Treatment of wastewater contaminated with detergents and mineral oils using effective and scalable technology

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ABSTRACT

In this work, effective, cheap and scalable methodology is introduced to treat oily wastewater. The water produced from car-wash processes was utilized as a model because it has various pollutants – oil, lubricants, detergents, solid particles, etc. The results showed that the turbidity and chemical oxygen demand (COD) values dramatically decrease by using the proposed treatment process, which consists of coagulation, flocculation, sand filtration, and oxidation followed by sand as well as activated carbon filtration. Moreover, the operating conditions were optimized. Without adjustment of the pH value of car-wash wastewater, it was found that 200 ppm of ferric chloride, as a coagulant, and 1 ppm of potassium permanganate, as an oxidant, are the optimum doses. The COD and turbidity values of the final treated wastewater were reduced by almost 88 and 100%, respectively. A prototype with 15 L capacity was designed and fabricated to investigate the scaling up and continuity of the proposed treatment strategy. The results were very promising and indicated that the introduced methodology can be industrially applied.

Key words | car-wash wastewater, coagulation, COD, oily water, wastewater treatment

INTRODUCTION

Freshwater is a vital natural resource that will continue to be renewable as long as it is well managed. Preventing pollution from domestic, industrial, and agro-industrial activities is important to ensure the sustainability of local development. Wastewaters containing oil-in-water (O/W) emulsions are generated in many industrial processes, such as those in the metallurgical, petroleum refining, petrochemical, food, leather and metal-finishing industries and car-wash stations (McVicar et al. 2012). Sources of such wastewaters include cooling lubricants in metal-working processes (metal rolling, metal cutting, and wire drawing), scouring baths for cleaning metal parts, and waste coming out from the car-washing process. Among those various sources, the water obtained from the car-wash centers can be considered the most polluted as it contains various kinds of impurities, such as sand and solid particles, free oil, grease, oil/water emulsion, carbon, asphalt, salts, surfactants and organic matter, which may deteriorate the treatment facilities as well as the wear network itself if it is discharged directly into a municipal sewage treatment plant without pretreatment. Therefore, in this study, the car-wash water was chosen to model.

Although an average of 100 L of water is generated per car, and at least about 10 m³ of water is discharged from a car-wash station per day, there is still no applicable system for car-wash wastewater treatment. Due to the amount of the water and complexity of the water quality, reuse of car-wash water is an important subject specifically in the countries with a shortage of freshwater sources (Zaneti et al. 2011a; Lau et al. 2012). Furthermore, small space and highly efficient treatment processes are required due to the limited space of car-wash stations and the required high water quality for car-washing aspects (Bhatti et al. 2011; Zaneti et al. 2011b). For such oily wastewater there are mainly three different techniques employed. These include primary, secondary, and tertiary treatments. The primary treatment is used to remove free oils, including tramp oils from the emulsion or suspension. The secondary treatment is needed to break the oil/water emulsion and to remove the dispersed oil. Common techniques used in the secondary treatment processes are chemical treatment, flotation, filter coalescence, and membrane filtration (microfiltration and ultrafiltration) (Johnson Jr & Sudduth 1989; Mueller et al. 1997; Gu & Chiang 1999; Rubio et al. 2002). Tertiary
treatment is used to remove finely dispersed, emulsified, and soluble oil fractions (Lipp et al. 1988). Moreover, the levels of dissolved organic and inorganic compounds can be decreased to acceptable limits by using techniques such as evaporation, reverse osmosis (RO) membrane, and active carbon adsorption (Bhatti et al. 2011).

