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Handling of used lubricating oil in Tabasco, Mexico

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Abstract
The improper handling of used lubricating oil (ULO) in Tabasco, Mexico, and worldwide is a serious problem posing a high risk of soil and water pollution. Therefore, this study evaluated the handling of ULO in 10 municipalities in the state of Tabasco. Collection sites were chosen by simple random sampling. The ULO collected was assessed for solids, water, oil and density. The results show that small generators have the greatest potential to generate ULO in Tabasco. Huimanguillo, Comalcalco and Cardenas were the municipalities with the highest ULO generation. The ULO with the highest quality for its low water and solids content was collected in Jalpa de Mendez, Comalcalco and Car Dealerships. 1,287 automotive repair shops were tested in the 10 municipalities that were included.

Keywords: collection; collection center; refining; comprehensive management.

Manejo de aceites lubricantes usados en Tabasco, México

Resumen
El mal manejo de los aceites lubricantes usados (ALU) en Tabasco, México, y en el mundo es un problema serio que genera un alto riesgo de contaminación de suelo y agua. Por lo anterior, en el presente estudio se evaluó el manejo que reciben los ALU en 10 municipios del estado de Tabasco. Los sitios de recolecta se eligieron mediante muestreo simple aleatorio. A los ALU colectados se les determinó el contenido de sólidos, agua, aceite y densidad. Por los resultados encontrados se concluye que el mayor potencial de generación de ALU en Tabasco se debe a los pequeños generadores. Los municipios con mayor generación de ALU fueron Huimanguillo, Comalcalco y Cárdenas. El ALU de mejor calidad por el bajo contenido de agua y sólidos, se colectó en Jalpa de Méndez, Comalcalco y Agencias Automotrices. Se cuantificó un total de 1,287 talleres automotrices en los 10 municipios evaluados.

P*alabras clave*: colección; centro de acopio; refinación; manejo integral.

1 Introduction

The handling of used lubricating oil (ULO) consists of its collection, transportation and final disposal [3]. There are three types of companies in charge of handling ULO in Mexico; according to [1], there are companies that collect and transport it, others that store it, and others that refine and co-process it. The latter include refined ULO in certain production chains in the state of Tabasco and a large part of Mexico [1].

ULO is hazardous waste, as it is toxic and flammable, and is produced in large quantities, mostly in clandestine automotive repair shops [1]. These types of repair shops are not registered in the registry of hazardous waste generators of Mexico Ministry of the Environment and Natural Resources (SEMARNAT) [1]. Apparently there is a lack of registration of this type of repair shop in some parts of the world, where there is an attempt to identify gaps in environmental policies, as ULO contains hazardous heavy metals such as lead (Pb), mercury (Hg), and organic substances persistent in the environment, which according to Ahmed et al. [2], have a high potential to pollute water sources and soils**.** ULO should be collected and recycled to avoid environmental pollution and preserve natural resources [3].

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The purpose of this study was to evaluate the handling and physical characteristics of used lubricating oil (ULO) during a four-month period in 10 municipalities in the state of Tabasco.

2 Materials and methods

2.1 Census of generators of used lubricating oils (ULOs) in 10 municipalities of Tabasco

10 municipalities were selected based on their location in the four regions comprising the state of Tabasco: Centro, Nacajuca and Jalpa de Mendez (Centro region), Cardenas, Comalcalco, Cunduacan, Paraiso and Huimanguillo (Chontalpa region), Macuspana (Pantanos region), and Teapa (Sierra region). Another selection criterion was the higher population density found in these municipalities [4].

Visits were made to urban areas to identify the location of automotive repair shops generating used lubricating oil (ULO). Collection routes were then mapped and at the same time, personnel from each selected repair shop as well as collection, transportation and final disposal companies located in the aforementioned municipalities were surveyed. The purpose of the survey was to prepare a census of the existing repair shops and based on this, to select five oil-generating automotive repair shops offering maintenance services in each municipality.

The selected automotive repair shops in each municipality were visited and the major oil activity in each of them was taken as a selection criterion (Table 1) and the ULO collected was measured and its physical properties were assessed. Mastrack software was used to track and locate the vehicles used to collect and transport the ULO. The database used in this work was created with the information obtained in the field (volume of collected ULO in liters).

