Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2021.26534

210 (2021) 81–90
January

A systematic review on membrane technology for carwash wastewater treatment: efficiency and limitations

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Received 13 October 2019; Accepted 4 September 2020

ABSTRACT

Car cleaning in carwash centers is one of the most important parts of water use. Carwash wastewaters (CW) contain significant quantities of contaminants such as oil and grease, surfactants, solids, nitrogen, and phosphorus. Various treatment technologies like membrane processes have been utilized for the treatment of CW; it should be noted that all these methods have advantages and disadvantages. Therefore, in this study, a systematic review of the benefits and limitations of the application of membrane technology for CW treatment was carried out. To this end, first, keywords were identified, and a search protocol was defined. Then, search in Scopus, PubMed, and Web of Science was explored to find related articles in June 2019. The results showed that ultrafilter is the most used membrane type for CW treatment; furthermore, the efficiency of membrane processes in the reduction of turbidity and chemical oxygen demand in most studies was reported to be more than 90% and 70%, respectively. However, the rapid and severe flux reduction and pH changes in permeate are the significant limitations of membrane technology for CW treatment. The use of the pretreatment processes for fouling mitigation can be useful in CW treatment through the membrane processes.

Keyword: Carwash wastewater; Membrane technology; Wastewater treatment; Ultrafiltration

1. Introduction

The common use of motor vehicles and their frequent need to water for washing cars have caused carwashes to be one of the most essential water consumers and wastewater sources [1,2]. According to the type of vehicle and equipment, water needed for washing each car is estimated in the range of 150 and 600 L [2,3]. Carwash wastewater (CW) quantity in many countries is unusually high; as, in Australia, wastewater produced by 10,000 carwashes has been estimated at 35 billion L/y [1].

CW contains various pollutants such as oil and grease, turbidity, suspended solids, soluble solids, surfactants, nitrogen, and phosphorus [2–6]. The contamination of CW is due to three common sources: carwash chemicals, car exploitation, and traffic pollutants such as road surfacing pollutants, dust, sand, salt and tiny exhaust particles [2]. The quality of water consumption at different carwashes

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may be entirely different. For instance, the turbidity and chemical oxygen demand (COD) rates in CW are expressed in the range of 180 to 500 NTU and 42 to 700 mg/L, respectively [2,3,5,7]. Other studies have also reported different qualities of CW, indicating a qualitative difference among CWs [8]. Even in a specific carwash, the quality of CW may vary at different times, which can be due to the effect of seasonal changes and the type of vehicle being washed [6].

Current processes such as sand filtration, electrocoagulation, chemical coagulation, ozonation, and biological methods applied for CW treatment [4]. Recently, membrane processes such as ultrafiltration (UF) [2,3,9], microfiltration (MF) [6,10], and nanofiltration (NF) [3,11], commonly used for the removal of carwash pollutants. The removal efficiency of membrane processes to reduce the CW conductivity has been reported in various studies from 10% to 60% [3,6,11], so that, the turbidity and COD reduction have been reported between 42% and 100% [2,5,6] and 70% and 97%, respectively [3,9,11]. The reported efficiency range for the membrane process used to CW treatment shows that different parameters are useful in membrane performance in decreasing CW pollutants [2–5,11].

This study aimed to evaluate the efficiency of the membrane technology used for CW treatment as well as to identify the factors affecting the membrane process efficiency in CW treatment. Also, the limitations of using membrane technology for CW treatment were studied.

2. Method

2.1. Search of literature

So as to find effect-based studies, in which the treatment of CW had been investigated, three databases: Scopus, PubMed, and Web of Knowledge were searched. Meanwhile, the search strings were used as follows: ("wastewater" OR "effluent" OR "sewage" OR "sewerage" OR "sullage" OR "water") AND ("carwash" OR "carwashing" OR "car-wash" OR "car-washing" OR "car wash" OR "car washing") (accessed June 01, 2019). This strategy resulted in 441 publications, from which duplicates were removed (Fig. 1).

2.2. Eligibility criteria

The final papers were chosen on the basis of the eligibility criteria; in this research, those studies that had investigated a membrane technology for CW treatment were exclusively focused. Hence, all studies that (1) only mentioned quantity data of CW, (2) investigated other treatment methods (like chemical ways), (3) not investigated the efficiencies and conditions of membrane technologies for CW treatment were excluded.

