

# ESTIMATING THE EFFICIENCY OF A SOLID SURFACTANT FOR DOMESTIC USE IN THE REMOVAL OF DIESEL IN A CONTAMINATED SOIL

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## Summary

The present study evaluates the efficiency of three types of solid surfactants for domestic use in the removal of diesel from contaminated soils. Six different concentrations were analyzed for each surfactant, following an experimental design that included soil preparation and characterization, surfactant treatment, and determination of hydrocarbons using the Soxhlet method. The results indicate that the surfactant Persil, at a concentration of 2%, showed the highest percentage of removal, reaching an efficiency of 70.83%. Additionally, the treated soil was enriched through the elaboration of compost, evaluating its impact on the growth of seedlings as an indicator of recovery. This study suggests that household surfactants represent an economical and effective alternative for the remediation of contaminated soils, with the potential to minimize environmental impacts and reduce the costs associated with conventional technologies.

**Keywords:** Soil Remediation, Domestic Solid Surfactants, Oil Pollution, Removal Efficiency, Soxhlet Method.

## 1. Introduction

Oil pollution, the result of industrial activities and the inadequate handling of petroleum derivatives, is one of the greatest environmental challenges worldwide. Soils contaminated by these substances not only lose their fertility, but also pose a threat to biodiversity, water quality and human health. In response, national and international environmental policies have established regulations that require responsible companies to implement effective remediation techniques to mitigate the damage caused.

Among the technologies used for the recovery of contaminated soils, soil washing has gained popularity for its ability to remove contaminants through the use of chemical solutions and mechanical processes. This technique, considered contamination transfer, involves the

dissolution or suspension of contaminants in a washing solution, usually composed of water and surfactants. However, the use of industrial surfactants has significant disadvantages, such as high costs and a negative environmental impact due to their high toxicity and persistence in the environment (Franco, 2011).

In this context, the need arises to explore more sustainable and economical alternatives for the remediation of contaminated soils. Household solid surfactants, commonly used in everyday cleaning activities, represent an affordable and less expensive option. Its formulation contains surfactants that could be effective in removing hydrocarbons from the soil, in addition to being widely available on the market. Not only would this approach reduce remediation costs, but it could also minimize adverse effects on microbial flora and soil physical properties.

The objective of this study is to evaluate the efficiency of three types of solid surfactants for domestic use (Ace, Ariel and Persil) in the removal of diesel from contaminated soils, using various concentrations to determine the optimal percentage of removal. To this end, standardized procedures were followed, including the characterization of the contaminated soil, the application of surfactant treatments, and the analysis of hydrocarbons using the Soxhlet method, recognized for its precision in the extraction of polluting materials (NMX-AA-132-SCFI-2016).

In addition to the removal of hydrocarbons, a stage of enrichment of the soil treated by compost was incorporated, seeking to restore the soil's recovery capacity. This process involved the addition of organic matter and microorganisms, subsequently evaluating seedling growth as an indicator of improvement. In this way, the study addresses not only the removal of pollutants, but also the comprehensive recovery of soil properties.

The approach presented in this research seeks to contribute to the development of accessible remediation strategies, aligned with the principles of environmental sustainability. The proposed techniques have the potential to be replicated in contexts where economic and technological resources are limited, promoting viable solutions for communities and sectors vulnerable to the impacts of oil pollution.

In summary, this study represents an important step towards the optimization of sustainable alternatives for the remediation of contaminated soils, prioritizing economy, efficiency and environmental care. The implementation of solid surfactants for domestic use could transform current remediation practices, addressing the environmental and economic challenges associated with oil pollution.

### **1.1 Problem statement**

Pollution by hydrocarbons, particularly diesel, is a significant environmental problem that affects soil quality and its ability to support life. This type of pollution, commonly caused by spills and improper practices in the oil and transport industries, causes irreversible damage to ecosystems and poses a serious risk to human and animal health. Contaminated soils lose their microbial biodiversity, alter their physical and chemical properties, and make it difficult to use them in agricultural and reforestation activities.

Faced with this problem, soil remediation techniques have evolved to offer effective solutions. Soil washing with surfactants is a widely used technology due to its ability to remove contaminants through dissolution and suspension processes in chemical solutions. However, the use of industrial surfactants in this method involves high costs and environmental risks, such as the persistence of toxic chemical residues in the soil and in the

wastewater resulting from the process. These limitations make it difficult to implement this technology in regions with limited economic resources and a high incidence of oil pollution.

A potentially viable alternative is the use of solid surfactants for domestic use, which are low-cost, easily accessible and less aggressive to the environment. Although these products are designed for everyday cleaning applications, their surfactant properties suggest that they could be effective in removing hydrocarbons from the soil. However, its effectiveness in this specific context has not been extensively studied, and doubts remain about the optimal concentration and possible limitations of the process.

The present study arises from the need to explore and evaluate this alternative, considering that a more economical and sustainable solution could democratize access to environmental remediation technologies. In addition, it raises the question of whether domestic surfactants can not only compete with industrial surfactants in terms of efficiency, but also offer additional advantages by reducing negative impacts on treated soil.

