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Car wash wastewater treatment combination: A systematic review

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Abstract

Car wash wastewater is a source of water pollution. Processing car wash waste is crucial to prevent environmental pollution. In this issue, car wash treatment has the potential to sustain of clean water. However, the effective treatment of car wash wastewater is still being determined, complicated to solve, limited resource capabilities, inadequate surrounding environmental support, and very expensive processing costs. This systematic review paper aims to review the combination technology of car wash wastewater treatment systematically. A literature survey was conducted, and 11 research articles were found suitable for inclusion in the investigation, which extracted information, country of origin, and method used. The best 8 of 11 articles were removed as secondary data for writing this manuscript to be included in the analysis table. Studies on flocculation-column-flotation, coagulation-flocculation, ultra-microfiltration, coagulation-flocculation, electrocoagulation, sedimentation-filtration, filtration-ozonation, electrocoagulation-adsorption, and each n=1. This systematic review shows that ultrafiltration and microfiltration membrane treatment methods effectively remove pollutants from car wash wastewater.

Keywords: Car wash; Pollutants; Wastewater treatment; Ultrafiltration; Microfiltration

1. Introduction

Many car wash industries have understood the importance of car wash wastewater treatment. It's been a long time since the rules for treating this type of waste were made and published depending on each country [1]. For example, several European countries stipulate that using drinking water as a vehicle wash is not permissible and only allowed no more than 70 L per car [2]. Wastewater treatment will be a severe challenge for water sustainability in the future.

Most effective technologies in recycling car wash water use physicochemical [2]. In the development of waste recyclers of this type, the use of combined methods provides enormous effectiveness in removing impurities from water. Several combined methods such as flocculation-column-flotation, coagulation-flocculation, ultra-microfiltration, coagula-tion-flocculation, electrocoagulation, sedimentation-filtration, filtration-ozonation, electrocoagulation-adsorption. Most wastewater treatment plants with low costs in recycling wastewater are reused for irrigation through sedimentation and filtration processes [3].

However, the application of an appropriate maintenance system with a low operating value in the treatment of car wash water waste needs to be considered. However, the existence of car wash wastewater treatment is a challenge and an issue that needs to be resolved immediately as stipulated in the framework of the implemented natural development [3]–[5]. There are many types of combination techniques in waste water treatment and have been applied for a long

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time. In addition, physico-chemical techniques and oxidation processes have long been applied to car wash wastewater treatment [6]. However, effectiveness performance and presented in the form of a percentage of published research results have not been systematically reviewed. This paper aims to review various combination technologies for the systematic treatment of car wash wastewater.

2. Material and methods

2.1. Methods

The methodology in the systematic review text follows that of the report for Systematic Review and Meta-Analysis (PRISMA) and the checklist. The PRISMA method guide is transparent and complete for a systematic review of manuscripts seen based on a 27-item section [12].

2.2. Protocols and registration

The transparency of this review literature is strengthened by methods that have been published in the Prospective Register of Systematic Review (PROSPERO), ID CDR42020142891 (accessed at the link https://www.crd.york.ac.uk/prospero/display_record.php?RecordID= 142891)

2.3. Information sources and search

They performed in-depth searches on four databases: ScienceDirect, Springer Link, Google Scholar, and PubMed. The first author created, developed, and tested the keyword on the specified database search engine. The end of the search was performed by the first author on December 8, 2022, with no date restrictions. During the search for the source of the article, there are no restrictions on the date of publication, the method of treating used car wash water, the country of origin of the authors, and their study data. To get specific study results and focus on articles related to the search terms car wash, water reclamation, and water reuse. These search terms are also carried out on other sources to get articles that match the criteria, i.e. on ResearchGate and the Google search engine.

2.4. Study selection

A team made a study selection of one leader (first author) and three members (non-authors). Established agreement between assessments through training on eligibility criteria led by the first author. During the training, team writers assessed eligibility with predefined notes on titles and abstracts before screening independently. All letters were screened by title and abstract by the first author, independently screening a portion of the notes. The author decides as yes, no, or full text is required based on the eligibility criteria. Access to the entire manuscript is done if the abstract is unclear because the research meets the inclusion criteria. During the screening process, a meeting was held to clarify the eligibility criteria.

