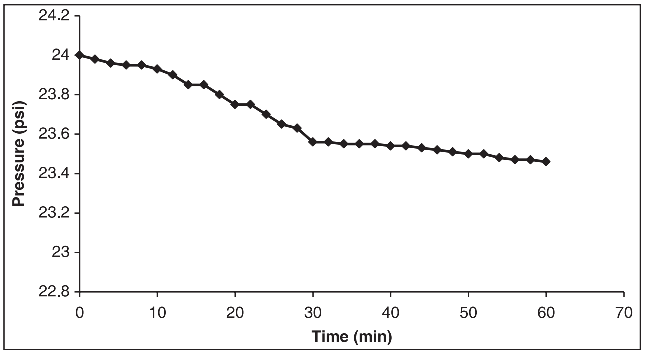

Figure 4: Change of pressure during of 1 h operation

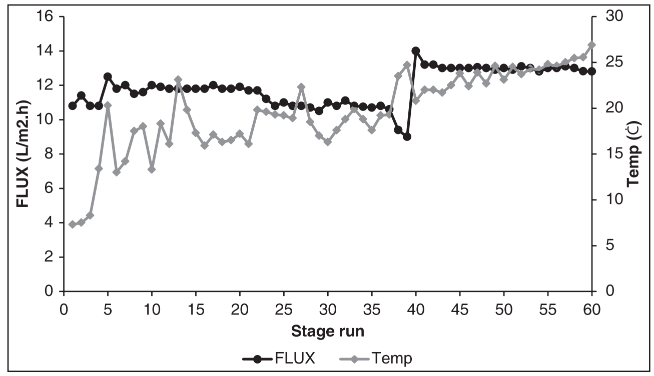

Figure 5: Flux and temperature changes during operation

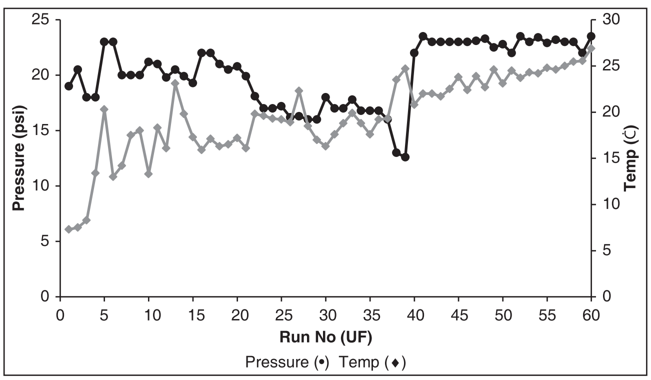

Figure 6: Pressure and temperature changes during operation

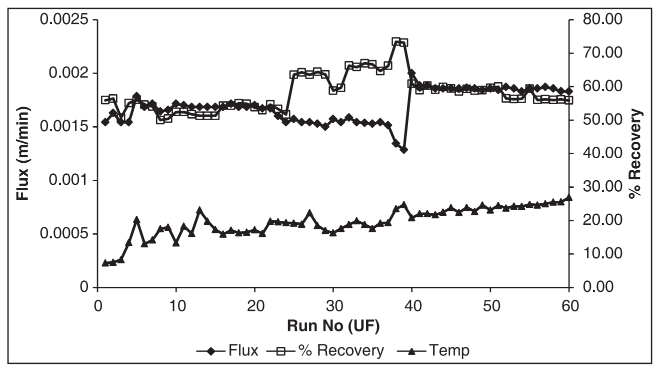

Figure 7: Flux and recovery changes during operation

4. poor packing and membrane insulation units during production.[24]

Consequently, although UF can reduce great extent of the effluent coliform bacteria, but it is better to use a compilation with other disinfection methods.[24]

Long-term experiments have indicated that *in vitro* conditions, especially at the first 30 min, intensity of fouling is high and subsequently reduced and appears a kind of balance in the final hours, flux is almost constant. These results are similar to observations obtained by Hadian and Fateme *et al*. [Figure 4].[8,25]

During the study, the reduction of inorganic matter and microbial contents of effluent by membrane were decreased which could indicate membrane fouling. Minimum operating point in Figures 5-7 (episodes flux and pressure), is due to fouling of the membrane. Figure 2, shows the flux and pressure were increased after cleaning in place (CIP) and replacement cartridge filters. The temperature rise was impressive by the addition of flux. Increase of flux after chemical cleaning had shown irreversible fouling. CIP is a manually initiated semi-automatic procedure used to wash membranes *in situ*.

Pearson correlation showed that an inverse relationship between flux and membrane recovery [Table 7].

During the study, the inlet water temperature of the membrane was raised (change from cool season to warm season). Water permeation through the membrane increased with water temperature raised. Because viscosity of the solution is reduced and higher diffusion rate of water through the membrane is obtained.[26]

UF membrane most often use as pretreatment for RO or NF, UF pretreatment can remove a small amount of larger organic matter and colloid materials.[27]

CONCLUSIONS

In industrial wastewater treatment it considered to be necessary an appropriate pre-treatment and effective cleansing system. Nonetheless, if the coagulation caused by partial removal of colloidal material is larger than the pore size UF, no effect on the removal efficiency can be seen and if the removal of colloidal material is smaller than the pore size UF result in improvement to elimination of contaminants and better filter functions.

Although large UF was able to reduce coliform bacteria in the effluent, but it had better performance with a combination of methods to be used for disinfection.

Inlet water temperature was effective on the production rate and the membrane fouling so that caused reduction in production and shortage the time to membrane fouling.

In consequent membrane must be replaced more frequently, but taken care of the membrane properly for example, backwashing system with clean water after each day's work, lifetime membrane and the each CIP time interval increases. Recommended due to the high fouling characteristics of the water, special provision was made for periodic high — velocity flushing of membranes, periodic biocide dosing and physical turbulence cleaning by means of air/water combination.

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Table 7: Correlation between flux and recovery in UF membrane

Parameter	Flux UF	Recovery UF
Flux UF		
Significant (2-tailed)		0.002
N	60	60
Recovery UF		
Significant (2-tailed)	0.002	
N	60	60

UF: Ultrafiltration

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