2.3. Study selection

The literature was screened independently by all the authors, based on the criteria mentioned above. After the initial screening of the titles, 41 studies were selected (Fig. 1). First, the English-language papers (23 other-language articles) were separated from the articles; next, the main screening stages were performed for them. In the case of conflicting decisions over the initial screening, the respective study was included in the next step of screening. Then, the articles, in which CW had been treated by membrane processes, were extracted. Finally, the contents of the articles were studied, and 14 articles were selected because in which membrane process efficiencies and conditions affecting the CW treatment rate had been included.

2.4. Extraction of data

Data from totally eligible articles were extracted into a pre-defined data extraction file. The following data were extracted based on the content of the eligible papers: (1) quality properties of CW, (2) kind of membrane utilized for treatment, (3) pre-treatment processes for the membrane technology in CW treatment, (4) efficacy of membrane method in CW treatment, and (5) flux and affecting factors.

3. Results

As can be seen in Fig. 1, 14 articles related to this review were selected. These articles had been published between 2004 and 2018. It should be noted that 11 types of research on the application of the membrane technology for CW treatment were published after 2013. Among different membrane types, UF has been the most used to treat CW (Table 1).

Besides, in some articles, related processes such as the application of a cartridge filter have been reported for CW treatment; of course, this filter has not been used as the main mechanism for the treatment system [12].

The most pre-treatment methods for the membrane technology in CW treatment to reduce suspended particles and turbidity of CW were chemical coagulation and filtration (Table 2).

In many cases, membrane processes had high efficiency in COD, turbidity, and total dissolved solids (TDS) removal. Of course, in some types of membranes, the removal efficiency has not been reported appropriately for reducing pollutants and improving permeate quality due to CW characteristics, as well as the type of membrane (Table 3).

4. Discussion

4.1. Efficiency and its influencing factors

The most important limitation of this review was that there were few numbers of relevant articles that contained comprehensive information on the use of a membrane process as the main stage of CW treatment (14 articles). However, having appropriate data in the selected articles and presenting the results in a comprehensive and beneficial scientific discussion was the strength of this study. These led to the identification of various aspects of membrane technology application in CW treatment and its effective factors.

The results of this review showed that, despite the high efficiency of membrane processes for the reduction of CW pollutants, due to CW characteristics, membrane structure, and membrane type, different types of membranes