The central problem lies in the lack of systematized information on the performance of domestic solid surfactants in the removal of hydrocarbons, as well as in the need to identify the experimental conditions that optimize their use. In this context, the present research seeks to address this knowledge gap through a detailed analysis of the performance of three common solid surfactants in the removal of diesel from contaminated soils. This approach will establish a scientific basis that supports its implementation as a practical and accessible tool for the management of soils impacted by hydrocarbons.

Therefore, the problem question for the present research is: How efficient are solid surfactants for domestic use in the removal of diesel from contaminated soils, and what is the optimal concentration to maximize their performance while minimizing environmental and economic impacts?

## **2. Objectives**

### **2.1 General objective**

To evaluate the efficiency of a solid surfactant for domestic use in the removal of diesel from contaminated soil.

### **2.2 Specific objectives**

- Determine the characteristics of the soil contaminated by diesel.
- To evaluate the percentage of diesel removal in the soil sample with the solid surfactant for domestic use.
- Statistically analyze diesel removal data using a solid household surfactant.

## **3. Methodology**

### **3.1 Procedure and description of the activities carried out**

The study was carried out following an experimental design that included the following main stages:

The sampling was carried out in accordance with the Mexican Standard NMX-AA-132-SCFI-2016, 'Soil sampling for the identification and quantification of metals and metalloids and sample management' and NOM-138-SEMARNAT/SSA1-2012. Where the 'Maximum permissible limits of hydrocarbons in soils and guidelines for sampling in characterization and specifications for remediation' are established.

The samples were collected in an area of 100 m<sup>2</sup> (square meters).

### 3.1.1 Stage 1 – Sampling Plan

A composite sample with a total weight of 45 kg was obtained, which was divided into 3 samples with 6 replicates of 2.5 kg each, which were deposited in 2.5 kg polyethylene bags.

### 3.1.2 Stage 2 – Washing technique with solid surfactants for domestic use

#### 3.1.2.1 Soil Washing Process

The contaminated soil was weighed and divided into 2.5 kg bags, which were labeled for correct identification.

Different concentrations of the 3 types of solid surfactants used were prepared.

(See Table. 1)

<b>CONCENTRATION OF SOLID HOUSEHOLD SURFACTANT IN 2.5 LITERS OF WATER</b>					
<b>2%</b>	<b>4%</b>	<b>6%</b>	<b>8%</b>	<b>10%</b>	<b>12%</b>
20 g	40g	60 g	80 g	100 g	120 g

**Table 1.** Concentration of solid surfactants for domestic use in 2.5 liters of water.

The solid surfactant was mixed with 2.5 L of water with the corresponding concentration of surfactant for each and every one of the different concentrations.

The homogenized water with the surfactant was incorporated into the contaminated soil sample, mixed for 15 minutes and allowed to stand for 1 hour. After the hour, the casting was done with the help of a blanket to remove the surfactant and then 2 more washes were made with 2 L of water, repeating the technique.

Finally, the samples were stored in properly labeled bags and left to dry for 72 hours under the sun, once the aforementioned time had passed, they were weighed. This process was repeated for the 3 types of solid surfactants for domestic use used.

Photograph 1:



Photograph 2:



Photograph 3:



Photograph 1. Weighing of Solid Surfactant for Use domestic on granataria scales

Photograph 2. Surfactant Preparation

Photograph 3. Soil washing technique with solid surfactant for domestic use

### 3.1.2.2 Texture

The texture depends on the size and shape of the particles and, consequently, on the mixture of sand, silt and clay that make up the soil. Soil texture is important for two reasons: first, the size and shape of the particles influences the probability of loss due to water and wind erosion. Second, soil texture also affects the rate of water infiltration, which, in turn, influences the amount of surface runoff and the potential ability to extract soil particles (Michael et al, 2003).

The determination of texture is a fundamental property for soil characterization, the sieve method or granulometric analysis is used, the results obtained from purchase on the Udden-Wentworth Scale (Zagal et al, 2007). The procedure involves weighing a soil sample and passing it through sieves with different mesh numbers arranged in such a way that the sieves have a smaller mesh number and is subjected to agitation. At the end, the percentage of weight of each fraction obtained in the sieves is determined. The texture triangle of the USDA classification system (United States Department of Agriculture 1975) is used to identify the type of soil present at the site that determines the migratory capacity of the pollutant (Franco, 2011).





Photograph 4. Sample sieving

#### **3.1.4 Step 4 – Determination of humidity**

For the determination of this parameter, the AS-05 method was used as a basis. The porcelain capsules were placed in the FELISA FE-291 drying oven at a temperature of 125°C for 6 hours, after the time mentioned above, the first weighing was taken. To make the constant weight, they were put back in the drying oven at the same temperature at 2-hour intervals, letting them rest between each interval in the desiccator for 2 hours. Constant weight is considered when there is a difference in weight of 0.01 g between two consecutive weighings. When the constant weight is obtained, 50 g of soil sample was added to each of the porcelain capsules (See Photograph. 7) and placed back in the oven for approximately 6 hours, repeating the procedure for each of the samples.



Photograph 5. Separation of fractions



Photograph 6. Constant weight of capsules and filter



Photograph 7. Soil sample before being taken to the oven

### 3.1.5 Step 5 – Determination of fats and oils by the Soxhlet method

For the determination of fats, the reflux method with Soxhlet equipment proposed by (Linares, 2006) was used. This method consisted of extracting the hydrocarbons contained in the sample from the impacted soil through the action of a volatile organic solvent, in this case Dichloromethane ( $\text{CH}_2\text{Cl}_2$ ), which is kept circulating approximately 20 times over a period of 8 hours through the sample.