2.2 Assessment of the oil's physical properties

A sample of 1 L of ULO was taken from each selected repair shop and a small generator was considered to be a repair shop that produces 400 L to 10,000 L annually [1] from each of the 10 municipalities visited between January and April 2019. The water, solids and oil content of each oil sample was determined using the API RP 13B2 method [18], and its density was determined using the ASTM-D854 method [17].

The four measured variables (water content, solids, oil and density) on the four oil collection dates were analyzed with multivariate statistics of principal component analysis (PCA) and hierarchical cluster analysis by the UPGMA method (Unweighted Pair Group Method with Arithmetic Averages), which standardizes the information of each variable to $\mu=0$ and $\sigma^2=1$, so that the measured variables are more proportional to the similarity estimate [6] of the Euclidean distance. Statistical analyses (Principal Components and Cluster) were performed with the SAS package [7].

3 Results

3.1 Repair shop census by study area

1,287 automotive repair shops (generators) were tested. The Central region has the largest number of ULO generators with 1,046 repair shops; of these, 985 (94.2%) are informal, as they are not registered with SEMARNAT, while the remaining 61 (5.8%) are formally registered [1]. The municipality of Centro, in the central region, has the largest number of ULO generators, with 991 repair shops. Moreover, the Chontalpa region has 186 generators, of which 174 (93.5%) are informal automotive repair shops, and only 12 of them (6.5%) are registered with SEMARNAT. In contrast, the municipality of Macuspana, in the Pantanos region, has 32 ULO generators, 23 (71.9%) are informal repair shops and 9 (28.1%) are formal. The municipality of Teapa, in the Sierra region, has 23 repair shops, 21 (91.3%) are informal and only 2 (8.7%) are registered in [1] (Table 1).

3.2 Collection, transportation and storage of used lubricating oils in Tabasco

The ULO generated in the formal repair shops in Tabasco is collected and transported to collection centers authorized by SEMARNAT (Table 2). Nine companies that collect and transport ULO were identified in the municipalities studied; seven are located in the city of Villahermosa, which is part of the municipality of Centro, and the other two are located in the municipality of Nacajuca. In addition, seven of these companies are used as collection centers where all of the ULO generated in the state of Tabasco is stored.

Table 1.
Number of repair shops generating used lubricating oils (ULO) in the 10 municipalities sampled in the state of Tabasco.

Region	Municipality	Generador Number	Generador I	Generador F	SRS
Centro	Centro	931	60	991	5
	Nacajuca	44	1	45	5
	Jalpa de Mendez	10	0	10	5
	Cadenas	73	9	82	5
	Comalcalco	38	2	40	5
Chontalpa	Cunduacan	43	0	43	5
	Paraiso	9	1	10	5
	Huimanguillo	11	0	11	5
Pantanos	Macuspana	23	9	32	5
Sierra	Teapa	21	2	23	5

I: Informal, Used Lubricating Oil generators that do not have an Environmental Registration Number
F: Formal, Used Lubricating Oil generators that have an Environmental
SRS: Selected repair shops
Source: Self-made.

Table 2.
Companies that collect and transport used lubricating oil (ULO) in the 10 municipalities sampled in the state of Tabasco.

Company Number	Municipality	Type of waste	Authorization number
1	Centro	ULO	27-I-144D-2013
2	Centro	ULO	27-I-148D-2013
3	Nacajuca	ULO	27-I-156D-2014
4	Centro	ULO	27-I-158D-2014
5	Nacajuca	ULO	27-I-163D-2014
6	Centro	ULO	27-I-167D-2016
7	Centro	ULO	27-I-176D-2017
8	Centro	ULO	27-I-184D-2019
9	Centro	ULO	27-I-186D-2019

Source: Self-made.

3.3 Final disposal of used lubricating oils in Tabasco

The used lubricating oils generated and collected in Tabasco are disposed of in two southeastern Mexican states: the state of Veracruz has four refineries, and the state of Tabasco has three.

The collection results show that all ULO generated in the state of Tabasco is mainly used to produce alternative fuels; no other post-refining uses were reported, which opens the possibility of including ULO in other activities within the industrial sector.

