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Review article

Techno-environmental study on the consequences of carwash wastewater and its management methods

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ABSTRACT

Carwash wastewater (CWW) is an important source of environmental pollution. The aim of this study was to investigate the characteristics of CWW and technical comparison of its treatment methods. For this purpose, a systematic search was conducted and after three stages of screening the found articles, finally 30 articles were selected for this review. The results showed that due to the differences in the type of washing, the geological condition, the type of car, and the climatic conditions, the CWWs have temporal and spatial variation in the concentration of pollutants. However, the most important pollutants of CWW include oil, suspended solids, detergents, and organic compounds. The most widely used methods in CWW treatment in the main stages included chemical coagulation and electrocoagulation, which reduce turbidity by more than 90% and COD by more than 50% in the best efficiency. Also, membrane technology was a common method in CWW treatment systems to achieve proper effluent quality. COD reduction by ultrafiltration, nanofiltration, microfiltration, and reverse osmosis was 95-77%, more than 90%, 81-73%, and 87%, respectively. The efficiency of membrane technologies in reducing turbidity was often more than 90% and in few cases more than 50%. Sludge production in the coagulation process, energy consumption in electrochemical processes, and the low water recovery rate in membrane processes are important challenges in CWW treatment that must be managed by modifying the process or using combined methods.

1. Introduction

All over the world, motor vehicles are widely used. One of the issues related to these devices is the need for periodic washing. Therefore, one of the main water consumers in society are carwash industries, which have different consumption rates according to the type of vehicle and also the washing technology [1]. In studies, the lowest and highest amount of water consumption for washing a car was reported 150 L and 600 L, respectively [2]. Some reports stated the average amount of water consumption in carwashes is 200 L for

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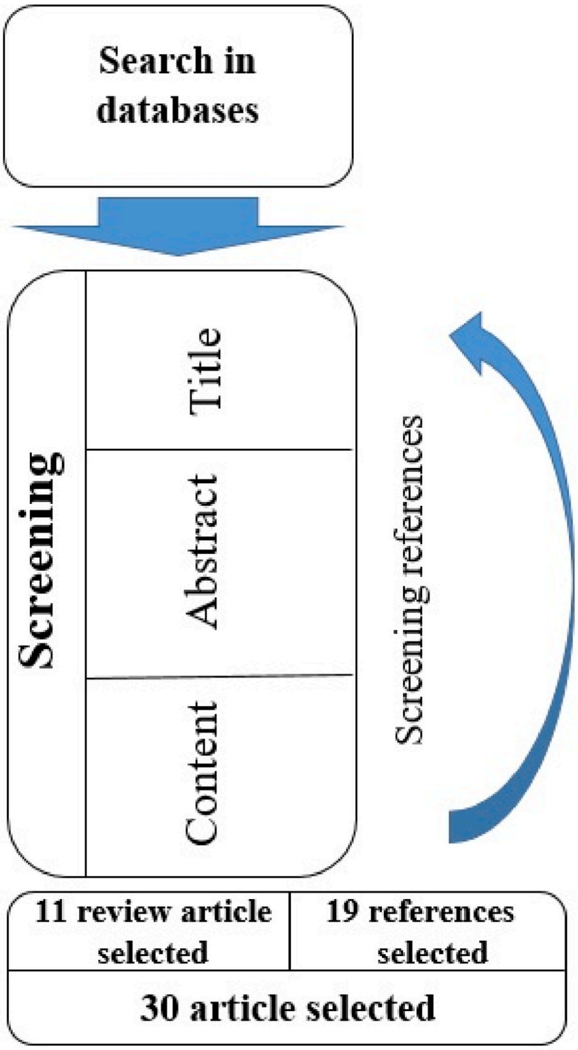

Fig. 1. The process of articles selection for this review.

each car and 10,000 L per day for each carwash station [3]. Therefore, one of the important sources of wastewater production in the world are carwash units [1]. Considering the importance of the water crisis in different regions of the world and water resources management, carwash wastewater (CWW) treatment and reuse is necessity [4].

CWW has various pollutants that can be caused by the car engine or environmental pollution on the car [5]. The most important quality parameter of CWW is oil, which has caused CWW to be classified as one of the oily wastewaters [6,7]. However, local conditions and the type of car can be effective in the quality of CWW pollution [3,4]. Also, washing technology is also effective in the concentration of CWW pollutants due to the amount of water and detergents used [8]. Turbidity and surfactant are other quality parameters of CWW, which some treatment processes are designed to reduce them [5].

