# Study of Bird Feathers to Improve Design of Absorbent Pads for Greater Efficiency of Oil Spill Removal

**Alicia Chua Hao Shan and Daphne Chu Zhiying**

**Abstract** Oil spills in the ocean cause both short and long-term environmental damage and can pose threats to wildlife and ecosystems. The use of sorbents such as absorbent pads is one method which can remedy oil spills, because of their hydrophobicity and oleophilic nature. However, many of such absorbent pads are non-biodegradable and costly. Bird feathers are able to adsorb oil well due to their structure and are cheap organic materials. This research aims at studying the features of bird feathers which contribute to their oil adsorbing ability, so as to adapt these features to current absorbent pad models to determine an ideal structure that can increase efficiency of oil removal. In this research, pheasant and duck feathers were compared with four types of oil absorbent pads by determining which material absorbs the most oil relative to its initial mass. The materials were further observed using microscopes and a SEM machine. It was determined that pheasant feathers are better at oil adsorbing due to the size of their apparent contact angles, which affect the amount of oil which can enter the pores between the feather fibres (Cassie and Baxter in Trans Faraday Soc 40:546, [1]). It was also found that absorbent pads with larger fibre widths were able to adsorb and retain more oil, which may be due to a higher surface area or a lower contact angle of the oil on the surface of the pad.

**Keywords** Oil spills · Sorbents · Oil absorbent pad · Hydrophobic · Oleophilic · Bird feather · Adsorption

## 1 Introduction

Oil spills in the ocean are common occurrences which have great impact on the pollution and destruction of the environment. Being a major concern to the industry, certain methods such as the use of sorbents (absorbent pads) and biological agents have been used to tackle oil spills.

Pertaining to the use of biological agents, microbes are used to promote degradation of oil. However, due to the vast number of components in the oil, large numbers

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H. Guo et al. (eds.), *IRC-SET 2018*,
https://doi.org/10.1007/978-981-32-9828-6_4

of multiple types of bacteria are required to make changes to oil spill conditions. This can result in oxygen depletion in ocean waters in the areas where the microbes are active. Furthermore, a large amount of bacteria would require large amounts of nutrients from the ocean to work efficiently, which can lead to insufficient nutrients in the ocean and eventually result in inefficient bacteria activity, leading to the formation of sedimentation due to incomplete breakdown of hydrocarbons. Many hydrocarbons are also too big for microbes to clean up, resulting in ineffective oil spill cleanup.

Thus, the use of sorbents is ultimately the preferred method of cleaning up oil spills, because they are both highly hydrophobic and oleophilic and are able to retain oil due to adsorption and, though less commonly, absorption [2].

This research therefore focuses on sorbents rather than biological agents. Conventional sorbents such as oil absorbent pads are largely non-biodegradable and costly. Bird feathers are known for their hydrophobic as well as oleophilic properties. They are also low-cost, organic materials [3]. As such, this research aims to study the structure of feathers of both land and sea birds, as well as compare these structures to current absorbent pads used. This research uses two types of bird feathers, pheasant and duck, to represent the differences between land and sea birds. Four oil absorbent pads with different structural features were also compared and numbered for easier reference [Pad 1 (Cloversoft), Pad 2 (Joylife), Pad 3 (3M), Pad 4 (티투컴)].

By observing and relating the oil adsorbing abilities of each of these materials to their structural properties, this research hopes to determine an ideal structure and feature for absorbent pads used to tackle oil spills, such that the efficiency of oil removal can be increased. In order to explain the reasons behind observations made during experimentations to allow the research to advance further, this research tapped on the previous research on the structural features of bird feathers. This research strictly focuses on the physical properties and features of the materials, which allow feathers and oil absorbent pads to adsorb and retain oil and repel water. The oils used in this research were gasoline and lubricants to mimic different types of oil spill conditions.

## 2 Hypothesis

With respect to the physical structural properties of feathers, feathers are able to adsorb oil more effectively than absorbent pads. In addition, feathers of sea birds are able to adsorb oil more effectively than that of land birds due to their water repellent properties.