The main problem in the handling of ULO is attributable to the generators, since a large number of them are not regulated by [1], which can cause serious environmental damage (water and soil), given that they are not monitored by SEMARNAT and therefore are not required to comply with waste regulations.

The municipalities of Comalcalco, Jalpa de Mendez and Nacajuca generated the most used lubricating oil (ULO). The samples with the highest water content were collected in Comalcalco, Teapa, Paraiso and Centro. The municipalities with the highest percentage of oil were Comalcalco, Jalpa de Mendez and Nacajuca, ranging from 86.33% to 88.78%, while the car dealerships had 96% oil. The highest percentages of solids were in the municipalities of Centro, Paraiso, Huimanguillo, Cunduacan and Teapa, ranging from 15.73% to 20%. Car dealerships had the lowest values (1.19%). Meanwhile, the ULO collected from car dealerships showed the most favorable characteristics in terms of percentage of oil, low percentage of water and solids in the used oil generated. Regarding the density variable, the densest oil was collected in Teapa, Nacajuca and Huimanguillo; and the least dense oil was collected in Comalcalco, Paraiso and Centro, along with the oil from the car dealerships.

The Principal Component Analysis (PCA) performed on the ULO volume in the four collection stages accounted for 94.3% of the total variation (Table 3). PC1 accounted for 86.0% and PC2 the remaining 8.43%. The eigenvalues of each PC were 3.45 and 0.32.

The distribution of municipalities by principal component analysis (PCA) is shown in Fig. 1. Huimanguillo and Comalcalco are in Quadrant I. Nacajuca, Jalpa and Paraiso are in Quadrant II, Cunduacan in Quadrant III, and Cardenas, Centro and Macuspana are grouped in Quadrant IV.

Table 3.
Eigenvalues, eigenvectors, and variance explained by each principal component (PC) in the four stages of ULO collection in automotive repair shops in 10 municipalities of Tabasco.

Collection Number	Eigen vectors PC1	PC2
Y1	0.49*	-0.58*
Y2	0.47	0.80*
Y3	0.51*	-0.08
Y4	0.52*	-0.11
Eigenvalues	3.45*	0.32
Applied variance (%)	86.00	8.43
Applied variance (%)	86.00	8.43
Cumulative variance (%)	86.00	94.3

Significant values * [14].
Source: Self-made.

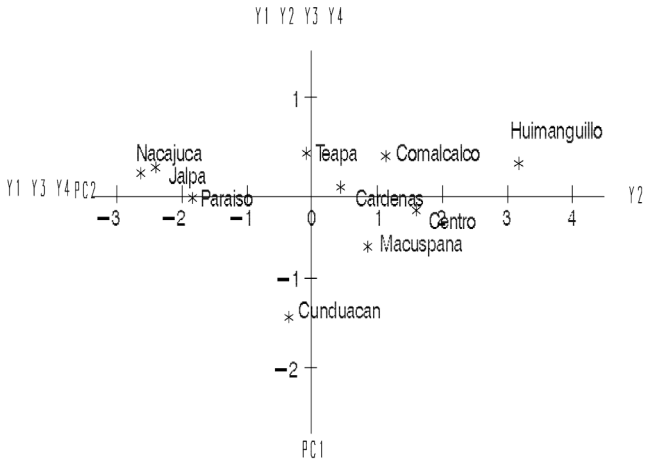

Figure 1. Distribution of 10 municipalities in the state of Tabasco where ULO was collected.
Source: Self-made.

Cluster analysis (Fig. 2) shows a group formed by Jalpa de Mendez, Nacajuca and Paraiso, which have the lowest average volume of used oil (ULO). These municipalities are at a distance of 0.32; while another group comprised of Cardenas, Macuspana, Centro, Comalcalco and Teapa, had a distance of 0.5; Huimanguillo and Cunduacan form a group at a distance of 1.0, which stands out for having the highest average volume of oil collected.

Table 4 shows the eigenvalues and eigenvectors of the principal component analysis (PCA) of the variables measured in the ULO. The first two components (PC1 and PC2) accounted for 85.96% of the total variation. PC1 accounted for 52.83% of the variation and an eigenvalue of 2.11 and was related to the variable percentage of oil and solids. PC2 accounted for 33.13% of the observed variation with an eigenvalue of 1.325.