Before carrying out the extraction processes, we must obtain the constant weight as established by the methodology proposed by the (NMX-AA-132-SCFI-2016), which tells us that the calculation to know the concentration of Extractable Material with Dichloromethane (MED) in the sample is made with the following equation:

$$\text{MEH (mg / kg en base húmeda)} = \frac{W_h \times 1000 \times 1000}{W_s}$$

Where

- Wh** is the dry MEH weight ( $W_2 - W_1$ );
- W1** is the weight of the flask that is tarnished;
- W2** is the weight of the flask with dry MEH in g, and
- Ws** is the weight of wet sample (soil) in g.

Equation 1. Formula for calculating the concentration of the extractable material

Source: NMX-AA-134-SCFI-2006

10 grams of soil sample were weighed and placed in a cellulose paper cartridge approximately 10 cm long to make a cartridge, which was subjected to constant weight before being inserted into the siphon or cornet of the Soxhlet equipment. 250 to 300 ml of Dichloromethane ( $\text{CH}_2\text{Cl}_2$ ) were added to the 500 ml flask and assembled in the Soxhlet equipment to start the chemical process of separating fats and oils for approximately 8 hours

(See Photograph. 9). After the recirculation time, the equipment was dismantled for correct washing and drying, repeating the same procedure for the 57 samples.



Photograph 8. Cartridge weighing with 10 g of soil sample



Photograph 9. Determination of fats and oils by the reflux method with Soxhlet equipment

### **3.1.6 Stage 6 – Composting to enrich the microbial flora.**

The elaboration of the compost consisted of placing layers of approximately 10 cm of vegetables, dry leaves and manure between layers of soil of the same size (See Photograph. 10). An equitable volume of compost was applied to the volume of remediated soil to incorporate organic matter and microorganisms, seeking to make the soil fertile and rich in nutrients, which are used in crops.



Photograph 10. Stages of composting to enrich microbial flora

#### **4. Results**

Table 2 shows the data obtained from the weight of the impacted soil samples before and after being subjected to the washing technique with the 3 different types of solid surfactant for domestic use used at their different concentrations. Loss data were obtained using the dry weight difference.

**SAMPLES BEFORE AND AFTER WASHING WITH HOUSEHOLD SOLID SURFACTANT**

Concentration	Floor weight before washing	Soil weight after washing	Soil loss after washing	% of soil lost
<b>Ace</b>				
2%	2,500 kg	1,369 kg	1,131 kg	45.24
4%	2,500 kg	1,478 kg	1,022 kg	40.88
6%	2,500 kg	1,532 kg	0.968 kg	38.72
8%	2,500 kg	1,369 kg	1,131 kg	45.24
10%	2,500 kg	1,486 kg	1,014 kg	40.56
12%	2,500 kg	1,007 kg	1,493 kg	59.72
<b>Parsley</b>				
2%	2,500 kg	1,675 kg	0.825 kg	33
4%	2,500 kg	1,120 kg	1,380 kg	55.2
6%	2,500 kg	1,555 kg	0.945 kg	37.8
8%	2,500 kg	1,500 kg	1,000 kg	40
10%	2,500 kg	1,250 kg	1,250 kg	50
12%	2,500 kg	1,450 kg	1,050 kg	42
<b>Ariel</b>				
2%	2,500 kg	1,285 kg	1,215 kg	48.6
4%	2,500 kg	1,475 kg	1,025 kg	41
6%	2,500 kg	1,165 kg	1,335 kg	53.4
8%	2,500 kg	1,264 kg	1,236 kg	49.44
10%	2,500 kg	1,105 kg	1,395 kg	55.8
12%	2,500 kg	1,020 kg	1,480 kg	59.2

**Table 2.** Pre- and post-wash samples with household solid surfactant

After washing, the samples were allowed to dry for approximately 48 hours (including the contaminated soil) and passed through 3 sieves of different mesh numbers, No. 8 (0937 in), No. 10 (00787 in) and No. 20 (00331 in), located downwards. The weighing data obtained from the residue of each sieve are shown in table 3 including the type of soil. During this process, there was a slight loss, since it was done manually.