Due to the diversity of CWW pollutants, various methods have been developed for its treatment, which include effective processes in reduction of oil, solids, phosphorus and other CWW pollutants [1,9,10]. Chemical, biological and advanced processes such as membrane technology have been evaluated for the CWW treatment, each of which has the potential to reduce the various pollutants of this type of wastewater [11]. The aim of this study was to investigate the characteristics of CWW and classify its treatment methods in terms of efficiency and operational challenges. In this study, an attempt was made to evaluate the technical aspects of each method and their impact on the environment in order to choose the best option for different scenarios.

2. Method

This review was conducted based on a systematic search of evidence-based articles on CWW treatment systems. This search was done based on the keywords of wastewater and carwash, as well as mesh terms in the database. The main question of the study is "*What are the main pollutants of CWW and their appropriate treatment methods?*". In this study, it was also important to find answers to the

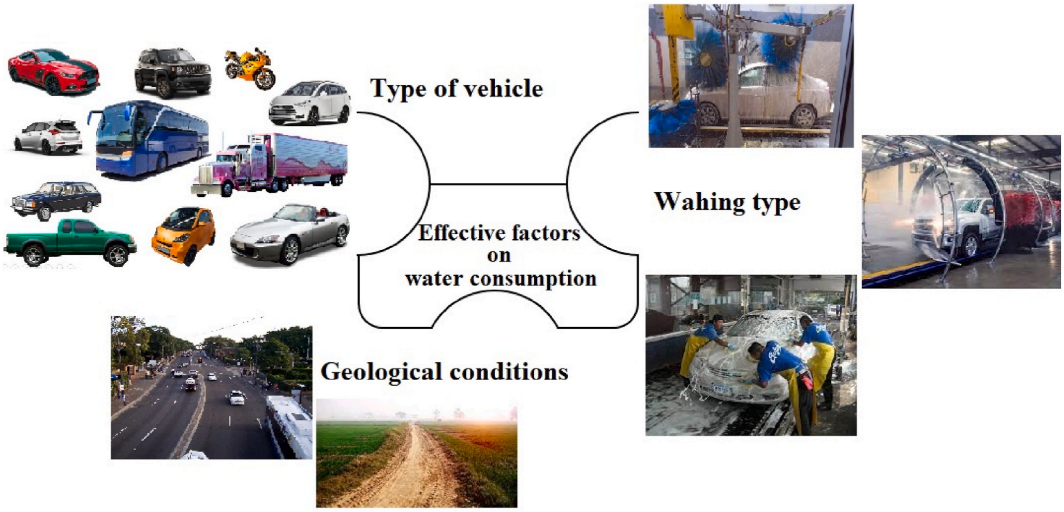

Fig. 2. effective factors in carwash water consumption.

Table 1
The origin of CWW pollutants.

Origin		pollutants
Traffic	Road dust	Solids: sand particles, dust, exhaust particles, metal particles
	Atmospheric dust	Detergent, solvent, surfactant, naphthalene
Washing process		Oil and grease, aromatic hydrocarbons, heavy metals
Leakage from engine		

following complementary questions.

1. What is the origin of CWW pollutants?
2. How effective is each of the CWW treatment methods in reducing various pollutants?
3. What are the technical criteria for choosing the appropriate CWW treatment method?

The articles were selected based on a criteria including several screening stages. The final search was conducted in March 2023 and review articles on CWW treatment were used as sources of information. To ensure the completeness of the search, the references of the selected articles were also checked and entered into the article selection criteria. In this search, time limitation was not considered. The entry criteria for this study included the presence of information on one or more CWW treatment methods, which was performed in three screening stages. The screening stages include the study of the title, abstract, and content of the searched articles, which were done by the authors separately. The screening steps are shown in Fig. 1, and finally 30 articles were selected for this review.

