Pollutant removal from oily wastewater discharged from car washes through sedimentation–coagulation

H. Rubí, C. Fall and R. E. Ortega

ABSTRACT

Wastewater from car washes represents a potential problem for the sewer system due to its emulsified oils and suspended material. Treatment of wastewater discharged from four car washes was investigated by sedimentation and coagulation. The effect of the coagulants Servical P (aluminium hydroxychloride), Servican 50 (poly(diallyldimethylammonium chloride)), aluminium sulfate and ferric chloride was evaluated. The achieved removal using sedimentation was of 82%, 88% 73% and 51% for oils, total suspended solids, COD, and turbidity, respectively. In the treatment by coagulation we achieved average efficiencies nearly to 74% for COD removal, greater than 88% in the case of total suspended solids removal and 92% in the case of turbidity and except the performance of Servican 50 greater than 90% in oil removal. We concluded that the oil residual concentration and COD in the treated water allows pouring it in the sewer system complying with the limits of the Mexican rule NOM-002-ECOL-1996 and it is possible even its reuse, at least in the case of the chassis washing of cars.

Key words | car washes, coagulation, emulsified oil, sedimentation

INTRODUCTION

Continuous population growth in urban areas demands a great amount of public services including transportation, which in the city of Toluca, Mexico, are involves private and public cars as wells as busses. These means of transport require periodical maintenance and repairs. This demand of services is met by establishments that unfortunately generate a considerable amount of harmful waste. One finds that car washes have caused an environmental problem since they discharge, to a certain degree, oily wastewater to sewer system without means of control (Duke & Chung 1995). An alternative proposal to reduce the release of grease and oil present in wastewater of those establishments which are causing the problem would be to implement conventional oil-water separators to remove free oil; nevertheless, in many cases, the amount of water produced does not reach the required levels for its reuse or pouring it into the sewer system (López 2002; López & Fall 2004; Fall et al. 2007).

The difficulty of separating the remainder oil from wastewater discharged from car washes is due to the fact that they are found as emulsified oil. This is not a new problem and it has already been identified by many different authors in areas such as processing of non-ferrous metals (Lissant 1983), iron and steel industry (Benito et al. 1999), and effluent of refineries (Moursy & Abo 1982), to name a few. Panpanit et al. (2000) report that by using nanofiltration and ultrafiltration membranes in treatment of synthetic water, that simulates being oily wastewater generated in car washes, it is possible to recycle the obtained water, reducing the amount of fresh water needed for this activity.

Several mechanical processes have been used to try to remove oil in emulsion, among which include filtration, filtration adsorption, filtration coalescence and membrane processes. The electric methods consider electroflotation, electrocoalescence and electroe coagulation. Finally, chemical processes have devised the addition of
a coagulating or flocculating agent that favors the 
formation of aggregates with drops of oil dispersed so 
that they can be removed mechanically (Benito et al. 1998).

Many car washes in city of Toluca, Mexico are not 
formally established which makes it difficult to introduce 
sophisticated and costly treatment systems. Accordingly, 
the main objective of this work is to evaluate the pollutants 
removal from wastewater of these establishments, utilizing 
both simple and cost-effective processes such as sediment-
tation and coagulation in order to determine if the treated 
water reaches the established limits by Mexican rules for 
itself disposal into the sewer system. Likewise, a comparison 
of coagulants performance in relation to the yield and 
removal efficiency was made to choose the most advisable 
for the treatment.

MATERIALS AND METHODS

Experimental design

For the present work, we first characterized the wastewater 
from car washes. Afterwards, we evaluated the removal by 
sedimentation for 30 minutes and finally we evaluated the 
removal obtained by coagulation. We selected four car 
washes called A, B, C and D. Each one has its own kind of 
vehicles and washing techniques. A well known difference 
among them is that carwashes C and D wash trucks and 
buses, in the former predominantly trucks, in the latter buses. 
On the other hand, in carwashes A and B compact and 
subcompact vehicles as well as light trucks are washed. These 
four establishments were selected according to the willing-
ness of owners and managers to cooperate and budget limits.