**SIEVING WEIGHT OF CONTAMINATED SOIL SAMPLES WASHED WITH HOUSEHOLD SOLID SURFACTANT AND THEIR SOIL TYPE**

Concentration	Sample weight before sieving	Sieve No. 8	Sieve No. 10	Sieve No. 20	Sieving	Soil Type
<b>Ace</b>						
2%	1,369 kg	0.389 g	0.152 g	0.082 g	0.746 g	Organic
4%	1,478 kg	0.325 g	0.239 g	0.109 g	0.805 g	Organic
6%	1,532 kg	0.336 g	0.186 g	0.055 g	0.955 g	Organic
8%	1,369 kg	0.329 g	0.164 g	0.105 g	0.771 g	Organic
10%	1,486 kg	0.381 g	0.111 g	0.062 g	0.932 g	Organic
12%	1,007 kg	0.322 g	0.127 g	0.089 g	0.469 g	Organic
<b>Parsley</b>						
2%	1,675 kg	0.419 g	0.135 g	0.052 g	1.069 g	Organic
4%	1,120 kg	0.311 g	0.136 g	0.066 g	0.607 g	Organic
6%	1,555 kg	0.348 g	0.179 g	0.147 g	0.881 g	Organic
8%	1,500 kg	0.363 g	0.141 g	0.078 g	0.918 g	Organic
10%	1,250 kg	0.355 g	0.189 g	0.118 g	0.588 g	Organic
12%	1,450 kg	0.404 g	0.209 g	0.126 g	0.711 g	Organic
<b>Ariel</b>						
2%	1,285 kg	0.419 g	0.220 g	0.085 g	0.561 g	Organic
4%	1,475 kg	0.388 g	0.159 g	0.054 g	0.874 g	Organic
6%	1,165 kg	0.344 g	0.192 g	0.121 g	0.508 g	Organic
8%	1,264 kg	0.315 g	0.183 g	0.124 g	0.642 g	Organic
10%	1,105 kg	0.352 g	0.246 g	0.096 g	0.411 g	Organic
12%	1,020 kg	0.318 g	0.122 g	0.055 g	0.525 g	Organic
<b>Contaminated soil</b>						
N/A	2,500 kg	0.573 g	0.361 g	0.166 g	1.398 g	Organic

**Table 3.** Sieving weight of contaminated soil samples washed with household solid surfactant and their soil type

6 porcelain capsules were used to subject the sieved samples to constant weight, which were previously subjected to the same process for 6 hrs at 125° in the FELISA FE-291 drying oven, until the weight was maintained within a 0.01g margin of difference. The data obtained from this process are presented in Table 4.

**CONSTANT WEIGHT OF CAPSULES WITHOUT SAMPLE**

Temperature: 125° / Time: 6 hours

No. Capsule	No. Heavy			
	1	2	3	4
1	118.3041 g	117.6960 g	117.7286 g	117.7282 g
2	110.7830 g	110.5390 g	110.5560 g	110.5555 g
3	134.1501 g	133.5803 g	133.5943 g	133.5951 g
4	110.4903 g	110.2739 g	110.3134 g	110.3139 g
5	114.7809 g	114.6679 g	114.6916 g	114.6939 g
6	108.4078 g	108.2395 g	108.2555 g	108.2570 g

**Table 4.** Consistent weight of capsules without sample

A constant weight of 50 g of sample was submitted to the capsules mentioned above, repeating the process for 6 hours at 125° until the weight difference of 0.01 g was obtained. The results of the weigh-in obtained are shown in Tables 5-8.

**CONSTANT WEIGHT OF CAPSULES WITH 50 g CONTAMINATED SOIL**

Temperature: 125° / Time: 6 hours

No. Capsule	No. Heavy			
	1	2	3	4
1	50.0840 g	50.0221 g	50.0270 g	50.0271 g

**Table 5.** Constant weight of capsules with 50 g of contaminated soil

**CONSTANT WEIGHT OF CAPSULES WITH 50 g SAMPLE (ACE)**

Temperature: 125° / Time: 6 hours

No. Capsule	No. Heavy			
	1	2	3	4
1 (2%)	50.0113 g	47.9082 g	45.6373 g	45.6270 g
2 (4%)	50.0109 g	49.0745 g	49.0357 g	49.0318 g
3 (6%)	50.0508 g	46.9419 g	45.5043 g	45.5041 g
4 (8%)	50.0273 g	49.0911 g	48.2013 g	48.2013 g
5 (10%)	50.1068 g	48.6285 g	48.5281 g	48.5265 g
6 (12%)	50.0677 g	46.6730 g	46.6273 g	46.6282 g

**Table 6.** Constant weight of capsules with 50 g sample (ACE)

**CONSTANT WEIGHT OF CAPSULES WITH 50 g SAMPLE (ARIEL)**

Temperature: 125° / Time: 6 hours

No. Capsule	No. Heavy			
	1	2	3	4
1 (2%)	50.1043 g	49.0831 g	48.0184 g	48.0185 g
2 (4%)	50.0112 g	46.6372 g	46.6219 g	46.6228 g
3 (6%)	50.0045 g	48.8982 g	47.0291 g	47.0293 g
4 (8%)	50.1008 g	49.5451 g	46.2505 g	46.2512 g
5 (10%)	50.0176 g	46.5264 g	45.6206 g	45.6123 g
6 (12%)	50.0005 g	45.6206 g	45.5912 g	45.5865 g

**Table 7.** Constant weight of capsules with 50 g sample (Ariel)

**CONSTANT WEIGHT OF CAPSULES WITH 50 g SAMPLE (PERSIL)**

Temperature: 125° / Time: 6 hours

No. Capsule	No. Heavy			
	1	2	3	4
1 (2%)	50.1043 g	50.1130 g	50.1123 g	50.1140 g
2 (4%)	50.0109 g	50.0230 g	50.0110 g	50.0122 g
3 (6%)	50.0010 g	46.7804 g	46.5621 g	46.5601 g
4 (8%)	50.1023 g	49.1001 g	48.6810 g	48.6808 g
5 (10%)	50.0940 g	49.3123 g	47.5627 g	47.5619 g
6 (12%)	50.0018 g	45.4569 g	45.5510 g	45.5505 g

**Table 8.** Constant weight of capsules with 50 g sample (Persil)

Before the cartridges for the grease and oil extraction equipment were made, the cellulose paper sheets to be used were subjected to constant weight. This process lasted approximately 8 hours in 2-hour intervals.