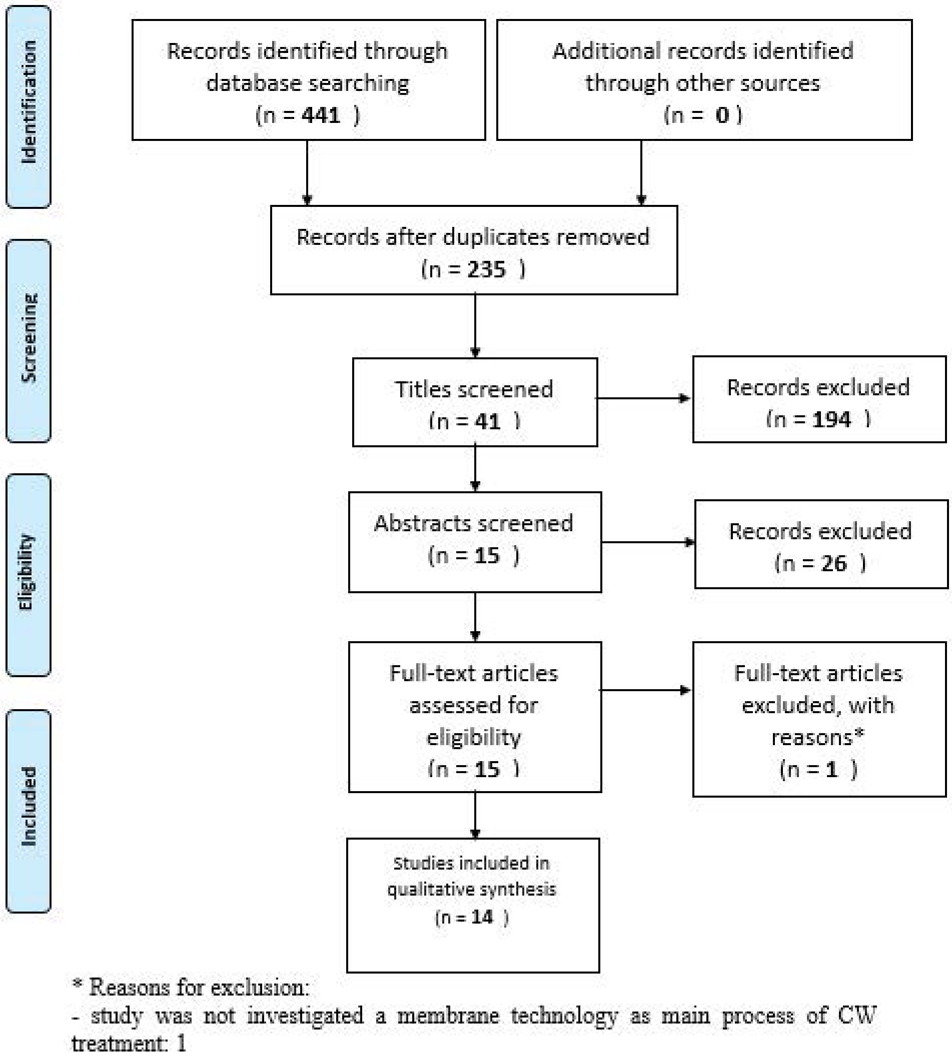

Fig. 1. Searching and selecting articles process for use in this review.

Table 1
Percent of application of different types of membrane for CW treatment in the articles used in this review

Membrane type	MF	UF	NF	RO
Use of different membranes in studies (%)	14	69	14	3

have different removal efficiencies (Table 4). As shown in Table 3, the membrane process efficiency is very high in turbidity reduction (42.2%≥90%), compared with a 15%–95% COD reduction. Along with the above information, another research reported that, during the operation, COD and SS decreased from 67 to 230 mg/L to less than 20 to 10 mg/L, respectively [10].

As can be seen from Table 2, CW quality is very variable, and one of the reasons for these differences is the effect of seasonal changes in car pollutants such as dust leading to a change in CW quality [6]. Therefore, the efficacy of membrane processes reported in the researches has mostly depended on CW quality. It has been explained that the properties of CWs affect the performance of membrane processes. For example, it is mentioned that proper reduction of CW turbidity by the membrane process can be due to the large size of the particles in this type of wastewater, as well as the sieving mechanism due to steric hindrance [11]. Furthermore, the type of different surfactants in CW is effective in membrane process efficiency in removing these pollutants from CWs. Anionic surfactants are removed in the membrane process more than other surfactants due to electrostatic repulsion forces between the negative membrane surface and the negative surfactant. On the other hand, the removal of cationic surfactants by the membrane process is less than that of non-ionic surfactants. Of course, an increase in the concentration of surfactants in CW can lead to a reduction in the removal efficiency rate in membrane processes [13].

Besides, the membrane structure is also effective in CW treatment. It has been stated that the removal efficiency of pollutants such as COD and surfactants declined with increasing the molecular weight of the UF membrane

Table 2
Pre-treatments used in some studies for membrane application in CW treatment

Membrane	Wastewater characteristics	Pretreatment	References
UF and NF	pH = 7.3; COD (mg/L) = 314; conductivity (µs/cm) = 729; PO_4^{3-}–P (mg/L) = 9.05	Settling and coarse filtration	[3]
MF	COD (mg/L) = 42–345; suspended solids (mg/L) = 5–122	Biological treatment	[10]
UF	COD (mg/L) = 700; oil and grease (mg/L) = 36; turbidity (NTU) = 186.6	Using Whatman filter paper (grade 40)	[2]
UF	–	Chemical coagulation	[9]
UF	pH = 6.42; COD (mg/L) = 295; suspended solids (mg/L) = 1,275; turbidity (NTU) = 522	Chemical coagulation and sand filtration	[5]
RO	pH = 6.42; COD (mg/L) = 295; suspended solids (mg/L) = 1,275; turbidity (NTU) = 522	Chemical coagulation and sand filtration and UF	[5]
UF	pH = 6.9–7.6; oil and grease (mg/L) = 5–13.4; turbidity (NTU) = 362–450	Coagulation and flotation	[7]

[2,3]. Also, in the reduction of CW turbidity, the membrane pore size plays a significant role, and the use of membranes with smaller pore size results in less turbidity in permeate. In contrast, COD reduction is dependent on the role of the membrane material in the retention of the substances it does not depend on the pore size [6]. Therefore, the modification of membrane structure or selection of a membrane that more matches the goals of CW treatment can improve the performance of the process. Application of the ultrafilter structure modified by using sulfonated polyether ether ketone (SPEEK) indicated that the presence of a negative structure in SPEEK causes more pollutant removal due to decreasing in adsorption of solutes on the membrane surface [4].