Characterization of wastewater discharged 
by car washes

In order to determine the characteristics of raw effluents 
before and after sedimentation, composite samples were 
taken at the outflow streams to collect an approximated 
volume of 80 L. After applying an agitation to collected 
water, samples were taken for parameter determination 
of total chemical oxygen demand (CODT) and soluble 
chemical oxygen demand (CODS) through oxidation by 
the mixture of chromic-sulfuric acid in closed reflux and 
spectrophotometric reading, oils and greases (O&G), 
total solids (TS), suspended (TSS) and dissolved (TDS) by 
gravimetric method, turbidity through spectrophotometry, 
conductivity (Cond), pH with an electrochemical meter 
and Methylene Blue Active Substances (MBAS). Determin-
ations were performed according to the techniques 
described in APHA (1999).

Emulsified oil was determined with a susceptibility 
test by gravity separation according to a procedure deve-
developed by the American Petroleum Institute (API 1990). Raw 
effluent is separated by sedimentation for 30 minutes 
inside a separation funnel, the oily fraction is foamed 
and the deposit eliminated by decantation. The remanent 
oil and grease in the clarified water allows knowing the 
amount of oil in emulsion.

Coagulation of wastewater

Pretreated water by sedimentation was treated by coagu-
lation using a conventional jar test Phipps & Bird paddle-
stirred Standard Jar-tester with bottom illumination. 
Jars are square with graduations of 1 and 2 L. For the 
coagulation experiments, fast mixing occurred at 200 rpm 
during 2 minutes and slow mixing at 20 rpm during 15 
minutes. Afterwards, a lapse of 20 minutes was let to 
allow the sedimentation of formed flocs. The coagulants 
evaluated were two metallic salts ferric chloride (FeCl₃·6-
H₂O), aluminium sulfate (Al₂(SO₄)₃) and two polymers, 
one organic, poly(diallyldimethylammonium chloride) 
(Servican 50) with molecular weight of 5.1×10⁵ g/mol 
and charge density of 100%, and one inorganic, aluminium 
hydroxychloride (Servical P). For the dosage, salts were 
dissolved in distilled water to obtain concentrations of 
0.2 M and the polymers were diluted to form solutions 
at 5%. The proper volume of polymer or salt solution were 
added to pre-settled (during 30 minutes) wastewater in 
jars in order to reach the respective dose.

RESULTS AND DISCUSSION

Characterization of wash wastewaters

The characterization of wastewaters of the four car washes 
is depicted in Table 1. These waters are characterized
by high values of COD$_T$, O&G, TSS and turbidity. The values for the COD$_T$ fluctuated between 2,940 and 8,350 mg/l having a soluble fraction between 400 and 900 mg/l, O&G were found between 953 and 4,855 mg/l, turbidity fluctuated between 1,490 and 3,770 NTU. The ST concentration resulted between 3,994 and 7,329 mg/l, being predominant the fraction of suspended solids that oscillated between 3,082 and 5,778 mg/l. The high variability among parameters could be related to the type of vehicles that visit the different stations of service such as automobiles, light trucks, buses or trucks, the type of degreaser used such as diesel, commercial degreasers or domestic detergents as well as the washing practices used in each of them. Likewise, among the different parameters there was no apparent proportion, i.e. there is no linear relation between the amount of COD$_T$ and the content of O&G or the solids, even between the COD$_T$ and the COD$_S$ lacks in correlation. This latter was defined by light oils and tensoactive agents that were used. Without including the pH registered in car wash C (8.0), the slightly basic pH values fluctuating between 7.3 and 7.6 are within the typical ranges found in common municipal wastewater.

Samples of the four car washes contained MBAS concentrations ranged from 18 to 30 mg/l, with an average of 25.4 mg/l. This value was slightly higher than the upper limit (20 mg/l) indicated in APHA (1989), which corresponds to domestic wastewaters. With respect to the same sample, the concentrations obtained before and after sedimentation were very similar. In no case there was a difference greater than 1.5 mg/l.

