Utilizing Porous Materials for Oil Spill Cleanup

Jenny Cai jennycai20@gmail.com
Yegor Chekmarev cegorr@gmail.com
Jessica Luo jessicaa.luo@gmail.com
Chanelle Sears abchanelle14@yahoo.com

July 22, 2010

Abstract

The damage to the environment caused by an oil spill of any size demands immediate cleanup. This project studied the ability of different porous materials to absorb oil, particularly sol-gels, polypropylene, and cotton. Each material was placed in tap water, mineral or paraffin oil, and a water-oil mixture. After soaking for one day, the material’s uptake of liquid was calculated. The reusability of the materials was also tested. Cotton and polypropylene fibers proved to be the most absorbent, with cotton absorbing fifteen to twenty times its own weight and polypropylene fibers absorbing about three to five times its own weight in oil and mixtures of oil and water. These materials also had the added benefits of being inexpensive and reusable. Thus, using a combination of polypropylene fibers and cotton in addition to current oil spill cleanup methods could greatly accelerate the cleanup initiative.

1 Introduction

Human dependence on oil has resulted in disastrous effects in the past and will likely create devastating effects in the future. Because oil and water do not mix, the oil eventually forms a thin and often large layer on the surface of the water. Animals that consume the oil suffer health problems and the oil slick that covers their fur and feathers impairs animals mobility. Furthermore, the impact of oil spills is not exclusively confined to the water—oil can wash up on shores, damaging ecosystems for years to come. Due to the oil contamination in the Gulf of Mexico, fishermen can no longer earn a living by fishing. Thus, methods such as dispersants, booms, and skimmers have been developed to combat the widespread repercussions of oil spills. Although a myriad of methods that have been employed, the field of materials science has not been fully explored to find a solution to the problem.

The recent Deepwater Horizon explosion and oil spill in the Gulf of Mexico has been the source of much controversy. Current oil spill cleanup methods include booms, skimmers, and centrifuges, which physically collect and contain the oil; dispersants, which break up the oil on the surface; and flaring, the burning of oil. However, these containment methods have not been successful—nearly 60,000 barrels of oil are released into the water each day [3], and much of it is not contained. Our approach to solving this problem is to use porous materials that can absorb oil effectively. We propose a new approach to this problem through the use of porous materials, which, with further research, could not only help clean up the oil, but also provide fishermen with a source of employment.

2 Background

2.1 A History of Oil Spills

The world has had a history of oil spills starting from the first major commercial spill of 1967 in the United Kingdom and continuing with the present day BP Deepwater Horizon Oil Spill in the Gulf of Mexico. Beginning from April 20, 2010, thousands of barrels of oil have been leaked into the Gulf of Mexico each day. As with other large scale oil spills, such as the Kuwait oil spill of 1989 with 10 million barrels of oil spilled and the Exxon Valdez spill of 1989 with about 240 thousand barrels of oil leaked onto Alaskan shores, the effects have been disastrous [1]. Despite the fact that the Exxon Valdez oil spill occurred over 21 years ago, the community in Alaska, as well as the marine wildlife is still recovering. As long as petroleum is the main source of energy used by nations, there will always be the danger of oil spills. Oil spill cleanup methods must be updated with the latest technologies so that nations can be prepared to deal with an oil spill effec-
tively and quickly.

2.2 Current Methods of Oil Spill Recovery

Burning, isolating and skimming, and collection are the three main methods of oil spill cleanup in use since the explosion of the Deepwater Horizon Oil Rig. In burning, oil is corralled by fast-moving boats with buoys and booms, and then isolated and set on fire. This approach has very questionable effects on the marine environment and is not widely used. Another technique employs booms and skimmers to first contain the oil slick, and then painstakingly removes it from the surface of the water. This is neither very effective nor efficient, as waves and poor weather allow oil to overcome its containment and spread with the currents. The last procedure which involves collecting oil and sea water indiscriminately through the use of tankers is also being heavily criticized for its unsatisfactory results. In this process, large tankers enter the oil slick and vacuum huge amounts of both oil and water. A centrifuge inside of the ship separates the two liquids, and the water is pumped out while the oil is stored safely inside. The problem with this technique is in the strict regulations concerning the quality of recently filtered water released back into the ocean. Such an immense disaster requires approaches from various different angles to ensure that the problem is resolved as soon as possible. Although current methods have been slowly but steadily cleaning the oil, additional methods would greatly accelerate the cleanup process.

2.3 Porous Materials

The goal in creating a highly effective porous material is to maximize the level of absorbency so that it can be used in many applicable fields. To be considered a viable oil spill absorbent, a porous material must satisfy several criteria. The material should be hydrophobic and oleophilic, have a high rate of uptake and retention, and be able to release the oil it has absorbed [4]. The hydrophobicity and oleophilicity ensure that only oil is absorbed, and not water. The high uptake capacity ensures that a large quantity of oil can be picked up relative to weight of material. The high rate of uptake signifies that the material absorbs the oil quickly. The retention over time ensures that oil does not leak from the material after it has been picked up. On the other hand, it is also important to be able to cheaply and easily remove the oil from the material, because otherwise it becomes cumbersome and not very efficient in the long run. Ideally, the material should also be reusable and biodegradable. The three porous materials tested in this study are sol-gels, polypropylene, and cotton.