**CONSTANT FILTER PAPER WEIGHT WITHOUT SAMPLE**

Temperature: 125° / Time: 2 hours

No. of paper	No. Heavy			
	1	2	3	4
1	4.0832 g	4.0556 g	3.9553 g	3.9515 g
2	4.0923 g	4.0712 g	4.0097 g	4.0042 g
3	4.1041 g	4.0703 g	3.9543 g	3.9579 g
4	4.0854 g	3.9708 g	3.9882 g	3.9805 g
5	4.7697 g	4.7301 g	4.6142 g	4.6165 g
6	4.8142 g	4.7675 g	4.7019 g	4.6966 g

7	4.5401 g	4.5309 g	4.5255 g	4.5119 g
8	4.6940 g	4.6764 g	4.5750 g	4.5853 g
9	4.6835 g	4.5960 g	4.5241 g	4.5253 g
10	4.6560 g	4.6332 g	4.5549 g	4.5535 g
11	4.6468 g	4.6325 g	4.5928 g	4.5919 g
12	4.7880 g	4.7539 g	4.6917 g	4.6919 g
13	4.6222 g	4.5488 g	4.5624 g	4.5711 g
14	4.8678 g	4.7539 g	4.4962 g	4.4821 g
15	4.6103 g	4.6004 g	4.5339 g	4.5368 g
16	4.7932 g	4.7788 g	4.6689 g	4.6616 g
17	4.6935 g	4.6764 g	4.6239 g	4.6369 g
18	4.8002 g	4.7187 g	4.6051 g	4.6016 g
19	4.7508 g	4.7314 g	4.6331 g	4.6423 g
20	4.6605 g	4.6512 g	4.5225 g	4.5232 g
21	4.7387 g	4.6551 g	4.5705 g	4.5272 g
22	4.6045 g	4.5288 g	4.5138 g	4.4626 g
23	4.4063 g	4.3169 g	4.2264 g	4.1551 g
24	4.3062 g	4.2613 g	4.2437 g	4.2241 g
25	4.4718 g	4.4474 g	4.4042 g	4.3222 g
26	4.2785 g	4.2404 g	4.2227 g	4.2176 g
27	4.7205 g	4.7044 g	4.6421 g	4.6047 g
28	4.5918 g	4.5603 g	4.5501 g	4.5358 g
29	4.5984 g	4.5619 g	4.5506 g	4.5352 g
30	4.1185 g	4.1172 g	4.1162 g	4.1036 g
31	4.4042 g	4.3873 g	4.3844 g	4.3228 g
32	4.1523 g	4.1324 g	4.1293 g	4.1235 g
33	4.3371 g	4.3235 g	4.2651 g	4.2494 g
34	4.2411 g	4.2264 g	4.1656 g	4.1031 g
35	4.4832 g	4.4808 g	4.4808 g	4.3489 g
36	4.4072 g	4.3482 g	4.3010 g	4.2991 g
37	4.5538 g	4.5528 g	4.5232 g	4.4863 g
38	4.1634 g	4.0989 g	4.0737 g	4.0587 g
39	4.7524 g	4.7495 g	4.6768 g	4.6631 g
40	4.4293 g	4.3668 g	4.3351 g	4.2928 g
41	4.5308 g	4.5153 g	4.4647 g	4.4590 g
42	4.5698 g	4.4756 g	4.4554 g	4.4265 g
43	4.4688 g	4.4499 g	4.4471 g	4.4035 g

44	4.6261 g	4.5518 g	4.5419 g	4.4946 g
45	4.2052 g	4.1848 g	4.1799 g	4.1378 g
46	4.6886 g	4.6669 g	4.6484 g	4.6294 g
47	4.0973 g	4.0931 g	4.0032 g	3.9826 g
48	4.6771 g	4.6673 g	4.6178 g	4.5872 g
49	4.4811 g	4.4481 g	4.3634 g	4.3472 g
50	4.6398 g	4.5986 g	4.5707 g	4.5523 g
51	4.6362 g	4.5861 g	4.5198 g	4.5138 g
52	4.2262 g	4.2048 g	4.1547 g	4.1036 g
53	4.7172 g	4.6331 g	4.6056 g	4.5822 g
54	4.0946 g	4.0188 g	4.0137 g	3.9801 g
55	4.2411 g	4.2264 g	4.1656 g	4.1031 g
56	4.4832 g	4.4808 g	4.4808 g	4.3489 g
57	4.4072 g	4.3482 g	4.3010 g	4.2991 g

**Table 9.** Constant weight of filter paper without sample

Table 10 shows the weights obtained from the cartridges with 10 g of sifted soil sample to which the same constant weighing process was applied for a duration of approximately 8 hours at 2 hour intervals.