Table 1: General characteristics of the wash waters coming from the four car washes in Toluca city before and after sedimentation for 30 minutes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>O&amp;G</td>
<td>1,401±307 mg/l</td>
<td>2,877±173 mg/l</td>
<td>4,855±477 mg/l</td>
<td>1,832±411 mg/l</td>
</tr>
<tr>
<td>COD$_T$</td>
<td>4,103±1,050 mg/l</td>
<td>4,585±770 mg/l</td>
<td>8,350±1,270 mg/l</td>
<td>2,940±1,340 mg/l</td>
</tr>
<tr>
<td>COD$_S$</td>
<td>780±599 mg/l</td>
<td>430±390 mg/l</td>
<td>900±600 mg/l</td>
<td>400±390 mg/l</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1,590±790 NTU</td>
<td>1,920±570 NTU</td>
<td>3,770±1,420 NTU</td>
<td>1,500±1,180 NTU</td>
</tr>
<tr>
<td>ST</td>
<td>4,814±1,232 mg/l</td>
<td>7,015±1,328 mg/l</td>
<td>7,329±982 mg/l</td>
<td>4,420±945 mg/l</td>
</tr>
<tr>
<td>TSS</td>
<td>3,620±533 mg/l</td>
<td>5,778±250 mg/l</td>
<td>5,460±460 mg/l</td>
<td>3,388±632 mg/l</td>
</tr>
<tr>
<td>TDS</td>
<td>1,194±699 mg/l</td>
<td>1,237±1,078 mg/l</td>
<td>1,869±522 mg/l</td>
<td>1,032±313 mg/l</td>
</tr>
<tr>
<td>VDS</td>
<td>406±216 mg/l</td>
<td>695±468 mg/l</td>
<td>768±159 mg/l</td>
<td>372±186 mg/l</td>
</tr>
<tr>
<td>MBAS</td>
<td>25±24.3 mg/l</td>
<td>18±19 mg/l</td>
<td>28.7±30 mg/l</td>
<td>29.4±28.5 mg/l</td>
</tr>
</tbody>
</table>

Comment

In the case of water treatment by coagulation a similar behavior was observed. After the treatment, MBAS concentrations in water discharged by the car wash A remained at ± 1.5 mg/l compared to the initial concentration ($C_i$) equal to 24.3 mg/l. Similarly, car wash B showed concentrations between ± 1.5 mg/l with $C_i$ = 19 mg/l, car wash C between ± 2 mg/l with $C_i$ = 30 mg/l and car wash D between ± 1.8 mg/l with $C_i$ = 28.5 mg/l. For this reason, the concentrations were not initially considered in the article.

For comparison purposes, Fall et al. (2007) reported concentrations for contaminants between 404–2,876 mg/l, 897–7,814 mg/l, 6–36 mg/l, 728–4,887 mg/l and 905–2,442 mg/l in G&A, COD$_T$, MBAS, TSS and TDS, respectively, these results obtained from nine car washes offer “complete service”, called thus because, like in this investigation, the car washes perform the washing of body, motor and chassis. The concentration obtained of G&A, COD$_T$ y TSS were lower more likely because they came from a greater number of car washes where compact and subcompact vehicles are washed.

Sedimentation after 30 minutes

As part of the initial process of depuration we considered the separation through gravity in static conditions, removal percentages that comprise the four car washes are shown in Table 2. From the table, it is clear that the highest removal correspond to 88%, followed of 82%
in TSS and O&G, respectively. This is expected because the action of gravity during sedimentation process cause that a fraction of TSS was deposited at bottom and that the “free” oils emerged towards the surface. The concentration decrease of O&G and TSS, also entailed a reduction of CODT and turbidity, which reached an efficiency, in average, of 72.8% and 50.8%, respectively.