## 3 Methodology

For each of these experiments, each material (absorbent pad 1, 2, 3 and 4, pheasant and duck feather) was dipped into their respective petri dishes for 10 s, then removed to be placed on a paper towel for 5 s, in order to drain excess oil. The materials' initial and final mass were recorded, in order to obtain the change in mass. The percentage of change in mass due to adsorbed oil (percentage of change) was derived by taking the change in mass over the initial mass.

## *3.1 Comparison of Oil Adsorption Ability of Feathers and Regular Paper Towels*

The aim of this section was to determine the amount of oil that should be used in order to be able to observe how the structure of the bird feather changes with the addition of oil, as well as to compare the oil adsorbing ability of pheasant feathers, duck feathers and regular paper towels. The two types of feathers and the regular paper towel were cut to roughly the same length (between 3.80 and 4.50 cm). A total of 15 petri dishes were set up, including three negative controls, prepared with just tap water to prove that both types of feathers are hydrophobic, while the regular paper towel is not. The other 12 setups were prepared with either sunflower cooking oil or gasoline, with two different amounts of the oils, 0.5 and 10.0 mL. The recordings of the various setups and data are listed in the table of experimental data (found in Appendix). The materials were observed under a microscope before and after the experiments.

## *3.2 Effect of Surface Area to Mass Ratio on Oil Absorption Ability of Absorbent Pads*

This experiment was conducted to test out the hypothesis that a stretched piece of absorbent pad is a more effective oil adsorber as compared to an untouched piece of absorbent pad, because the ratio of surface area to mass is larger for a stretched absorbent pad. Two pieces of the absorbent pad were cut out. One piece was stretched out until light was able to penetrate the pad, while the other piece remained at its original length and thickness. This experiment was conducted with petri dishes containing grapeseed oil. The table of experimental data shows the data collected (details in Appendix).

## *3.3 Comparison of Oil Adsorbency of Materials*

In this experiment, the oil adsorbency of all the materials used in this research were compared. The structures of these materials were observed using the Scanning Electron Microscope (SEM). From there, the absorbent pad and feather that could adsorb