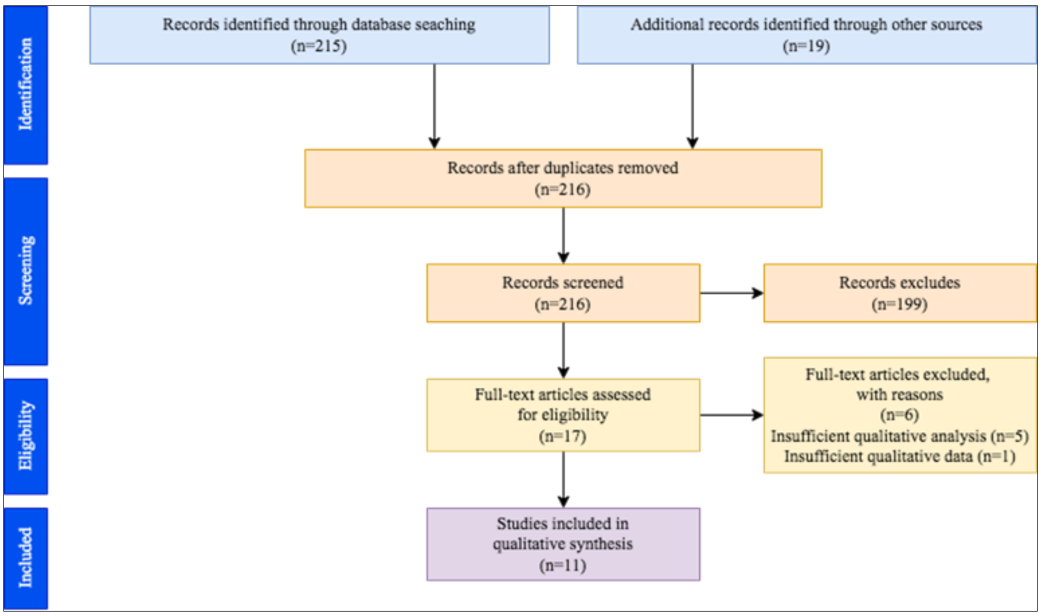

Figure 1 PRISMA flow diagram of the study selection process

2.5. Identification

The reference search used in the analysis of this manuscript uses databases originating from ScienceDirect, Springer Link, Google Scholar, and PubMed. During the reference search process, using three groups in each database, i.e. car wash, water reclamation, and water reuse. The three keywords are grouped using the Boolean operator AND combination method, containing keywords from the three groups. The keywords used for the search are car wash AND water reclamation AND water reuse. The references used during the investigation were from 2010 to 2022, with the reference criteria as articles.

2.6. Screening

The author first screens the determination of articles obtained from database search engine results regarding the title. Duplication results are removed by merging. Then sort the results obtained by a combination of keywords taking into account the inclusion-exclusion criteria. Duplications must complete the eligibility criteria must be deleted. However, article excerpts were screened to find relevant additional text references and entered according to predetermined criteria. The initial search was performed according to a systematic review protocol and meta-analysis.

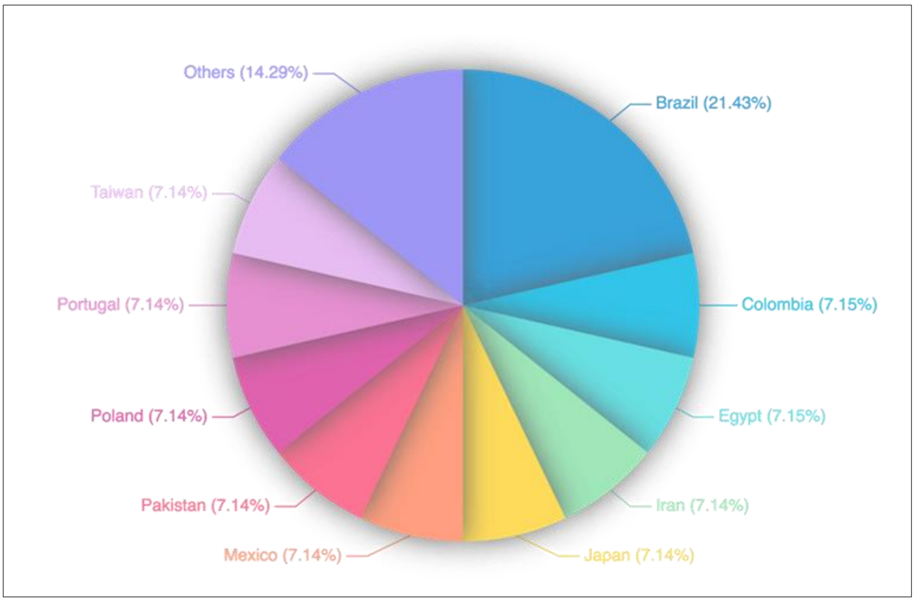

Figure 2 Percentage of countries that treat car wash wastewater

2.7. Eligibility

In the eligibility stage, the full text was selected carefully (n = 17). Then further checks for eligibility to obtain the same exclusion criteria used in abstract screening.