In spite of the significant removal of O&G, the maximum acceptable concentration (100 mg/l) for disposal into the sewer system established by the Mexican rule NOM-002-ECOL-1996 (DOF 1998) was not reached. This is explained by the presence of emulsified oils that prevent a simple separation by gravity. There was a significant reduction of TDS in sedimentation assays (45% on average, Table 2) that can be explained as a partial coprecipitation of its volatile fraction (hydrocarbons) with the suspended solids that are present in water treated. This assertion was in accordance with the resulting mean reduction of the volatile fraction in dissolved solids, from 42% in the raw wastewaters, to 41% in settled waters. This phenomenon had already been noticed previously during the treatment of oily wastewaters with a conventional oil-water separator (Fall et al. 2007). The sedimentation tests showed high removal consistency regarding TSS and O&G as it indicates the coefficient of variation equal to 7% and 11%, respectively.

### Coagulation efficiency

In order to achieve acceptable levels of pollution in water, this study proposed the coagulation using ferric chloride, aluminium sulfate and the polymers Servical P and Servican 50 in wastewater discharged from car washes. Figure 1 shows the effect of coagulant dose on the O&G, CODT, TSS and turbidity removal for car wash A. The profile for the different parameters was similar for all car washes; with low dosages undergoes a sudden decrease, then they maintain a narrow interval and afterwards, mainly in the case of metallic salts, they exhibits a restabilization of the suspension with greater dosages, thus increasing the concentrations of parameters in water. A marked difference in relation to the described behavior happened with the application of Servican 50 to waters of car wash C (not shown). At a dose of 175 mg/l, this coagulant was seen to remove 21% of the initial turbidity, after was observed a decrease to 13% with a dose of 275 mg/l and finally, the removal was 40% with a dose of 425 mg/l. Generally, to reach the maximum removal efficiency, the required dosages of polymers were lower than the dosages of metallic salts in each run. Additionally, the required doses to obtain a maximum removal were different according to the parameter. For example, in order to achieve a minimal residual concentration, a dose of 275 mg/l was required for TSS, while a dose of 325 mg/l was required for O&G with Servical P or Servican 50.

For comparison purposes, Ghaly et al. (2006) carried out a coagulation study of grease filter washwater. Aluminium sulfate, ferric chloride and ferric sulfate were found to remove 89.6%, 88.8% and 27.8%, of the original total solids at dosages of 2,000 mg/l, 1,000 mg/l and 1,000 mg/l, respectively. The required doses were higher because the initial total solids concentration (22,775 mg/l) also was greater. Ikeda et al. (2002) reported that the removal efficiency changed according to the initial concentration of TSS, CODT and O&G contained in wastewater from poultry slaughterhouse. At 300 mg/l of aluminium sulfate and 0.8 mg/l of natural polyelectrolytes, the O&G removal efficiency was found between 90% and 95%, whereas the removal efficiency ranged from 70 to 85% using only 300 mg/l of aluminium sulfate when initial O&G concentration was 1,746 mg/l. Aluminium sulfate or the mixture of aluminium sulfate and natural polyelectrolytes reduced the CODT of the wastewater by 86%. Finally, the TSS removal efficiency was found, in average, between 90 and 95% with the mixture of aluminium sulfate and natural polyelectrolytes, while the removal efficiency obtained using

### Table 2 | Removal efficiencies obtained after treating wash wastewaters by sedimentation for 30 minutes

<table>
<thead>
<tr>
<th></th>
<th>O&amp;G (%)</th>
<th>CODT (%)</th>
<th>CODs (%)</th>
<th>Turbidity (%)</th>
<th>ST (%)</th>
<th>TSS (%)</th>
<th>TDS (%)</th>
<th>VDS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>82</td>
<td>73</td>
<td>18</td>
<td>51</td>
<td>79</td>
<td>88</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>Minimum</td>
<td>69</td>
<td>54</td>
<td>3</td>
<td>21</td>
<td>71</td>
<td>81</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>Maximum</td>
<td>94</td>
<td>85</td>
<td>33</td>
<td>70</td>
<td>87</td>
<td>96</td>
<td>72</td>
<td>79</td>
</tr>
<tr>
<td>S.D.</td>
<td>9</td>
<td>12</td>
<td>12</td>
<td>19</td>
<td>6</td>
<td>6</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>C. V.</td>
<td>11</td>
<td>16</td>
<td>67</td>
<td>37</td>
<td>8</td>
<td>7</td>
<td>60</td>
<td>44</td>
</tr>
</tbody>
</table>

S.D.: Standard deviation, C. V.: Coefficient of variation (S.D. × 100/Mean).
aluminium sulfate ranged from 70 to 75%. The removal efficiencies obtained are comparable to the values reported in these investigations.