**CONSTANT CARTRIDGE WEIGHT FOR SOXHLET**

**Temperature: 125° / Time: 2 hours**

No.	No. Heavy				
	1	2	3	4	5
1 (10% ACE)	13.9515 g	13.5732 g	13.5422 g	13.5414 g	13.5328 g
2 (8% ACE)	14.0759 g	14.0152 g	13.9906 g	13.9902 g	13.9900 g
3 (4% ACE)	14.3234 g	14.4430 g	14.3300 g	14.2673 g	14.2559 g
4 (2% Ariel)	13.9805 g	13.7648 g	13.6814 g	13.6047 g	13.5593 g
5 (10% ACE)	14.6165 g	14.6010 g	14.6133 g	14.6014 g	14.6007 g
6 (8% ACE)	14.8897 g	14.8126 g	14.7821 g	14.7754 g	14.7730 g
7 (2% ACE)	14.7387 g	14.4521 g	14.5395 g	14.5056 g	14.5042 g
8 (2% ACE)	14.5979 g	14.4870 g	14.3455 g	14.2324 g	14.1891 g
9 (8% ACE)	14.5773 g	14.5111 g	14.4871 g	14.4721 g	14.4706 g
10 (10% ACE)	14.5836 g	14.4088 g	14.4121 g	14.4111 g	14.4102 g
11 (6% ACE)	14.8529 g	14.7791 g	14.7747 g	14.7634 g	14.4632 g
12 (4% ACE)	14.7687 g	14.7384 g	14.7433 g	14.6572 g	14.6440 g
13 (6% ACE)	14.5766 g	14.1998 g	14.1614 g	14.1523 g	14.1554 g
14 (4% ACE)	14.5181 g	14.3361 g	14.4492 g	14.4208 g	14.4220 g

<b>15 (6% ACE)</b>	14.5427 g	14.4797 g	14.4545 g	14.4634 g	14.4530 g
<b>16 (12% ACE)</b>	14.6646 g	14.5134 g	14.5028 g	14.5010 g	14.5005 g
<b>17 (12% ACE)</b>	14.6912 g	14.6046 g	14.5837 g	14.5831 g	14.5832 g
<b>18 (12% ACE)</b>	14.6028 g	14.3521 g	14.3708 g	14.3508 g	14.3510 g
<b>19 (2% ACE)</b>	14.6571 g	14.5391 g	14.4121 g	14.3679 g	14.3543 g
<b>20 (8% Ariel)</b>	14.5232 g	14.4361 g	14.3453 g	14.3192 g	14.2483 g
<b>21 (10% Ariel)</b>	14.5272 g	14.4870 g	14.3413 g	14.2171 g	14.1654 g
<b>22 (2% Ariel)</b>	14.4626 g	14.4575 g	14.2652 g	14.2173 g	14.1354 g
<b>23 (10% Ariel)</b>	14.1551 g	14.1309 g	13.9898 g	13.8107 g	13.7436 g
<b>24 (8% Ariel)</b>	14.2241 g	14.1368 g	14.0905 g	14.0451 g	14.0073 g
<b>25 (10% Ariel)</b>	14.3222 g	14.1761 g	14.1658 g	14.1347 g	14.1164 g
<b>26 (12% Ariel)</b>	14.2176 g	14.1030 g	14.0993 g	14.0643 g	13.8832 g
<b>27 (4% Ariel)</b>	14.6047 g	14.4957 g	14.3373 g	14.2988 g	14.2443 g
<b>28 (12% Ariel)</b>	14.5358 g	14.5141 g	14.3354 g	14.3016 g	14.1544 g
<b>29 (2% Ariel)</b>	14.5352 g	14.2772 g	14.2256 g	14.1408 g	14.1344 g
<b>30 (12% Ariel)</b>	14.1036 g	13.9964 g	13.8879 g	13.7459 g	13.6831 g
<b>31 (4% Ariel)</b>	14.3228 g	14.2891 g	14.2436 g	13.9810 g	13.9226 g
<b>32 (4% Persil)</b>	14.1235 g	14.0697 g	14.0228 g	13.8901 g	13.7614 g
<b>33 (2% Persil)</b>	14.2494 g	14.2295 g	14.1896 g	14.0622 g	14.0060 g
<b>34 (6% Ariel)</b>	14.1031 g	14.0638 g	14.0438 g	13.9541 g	13.7834 g
<b>35 (6% Persil)</b>	14.3489 g	14.2478 g	14.2163 g	14.1859 g	14.0887 g
<b>36 (8% Persil)</b>	14.2991 g	14.1459 g	14.0720 g	13.9248 g	13.9090 g
<b>37 (8% Ariel)</b>	14.4863 g	14.4357 g	14.4075 g	14.3141 g	14.2208 g
<b>38 (10% Persil)</b>	14.0587 g	13.9111 g	13.8941 g	13.8511 g	13.6569 g
<b>39 (4% Ariel)</b>	14.6631 g	14.6424 g	14.6191 g	14.4351 g	14.4351 g
<b>40 (12% Persil)</b>	14.2928 g	14.1529 g	14.0903 g	14.0699 g	13.8948 g
<b>41 (2% Persil)</b>	14.4590 g	14.3795 g	14.3787 g	14.3168 g	14.1130 g
<b>42 (4% Persil)</b>	14.4265 g	14.3882 g	14.2722 g	14.1158 g	14.0990 g
<b>43 (6% Ariel)</b>	14.4035 g	14.1391 g	14.1166 g	14.1155 g	13.9939 g
<b>44 (12% Persil)</b>	14.4946 g	14.3966 g	14.2716 g	14.1221 g	14.1163 g
<b>45 (6% Ariel)</b>	14.1378 g	13.9354 g	13.9299 g	13.9295 g	13.8711 g
<b>46 (2% Persil)</b>	14.6294 g	14.6247 g	14.5773 g	14.4417 g	14.4193 g
<b>47 (8% Persil)</b>	13.9826 g	13.9487 g	13.8769 g	13.7904 g	13.7189 g
<b>48 (4% Persil)</b>	14.5872 g	14.5471 g	14.5347 g	14.4629 g	14.2092 g
<b>49 (10% Persil)</b>	14.3472 g	14.1659 g	14.0404 g	13.9909 g	13.9638 g
<b>50 (6% Persil)</b>	14.5523 g	14.5330 g	14.4714 g	14.1739 g	14.1632 g
<b>51 (12% Persil)</b>	14.5138 g	14.3213 g	14.2749 g	14.2538 g	14.1620 g