2.8. Inclusions

Qualified records, information related to car washes and in addition to the results of car wash water treatment methods are also included in the preparation of this systematic manuscript.

2.9. Data extraction

From each study, information from the author, the year the article was published, the origin of the author, the parameters used, study findings, research data, and schematic drawings were extracted and then systematically compiled.

3. Results

3.1. Study selection

Total titles and abstracts (n=215) were retrieved from a database derived from ScienceDirect (n=15), Springer Link (n=54), Google Scholar (n=146), PubMed (n=0), and other sources (n = 12). Eleven abstracts were identified as duplicates. During the screening process, articles (n = 199) were removed from the selected manuscripts, resulting in articles that were eligible for the next stage of selection. The eligibility stage showed that there were articles (n=17) which were read in full-text and were excluded from articles (n=6) due to insufficient qualitative analysis (n=5) and insufficient qualitative data (n=1). Then, in the included stage, 11 articles were synthesized, which extracted information related to countries, data, and other information that could be retrieved. The PRISMA diagram in this systematic review can be seen in Figure 1.

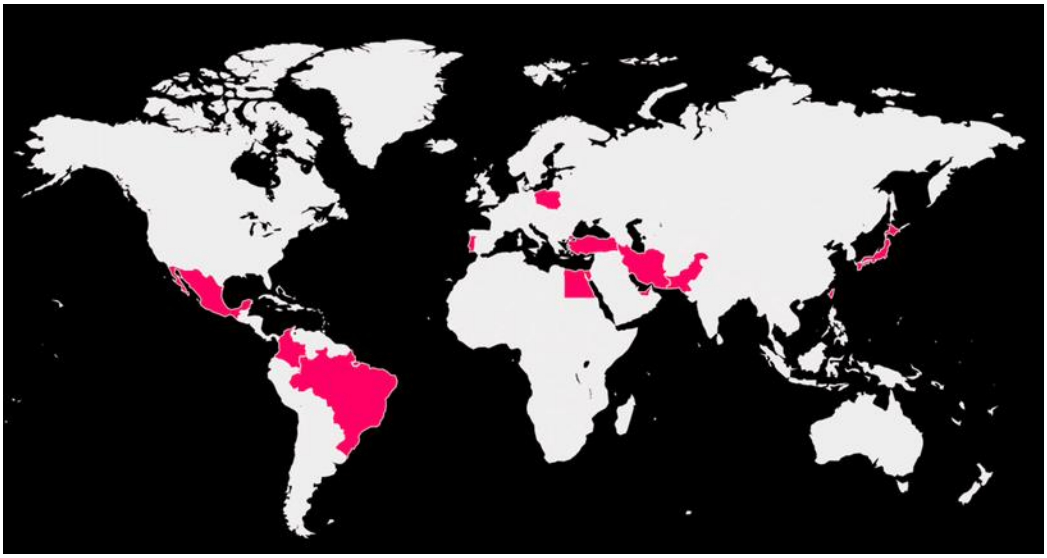

Figure 3 Representative distribution of selected studies

3.2. Study characteristics

The characteristics of the selected studies (n=11) can be described in table 1. Each article has a different combination of treatment methods. The study characteristics obtained from the synthesized sources can be illustrated in Figure 2-4. Figure 2 shows the percentage of 12 countries that treat car wash wastewater. The representation consists of Brazil (21.43%), Colombia (7.15%), Egypt (7.15%), Iran (7.14%), Japan (7.14%), Mexico (7.14%), Pakistan (7.14%), Poland (7.14). %), Portugal (7.14%), Taiwan (7.14%), and Others (Turkey 7.14%; United Arab Emirates 7.14%). Figure 3 shows the distribution of the countries the authors come from and are identified as information on the selected studies. Then, keyword information is used to see the distribution of the 11 selected articles; the software identifies 44 keywords. This identification is to notice the types of car wash wastewater treatment research methods often carried out. In these representative results, it was found that electrocoagulation, microfiltration, and ozonation research methods were the methods often used in published studies. In addition, carwash wastewater and water reuse as the main principles of the methods have been identified previously.