4.2. Differences and similarities of membrane types for CW treatment

The type of membrane used in the CW treatment process is effective in permeate quality (Table 3). For instance, it can be seen that ultrafilter can remove lower COD, phosphorous and nitrogen concentrations from CW, while reverse osmosis (RO) can remove 96% of COD and its removal efficiency for nitrogen is desirable (50%) [5]. The types of membrane applied for CW treatment have different performances owing to different pore sizes and surface charges. In comparison with ultrafilters, nanofilters have higher efficiency in the reduction of TDS and conductivity as a result of its different structural properties like their smaller pore size and negative charge surface [11].

The results of a study illustrated that the UF did not change the pH of the CW, whereas the RO could decline the pH in permeate due to the rejection of soluble ions and the passage of soluble gases such as CO_2. Hence, ultrafilter cannot cause a particular change in the TDS of CW, but RO has a high ability to decrease electrical conductivity (EC) and TDS in CW [5]. Furthermore, the operating conditions such as pressure highly affect the system efficiency like COD and oil and grease removal efficiency in car wash effluent decreased with increasing the pressure from 1 to 3 bar by using ultrafilter due to flux reduction following of the accumulation of particles on the membrane surface [2].

The possibility of integrating the membrane process with other treatment processes as a modified treatment system can lead to higher efficiency of CW treatment. As an example, Boluarte et al. [1] combined the membrane process with a biological process and created membrane bioreactor integration (MBR); they reported that the combined system was capable of removing 100% of suspended solids, 99.2% of COD, 97.3% of total organic carbon and 41% of ammonia from CW. However, the MBR system demands long operation time as a 90% and 88% reduction in COD and oil and grease from a CW through the MBR process needed 120 d [14]. Also, Moazzem et al. [5] achieved high efficiency in CW pollutant reduction by using two membrane processes in the series form; their findings have been indicated in Table 3.

Various researchers have claimed that a pre-treatment before the membrane technology for CW treatment is essential since it contains high turbidity and oil materials (Table 2) [1,3,5,7]. In different studies, sedimentation [3,9,15], flotation [7], chemical coagulation [1,5,7,16], sand filtration, and other types of filtration [2,3,5] have been used prior to the membrane technology. Comparison of the data presented in Tables 2 and 3 shows that through a pre-treatment of CW turbidity, which causes an increase in membrane fouling and a decline in flux can be largely removed. For example, in a study, suspended solids were reduced from 1,275 to 50 mg/L by using chemical coagulation and sand filtration and, after UF, suspended solids entering the RO were zero [5]. Nonetheless, the use of a few pre-treatments such as chemical coagulation can lead to sludge production and a reduction in the water recovery rate, which is a limitation for water reuse purposes. Furthermore, the amount of retentate in UF and RO affects the quality of permeate in a study that was reported to be 20%–28%, respectively [5].

4.3. Flux reduction and its affecting factors

Fouling and flux reduction results in increasing operational costs, reducing treatment efficiency, as well as declining productivity [17–19]; thus, they are important limitations to the expansion of the application of membrane

Table 3
Efficiency rates reported in the studies of various membrane processes for CW treatment