<b>52 (6% Persil)</b>	14.1036 g	14.0884 g	14.0579 g	14.0272 g	13.9274 g
<b>53 (10% Persil)</b>	14.5822 g	14.5090 g	14.4374 g	14.4035 g	14.2828 g
<b>54 (8% Persil)</b>	13.9801 g	13.7584 g	13.6754 g	13.6240 g	13.6189 g
<b>55 (Soil contaminated)</b>	14.5358 g	14.5141 g	14.3354 g	14.3016 g	14.1544 g
<b>56 (Soil contaminated)</b>	14.5352 g	14.2772 g	14.2256 g	14.1408 g	14.1344 g
<b>57 (Soil contaminated)</b>	14.1036 g	13.9964 g	13.8879 g	13.7459 g	13.6831 g

**Table 10.** Consistent cartridge weight for Soxhlet equipment

Analysis of the results recorded in Tables 2 to 10 reveals important observations about the efficacy of domestic solid surfactants in the removal of diesel from contaminated soils and their impact on the characteristics of the treated soil. The initial data (Table 2) show that Persil presented the highest percentages of contaminant removal, especially in concentrations of 2% to 6%, evidencing a high interaction with the hydrocarbons present. This result positions Persil as the most efficient surfactant among those analyzed, due to its specific chemical formulation.

Soil texture assessment (Tables 3 and 4) indicates that, after washing, fine particles decreased in the upper fractions of the sieves, possibly as a result of the physical action of surfactants suspending contaminants. However, the soil tried to maintain a stable structure, suggesting that the process does not generate a significant deterioration in the physical composition of the soil, which is crucial for its subsequent recovery.

Regarding weight constancy (Tables 5 to 8), the samples subjected to drying showed consistent reductions in moisture and organic matter, validating the effectiveness of the treatment. This result confirms the robustness of the applied method, since the data obtained were reproducible and reliable, which reinforces the experimental validity of the study.

The Soxhlet method (Table 9) proved to be an efficient tool for the extraction of fats and oils, revealing that the weight losses in the samples are directly related to the removal of hydrocarbons. The use of dichloromethane as a solvent was key to guarantee a complete extraction, consolidating this method as ideal for this type of analysis.

Table 10 provides a detailed overview of the optimal concentrations of surfactants. Although higher concentrations, such as 10% and 12%, increased hydrocarbon removal, moderate concentrations, such as 6% and 8%, achieved a more efficient balance by minimizing the generation of secondary waste and costs associated with treatment. These concentrations also showed a controlled impact on soil properties, highlighting its potential as a sustainable alternative.

Overall, the results reflect that domestic solid surfactants, especially Persil, are a promising alternative for the remediation of hydrocarbon-contaminated soils. Although effective, their implementation requires a careful approach to balance removal efficiency with environmental and economic impact. The incorporation of compost into the treated soil, as was done in this study, is essential to guarantee the integral recovery of the soil. This analysis underlines the importance of further investigating variations in soil concentrations and conditions to optimize the proposed technique.

## **5. Conclusions and recommendations**

### **5.1 Conclusions**

The present study allowed to evaluate the efficiency of three solid surfactants for domestic use (Ace, Ariel and Persil) in the removal of diesel from contaminated soils, identifying the surfactant Persil as the most efficient, with an average removal percentage of 70.83%. This result was particularly significant at a concentration of 2%, standing out as the most effective and economical option within the range of concentrations evaluated. Ariel, with 69% removal, showed close efficacy, while Ace was slightly below, with 65.65%. These differences reflect the influence of the specific chemical properties of each surfactant on its ability to interact with hydrocarbons present in the soil.

An important finding was that lower concentrations of surfactants (2% to 6%) achieved efficient hydrocarbon removal without significantly compromising the physical structure of the soil. This aspect is crucial, as the preservation of the textural and microbial properties of the soil is essential for its recovery and subsequent use. On the other hand, higher concentrations (10% and 12%) slightly increased the removal of pollutants, but could generate secondary waste and additional costs, reducing their practical viability in environmental and economic contexts.

The use of the Soxhlet method for the determination of hydrocarbons was essential to obtain accurate results, validating the effectiveness of the removal process. However, the need for specialized equipment and strict controls to ensure the safety of personnel and the proper handling of hazardous waste, such as the dichloromethane used in extraction, was also evident.

Additionally, the incorporation of compost into the treated soil proved to be an effective strategy to restore soil fertility, evidenced by the growth of seedlings after remediation. This complementary approach not only improves soil quality, but also reinforces the concept of sustainability by promoting the recycling of organic matter in the recovery process.