3. Results and discussion

3.1. Type of carwash and water consumption

In many studies, the amount of water consumption for washing each car has been reported, which are in a wide range. This difference in the amount of water consumption is directly related to the type of carwash, the type of vehicle, the geological conditions, and the type of detergent [2]. The water consumption in the carwash per car has been reported in the range of 60–600 L, and the most cases were in the range of 60–100 L [4]. Therefore, according to this volume of water consumption and the number of cars in the world, carwashes can be introduced as one of the importance water consumers. One of the recommended methods for providing carwash water is on site reuse of treated wastewater [1]. Water supply by reuse of treated wastewater depends on the existence of laws, standards, and available technology for treatment. As shown in Fig. 2, the type of carwash has an effect on the volume of water consumption. Sarmadi et al., 2020, classified the types of carwashes into 4 groups and stated that the volume of water consumption in hand wash and self-service wash is more than tunnel wash and automatic wash methods [4]. Therefore, the use of automatic and semi-automatic methods can be effective in the environmental management in two ways; First, reducing the water need and secondly reducing the wastewater production. Also, heavy cars require more water consumption compared to small cars, and when the car is used in areas with a higher potential for pollution, such as rural roads, as well as in rainy seasons, the number of washes and the volume of consumed water will increase [1,12].

Table 2
Reported quantity in CWW pollutants.

Parameter	COD (mg/L)	BOD (mg/L)	Turbidity (NTU)	TN (mg/L)	TP (mg/L)	Oil (mg/L)	TDS (mg/L)	Conductivity (μS/cm)
Quantity	155–4250	68–572	128–3649	3–11	9–25	1–125	259–644	300–1290
Ref.	1, 3, 12	1, 3, 12	1, 3, 12	3, 12	2, 3	1, 2, 3	1, 12	1, 12

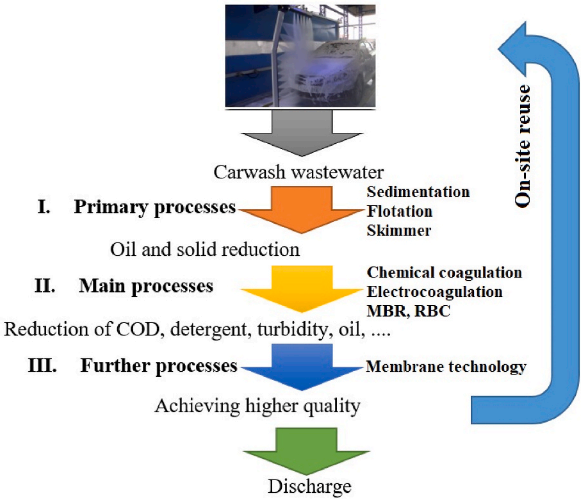

Fig. 3. CWW treatment processes.

3.2. CWW pollutants

CWW pollutants are directly related to the car pollution that listed in Table 1. In general, pollutants in CWW can be classified into main pollutants (high concentration) and other pollutants (low concentration). Solids, oil, and detergent are main pollutants that have been reported in high concentration in CWW [13]. However, pollutants such as heavy metals have been observed in low concentrations in CWW [4]. As stated in Table 1, some of the CWW pollutants are caused by the washing process, which is the main source of detergent in the CWW [14]. However, the particles on the car body as well as the pollutants caused by the traffic are among the environmental pollution that are finally transferred to the CWW. Also, the source of some of the pollutants in the CWW is the oil and grease leaked from the car engine [1,15]. The most important pollutant of CWW is oil, which has caused this wastewater to be classified in the oily wastewaters. However, the concentration of different pollutants in CWW has been reported in different studies by different values. The difference in the amount of pollutants in CWW in different studies can be caused by the washing method, type of detergent, type of vehicle, geological conditions, and seasonal differences [1,3]. Table 2 shows the concentration of different CWW pollutants reported in different studies.

3.3. CWW treatment processes

Due to the variety of pollutants in CWW, the treatment of this type of wastewater should be done in several different processes. Various methods have been studied for CWW treatment. Some of these methods have been used as a pre-treatment for the main treatment steps and some processes have been used as an advanced treatment to achieve reuse standards [1]. The sequential processes used in CWW treatment can be classified into three groups, which include primary processes, main processes, and advanced processes (Fig. 3). Primary processes include sedimentation to separate suspended solids as well as skimming to separate oil from the surface [4]. The main processes, according to the nature and origin of pollution in the CWW, can be selected among chemical methods such as absorption and coagulation [3], and biological methods [4]. Advanced processes include membrane technologies for higher removal efficiency [2].