Process	Membrane	Membrane influent	Membrane effluent	Reduction	References
UF	UF-GE 1 kDa	COD (mg/L) = 282; conductivity (µs/cm) = 701; PO_4^{3}–P (mg/L) = 5.8; color (Pt-Co) = 40	COD (mg/L) = 64.5; conductivity (µs/cm) = 523; PO_4^{3}–P (mg/L) = 0.3; color (Pt-Co) = 30	COD 77%, conductivity 25.4%, PO_4^{3-} 94.8%, color 25%	[3]
	UF-PW 10 kDa	COD (mg/L) = 282; conductivity (µs/cm) = 701; PO^{3}_{4-450}–P (mg/L) = 5.8; color (Pt-Co) = 40	COD (mg/L) = 82.2; conductivity (µs/cm) = 529; PO_4^{3}–P (mg/L) = 0.7; color (Pt-Co) = 27	COD 70.8%, conductivity 24.5%, PO_4^{3-} 87.9%, color 32.5%	[3]
	UF-MW 50 kDa	COD (mg/L) = 282, conductivity (µs/cm) = 701; PO_4^{3-}P (mg/L) = 5.8; color (Pt-Co) = 40	COD (mg/L) = 85.5; conductivity (µs/cm) = 629; PO_4^{3}–P (mg/L) = 0.7; color (Pt-Co) = 26	COD 69.6%, conductivity 10.3%, PO_4^{3-} 94.8%, color 35%	[3]
	PES 10 kDa	COD (mg/L) = 700; turbidity (NTU) = 186.6; oil and grease (mg/L) = 36	COD (mg/L) = 36.7; turbidity (NTU) = 0.23; oil and grease (mg/L) = 2	COD 95%, turbidity 100%, oil and grease 94%	[2]
	PS 100 kDa	COD (mg/L) = 700; turbidity (NTU) = 186.6; oil and grease (mg/L) = 36	COD (mg/L) = 70; turbidity (NTU) = 0.57; oil and grease (mg/L) = 8	COD 90%, turbidity 100%, oil and grease 78%	[2]
	PVDF 100 kDa	COD (mg/L) = 738; conductivity (µs/cm) = 138.8; turbidity (mg/L) = 68.9	COD (mg/L) = 132.8; conductivity (µs/cm) = 115; turbidity (mg/L) = 5.5	COD 82%, conductivity 16.9%, turbidity 92%	[11]
	PES 30 kDa	COD (mg/L) = 738; conductivity (µs/cm) = 138.8; turbidity (mg/L) = 68.9	COD (mg/L) = 118.1; conductivity (µs/cm) = 91; turbidity (mg/L) = 2.06	COD 84%, conductivity 34.4%, turbidity 97%	[11]
	UF 0.02 µm	COD (mg/L) = 104; turbidity (NTU) = 1.49; SS (mg/L) = 50	COD (mg/L) = 88.5; turbidity (NTU) = 0.86; SS (mg/L) = 0	COD 15%, suspended solids 100%, turbidity 42.2%	[5]
	UF 100 kDa	COD (mg/L) = 85; conductivity (µs/cm) = 300; turbidity (mg/L) = 85	COD (mg/L) = 13; conductivity (µs/cm) = 260; turbidity (mg/L) = 0.64	COD 84.7%, conductivity 13.3%, turbidity 99.2%	[5]
NF	NF270	COD (mg/L) = 738; conductivity (µs/cm) = 138.8; turbidity (mg/L) = 68.9	COD (mg/L) = 62.7; conductivity (µs/cm) = 50.5; turbidity (mg/L) = 3.8	COD 91.5%, conductivity 63.6%, turbidity 94.4%	[11]
	NF270, 300 Da	COD (mg/L) = 282; conductivity (µs/cm) = 701; PO_4^{3}–P (mg/L) = 5.8; color (Pt-Co) = 40	COD (mg/L) = 8.1; conductivity (µs/cm) = 391, PO_4^{3}–P (mg/L) = <0.05; color (Pt-Co) = <0.01	COD 97.1%, conductivity 44.2%, PO_4^{3-} >99%, Color >99%	[3]
MF	0.22 µm	COD (mg/L) = 85; conductivity (µs/cm) = 300; turbidity (mg/L) = 85	COD (mg/L) = 23; conductivity (µs/cm) = 260; turbidity (mg/L) = 0.93	COD 72.9%, conductivity 13.3%, turbidity 98.8%	[5]
	0.8 µm	COD (mg/L) = 85; conductivity (µs/cm) = 300; turbidity (mg/L) = 85	COD (mg/L) = 16; conductivity (µs/cm) = 280; turbidity (mg/L) = 3.2	COD 81.2%, conductivity 6.6%, turbidity 96.2%	[5]
RO	SG1812C-28D	COD (mg/L) = 88.5; turbidity (NTU) = 0.86	COD (mg/L) = 11.5; turbidity (NTU) = 0.28	COD 87%, turbidity 69.7%	[5]

technologies [20–22]. Fouling occurs as a result of the accumulation of undesired deposits or adsorption of colloids and particles on the membrane surface and inside pores and pore walls, leading to flux reduction [19,22]. Based on the characteristics of foulants, fouling can be categorized into four groups, including crystalline fouling, organic fouling, biofouling, and colloidal fouling [23]. Several factors cause this phenomenon in the application of membrane technology for water and wastewater treatment. The presence of fouling contaminants in feed water/wastewater, such as natural organic matters [17] and extracellular polymeric substances secreted by microorganisms [20], as one of the