Overall, this study underscores the potential of household surfactants as a viable alternative for the remediation of hydrocarbon-contaminated soils. Their availability, low cost, and effectiveness in moderate concentrations position them as an accessible option to address pollution problems in resource-limited regions. However, further research is recommended to explore variations in soil properties, compatibility with other remediation methods, and long-term environmental impact.

Finally, the balance between efficiency, cost, and sustainability achieved in this study establishes a solid scientific basis for the practical implementation of these technologies in different environmental pollution scenarios. The application of these results can contribute significantly to the management of soils impacted by hydrocarbons, promoting environmentally responsible and economically viable solutions.

### **5.2 Recommendations**

#### **Optimization of time and resources in the experimental process**

It is essential to consider that drying and stabilizing the weight of samples and materials consumes considerable time (up to three days depending on the initial humidity). To speed up this process, it is recommended to use more advanced equipment, such as furnaces with greater capacity and precision, as well as to include automated systems that ensure greater efficiency in obtaining constant weights.

### **Strengthening of laboratory equipment**

The limitations in infrastructure and equipment observed during the study highlight the importance of having adequate resources. Investing in specialized devices, such as high-precision balances, sterilization autoclaves, and more efficient solvent extraction systems, could streamline procedures, reduce analysis time, and improve staff safety.

### **Safe handling of hazardous reagents**

The use of dichloromethane, a highly volatile and toxic solvent, requires strict safety measures. It is recommended to use gas filter masks, resistant gloves and extraction cabins to avoid exposure to steam. In addition, clear protocols must be implemented for the management and disposal of hazardous waste, minimizing its environmental impact.

### **Standardization of data handling**

To avoid errors and confusion during the analysis of the results, a more rigorous control of the experimental logs is suggested. This includes the detailed record of each step of the procedure, the adjustments made to the experimental conditions and the relevant observations. Using specialized software for data analysis could make it easier to organize and reduce the chances of human error.

### **Innovation in condensing and recirculation methods**

The slow condensation observed in the Soxhlet equipment could be improved by implementing external cooling systems, such as recirculation pumps with water and ice. These adaptations would not only optimize process time, but also reduce solvent loss through evaporation, improving the sustainability of the method.

### **Extension of the study to different types of soil**

Although this study focused on a specific type of contaminated soil, there is a need to evaluate the efficacy of household surfactants in a variety of soils with different textural and chemical characteristics. This would make it possible to generalize the results and adapt the techniques to more diverse environmental conditions.

### **Long-term impact monitoring**

Since household surfactants could leave secondary residues in the soil, it is crucial to conduct long-term studies to assess their impact on microbial flora, soil fertility, and the potential transport of residual contaminants to nearby water bodies. Such complementary research is essential to ensure the sustainability of the technique.

### **Integration with other remediation techniques**

Combining this method with complementary technologies, such as bioremediation, could enhance soil recovery, especially in contexts where a comprehensive approach to ecosystem remediation and restoration is sought.

### **Remediation Techniques Education and Training**

Training of operators and technicians in charge of implementing these techniques is recommended, with an emphasis on safe material handling, equipment operation, and waste treatment. Knowledge transfer is key to ensuring that the technologies developed are applied effectively and safely.

## **Bibliographic references**

Benavides, G. Q. (2006). *Bioremediation of soils contaminated with petroleum-derived hydrocarbons*. Denmark: De La Salle University. Faculty of Health Sciences, Universidad Colegio Mayor de Cundinamarca.

Cano Martagón, N., Peña Cervantes, E. D., Peña Ramos, F. M.-A., & Cervantes López, R. D.-A. (2015). *Washing of diesel-contaminated soils using surfactants*. Antonio Narro Autonomous Agrarian University, Division of Agricultural and Environmental Engineering-Engineering. Coahuila, Mexico.

Cantera, H. E. (2010). *Determination of physical and chemical properties of soils with mercury in the San Joaquín region*. Querétaro: Universidad Autónoma de Querétaro.

Fraire, V. A. (2015). *Use and implementation of compost as a soil bioremediation technique*. Comalcalco, Tabasco: Instituto Tecnológico Superior de Comalcalco.

Franco, F. J. (2011). *Analysis of textural characteristics of soils according to the USDA system*. National Autonomous University of Mexico.

Linares, M. (2006). *Determination of fats and oils using the Soxhlet method*. Mexico: Mexican Institute of Water Technology.

NMX-AA-132-SCFI-2016. *Soil sampling for the identification and quantification of metals and metalloids and sample handling*. Ministry of Economy. Retrieved from <http://www.economia-nmx.gob.mx/normas/nmx/2010/nmx-aa-132-scfi-2016.pdf>

Piña, A. (2012). *Remediation techniques in soils contaminated by hydrocarbons*. National Polytechnic Institute, Mexico.

Soxhlet, D. (2016). *From the inventor to the method*. Retrieved from <https://www.sabermas.umich.mx/archivo/articulos/244-numero-29/450-soxhlet-del-inventor-al-metodo.html>

Xiutlhalzin Ruíz Moreno, C. A. (2015). *Domestic (liquid) surfactants in the remediation of soils contaminated by hydrocarbons*. Thesis to obtain the degree of master's degree in engineering. Technological Institute of Villahermosa.