Table 1 Characteristics of the studies synthesized in this systematic manuscript

No	References	Study parameters	Others
1	[1]	pH; BOD; COD; TSS; TDS; conductivity; turbidity, total coliforms; tannins; oil and grease; phenols; surfactants; phosphorus; nitrogen; hydrogen sulphide; calcium; magnesium; sodium; sulphates; chloride	Treated water (flocculation-column flotattion) shows high fecal and total coliform counts. Concluded that no direct reclamation of this water is suitable without disinfection.
2	[3]	total solids; TTS; TDS; turbidity; pH; hardness; alkalinity; oil	The sewage treatment unit uses sedimentation and filtration which are suitable for car wash wastewater treatment.
3	[7]	COD, TOC, SS	The performance of the ultrafiltration membrane system proves that it is a suitable treatment system for car wash wastewater reclamation.

4	[8]	turbidity; pH; TSS; TDS; *E. coli*; total coliforms; BOD; COD; sulfides; conductivity; surfactants	The results obtained show that the flocculation-flotation-ozonation process has great potential for car wash wastewater reclamation.
5	[9]	pH; steering time; voltage; electrode type BOD; COD	Electric coagulation process with iron and aluminum electrodes to remove chemical and biological oxygen demand (COD and BOD) from gray water in different car washes.
6	[10]	pH; turbidity; conductivity	Membranes with an average pore diameter of 0.4 μm show good results and have the potential to be commercialized.
7	[11]	pH; conductivity; color; COD; turbidity; aluminum; fecal coliforms; oil and grease	This study demonstrates the feasibility of car wash wastewater reclamation involving a simultaneous electrocoagulation-adsorption technique.
8	[12]	pH; COD; anionic surfactants; Oil-grease; total hardness; chlorides; Sulphates; Conductivity; suspended solids; Fecal coliforms	Integrated electrocoagulation-nanofiltration process was successfully applied to carwash wastewater.
9	[13]	pH; DO; conductivity; salinity; TDS; COD; color; turbidity; alkalinity; BOD; total coliforms; oil and grease	The coagulation-flocculation method has the potential to be an effective wastewater reclamation that can help regulate car wash wastewater reclamation in the future.
10	[14]	pH; turbidity; conductivity; total dissolved solids; temperature; chloride; COD; oil and grease; surfactants	The study output is highly correlated with the SDGs related to environmental conservation, economic feasibility and social acceptance.
11	[15]	pH; turbidity; COD; BOD; TSS; BOD	This study investigates electrocoagulation as a cost-effective method of treating car wash wastewater.

COD (chemical oxygen demand), BOD (Biochemical Oxygen Demand), TOC (total organic carbon), SS (suspended solids), TSS (total suspended solid), TDS (total dissolved solids)

4. Discussions

4.1. Consumption of clean water in car washes

Clean water consumption per capita (litres per car) is related to geographical area and type of car wash. The water consumption range varies from 100-1000L/car depending on these factors and the level of vehicle cleanliness and vehicle washing method that consumers want. The large amount of water needed for washing vehicles is due to impurities. A car with light soil and dust impurities requires at least 100 L of water. Contaminants such as oil, clay, and other pollutants that enter the gaps (the engine and the car body) result in a water requirement of up to 1000L. About half of the water is 600 L/car, used before washing, and the rest is used for the following washing process [16]. As confirmed by [17], the capital has been reported to be between 60-70 L/car in the Netherlands and Scandinavia and 100 L/car in Australia [18]. Some studies also report that implementing a reuse system can save up to 75% of water consumption [1], [19].

4.2. Car wash pollution sources

Sources of impurities in car wash wastewater include sand, dust, oil, grease, salt, surfactants, organic matter, carbon and asphalt [5], [20]. Car wash wastewater flows down the drain. On the wastewater's surface, it contains some impurities in the form of suspended, colloidal and dissolved solids, dyes, and microorganisms (bacteria). Wastewater is very complex and varied. Apart from detergents and other impurities, some oils, heavy metals and emulsions can cause environmental problems [21]. Reports of Al-Odwani et al. [19] sources of pollutants such as heavy silt particles, dust and sand. They process waste by settling it at the bottom of the tank due to gravity. Pollutants such as sludge will be discharged through the sludge discharge valve. Oil-type pollutants are removed by using oil skimmer agents. High levels of oil and organic matter in car wash wastewater [4], [20], [22]. Another vital car wash wastewater pollutant can be found in the solids that enter the car from mud, dust and detergent organic matter. Moreover, metallic pollutants such as lead, chromium, nickel, and polycyclic aromatic hydrocarbons are other important pollutants reported even at low levels by various studies [4], [23].