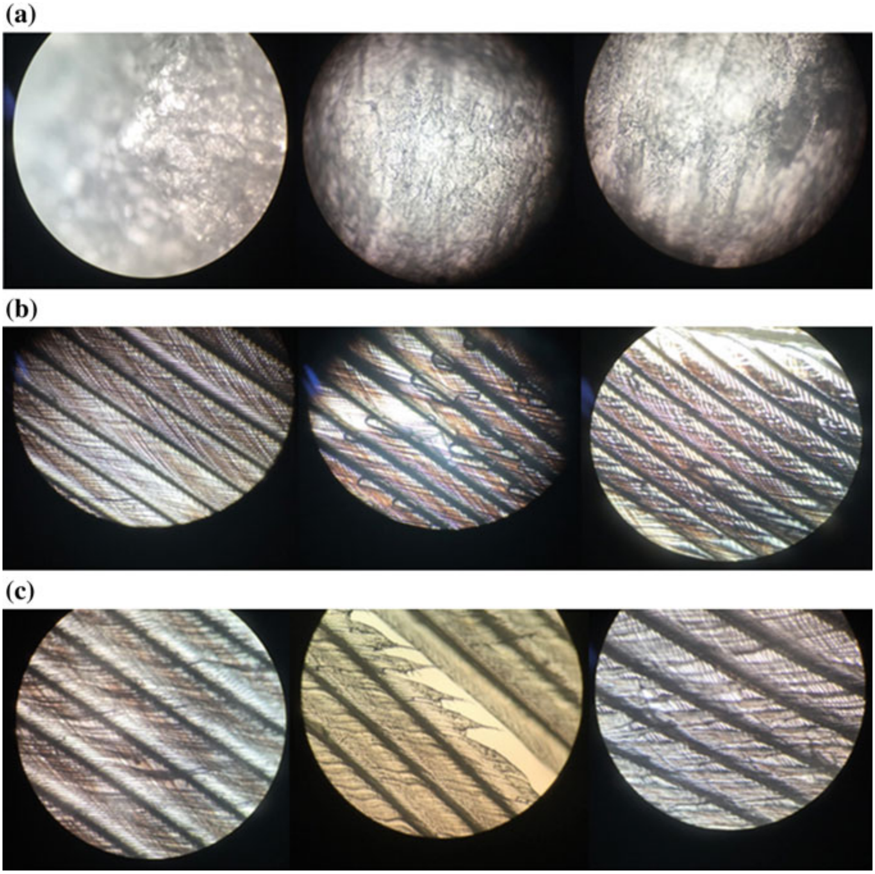


**Fig. 1** **a** Duck feather—left to right: before oil, 0.5 mL cooking oil, 0.5 mL petroleum, **b** pheasant feather—left to right: before oil, 0.5 mL cooking oil, 0.5 mL petroleum, **c** paper towel—left to right: before oil, 0.5 mL cooking oil, 0.5 mL petroleum

oil the best were determined. The second part was done on the best absorbent pad and feather with motorcycle lubricant and salt water, which was made with sea salt to mimic sea water. The purpose of these experiments was to determine whether existing absorbent pads were better than bird feathers at adsorbing oil. Acetone was used to remove any traces of uropygial oil left on the feathers, to eradicate the possibility of the oil affecting the adsorbing ability of the feathers. The feathers were left in a beaker filled with acetone for roughly two minutes, then washed and dried thoroughly but carefully. The salt water was prepared by mixing 33.4 g of Red Sea Coral Pro Salt to 1 L of water. These feathers and absorbent pads were trimmed to similar lengths (~2.5 cm) and their initial masses were recorded.

(i) Comparing oil adsorbency of feathers and absorbent pads

A total of 18 petri dishes were set up in a way similar to the set-ups in Trial Run I. The oils used were 1.0 mL each of gasoline, motorcycle lubricant and automobile lubricant, and the materials being tested on were the four types of absorbent pads and the two types of feathers.

(ii) Comparing oil adsorbency of materials under conditions which mimic oil spills

The pheasant feather and absorbent pad 3 were tested on as they were determined to be the best out of the feathers and absorbent pads. Two set-ups were prepared with a mixture of saltwater and 1.0 mL of motorcycle lubricant (Fig. 1).

## 4 Results and Discussion

In the comparison of oil absorption ability of feathers and regular paper towels (Fig. 2a), when both petroleum and cooking oil were used, pheasant feathers had highest percentage of change, followed by duck feathers, then paper towels. In short, pheasant feathers were able to adsorb more petroleum and cooking oil as compared to duck feathers due to its structure, which was then observed using the SEM.

While comparing the oil adsorbency of absorbent pad 2 while varying the surface area, the percentage of change in the stretched absorbent pad was 6.530 (4 significant figures) times more than an untouched absorbent pad (Fig. 2b), confirming the hypothesis that an increased surface area contributes to a higher oil absorbent ability.

While comparing oil adsorbency of all the materials, for the absorbent pads that were dipped in motorcycle lubricant, the percentage of change was the highest for pad 3, followed by pad 1, then pad 4 and lastly pad 2 (Fig. 2c). Current sorbents rely on the use of mostly adsorption, which is determined by certain factors such as the difference in the critical surface tension of the material compared to the liquid and the surface area of the material [3]. It was observed that the thickness of absorbent pad 2 could not be reduced as it was not made up of layers like the other pads. This suggests that absorbent pad 2 might be able to adsorb more oil, which was proven when the stretched piece was able to adsorb more oil than an untouched piece (Fig. 2b). Therefore, the results that absorbent pad 2 adsorbed the least may be considered inaccurate. However, this may suggest that an absorbent pad that is unable to separate into layers is less efficient in oil adsorption, as a large part of the pad will be unable to make contact with the oil.

With reference to the SEM pictures (Fig. 3a–d), it can be observed that all the oil absorbent pads were made up of non-uniform network of fibres which have air spaces between them. These fibres differ in width (from ~10 to ~40 μm) as well as density. However, the fibres in absorbent pad 4 (Fig. 3d) are much thinner and inconsistent in terms of the width (differing from 2.988 to 12.02 μm) and more dense than the other structures. The fibres in absorbent pad 3 are mostly consistent in terms of width (from 22.38 to 23.66 μm) (Fig. 3c), while absorbent pad 1 consists of fibres that are less than 20 μm in width (Fig. 3a), and absorbent pad 2 consists of fibres of width from 31.65 to 31.65 μm (Fig. 3b).