Table 4
Summary of utilities and limitations of membrane process for carwash wastewater treatment

Remarks	References
Utility	
Membrane process efficiency is very high in the turbidity reduction and is often more than 90%	[2,6,11]
Efficiency of membrane processes in COD reduction in the range of 15% to 95%	[2,3,5,6,11]
Membrane structure modifying will improve the efficiency of this process	[4]
Different pore size and surface charge have a significant role in treatment efficiency	[5,11]
Recovery of the flux rate by chemical washing is possible	[13]
Limitation	
Type of detergent used is effective in membrane process efficiency in removing this pollutant	[12]
Removal efficiency of COD and surfactant were reduced by increasing the molecular weight of the membrane	[2,3]
Reject of soluble ions and the passage of soluble gases such as CO_2 by some type of membrane lead to reduce pH in permeate	[5]
Due to the high turbidity and high oil materials in CW, the use of a membrane process for CW treatment requires pre-treatment	[1,3,10,14]
Ratio of retentate to permeate is significant	[5]
Rapid and severe flux reduction	[2–5,11,13]

most important reasons of flux reduction. Operating conditions can also be an effective factor in fouling and flux reduction, but the effect of different factors is not the same. For example, it is mentioned that the effect of pressure and feed concentration (concentration of pollutants in wastewater) on the fouling of an ultrafilter is more than feed temperature and flow velocity [24].

Solutions for fouling mitigation have been proposed by researchers, including feed water/wastewater pretreatment, membrane modification, and membrane monitoring and cleaning [17,19]. Coagulation, adsorption, filtration, and oxidation are common processes used by researchers for feed water/wastewater pretreatment, as well as blending, bulk modification, and surface coating are common membrane modification methods that can be effective in fouling mitigation [17,21,25–29]. Each of these methods has different properties; of course, coagulation has been reported as the most cost-effective method [29]. Also, physical cleaning methods, such as backwashing are effective in reducing concentration polarization and mitigating membrane fouling [18].

The major downside of membrane processes used for CW treatment is the rapid and severe flux reduction. The observations of a study showed that in the ultrafilter after 10 min, the flux decreased from 168 to 60 $L/m^2/h$ [5]. Lau et al. [11] observed that in the UF membrane flux lost up to 60% after 120 min. Kiran et al. [4] showed that the application of UF as a pretreatment in all the membranes, the flux sharply reduced (20%) at 30 min and was invariant within 40 min. The results of the research by Istirokhatun et al. [2] illustrated that more than half of the initial flux was reduced in all the membranes in about 30 min after beginning the treatment process, and it reached less than 10% in 180 min. Uçar [3] perceived high flux reduction (more than 50%) in the initial 10 min, and a flux reduction (more than 80%) in 60 min for UF, while the flux reduction for the nanofilter was 35% at the end of the experiment.

The employment of the membrane technology for CW treatment using the MBR process suffers from the rapid loss of permeability. In a study, the permeability was determined to be 94.4% [14]. Of course, this decline in flux is reversible via washing the membrane as a 96% recovery of flux with acid, and alkaline wash in the applied membrane in MBR process was reported [14]. The use of the MBR process for CW treatment compared to the membrane processes (MF, UF, NF, and RO) will increase the treatment time but inducting conditions for biological process involvement can increase the removal efficiency of parameters such as NH_4^+ under the influence of microbial activity [1].

The membrane flux reduction in CW treatment is related to CW characteristics, structure, and type of membranes utilized. Besides, the membrane flux is affected by the membrane porosity and structure, and also pH and compounds of CW effluent, due to the tendency to faster clogging in large pores as compared to the case of small pores [2]. Hydrophobic membrane structures, compared to hydrophilic membrane structures, have faster and more sever flux reduction due to increased membrane fouling and the presence of oily materials in CW [11]. Therefore, the hydrophilic membrane structure and the negatively charged surface can provide good rejection and high flux levels, which are observed in NF270 (0.45 nm) membrane [3]. The lower flux in hydrophobic membrane structure compared to the hydrophilic membrane structure can result in more interaction between surfactants and membrane surface and, in turn, less binding affinity in materials such as oil and grease and surfactants [4,13]. Also, higher hydrophilicity in membranes leads to better flux recovery rates because it increases the membrane water absorption capacity, and thus the fluid passes through it with the lowest hindrance [4]. Modifying the membrane structure by sulfonated polyether ether ketone (SPEEK) and bentonite as nano clay in membrane construction to increase hydrophilicity can cause an improvement of flux. Also, the application of SPEEK leads to the formation of larger pores on the membrane surface. And, the use of bentonite causes the membrane to have a larger surface area and in a smaller size [4]. These conditions have resulted in the same results in CW treatment studies for membrane flux reduction. Lau et al. [11] stated that the ultrafiltration membranes lost up to 60% of the flux after 120 min. This reduction in the higher molecular weight membrane and the hydrophobic membrane was much faster and higher. At the same time, the nanofilter lost up to 15% of the initial flux, which is because the nanofilter (NF270) has a high resistance to flux loss owing to its hydrophilic structure and the negative charge of the membrane surface.