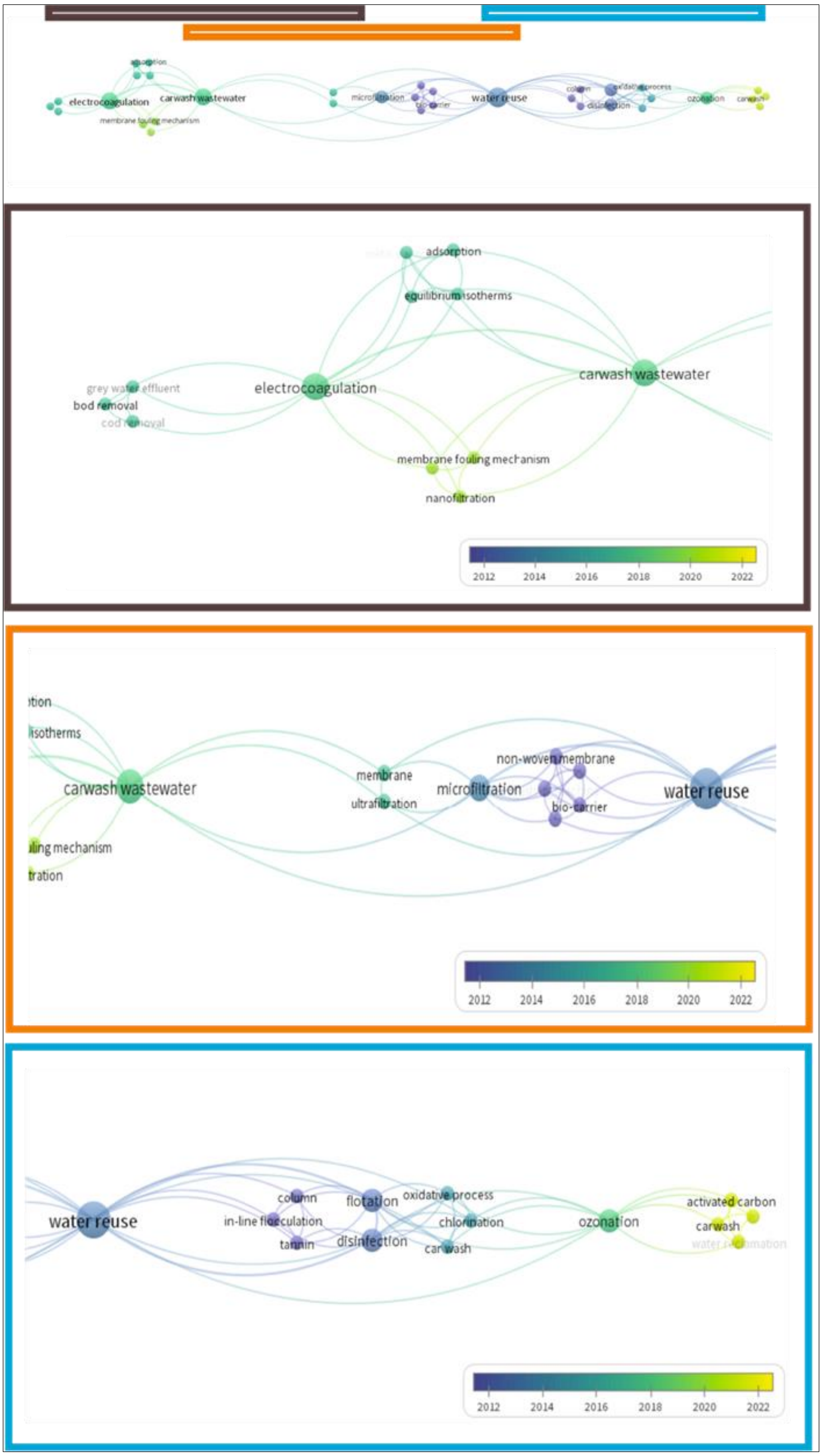

Figure 4 Relation of found reference keywords

4.3. Implemented treatment methods

4.3.1. Coagulation

Coagulation-based treatment methods have long been used in wastewater treatment in many small-large industries. This technique is highly effective in removing dissolved solids and purifying water from turbidity, but its effectiveness in reducing incoming organic matter (COD and BOD) is relatively low [4], [24]. This technique is often used with other methods such as adsorption, membrane, and flocculation. The reduction rate of the results of the combined coagulation-flocculation method is shown in Table 2, Table 3, and Table 4. The technique carried out by [13] has advantages in the parameters of oil (90.00%) & grease, and turbidity (86.42%). Meanwhile, the technique carried out by [14] has advantages in reducing COD and turbidity.