3.3.1. Primary processes

One of the important challenges in CWW treatment is the high concentration of solids and oil [4,6]. Solids can have an adverse effect on the efficiency of the main CWW treatment and also limit the use of advanced processes such as membrane technology [2]. Also, high concentration of oil can have a negative effect on biological processes, especially aerobic processes, and disrupt absorption and membrane processes [1]. Therefore, it is necessary to separate solids and oil in the initial stages of CWW treatment. The most widely used method to separate solids from CWW includes sedimentation and filtration, which have good efficiency [1].The most important limitation of these methods is the retention time and also the clogging [1].These limitations can be a challenge in cases

Table 3
Effective factors in the efficiency of CWW treatment by coagulation process.

Process	Factors	Effect
Electrocoagulation	Conductivity	+++
	Type of matter	Increase by increasing suspended solids ratio
	pH	Increase in neutral or weakly acidic
	Treatment time	+
	Electrode distance	+
	Current intensity	+++
	Temperature	+
Chemical coagulation	Coagulant concentration	++
	Type of coagulant	±
	Co-coagulant	+++

Table 4
Effective parameters in the efficiency of electrocoagulation.

Parameter	Effect	Ref.
Conductivity	Increasing the conductivity by affecting metal dissolution and electron transfer will improve the efficiency of electrocoagulation	[25]
pH	It is different according to the type of electrode, but to achieve optimal efficiency, the best pH is neutral and weakly acidic	[3]
Type of component	The efficiency of the process is directly dependent on the proportion of suspended solids in the CWW	[22]
Temperature	The increase in temperature has a positive effect on the efficiency of the process due to the effect on the characteristics of wastewater such as conductivity, as well as the process of electrocoagulation-related reactions, such as the solubility of metal hydroxides and the kinetics of gas bubbles. The increase in efficiency is not continuous with the increase in temperature and after a certain temperature the efficiency will not change significantly.	[3]
Electrode distance	Increasing the electrode distance due to the effect on polarization, bubbles escaping, and energy transfer will increase the efficiency of the process.	[23]
Current intensity	An increase in current density will increase bubble production and also floc growth, which will increase process efficiency	[23,24]
Treatment time	It is directly related to increased efficiency	[3]

where on-site reuse is the goal [1]. Also, skimming technique, flotation are methods used to separate oil in the primary processes of CWW treatment [4].

3.3.2. *Main processes*

The selection of the main process for CWW treatment among chemical methods and biological methods such as adsorption, coagulation, MBR, and anaerobic methods, depends on the concentration and the origin of pollutants [1,4].

3.3.2.1. Adsorption. Due to the complex pollutant matrix in CWW, methods such as absorption do not have much ability to treat this type of wastewater [4]. However, in some reports, adsorption has been one of the mechanisms used to solid and other CWW pollutants reduction by electrostatic and van der Waals reactions [16]. The performance of this process is particularly dependent on the particles size, but in general, due to the significant size of the particles in the CWW, the performance of this process suitable for solids reduction [16]. In addition to particle size, the presence of alkaline conditions, functional group, and negative charge on the absorbent surface can be effective in improving the oil reduction efficiency and other pollutants [16]. By using modified natural adsorbents, pollutants such as heavy metals can be separated from CWW [4].

3.3.2.2. Coagulation. As shown in Table 3, two methods of chemical coagulation and electrocoagulation can be used for CWW treatment. These methods are generally the most used among the chemical methods in CWW treatment [3]. The widespread use of coagulation process is due to the high concentration of solids and turbidity as an important characteristic of CWW. The most important characteristic of this process are the proper turbidity and COD reduction efficiency (more than 90%), which is influenced by the coagulant concentration [17,18]. Also, the results of studies have shown that the main mechanisms of coagulation in CWW treatment include destabilization and trapping, which are observed in low coagulant dosage and high coagulant dosage, respectively [3]. One of the reasons for the different efficiencies observed in different studies is the use of different types of coagulants, which are effective in efficiency due to characteristics such as surface charge. The most widely used coagulants used in CWW treatment include alum, ferrous sulfate, bentonite, and $FeCl_3$ [19,20]. Therefore, choosing the proper coagulant has an important effect on the coagulation process in CWW treatment, because in addition to the effect on efficiency, it can also be effective on the quality of color and pH [3]. Also, the use of coagulant has a positive effect on the efficiency of the coagulation process, which has been shown in various studies [21].