Fig. 3, shows the distribution of the municipalities regarding the quality of the ULO sampled in each one. Quadrant I show Huimanguillo with the highest averages in the variables measured in oil collected, followed by Comalcalco (Quadrant IV). Quadrant III shows Cunduacan with the lowest averages in the variables measured in the ULO collected.

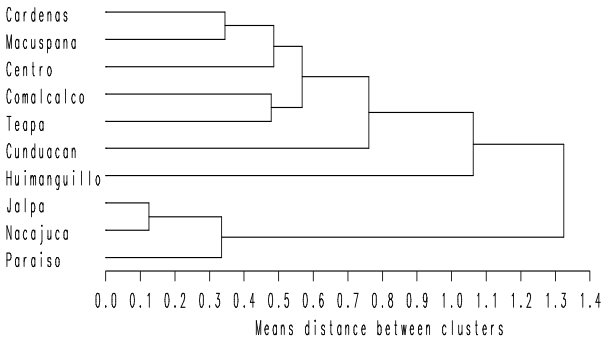

Figure 2. Dendrogram with the Euclidean distance of 10 municipalities in the state of Tabasco in which ULO was collected.
Source: Self-made.

Table 4.
Eigenvalues, eigenvectors, and variance explained by each principal components (PC) in four variables measured in the oils collected in five repai shops in each of the 10 municipalities in Tabasco.

	Eigen vectors	
Collection Number	**PC1**	**PC2**
Eigenvalues	2.11*	1.33*
Explained variance (%)	0.53	0.33
Cumulative variance (%)	0.53	0.86
Variables	**Eigenvectors**	
Water	- 0.21	- 0.72*
Oil	0.67*	- 0.17
Solids	- 0.61*	0.39
Density	0.36	0.55*

Significant values * [14].
Source: Self-made.

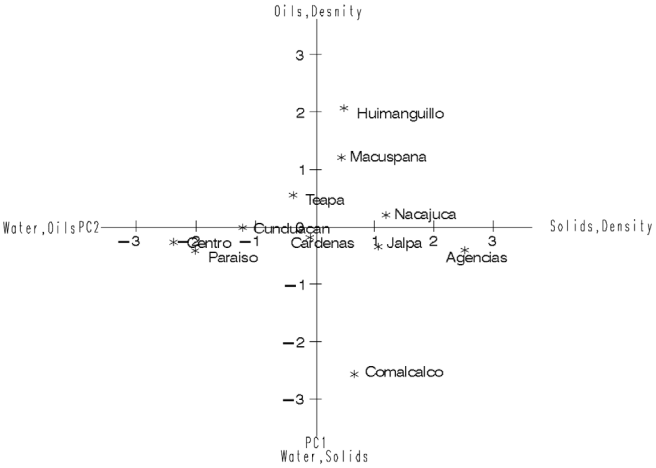

Figure 3. Distribution of the 10 municipalities in which four variables of the ULO collected in the state of Tabasco were evaluated.
Source: Self-made.

In Fig. 4, 4 clusters (CL) were observed; the CLI consisted of the car dealerships and the municipality of Comalcalco at a distance of 1.1, CLII grouped Cardenas, Jalpa de Mendez, Nacajuca and Teapa at a distance of 0.5; CLIII was consisted of Huimanguillo and Macuspana at a distance of 0.9, and CLIV has the municipalities of Centro, Paraiso and Cunduacan at a distance of 0.4.

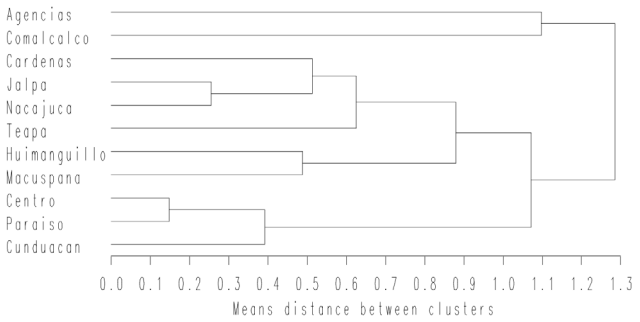

Figure 4. Dendrogram with the Euclidean distance of 10 municipalities in the state of Tabasco in which the quality of ULO was evaluated, based on four quantitative variables.
Source: Self-made.