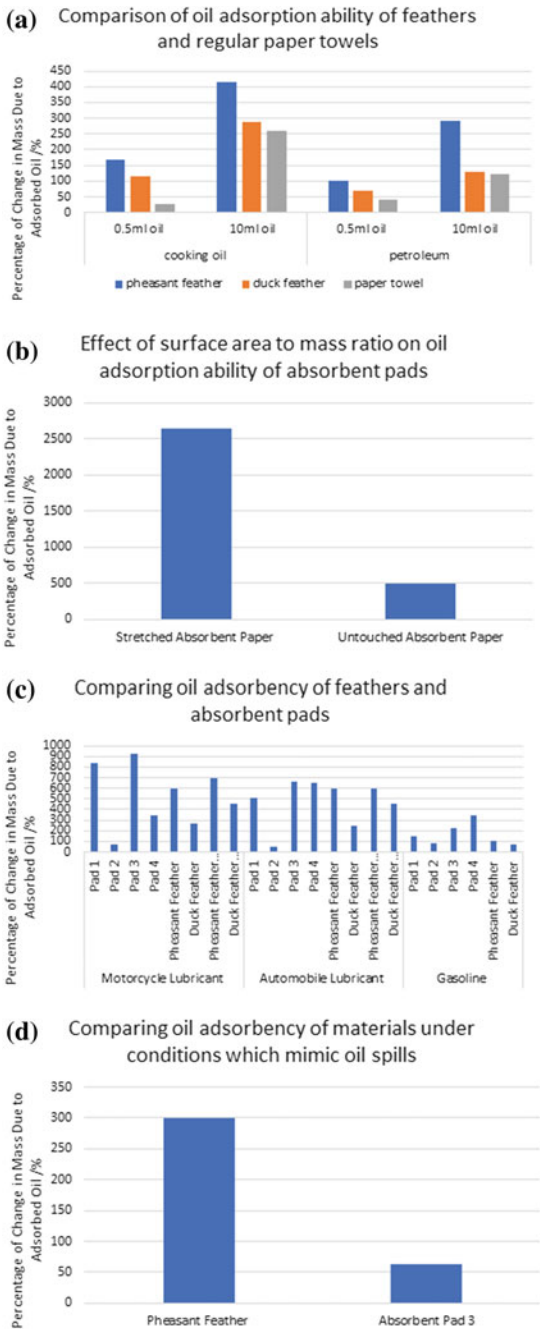


**Fig. 2** Comparison of oil absorption ability of feathers and regular paper towels

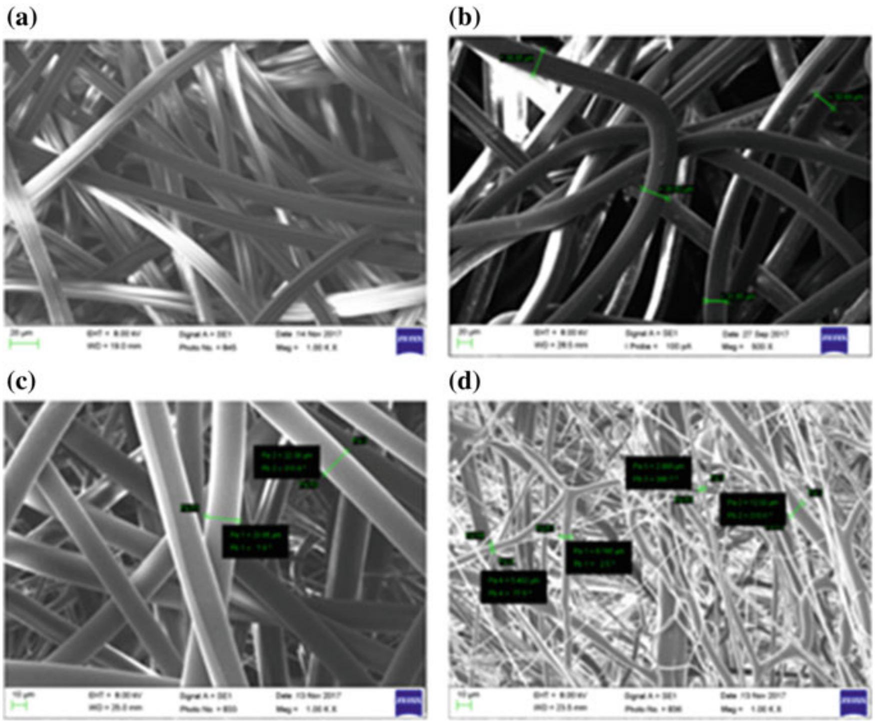


**Fig. 3** **a** SEM of absorbent pad 1 at 1.0k×, **b** SEM of absorbent pad 2 at 500×, **c** SEM of absorbent pad 3 at 1.0k×, **d** SEM of absorbent pad 4 at 1.0k×

As such, an efficient absorbent pad should not have a network of thin fibres, but should contain fibres that are larger in width. This can be seen when absorbent pads 3 and 1 were able to adsorb more oil than 4. One theory as to why a larger fibre width allows for more oil to be adsorbed is that it lowers the contact angle of the oil on the surface of the pad and decreases the critical surface tension of the material. Alternatively, a larger fibre width may also enable a larger surface area for adsorption of oil to occur.