In order to illustrate the efficiency that was obtained in the coagulation treatment of waters discharged from car washes, Figure 2 shows the removal percentages that were reached with the optimum dose of each of the coagulants. The removal reached for O&G was superior to 70% as observed in Figure 2, being Servican 50 the less efficient coagulant in all cases. In contrast, the highest efficiency does not correspond to one single coagulant for the different car washes, while the ferric chloride was efficient for car washes A and C, for car wash B was Servical P and in the case of car wash D aluminium sulfate was slightly better of all. In any case, the residual average values were registered nearly to 28 mg/l, except in the case of Servican 50 that reported an average of 69 mg/l. These residual oil concentrations are already below the limit (100 mg/l) set by the Mexican rule NOM-002-ECOL-1996 (DOF 1998).

With respect to the COD, the minimum removal was 61% and the maximal was 83% corresponding to Servican 50 both values. The behavior for this parameter was diverse with the coagulants in all waters that were treated, as shown in Figure 2. The residual average concentration fluctuated between 247 and 266 mg/l, which indicate the presence of non-oxidizable compounds that cannot be eliminated by coagulation process, being common to waters discharged by car washes under study. Regarding turbidity, the general removal efficiency is at least 90%. For example, at a dose between 325 mg/l and 375 mg/l, Servical P was found to reduce, in average, 94% of the original turbidity. Similarly, the metallic salts showed a great performance although with dosages slightly more concentrated. The residual average values were found between 38 and 64 NTU, which correspond to Servical P and Servican 50, respectively.

Figure 1 | Residual values of O&G, COD, turbidity and TSS after coagulation treatment with ferric chloride, aluminium sulfate, Servical P and Servican 50 in wastewater from car wash A.
Likewise, a high reduction greater than 90% was obtained in TSS concentration with water treatment from car washes A, C and D, while car wash B reported slightly lower values. Ferric chloride was found to be the coagulant with most consistency regarding the TSS removal efficiency achieved for water coming from the four car washes. Additionally, the residual concentrations comply with the requirements for basic pollutants included in the Mexican rule NOM-001-ECOL-1996 (DOF 1997) except some sections in “urban public use (40 mg/l monthly mean) and protection to the aquatic life (40 mg/l monthly mean)”.

Effect on the pH in coagulation treatment

The pH variation associated with the different doses of coagulants applied to wash wastewaters from the car washes A, B and D were similar, whereas in the case of car wash C they differ a bit. Figure 3 shows the pH values registered for car wash A (continuous line) and car wash C (dotted line). Servican 50 produced a slight increase with respect to original pH of the raw wastewater (7.35), which was registered up to a value of 8 for the car wash A. Also Servical P increases slightly the pH having a maximum value of 7.7.
On the other hand, the metallic salts produced a decrease in this parameter, even though more evident changes took place in water from car wash A reaching a value of 4.6 with aluminium sulfate and 3.2 with ferric chloride. In this case, low pH values can be attributed to both Fe$^{3+}$ and Al$^{3+}$ ions are Lewis acids that reacting with OH ions of aqueous solution to produce Fe(OH)$_3$ or Al(OH)$_3$ (Letterman et al. 1999; Song et al. 2004). The pH decrease would demand the supply of a substance in order to neutralize this acidity in the treated water before pouring it into the sewer system. Another option involves pre-adjust pH to obtain a neutral or slightly lower pH values in the effluent.