4 Discussion

Based on the number of formal and informal repair shops measured during the study, it was established that the majority (71.13%) of the ULO generators in the sampled municipalities were informal, and the remaining 28.87% were formal or registered with SEMARNAT [1]. It can therefore be established that most of the repair shops that generate used lubricating oils are providing informal services in these municipalities. As a result, environmental managers have work to do, and the regulatory authority lacks information on the status of these repair shops (registered or unregistered). The results obtained in this research show that most of the ULO was generated by the unregulated repair shops. Similar results were reported by [10], who indicated that in Ghana, used oil generators engage in improper disposal practices, causing excessive environmental pollution.

SEMARNAT and PROFEPA are the institutions in the state of Tabasco that regulate and oversee the collection and handling of hazardous waste, and support repair shops that generate ULO by authorizing the collection, transportation, storage, refining and/or co-processing performed by private companies. According to [12], current Brazilian legislation encourages companies producing and importing finished oils to keep the current level of collection of used and contaminated oils for convenience, the same happens according to [11] in Nigeria.

Regarding variations in used oil density, this study confirmed that there were no significant changes in the density of ULO collected in the municipalities sampled; it varied within a narrow range between 0.88 and 0.89 g cm^{-3}. These results match those reported by [15], who evaluated different samples, finding that the average ULO density was 0.89 g cm^{-3}; however [9], found an average density of 0.96 g cm^{-3} in their study.

The moisture content of the ULO analyzed in this study showed values in the range of 1.92% to 7.66%, which is a high percentage if compared with that reported for this variable by [13] in the different ULO samples analyzed. According to their study [13], moisture percentages in the range of 0.0094 to 2.44%, settleable solids from 0.01 to 1.57% and density from 0.86 to 0.99 g cm^{-3} were detected. For solids, the values were lower and for density, they were higher than those found in this study.

The highest percentage of oil was found at the car dealerships, followed by the municipalities of Comalcalco, Jalpa de Mendez and Nacajuca. The Car dealerships also had the lowest percentage of solids, and the highest percentage of solids was found in the municipalities of Centro, Paraiso, Huimanguillo, Cunduacan and Teapa. This is likely to have been due to the fact that oil change service at dealerships is scheduled according to a quality system.

The results found in ULO generation show that only the municipalities of Huimanguillo, Cardenas and Comalcalco generated the greatest amount of oil during the sampling period. However, it cannot be ruled out that the municipality of Centro produces a larger inventory of used oil, since a total of 991 repair shops are registered, not including the Car Dealerships.

The results of the principal component and cluster analysis according to [14]; in the first component, three of the variables were significant (collection 1, collection 3 and collection 4) and in component two only collection 1 and 2 were significant. Regarding the eigenvalues, the first two were significant.

Since the eigenvalues of the two principal component analyses account for more than 80% of the variance as suggested by [5], it can be said that the variables measured in the ULO in this analysis were classified correctly.

The two cluster analyses performed in this study grouped the municipalities based on the similarity of the variables measured in each case (ULO volume collected and content of water, solids, oil, and density), which coincides with the statement by [8] that cluster analysis is used to classify objects or cases into relatively standardized groups, and that the objects in each group (cluster) are expected to be similar among themselves and different from each other. The only work found in the literature reviewed was that of [16], which shows the results of the comparative analysis of certain lubricating oil properties used in five Wärtsilä internal combustion engines to generate electric power.

5 Conclusion

The collection, transport and final disposal of used lubricating oil (ULO) in the 10 municipalities sampled in Tabasco is properly performed by specialized companies, since they are authorized by the Mexican federal government (SEMARNAT). The principal components analysis showed that the municipalities with the highest ULO generation during the four months of collection were Huimanguillo, Comalcalco and Cardenas. The ULO with the highest quality due to its physiochemical properties was collected in the municipalities of Jalpa de Mendez, Comalcalco and the car dealerships. The largest amount of ULO in the state of Tabasco is produced by micro and small generators (automotive repair shops). Most of the ULO generated in Tabasco is used by the refining industry as a mineral base and then mixed with other solvents to produce alternative fuels with different characteristics. The results of this study indicate that the state of Tabasco generates a significant amount of ULO, which due to its characteristics is a viable source of alternative energy.

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