With regards to the feathers dipped into motorcycle lubricant, pheasant feathers had the higher percentage of change, as compared to duck feathers (Fig. 2c). Although the high water-repellency of duck feathers seem to indicate that they are better at adsorbing oil, when observed on a structural level, it can be seen that the features which contribute to the duck feather's high water-repellency also affect and decrease its ability to adsorb oil.

Large apparent advancing and receding contact angles of porous surfaces and mobile drops of liquids ensures that the substance can roll of the surface without wetting the material. Large apparent contact angles can be deduced when $(\gamma + d)/r$ is large, where $(\gamma + d)$ is the spacing of the fibres and $r$ is the radius of the fibres [1].

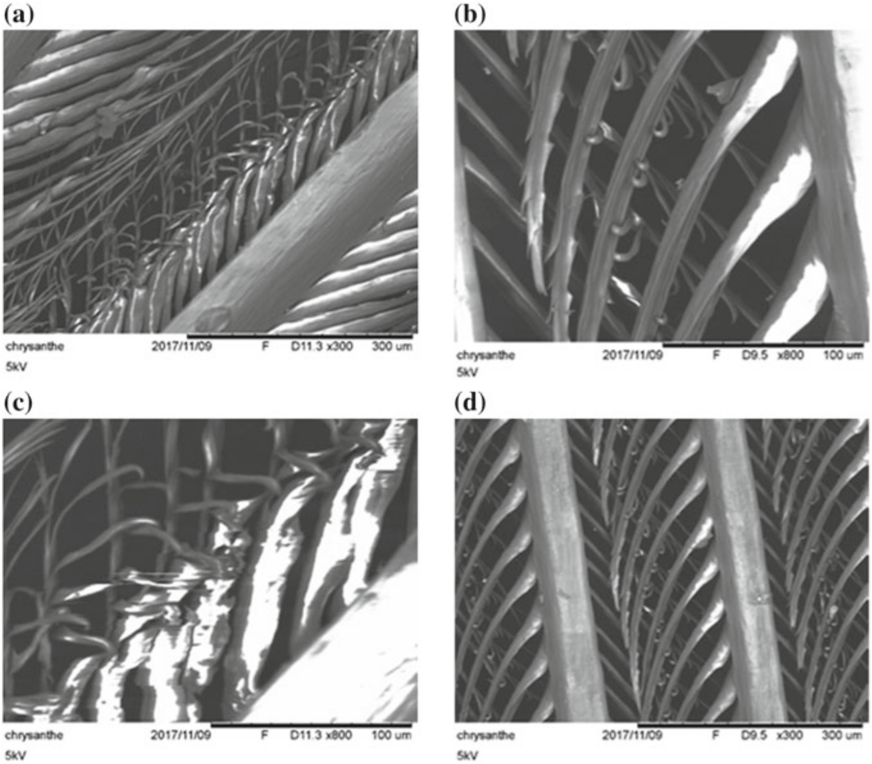


**Fig. 4** **a** SEM of pheasant feather at 300×, **b** SEM of duck feather at 300×, **c** SEM of pheasant feather at 800×, **d** SEM of duck feather at 800×