Table 2 Reducing ability of the coagulation-flocculation technique in car wash wastewater in Barranquilla, Colombia [13]

Parameter	OWS	CF	
	Wastewater	Reclamation	Reduction (%)
pH	7.58	7.14	5.80
BOD (mg/L)	56.49	33.58	40.56
COD (mg/L)	127.33	58.49	54.06
TSS (mg/L)	-	-	-
TDS (mg/L)	-	-	-
Turbidity (NTU)	79.51	10.80	86.42
Oil & grease (mg/L)	0.30	0.03	90.00
Surfactants (mg/L)	-	-	-
Nitrogen (mg/L)	-	-	-

* CF (coagulation-flocculation); OWS (downstream the oil or water separator)

The results of a study conducted by [13] using 1% $FeCl_3$ (ferric chloride) as a clotting agent. Ferric chloride is a very corrosive substance, so the use of this material as a coagulant needs to be aware of the dangers it poses. Thus, reclaimed water should be avoided for final rinsing. The results of the reported study showed that the combined use of the coagulation-flocculation method had an efficiency of more than 70% in removing organic matter and 90% in turbidity, as well as reducing oil & grease and coliforms.

Table 3 Reducing ability of coagulation-flocculation technique in car wash wastewater in Egypt [14]

Parameter	Coagulation-flocculation		
	Wastewater	Reclamation	Reduction (%)
pH	7.8	-	-
BOD (mg/L)	-	-	-
COD (mg/L)	406	93.35	77.01
TSS (mg/L)	-	-	-
TDS (mg/L)	358	-	-
Turbidity (NTU)	940	100	89.36
Oil & grease (mg/L)	200	-	-
Surfactants (mg/L)	250	99.93	60.03
Nitrogen (mg/L)	-	-	-

Then, [14] also reported regarding the use of the coagulation-flocculation combination method using natural ingredients, namely chickpeas (Cicer arientinum) and added with an inorganic coagulant, namely $AL_2(SO_4)_3.18H_2O$ (aluminium sulfate octadecahydrate). The results of the study show that the combined coagulation-flocculation method has the efficiency of turbidity (88.35%), surfactants (60.30%), and COD (54.25%). The chickpea polymer chains can bridge interfacial adsorption by increasing the entrapment of colloidal particles and anionic surfactants.

Table 4 Reduction ability of electrocoagulation techniques in car wash wastewater in Iran [9]

Parameter	**Electrocoagulation**		
	Wastewater	**Reclamation**	**Reduction (%)**
pH	3, 7, 11	7.08	-
BOD (mg/L)	-	102–246	-
COD (mg/L)	-	480 - 1560	-
TSS (mg/L)	-	-	-
TDS (mg/L)	-	-	-
Turbidity (NTU)	-	-	-
Oil & grease (mg/L)	-	-	-
Surfactants (mg/L)	-	-	-
Nitrogen (mg/L)	-	-	-

4.3.2. Adsorption

The general method repeatedly used in industry is adsorption in the wastewater treatment process. This method has been widely used in treating vehicle wash wastewater, including used car washes. This technique is rare because the components constructing the waste complex are difficult to process with this process. Studies show that this technique can remove organic and inorganic pollutants from car wash wastewater [4], [24]. One type of adsorption is an activated carbon filter that reduces taste, odour, heavy metals and organic compounds [13], [25]. This type of absorbent can be increased its effectiveness through physical screening beforehand. However, activated carbon filters cannot be used to remove microbial contaminants [13].

Table 5 Reduction ability of electrocoagulation-adsorption technique in car wash wastewater in Mexico [22]

Parameter	**Electrogulation-adsorption**		
	Wastewater	**Reclamation**	**Reduction (%)**
pH	7.8	8.81	+12.9
BOD (mg/L)	-	-	-
COD (mg/L)	1024	9	99.12
TSS (mg/L)	-	-	-
TDS (mg/L)	-	-	-
Turbidity (NTU)	925	16.7	98.19
Oil & grease (mg/L)	448	ND	-
Surfactants (mg/L)	-	-	-
Nitrogen (mg/L)	-	-	-

* ND (not detected)

The results of a study conducted by [14] used biochar (*Cicer arietinum*) as a fixed-bed column porous medium. The biochar they used showed a micro-mesoporous structure and had a rough and irregular surface morphology, where the matrix was relatively porous for pollutant adsorption. However, most voids are filled with pollutants after oil molecules, and other impurities are absorbed. Table 5 shows the reduction capability of the electrocoagulation-adsorption combination technique in the car wash water. Studies show an increase in pH (12.9%), COD (99.12%), and turbidity (98.19%). Adsorption techniques are unsuitable for reducing microbial contaminants, but combining electrocoagulation techniques can significantly improve this disadvantage.