The type of membrane can also be effective in flux reduction. It has been determined that different types of membranes have different flux reduction rates in CW treatment. The NF membrane provides better flux compared to the UF membrane because of electrostatic interactions between the membrane surface and wastewater constituents [3]. Moreover, the permeation of surfactants and other CW materials is higher in membranes with higher molecular weight, leading to more pore-clogging and lower flux, than lower molecular weight membranes [13].

In different types of membranes, CW characteristics which are caused by washing various parts of cars and the type of detergents used in the washing process are effective in flux reduction. High fouling and flux reduction in CW treatment by membranes can be due to the oil and grease in CW effluent [3], which leads to the conversion of the bulk layer to the gel layer formation following of compressed gel layer on the membrane surface and [4,13]. An increase in CW surfactant concentration leads to an increase in membrane fouling and, consequently, flux reduction. Furthermore, since electrostatic repulsion forces occur between the membrane surface and the anionic surfactants, the utilization of anionic surfactants leads to a reduction in pore-clogging and, in turn, a decline in fouling and an increase in membrane flux [13]. The use of surfactants containing high hydrophobic compounds in carwashes enhances fouling and decreases membrane flux in the hydrophobic membranes. Also, high concentrations of cationic and non-ionic surfactants, organic materials, and conductivity in CW decrease the flux [13]. Of course, some types of surfactants contain components that can reduce the gel layer and improve the flux. For example, the presence of linear alkylbenzene sulphonates in surfactants led to an improvement in flux in UF [8]. Generally, flux reduction in CW treatment processes during the filtration period indicates the effect of fouling, concentration polarization, adsorption, gel formation, and pores clogging on the membrane permeability [2,6].

The amount of EC in permeate increases because of flux reduction, stemming from changes in ion transfer rate from feed to permeate [5], which reduces the quality of CW in addition to reducing the quantity of the treated CW. However, changes in the operating conditions can affect the membrane flux reduction in CW treatment. For example, selecting the appropriate pressure in the membrane process for CW treatment can improve the flux because fouling increases with increasing the pressure due to the aggregation foulant particles on the membrane surface. Thus, at higher pressures, the more clogging of the membrane happens because of pressures a higher amount of solids or macromolecules to the interface [2,6]. Also, the polarized layer thickness decreases by increasing the flow rate and its compaction as a consequence of shear stress and reduction in the interaction of solutes and membrane, resulting in increased flux [6].

Membrane flux reduction in CW treatment can be recovered by both membranes cleaning with water and chemical cleaning [5,13,15]. Deionized water, sodium hydroxide, and alkaline solution are the most important substances used for membrane cleaning and flux recovery. Flux improvement by alkaline solution due to alkaline product has adsorbed onto the membrane surface, resulting in a more negatively charged membrane surface and hence in the stronger repulsion forces between the membrane and the distilled water [13].

Of course, the flux recovery rate is affected by the membrane structure, so that the use of a hydrophilic membrane causes only slight fouling owing to the concentration polarization, which after backflushing, will simply be recovered. On the other hand, the use of a hydrophobic membrane leads to fouling due to foulant attachment that cannot easily be recovered [11]. The cleaning of the NF270 membrane is carried out by water in 15 min, while for a hydrophobic membrane such as NFPES10, additional cleaning of the alkaline solution is required for 30 min [13].