Many reports have been introduced to purify the car-wash wastewaters using different treatment techniques. For instance, based on the primary treatment strategy, Al-Odwani et al. (2007) studied recycling of the car-wash water in Kuwait using a system consisting of a settling tank (separation tank), oil/water separator, primary product tank, and ending by a filtration system. Comparatively, the researchers focused on the secondary techniques; for example, Bhatti et al. (2011) studied chemical oxidation of car-wash wastewater as an effort to decrease water pollution, Rubio & Zaneti (2009) studied car-wash wastewater recycling using a new flocculation-column flotation (FCF) method followed by sand filtration and chlorination. However, Lu Yan et al. (2009) used a combined system consisting of both primary and secondary treatment techniques to treat oily wastewater of Daqing oil field. Based on tertiary treatment, Mysore et al. (2005) studied many materials to remove oil from wastewaters through including the using of activated carbon, bentonite, peat, sand, coal, fiberglass, polypropylene, amberlite, organoclay, and attapulgite.

Based on the above review it seems that this topic needs more investigation to get a reliable and systematic treatment method to be easily applied in developing countries without using complicated high technology, methods or devices. The aim of this study is to provide a new, scalable, cheap as well as simple treatment system for car-wash wastewater treatment based on combined processes from the three different aforementioned techniques.

**MATERIALS AND METHODS**

**Materials**

Analytical grade chemicals were used for all experiments except ferric chloride, which was commercial grade with 40% concentration. All chemicals were purchased from Al Nasr Company for Coke & Chemicals. Coconut-activated carbon was the product of Jacobi Carbons AB Co., Kalmar, Sweden. Actual car-wash samples were collected from Shalaby car-wash station at Elminia city, Egypt.

**Methods**

**Treatability study**

This step covers studying the possible pathways for treating the car-wash wastewater through selecting the type of coagulant and its optimum dose as well as other unit operations needed for the whole treatment conditions. The output of this step will be used as design criteria in the next step, which covers the design and fabrication of a prototype for a car-wash treatment unit. The treatability study includes the following activities and experiments.

**Selecting the optimum coagulant.** Coagulation/flocculation tests were conducted using a conventional jar test apparatus. For each trial, about 100–500 mL samples of car-wash wastewater were used. The pH was measured using a digital pH meter (HANNA, HI 98129, Padova, Italy) and adjusted to the desired value using hydrochloric acid, sodium hydroxide, or lime. Coagulant was added and jar tests begun with rapid mixing at 500 rpm for 1 min, followed by slow agitation of 33 rpm for 10 min. The flocs were formed then allowed to settle for 30 min. Then, the turbidity of the supernatant was measured using the turbidity meter bench photometers (HANNA, LP 2000, Padova, Italy). All the experiments were carried out at ambient temperature (25°C).

**Effect of the filtration step on the treatment process.** To study the effect of filtration on the treatment process, the above-mentioned steps concerning the coagulation using different coagulants were performed. Then a sand filter composed of a plastic column with 7 cm inner diameter and about 12 cm length, filled with different grades of sand in the range of about 0.6–1.2 mm particle size, was used to filtrate the supernatant coming out from the coagulation process. The turbidity and chemical oxygen demand (COD) of filtrated samples were measured and recorded. The COD was measured using multiparameter bench photometers (HANNA, C99, Padova, Italy) following the manufacturer’s instructions. All the experiments were carried out at ambient temperature (25°C).

**Effect of the oxidation followed by sand filtration steps on treatment process.** To study the effect of oxidation on the treatment process, the coagulation and filtration steps were followed as described above, then the filtrated water was subjected to an oxidation step. Potassium permanganate was used to oxidize the organic pollutant causing taste
and odor (Lalezary et al. 1986). Doses of potassium permanganate used to treat taste and odor-causing compounds were in the range 0.25–20 mg/L (USEPA 1999). It was reported that potassium permanganate has fairly strong oxidizing powers when it is used at standard 1–2.5 mg/L treatment dosages (Williams 2009). Based on that, 1 mg/L as the dose for the oxidation step was used, by adding the potassium permanganate and mixing for 5 min. After the oxidation step, a final sand filtration process was applied to remove any precipitant that may have resulted from the oxidation step. Then the turbidity and COD of the oxidized samples were measured and recorded. All the experiments were carried out at ambient temperature (25°C).