**Table 1** Experimental data from comparing oil adsorbency of feathers and absorbent pads

| | Initial mass (g) | Final mass (g) | Change in mass (g) | Percentage of change (%) |
|---|---|---|---|---|
| Pheasant feather | 0.005 | 0.020 | 0.015 | 300 |
| Absorbent pad 3 | 0.055 | 0.090 | 0.035 | 63.6 |

When any mobile drop of a liquid falls on the feather, due to the structure of the feather and depending on the surface tension of the liquid, the drop may or may not fall through the pores between the feather fibres. Water has higher surface tension than oil, due to the strong hydrogen bonds between water molecules, as compared to the weaker non-polar interactions between molecules in oil. Thus, the likelihood of oil droplets transiting from the Cassie state [1] to the Wenzel state [4, 5] by seeping into the pores between the fibres of bird feathers is higher than that of water, which is why feathers are able to adsorb oil, despite being water-repellent. Therefore, depending on their apparent contact angles, different types of bird feathers may or may not be more susceptible to adsorbing oil.

Based on the SEM pictures obtained in this research (Fig. 4a–d), although difficult to compare the spacing of the fibres due to the differences in angles, it can be seen that the radius of duck feather fibres is smaller than that of pheasant feather fibres, resulting in larger apparent contact angles for duck feathers. Thus, because of the structure of duck feathers, it is both highly water-repellent and more repellent to oil than pheasant feathers are. This explains why pheasant feathers have been shown to be better at adsorbing oil.

Therefore, it should be taken into account that the spacing and radius of the fibres must be such that $(\gamma + d)/r$ is substantially large, yet the spacing of the fibres must not be too big that droplets of liquid can pass into and out of the pores without difficulty. The data collected from this experiment is reflected in the table of experimental data (Table 1).

When the oil adsorbency of the pheasant feather and absorbent pad 3 were compared under conditions which mimic oil spills, the percentage of change for the pheasant feather was higher than that of absorbent pad 3 (Fig. 2d). This suggests that the structure of pheasant feathers enable it to adsorb more oil as compared to regular oil absorbent pads. The data collected is reflected in the table of experimental data (Table 2).

## 5 Conclusion and Future Works

Despite the fact that bird feathers are highly effective in adsorbing oil when observed on a volume per unit area level, the idea of directly using raw bird feathers to tackle oil spills is implausible and ineffective, because a large amount of bird feathers is required to make substantial impact on oil spill situations. On the other hand, if man-made materials were utilised, these materials can be used to produce absorbent pads in bulk to consistently tackle oil spills. As such, combining the features of bird feathers that aid them in their oil adsorbing abilities with current oil absorbent pad models would create an absorbent pad that is highly practical and effective in tackling oil spills.

Although this research managed to observe and determine the type and features of bird feathers that would be serve as an ideal template for absorbent pads, it was not able to explore the possibilities of physically creating an absorbent pad with said features due to the limitations of time and appropriate resources. If this research could be brought further, the following areas could be explored: varying the factors with which the experiments take place, such as temperature and humidity, to further mimic oil spill conditions. The type of oil used during experimentations could also become the dependent variable, to allow observation of how density and viscosity of different types of oils can affect the adsorbent properties of bird feathers and current absorbent pads. Once all thorough experimentations have been concluded, an ideal blueprint can be created and then 3D printed, such that the adsorbent properties of