4.3.3. Membranes

Membranes can be used to treat car wash wastewater with microfiltration, ultrafiltration, nanofiltration and reverse osmosis. This system has a significant efficiency in reducing organic matter and suspended solids in wastewater, as can be seen in Table 6. The weakness of the membrane is that impurities that fill the membrane's pores are called fouling and contribute to colloidal particles [26], [27]. Fouling affects small particles that cross the membrane. The fouling phenomenon depends on the membrane material and pore size and can be reduced by coagulation and flocculation.

Table 6 Reduction capability of ultrafiltration and microfiltration membranes in car wash wastewater in Minas Gerais, Brazil [18]

Parameter	Wastewater	Ultrafiltration		Microfiltration	
		Reclamation (100 kDa)	Reduction (%)	Reclamation (0.22 μm)	Reduction (%)
pH	7.5	7.9	+5.33	7.9	+5.33
BOD (mg/L)	-	-	-	-	-
COD (mg/L)	85	13	84.71	23	72.94
TSS (mg/L)	260	-	-	-	-
TDS (mg/L)	120	-	-	-	-
Turbidity (NTU)	85	0.64	99.25	0.93	98.91
Oil & grease (mg/L)	-	-	-	-	-
Surfactants (mg/L)	-	-	-	-	-
Nitrogen (mg/L)	-	-	-	-	-

However, this solution is not fully effective if the liquid waste is in large quantities. Using membranes as a technique for treating car wash wastewater is cost-effective. However, this also needs to be re-evaluated regarding the correct type of membrane and integration with other techniques to reduce the weaknesses of membranes [16]. Overall, a review of various studies from other journals shows that the membrane method effectively reduces contamination from laundry wastewater. The use of ultrafiltration and microfiltration membranes has been carried out by [18], which showed that the use of ultrafiltration membranes reduced COD (84.71%) and turbidity (99.25%). Then they also reported that using macro filtration membranes reduced COD (72.94%) and turbidity (98.91%). The reported study results show that the use of ultrafiltration membranes provides a more significant reduction of pollutants than microfiltration membranes. This is because large pores allow larger pollutant particles to pass in compared to ultrafiltration.

4.3.4. Sedimentation

Sedimentation is the most straightforward waste treatment technique among other sophisticated methods. However, A combination of filtration methods can increase sedimentation. This combination can reduce TSS, turbidity, TDS, COD, and BOD. The results of a study conducted by Syed et al. [3] showed that there was an increase in pH (24.64%) and a reduction in TSS (80%), TDS (32.32), turbidity (98.54%), and oil & grease (48.15%). The results of this study indicate that sedimentation and filtration techniques can significantly affect the TSS and turbidity parameters. The reduction capability with sedimentation techniques and combinations can be seen in Table 7.

Table 7 Reducing capability of sedimentation and filtration techniques in car wash wastewater in Iran [3]

Parameter	Sedimentation-filtration		
	Wastewater	Reclamation	Reduction (%)
pH	6.90	8.60	+24.64
BOD (mg/L)	-	-	-
COD (mg/L)	-	-	-
TSS (mg/L)	1000	200	80.00
TDS (mg/L)	591	400	32.32
Turbidity (NTU)	253	3.70	98.54
Oil & grease (mg/L)	27	14	48.15
Surfactants (mg/L)	-	-	-
Nitrogen (mg/L)	-	-	-

The results of a study conducted by [1] show that the complex combination of the column-flotation flocculation method combined with sand filtering and the addition of chlorination is shown in Tables 8 and 9.