4.4. Comparison of membrane performance with other methods in CW treatment

Although the membrane process is widely used in CW treatment, other processes such as electrochemistry have also been used in CW treatment and have shown an appropriate efficiency. The electrocoagulation process in CW treatment using two types of iron and aluminum electrodes has shown excellent treatment performance [30–34]. However, the efficiency of this process, as the membrane process is influenced by wastewater characteristics and operation conditions [31,32], although electrocoagulation is not efficient in reducing the dissolved pollutant of CW [33]. Therefore, the electrocoagulation process is incapable of lowering dissolved COD, whereas, according to the information presented in Table 2, the membrane process has high efficiency in declining COD of CW. Due to the efficacy of electrocoagulation in reducing turbidity above 85% [29,30] and the effectiveness of this process in reducing more than 65% of oil content in CW [32], this process can be used as a suitable pretreatment to membrane fouling mitigation.

Membrane technology was used to treat other types of pollutants/effluents such as organic micropollutants [35], wastewater from the dyeing industry [36], heavy metals [37], oil/water separation [38], effluents from the pulp and paper industry [39], textile industry [39], petrochemical industry [39], food industry [39–42], mining industry [43], and olive mill wastewater [44]. In the case of CW treatment by the membrane processes, in other wastewaters, efficiencies depend on the characteristics of wastewater and pollutant, membrane type, and operating conditions [35,39,44–46]. In contrast, the performance of the membrane technology in the treatment of CW is far higher; this has caused researchers to utilize this technology for CW treatment [48].

Table 5 presents the results of some researches on the application of membrane technology for the treatment of other wastewaters.

Table 5
Results of some researches on the application of membrane technology for the treatment of other wastewaters

Wastewater or pollutant	Remarks	References
Organic micropollutants	Removal of micropollutants by RO or NF membranes was reported more than 90% in most studies.	[35]
	Removal of micropollutants by UF membrane was reported between 20% and 75% in most studies, which is less efficient than RO and NF.	
	RO and NF are able to remove a wide spectrum of micropollutants based on the size exclusion mechanism while in UF, adsorption was the predominating removal mechanism.	
Heavy metals	Efficiency of NF membranes in the rejection of heavy metals was reported between 70% and 100% in most studies.	[37]
	Efficiency of NF and RO membranes in the rejection of heavy metals was mentioned as high and excellent, respectively. But high energy consumption was recognized as a disadvantage in both membranes.	
Effluents from pulp and paper mills	Efficacy of membrane types in the reduction of lignin was reported between 17% and 81% in most studies.	[39]
	Efficacy of the membrane process in the rejection of dye was reported between 39% and 74% by a study.	
Textile industry	Efficiency of UF and MF membranes in the reduction of dye was reported more than 90% in most studies.	[39]
	Efficacy of membrane types in the reduction of COD was reported between 62% and 80% in studies.	
Petrochemical industry	Efficacy of the membrane process in the oil rejection was reported more than 98% by the MF membrane.	[39]
Bamboo industry wastewater	99% rejection of dye by NF membrane	[45]
	Rejection of COD, ammonium and conductivity reached 98%, 95% and 94%, respectively.	
Lead	Efficiency of NF membrane in the rejection of lead from synthetic wastewater observed more than 92% at 6 bar and more.	[46]
	No significant improvement in lead reduction efficiency by increasing pressure to more than 9 bar.	
	The flux reduction, as well as a decrease in lead removal efficiency, was observed with increasing lead concentration in the feed solution.	
Dye	Dye removal from wastewater was closely linked to applied pressure, pH, TDS and dye content in the feed solution, but it was inversely linked to feed temperature.	[47]
	At the same operating conditions, one could get from NF system twice the permeated environmental accepted water flow rate and nearly 50% less electric power instead of RO membranes	

5. Conclusion

The application of membrane technology for CW treatment was systematically reviewed. It was found that, since 2004, efforts have increased to achieve this goal. CW quality characteristics illustrate that the membrane process requires a pre-treatment because 90% of turbidity and 70% of COD can be removed. However, the main limitation of the membrane processes for the CW treatment is a rapid and high membrane flux reduction. This phenomenon causes the water reclamation quantity to fall sharply and also to decrease in terms of quality. To overcome this challenge due to the effect of the membrane structure, the proper membrane selection considering CW conditions or membrane structure modification could be beneficial. The consumption of anionic surfactants and surfactants containing lower hydrophobic compounds in car washing processes leads to providing appropriate membrane flux in CW treatment. Therefore, despite the high efficiency of membranes for CW treatment, the need for pre-treatment and membrane flux reduction, resulting in a decrease in water recovery rate, is the most critical limitations of this technology for the CW treatment.

Acknowledgment

The authors gratefully acknowledge the financial support given by the Research Center for Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran (Grant Number: 97-04-61-14202).

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