**Adsorption using active carbon.** This experiment was carried out as an optional step if the treated water was colored or showed a bad smell. In this case the water coming out from the final sand filtration step (after the oxidation step) is passed through a column having 7 cm inner diameter with about 12 cm length filled with coconut-activated carbon. All the experiments were carried out at ambient temperature (25°C).

Figure 1 shows a block flow diagram summarizing the final treatment process.

**Design of a car-wash treatment prototype unit**

A prototype with 15 L/hr capacity was designed and fabricated based on the obtained results from the treatability study. Figure 2 shows the process flow diagram for the proposed treatment system. The design was based on the operating conditions obtained in the treatability study. These include the retention times needed for coagulation, flocculation, settling, and oxidation, and also the filtration rate in L/min needed for the sand filtration. Table 1 summarizes the design equations used for each unit involved in the treatment process.

**RESULTS AND DISCUSSION**

**Wastewater analysis**

The collected raw car-wash wastewater samples were firstly analyzed to evaluate their characteristics. Table 2 shows the water analysis, including the COD, pH, and the turbidity values.

**Results of the treatability study**

**Coagulant selection**

The first step in the treatability study was selecting the most appropriate coagulant and specifying the optimum dose needed. During coagulation, suspended particles are destabilized to promote their agglomeration producing larger particles that can be readily removed during subsequent treatment processes. In many cases, dissolved organic substances may be absorbed on the surface of suspended solids particles and are therefore partially removed as well (Tchobanoglous et al. 2005; Cantwell & Hofmann 2011). In order to select the most effective coagulant for our present car-wash wastewater treatment system, different parameters were investigated – type of coagulant, dose, pH, and finally the economic feasibility.

The comparison between the different coagulants was based mainly on the reduction of the turbidity value of the treated samples compared with the original wastewater. Three different coagulants have been tested – alum, poly aluminum chloride (PAC), and ferric chloride. In order to

![Figure 1](https://iwa.silverchair.com/wst/article-pdf/68/5/974/472736/974.pdf)
investigate the most appropriate coagulants, under various concentrations at different pH, several experiments were conducted under different conditions. Table 3 shows the effect of the coagulation process on the turbidity of the treated car-wash wastewater using various coagulant doses at 100, 150, and 200 ppm. The results showed that the three tested coagulants can be used in this process. The effect of pH on the coagulation process is also clear in the
tabulated results. As shown in the table, the coagulation process is pH-dependent for the same coagulant at the same dose. The results showed that the optimum pH for alum, PAC, and ferric chloride was 11, 9, and 4, respectively. Moreover, the turbidity was reduced by 98.8, 98.4, and 97.9% using alum, PAC, and ferric chloride, respectively, under the optimum pH condition at doses of 150, 200, and 200 ppm, respectively. An important and interesting conclusion can be drawn from these results that the difference between the reductions in turbidity, in the case of using PAC and ferric chloride, were insignificant at their optimum pH (pH 9 and 4) and pH 7. Based on that, PAC and ferric chloride could be used directly for car-wash wastewater without the need for pH adjustment, since the average value of pH of the raw wastewater is close to 7 (in most cases between 7 and 7.4).

**Economic evaluation of the tested coagulant**

Based on the obtained results, the three coagulants alum, PAC, and ferric chloride could be used in the treatment process; however, the overall treatment cost could be a key factor in the selection process. Table 4 shows the coagulation cost calculated according to the obtained optimum dose and pH values. The results show that the cost of using PAC and ferric chloride is the same. However, ferric chloride has the advantage of being locally manufactured and available in the Egyptian markets. Accordingly, ferric chloride was chosen to be the optimum candidate for the coagulation process.

**Influence of filtration after coagulation on the treatment process**

In order to investigate the effectiveness of sand filtration after the coagulation process, one set of experiments was carried out using 200 ppm ferric chloride as coagulant without any pH adjustment. The turbidity and COD were used as indicators to show the effectiveness of the filtration process. The obtained results are shown in Table 5. The results showed that the coagulation followed by sand filtration resulted in a 100% reduction in the turbidity and about 85% reduction in the initial turbidity and COD values, respectively.