Ghaly et al. (2006) also noticed the decrease in pH with the addition of metallic salts. Aluminium sulfate and ferrous sulfate decrease the pH value from 9.5 to 3.9 and 5.1, respectively, with an increase in coagulant concentration from 1,000 mg/l to 3,000 mg/l. Moreover, ferric chloride produced pH values of 2.2 and 3.8 with the same dosages. Song et al. (2004) reported a change in pH values of tannery wastewater treated by coagulation. At 100 mg/l ferric chloride or aluminium sulfate, the pH of the wastewater decreased to 8.9 when initially had a value of 9.21. When the dosages of the coagulants oscillated between 500 and 900 mg/l, aluminium sulfate and ferric chloride produced pH values of 6.57 and 5.72, respectively. With greater dosages the pH gradually decreased to 5.1 and 4.5 at a dose of 2,000 mg/l of aluminium sulfate or ferric chloride, respectively. Similarly, in our study the lower pH values occurred with the use of ferric chloride.

Effect of solution pH on coagulation

Comment

The effect of solution pH on the removal of COD$_T$ and turbidity also was evaluated. Wastewater discharged from car wash A was used for coagulation treatment with ferric chloride and aluminium sulfate. The coagulant doses that allowed obtaining more clarified water were used for further reduce the COD$_T$ and turbidity levels. For this purpose, the pH was adjusted to different basic and acid values.

The effect of solution pH on the removal of COD$_T$ and turbidity are shown in Figure 4. When the pH of raw water was not changed, ferric chloride achieved a maximum turbidity removal of 94% and COD$_T$ of 77%. However, the other pH values produced lower efficiencies. For example, the turbidity and COD$_T$ were reduced 87% and 63% with a solution pH of 9.9.

On the other hand, at pH 6.5, aluminium sulfate produced removal efficiencies of 98.8% and 77% regarding turbidity and COD$_T$, respectively. Similarly, at pH 7.6, this coagulant removed 98% and 74% of these same parameters. These removal efficiencies were higher compared with those obtained without changing the initial pH (7.9), which were 88% and 71%. Al-Shamrani et al. (2002) found that aluminium sulfate reached high petroleum oil removal percentages when the solution pH was 7, but the highest removal occurred at pH 8 (up to 98%). Additionally, at pH 7, ferric sulfate removed 99.94% of original oil concentration. In our study, aluminium sulfate exhibited better performance in pH interval close to that reported by those authors, whereas ferric chloride showed the best performance at pH values more distant.

Volume of sludge

Due to phases separation once the sedimentation took place we evaluated the volume of sludge produced since it will be necessary to handle in a proper manner this waste material. Figure 5 depicts the average volumes in mL/L obtained in water treatment of four car washes under study.

It is clear that the amount of sludge produced is similar for car washes A, B, and D, being for C markedly greater with values of 190 mL/L, 185 mL/L and 170 mL/L for the

![Figure 3](https://iwaponline.com/wst/article-pdf/59/12/2359/435427/2359.pdf)
coagulants ferric chloride, aluminium sulfate and Servical P, respectively. The sludge volume produced by these coagulants was very similar for all car washes evaluated. In contrast, Servican 50 produced nearly a half of the sludge volume in comparison with the other three coagulants.

Comment: residual concentration of the coagulants

It is not very common that the metallic ions or their counterions tend to be measured in coagulation treatment with sulfate or chloride salts. However, Aguilar et al. (2005) determined the concentration of iron and aluminium in slaughterhouse wastewater before and after coagulation-flocculation treatment by means of inductively coupled plasma. An iron concentration of 4.13 mg/l and aluminium of 0.10 mg/l was found in raw wastewater. After treatment with doses between 100 and 1,000 mg/l, the residual concentration ranged from 0.24 to 0.98 mg/l for iron and from 0.093 to 0.9 mg/l for aluminium. One can see that these concentrations are negligible compared with the used doses. This demonstrates that it is not so important to determine the concentration of metallic ions or their counterions when using metallic salts as coagulants.