**Table 2** Experimental data from comparing oil adsorbency of materials under conditions which mimic oil spills

| | Motorcycle lubricant | | | | Automobile lubricant | | | | Gasoline | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | Initial mass (g) | Filial mass (g) | Change in mass (g) | Percentage of change (%) | Initial mass (g) | Final mass (g) | Change in mass (g) | Percentage of change (%) | Initial mass (g) | Final mass (g) | Change in mass (g) | Percentage of change (%) |
| Pad 1 | 0.030 | 0.280 | 0.250 | 833 | 0.035 | 0.215 | 0.180 | 514 | 0.035 | 0.085 | 0.050 | 143 |
| Pad 2 | 0.225 | 0.390 | 0.165 | 73.3 | 0.245 | 0.370 | 0.125 | 51.0 | 0.230 | 0.420 | 0.190 | 82.6 |
| Pad 3 | 0.025 | 0.255 | 0.230 | 920 | 0.025 | 0.190 | 0.165 | 660 | 0.025 | 0.080 | 0.055 | 220 |
| Pad 4 | 0.050 | 0.220 | 0.170 | 340 | 0.030 | 0.225 | 0.195 | 650 | 0.010 | 0.045 | 0.035 | 350 |
| Pheasant feather | 0.005 | 0.035 | 0.030 | 600 | 0.005 | 0.035 | 0.030 | 600 | 0.005 | 0.010 | 0.005 | 100 |
| Duck feather | 0.015 | 0.055 | 0.040 | 267 | 0.020 | 0.070 | 0.050 | 250 | 0.015 | 0.025 | 0.010 | 66.7 |
| Pheasant feather (acetone) | 0.005 | 0.040 | 0.035 | 700 | 0.005 | 0.035 | 0.030 | 600 | | | | |
| Duck feather (acetone) | 0.010 | 0.055 | 0.045 | 450 | 0.010 | 0.055 | 0.045 | 450 | | | | |

the new absorbent pad. Following that, different compositions of the absorbent pad can be explored, such as other forms of hydrophobic structures that may prove to be more effective and also biodegradable.

## Appendix

See Tables 3 and 4.

**Table 3** Experimental data from trial run I

| Type of material used | Type of oil used (mL) | Volume of oil used (mL) | Length of material (cm) | Initial mass of material (Ml) (g) | Final mass of material (M2) (g) | Change in mass of material (M2 − M1) (g) | Percentage of change in mass due to adsorbed oil [(M2 − M1)/Ml * 100] (%) |
|---|---|---|---|---|---|---|---|
| Pheasant feather | – | 0 | 4.50 | 0.015 | 0.016 | 0.001 | |
| Duck feather | – | 0 | 4.20 | 0.029 | 0.029 | 0 | |
| Paper towel | – | 0 | 4.40 | 0.040 | 0.106 | 0.066 | |
| Pheasant feather | Cooking | 0.5 | 4.20 | 0.013 | 0.035 | 0.022 | 169 |
| Duck feather | Cooking | 0.5 | 4.00 | 0.037 | 0.079 | 0.042 | 114 |
| Paper towel | Cooking | 0.5 | 4.20 | 0.028 | 0.036 | 0.008 | 28.60 |
| Pheasant feather | Petroleum | 0.5 | 3.90 | 0.013 | 0.026 | 0.013 | 100 |
| Duck feather | Petroleum | 0.5 | 4.20 | 0.041 | 0.070 | 0.029 | 70.70 |
| Paper towel | Petroleum | 0.5 | 4.10 | 0.030 | 0.042 | 0.012 | 40 |
| Pheasant feather | Cooking | 10.0 | 4.00 | 0.014 | 0.072 | 0.058 | 414 |
| Duck feather | Cooking | 10.0 | 4.10 | 0.033 | 0.128 | 0.095 | 288 |
| Paper towel | Cooking | 10.0 | 4.30 | 0.036 | 0.130 | 0.094 | 261 |
| Pheasant feather | Petroleum | 10.0 | 3.80 | 0.010 | 0.039 | 0.029 | 290 |
| Duck feather | Petroleum | 10.0 | 3.90 | 0.040 | 0.091 | 0.051 | 128 |
| Paper towel | Petroleum | 10.0 | 3.90 | 0.035 | 0.078 | 0.043 | 123 |

**Table 4** Experimental data from trial run II

| Type of material used | Initial mass of material (Ml) (g) | Final mass of material (M2) (g) | Change in mass of material (M2 − M1) (g) | Percentage of change in mass due to adsorbed oil [(M2 − M1)/Ml * 100] (%) |
|---|---|---|---|---|
| Stretched absorbent pad 2 | 0.080 | 2.115 | 2.035 | 2540 |
| Untouched absorbent pad 2 | 0.700 | 3.425 | 2.725 | 389 |

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