**Effectiveness of the oxidation step**

In order to investigate the effectiveness of the oxidation step, after the filtration process, experimental studies were conducted. The turbidity and COD were used as indicating parameters to evaluate the oxidation step. The obtained results are shown in Table 5. The oxidized water was filtered using sand as described in the methods section. The results showed that this process results in about 95% reduction in the initial COD value.

**Prototype unit, testing, and running**

According to obtained data from the experimental phase, the dimensions needed for the prototype design were calculated.
Table 6 shows the dimensions of the prototype based on the design equation mentioned in the methods section. Figure 3 shows the layout of the prototype and pictures from different views of the unit. The process starts with feeding the car-wash wastewater through a submersible pump (P1) to a rapid mixing tank installed with a rapid mixer at 300 rpm for 1–2 min residence time. Then the wastewater is passed to the flocculator installed with a slow mixer (about 33 rpm) through a weir. The volume of the flocculation tank was calculated to allow for 10 min flocculation (as it was the optimum flocculation time). Then the flocs were settling in a settling tank for almost 30 min residence time. The supernatant was allowed to flow to a collecting tank, at which a submersible pump (P2) was used to pump the clarified water to a pressure sand filter. The filtrated wastewater was then reacted for about 5–10 min in an oxidation tank at which 1 ppm of potassium permanganate was added continuously. Then a submersible pump (P3) was utilized to transfer the oxidized water to another pressurized sand filter fluctuation tank. Finally a control valve was used to allow the treated water to go directly for discharge or to pass through an activated carbon filter (if the samples contained any color or had a bad smell). Figure 4 shows snapshots during the continuous running of the system.

Based on the described process, different complete runs were performed in a continuous mode. Table 7 shows the obtained average measured values of both the COD of the raw and treated car-wash wastewater results. The average reduction in the COD was about 88%, and almost 100% reduction in the turbidity was obtained. After 2 hr of

Table 6 | The dimensions of the prototype

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L (cm)</th>
<th>W (cm)</th>
<th>H (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coagulation tank</td>
<td>6.6</td>
<td>5.4</td>
<td>6.6</td>
</tr>
<tr>
<td>Flocculator tank</td>
<td>10.8</td>
<td>8</td>
<td>16.8</td>
</tr>
<tr>
<td>Settler</td>
<td>32</td>
<td>36</td>
<td>16</td>
</tr>
<tr>
<td>Filter</td>
<td>13</td>
<td>D 5.5 cm</td>
<td></td>
</tr>
<tr>
<td>Oxidation tank</td>
<td>10</td>
<td>8.4</td>
<td>11</td>
</tr>
</tbody>
</table>

N.B. All dimensions were multiplied by 1.2 considering 20% as a safety factor. □ - Calculated; □ - Actual Fabricated.

Table 5 | The filtration and oxidation effectiveness using ferric chloride as coagulant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>After filtration</th>
<th>After oxidation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity NTU</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>COD ppm</td>
<td>154</td>
<td>72</td>
</tr>
</tbody>
</table>

Figure 3 | Layout of the prototype, and pictures from different views of the unit.
continuous running, the run was stopped and the sludge resulting was collected, dried, and weighed. The amount of the produced sludge was about 0.827 gm/L.

**CONCLUSION**

An integrated treatment process for car-wash wastewater consisting of coagulation, flocculation, settling, sand filtration, oxidation, and final sand filtration can be established to produce almost clear water from the wastewaters obtained from the car-wash stations. Parameters like COD and turbidity can be reduced up to about 88 and 100%, respectively. The present approach is cost-effective and requires less space. Moreover, there is no need for pH adjustment prior to the treatment when using 200 ppm of ferric chloride as a coagulant and 1 ppm of potassium permanganate as an oxidant. Interestingly, scaling up is applicable for the proposed treatment process. Overall, this study opens a new avenue to treat and reuse the waste water, not only in the car-wash stations but also in any plant producing oily waste waters.

**REFERENCES**


First received 21 December 2012; accepted in revised form 18 March 2013