Table 8 Reduction capability of the flocculation column-flotation (FCF) technique in car wash wastewater in Porto Alegre-South Brazil [1]

Parameter	FCF-S			FCF-SC		
	Wastewater	Reclamation	Reduction (%)	Wastewater	Reclamation	Reduction (%)
pH	7.7	7	9.09	7.4	7.3	1.35
BOD (mg/L)	133	-	-	68	27	60.29
COD (mg/L)	241	-	-	191	71	62.83
TSS (mg/L)	68	-	-	89	8	91.01
TDS (mg/L)	502	-	-	345	387	+12.75
Turbidity (NTU)	89	12	86.52	103	9	91.26
Oil & grease (mg/L)	6	-	-	11	8	27.27
Surfactants (mg/L)	11.7	-	-	21	12	42.86
Nitrogen (mg/L)	5	-	-	9	8	11.11

* FCF (flocculation column-flotation); S (sand filtration); SC (sand filtration + chlorination)

Not much information on the test parameters in the flocculation column-flotation treatment with the addition of sand filtration indicated a decrease in pH (9.09%) and turbidity (86.52%). Then the addition of sand filtration and chlorination treatment showed that there was a significant decrease in the parameters turbidity (91.26%), TSS (91.01), BOD (60.29%), and COD (62.83%).

Another study conducted by [2] using the flocculation-flotation technique showed a significant reduction in the parameters TSS (82.08%), turbidity (88.98%), and surfactant (77.89%). They also reported that the addition of ozone gave satisfactory results where the significant parameters were COD (80.87%), TSS (82.44%), turbidity (92.91%), and surfactant (80.72%).

Table 9 Reducing capability of filtration and ozonation techniques in car wash wastewater in Porto Alegre-South Brazil [2]

Parameter	Wastewater	FF		FFO	
		Reclamation	Reduction (%)	Reclamation	Reduction (%)
pH	6.6	7.0	+6.15	8.2	+24.2
BOD (mg/L)	496	415.5	16.23	122.2	75.36
COD (mg/L)	873	536	38.60	167	80.87
TSS (mg/L)	279	50	82.08	49	82.44
TDS (mg/L)	797	937	+18.7	848	+20.1
Turbidity (NTU)	254	28	88.98	18	92.91
Oil & grease (mg/L)	-	-	-	-	-
Surfactants (mg/L)	22.3	4.93	77.89	4.3	80.72
Nitrogen (mg/L)	-	-	-	-	-

* FF (flocculation-flotation); FFO (flocculation-flotation-ozonation)

5. Conclusion

Systematically, this paper examines the latest technologies for treating used car wash wastewater in removing various pollutants from car wash industry waste. The results of a comprehensive identification show that the combination method of flocculation column-flotation, ultrafiltration and microfiltration membranes, coagulation-flocculation, electrocoagulation, sedimentation and filtration, filtration and ozonation, electrocoagulation-adsorption, has been proven to provide optimal car wash wastewater treatment results. However, of all the methods reviewed, the membrane filtration system method gives the best results in returning wastewater to ready-to-use clean water quality. However, this technique, used alone or in combination, consumes much energy, mainly when fouling occurs. The results of various systematic studies, a single method is rarely used in the study results, and combination methods are often used in the treatment of car wash wastewater. This combination method is used to complement other methods so that the final result is clearer water and suitable for disposal or use. Currently, the reduction of organic pollutants has been reported depending on the type of treatment and technology used, but actual applications are being considered. This relates to the effectiveness of processes, costs, and resources in support.

Limitations

The limitation of this systematic review is the need for a more comprehensive explanation regarding the methods of treating car wash wastewater. There need to be more published references regarding the various methods, and the efficiency of their methods still needs to be reported. However, information related to the amount of reduction of waste raw materials so that they can become usable water is presented in this systematic review. However, it is necessary to pay attention to the processing of car wash waste, namely the condition of the waste every time it continues to change depending on the type of car, the size of the car, consumer needs, the activity of the car, and the origin of the pollutant. These factors make it a limitation that each result presented cannot be an absolute reference and uniform all conditions in every car wash industry.

Future directions

Future research could have a significant impact on car wash wastewater treatment. Even though single and combination methods have been applied, weaknesses still need to be found, and the process is quite lengthy and takes a long time. There needs to be more than waste biodegradation to solve the problem. The treatment method that can potentially be applied to the car wash industry on a large scale is using microbes with a quick exponential development rate and a slow death rate. Bacterial genetic engineering has a role in this section. Although bacteria have been used for a long time, the mortality rate is also very significant, so it is less effective, and different treatment methods are needed to overcome this problem. However, the microbial engineering suggested for a single treatment method in this paper still requires considerable consideration. Considerations of sustainability, scale-up costs, and effectiveness need to be further identified.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests.

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