The results of various studies showed the efficiency of the electrocoagulation process in reducing surfactant and COD more than 90% [3]. It is common to use iron and aluminum as electrodes in the treatment of CWW [22–24]. Various parameters have an effect on the efficiency of the electrocoagulation process, which includes conductivity, type of organic material and pH [22,25]. Therefore, changes in the quality of CWW due to temporal and spatial variation can be the reason for the difference in the efficiency of the electrocoagulation process in the treatment of this type of wastewater. Considering the ability of the electrocoagulation process to reduce solids and the inefficiency of this process in reducing dissolved organic matter, the reduction of COD in the electrocoagulation process depends on the concentration of soluble and insoluble types in the CWW [3]. Therefore, the high concentration of solids as one of the characteristics of CWW [1] has caused the use of electrocoagulation process to it treatment. This condition is one of the reasons for stopping the reduction of COD by continuing the electrocoagulation process from a certain time of the start of the process [22]. Also, the increase in conductivity and neutral or weakly acidic pH due to the effect on metal dissolution, electron transfer and hydrolysis, and polymerization of metal increases the efficiency of electrocoagulation, but the optimal pH for different electrodes has been reported differently [22–25]. In addition, the operating order can change the efficiency of the electrocoagulation process. As stated in Table 4, increasing the temperature, increasing the electrode distance, increasing the current intensity, and increasing the treatment time will improve the efficiency of electrocoagulation in CWW treatment.

3.3.2.3. Oxidation processes. The use of chemical oxidation as well as electrooxidation to reduce CWW pollutants has been reported in various studies [3]. In using the electrooxidation process, as well as the electrocoagulation process, the parameters related to the quality of wastewater as well as operating parameters have been reported to be effective [3]. The use of lead electrode as well as modified boron electrode has had good results in reducing the COD of CWW even by more than 99% [26]. Although increasing the current intensity and the treatment time will improve the efficiency of the electrooxidation process, it is very important to determine the optimal efficiency point based on energy consumption, because the results of the studies showed that the change in the efficiency of the process after a certain time is insignificant [27]. Ozone and H_2O_2 were tested as chemical oxidation methods for the CWW treatment, which in addition to the positive effect on COD reduction has also caused a decrease in the color [3].

3.3.2.4. Biological processes. Although the characteristics of CWW, such as the high concentration of oil and detergent, may challenge the use of biological processes, but the use of biological methods such as MBR and RBC were studied for the CWW treatment [1,8]. The efficiency of the RBC method with filtration in reducing turbidity and COD was reported as 72–97% and 56–94%, respectively [28]. The efficiency of enhanced MBR in reducing suspended solids and turbidity was reported to be more than 99% [29]. However, the operating problems of biological methods in CWW treatment is a limiting factor in their widespread use. For example, clogging is a serious problem in the application of the MBR method for CWW treatment, which requires the use of chemicals to solve it [1]. These problems have caused biological methods to be used in combination with other. The efficiency of combined CWW treatment methods in which a biological method was used to reduce suspended solids, turbidity, and COD was reported as 99-84%, 99-72%, and 99-56%, respectively [3].

3.3.3. Advanced processes and combined treatment

Achieving more efficient CWW treatment requires the use of further methods, for which membrane technology has been widely considered [19,30–32]. Membrane technology in different classes, including ultrafilter, microfilter, nanofilter, and reverse osmosis were tested in CWW treatment. ultrafiltration by 70% had the largest ratio among the studies [2]. The efficiency of membrane technology in improving the quality of CWW depends on several factors, including the wastewater characteristics, the type of membrane, and other processes associated with the membrane [2]. The efficiency of different membranes in CWW treatment is different, so COD reduction by ultrafilter, nanofilter, microfilter, and reverse osmosis was reported by 77–95%, more than 90%, 73–81%, and 87%, respectively [19,30–32]. Also, the effectiveness of membrane technologies in reducing turbidity was often reported to be more than 90% and in a few cases more than 50% [2]. However, the limitations of membrane technology, such as the rapid and severe flux reduction, the change of effluent pH, and the low volume of water recovery were the challenges of using this method for the CWW treatment [1].

Due to the characteristics of CWW, a treatment method cannot have sufficient efficiency in reducing pollutants. Therefore, several methods have been used in the studies as a sequential purification method. Effective parameters in arranging CWW treatment methods include wastewater quality, effluent standard, energy consumption, technology, financial aspects, and water recovery volume [1]. Based on the suggestion of Torkashvand et al., 2020, the combination of processes for CWW treatment should meet two goals including proper efficiency and maximum water recovery volume [1].