Coagulation mechanism

Coagulants can act by means of four different mechanisms to remove the matter that is found suspended in the aqueous phase (Metcalf & Eddy Inc. 2002). They include the following: electric double layer compression, surface charge neutralization, enmeshment in a precipitate which has been termed “sweep floc” and interparticle bridging. The first three can be carried out with metallic salts, while the polymers form bridges between particles when they are absorbed in the reactive groups of the polymeric chain (Letterman et al. 1999). When a cationic polymer is found acting on suspended matter with a negative charge, then a neutralization of this charge would also occur apart from the formation of inter-particle bridges.

Presumably, in this study the metallic salts acted in either one of the following two ways: 1. By destabilizing a greater amount of the suspended solids contained in the wash wastewaters, which at the same time capture the oil droplets on their way to precipitation, or 2. The suspended...
solids absorbed some of the oil droplets functioning as nuclei or centres, causing the mechanism of sweep floc during coagulation. This proposal is analogous to one which derived from an investigation on the coagulation of highly concentrated oily wastewater with the use of aluminium sulfate combined with pulverized clay (Zunan et al. 1995).

**Global efficiency**

Regarding the global process, Figure 6 shows the removal efficiency achieved with the gravity separation and coagulation treatment. One can see that combining these processes, a minimal average removal of 97.7%, 91.5%, 98.9% and 94.5% in O&G, CODT, TSS and turbidity, respectively, was reached.

It is possible to note that the great efficiency obtained with separation-coagulation treatment would allow disposing water to the sewerage system, in accordance with the established limits (O&G < 100 mg/l) by the Mexican rule NOM-002-ECOL-1996 (DOF 1998), or even better, its reuse in the washing of automobiles’ chassis.

**CONCLUSIONS**

Wastewater that results from washing of automobiles presents variable polluting characteristics, reaching high...
levels for the parameters of O&G, CODₚ, CODₜ, TSS, TDS and turbidity (4,855 mg/l, 8,350 mg/l, 990 mg/l, 5,778 mg/l, 1,869 mg/l and 3,770 NTU). The average residual oil concentration (331 mg/l) reached after sedimentation treatment of the raw wastewater showed that the difficulty to reach concentrations below 100 mg/l, as dictates the Mexican rule (NOM-002-ECOL-1996), is due to the fact that this process is unable to remove emulsified oils.

Regarding coagulant agents evaluated aluminium sulfate, ferric chloride, Servical P and Servican 50 it was found that the last one produced a lower volume of sludge, however, it was inconsistent in its efficiency presenting in some cases the lowest removal percentage. The rest of the coagulants showed differences that are not very significant regarding its performance, but Servical P required lesser dosages to reach high removal efficiencies of O&G, CODₚ, TSS and turbidity (92%, 74%, 95% y 96.5%). Likewise, this coagulant produces a slight variation in the pH of treated water so that it does not require an additional treatment in order to adjust this parameter as it would be in the case of metallic salts. Based on this it is considered that, for the studied cases, the most advisable coagulant is Servical P.

Aluminium sulfate was able to increase turbidity and CODₚ removal efficiencies in the pH interval between 6.5 and 7.6. The removal efficiency gained was around 10% and 4.5% for turbidity and CODₚ, respectively, in comparison with a pH value in raw wastewater that was not changed. In contrast, ferric chloride did not increase the removal efficiency when pH was changed.

The combined process sedimentation–coagulation produced waters with O&G levels below 100 mg/l and residual average concentrations of CODₚ between 247 mg/l and 266 mg/l, which allow reused it, at least in the case of the chassis washing of automobiles. This would reduce the requirements of fresh water in the car washes, or at least it would be possible to pour it in the municipal sewerage system without constituting a significant risk of water contamination, or causing problems related to it.

**ACKNOWLEDGEMENTS**

The authors would like to acknowledge the employees Guillermina Sánchez Nahuacatl, Elizabeth Plata García, Luis A. Cruz Hernández and Eduardo Chávez Villalobos of the Institute of Engineering, National Autonomous University of Mexico, by provisioning articles for this research as well as to the carwash shop owners for their help and cooperation during collection of wash wastewater.

**REFERENCES**