3.4. Technical and environmental comparison of methods

The methods used in CWW treatment can be evaluated in terms of efficiency, pre-treatment requirement, water recovery rate, sludge production, and energy consumption. In the initial stages of CWW treatment, oil separation plays an important role in the performance of further processes, which can be achieved in two active and passive methods. The use of dissolved air flotation is a common method for separating oil from wastewater, which in the case of CWW has had an efficiency of up to 96% [18]. However, achieving this efficiency requires a long time, which will increase energy consumption. In short purification times (less than 30 min), oil reduction efficiency was reported between 10% and 49% [18,21]. Therefore, a limitation of the active flotation method is energy consumption and increased treatment costs. However, the passive method evaluated using the skimmer can be considered for cases with financial limitation and also in cases with energy management goals [33]. Removal of solids using sedimentation or filtration processes [30] will ultimately result in the sludge production that must be managed. However, the use of these methods at the beginning of the treatment will help the efficiency of the main processes and will reduce the operating costs [1].

Comparing the results of the studies shows that the main concern about the use of chemical coagulants is the increase in the volume

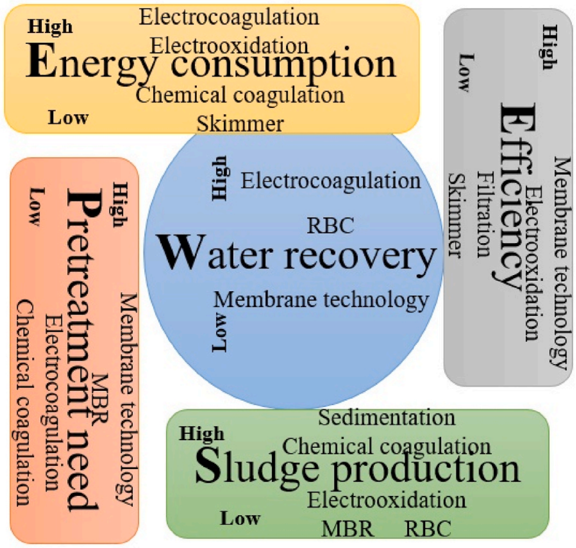

Fig. 4. Techno-environmental comparison of studied methods in CWW treatment.

of sludge in the treatment system. For example, 12% of the ferric chloride used in CWW treatment will turn into sludge [18]. However, the alternative process is electrocoagulation, which can produce less sludge, but energy consumption is a serious challenge in its use [3]. The results of various studies in combining processes such as ultrasonic with electrocoagulation or modification of the structure of electrodes, as an example of which was experienced in the electrooxidation process in CWW treatment, can reduce the energy consumption [1]. As shown in Fig. 4, the most important challenge of using membrane technology in CWW treatment, despite the high efficiency in reducing pollutants, is the significant retentate and the need for backwash, which will eventually reduce the water recovery rate [2].

4. Conclusion

The characteristics of CWW and its treatment methods were reviewed. The results showed that the most important challenge in CWW treatment is the high concentration of oil and suspended solids. This characteristic is present in all CWWs, but the quality of CWW has spatial and temporal variation that are caused by the different geological condition, the type of car, the type of washing, and different origin of CWW pollutants. For CWW treatment, a three-stage structure should be designed, which includes primary processes (to reduce particles and oil), main processes (to reduce COD, oil, detergent, turbidity, and conductivity), and further processes (to achieve more efficiency based on environmental and reuse standards). Using the sedimentation process and passive oil separation can be considered as primary processes by easy operation and acceptable efficiency. Chemical coagulation process is widely used in the CWW treatment, but it leads to the production of sludge, so the use of electrocoagulation will be suitable for the main method, and by combining processes such as ultrasonic and also modifying the electrode structure, energy consumption can be managed. Membrane technology is the most important further treatment method for CWW treatment, which is difficult to use due to clogging and fast and severe flux reduction. The need for backwash as well as the significant retentate volume are the main challenges of using membrane technology in CWW treatment, which can be managed by designing pre-treatment processes.

Author contribution statement

Farogh Kazembeigi: Analyzed and interpreted the data; Wrote the paper.
Solmaz Bayad: Analyzed and interpreted the data; Wrote the paper.
Ahmad Yousefi Nasab: Analyzed and interpreted the data; Wrote the paper.
Marziye Doraghi: Analyzed and interpreted the data.
Iman Parseh: Analyzed and interpreted the data; Wrote the paper; materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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