2.3.1 Sol-gels

Overall, the relatively low cost of preparation, the ease of creation, the porosity, and the ability to fine-tune the composition of gels makes them possible candidates for oil absorption. A sol-gel process is a specific network of particles with applications ranging from thermal insulation to capturing space dust. The “sol” refers to the solution in which the material is created, while the “gel” refers to the eventual creation of a substance with liquid-like properties but with the cohesiveness of a solid.

Depending on the chemicals and processes that a gel is treated with after its initial preparation, one of many different types of gels may be formed. The simplest and most common type of gel is the xerogel, which forms from natural shrinkage of drying at low temperatures. If the gel is heated to its supercritical temperature, the solvent evaporates without shrinking the solid, resulting in an extremely low density material with extremely high insulation and porosity. Unlike aerogels, xerogels have not been thoroughly researched as a viable material for oil absorption.

2.3.2 Cotton

Cotton is a well-known industrial textile that shows promise as an all-around effective absorbent of both oil and water. It is notable for its low density, high availability, and low cost. Cotton has a high oil uptake coefficient of up to 80 times its own weight. It is composed of mostly cellulose, which allows it to be a reusable and biodegradable material [2]. To maintain cotton’s high uptake capacity of oil, cotton should only come in contact with oil; otherwise, water and any other liquid will also be absorbed and take up space in cotton fibers that would otherwise be used for oil.

2.3.3 Polypropylene

Polypropylene is a porous material with the chief benefits of hydrophobicity and low cost. It can absorb about 10 times its own weight in oil [1]. It has a low density which allows a significant amount to be carried without having to worry about to weight. It is especially resistant to fatigue, recyclable, and environmentally friendly. Polypropylene might be used in a device that will effectively absorb oil.
3 Methods

3.1 Preparation of Sol-gels

We prepared three sol-gels by adding electrolytes to a silica sol, a suspension of very small, fine particles of silica in water. We half-filled three Petri dishes with silica sol and slowly stirred ammonia into one dish, cobalt chloride into another, and table salt (NaCl) into a third. The sol-gels then dried overnight.

3.2 First Trial: Testing the Uptake of Sol-gels and other Porous Materials

We tested the porous materials for uptake capacity, or ability to absorb its own weight in water. The materials tested for uptake were: 1M Pulled White String (a sol-gel prepared with a 1-molar NaCl solution), polypropylene fiber, polypropylene straws, microporous hollow fiber, and the three sol-gels created in the lab: ammonia, cobalt chloride, and sodium chloride. We recorded the weight of each sample with a triple beam balance. There were three samples of each material. One sample was placed into a test tube filled with water, one was placed in a test tube filled with oil, and one was placed in a test tube filled with a mixture that was 50% oil and 50% water, which was used to create a scenario that better portrays the current oil spill in the Gulf of Mexico. After the materials soaked the liquid in the test tube for at least one day, we removed them from the test tubes, weighed them again, and calculated the uptake of each material.

3.3 Second Trial: Testing the Uptake of Polypropylene, Cotton, and a Straw and fiber device

The two materials with the highest uptakes from the first trial were retested in order to ensure the accuracy of results along with cotton and a device that was constructed out of straws and fibers. Because mineral oil was not available, we used paraffin oil, which is chemically similar to mineral oil. We weighed the materials with a digital balance, which has a higher accuracy than the triple beam balance used to weight the previous samples.

Because the polypropylene straws and the microporous hollow fiber produced fairly high uptakes, they were combined in the hopes of creating a more absorbent device. The maximum number of microporous hollow fibers (seven) were strung through the polypropylene straws and tied, with the loose ends cut off. These devices were then placed in graduated cylinders with water, oil, and a mixture of 50% oil and 50% water.

The polypropylene fibers and polypropylene straws, which had two of the three highest uptakes, were retested. Cotton, an overall highly absorbent material, was also tested in the three liquids. The materials were removed from their containers after soaking in the liquids overnight, blotted, and weighed. The uptakes of the materials were calculated once again.

3.4 Testing Reusability of Porous Materials

3.4.1 Reusability of Polypropylene Fibers

A material can be considered reusable if it can soak up as much or almost as much oil during subsequent uses. To test the reusability of polypropylene fibers, we cleaned a sample of the material from the oil and water-oil mixture. We placed the sampled in a beaker filled with water, which was then placed on a hot plate stirrer. A few drops of diluted commercial dishwashing liquid were added to the beaker. The two samples were left to soak in the detergent overnight and a magnetic stirrer was placed in the beaker in order to continuously stir the solution.

The next day, the samples were removed from the solution and excess liquid was soaked up. The samples were weighed again to determine the effectiveness of the detergent and water solution. These weights were recorded and the process was repeated.

3.4.2 Reusability of Cotton

Cotton balls were removed from the oil, water, and water-oil mixtures they had been soaked in. Their weights were recorded and they were squeezed by hand with a constant force to remove the water and/or oil contained within. These samples were weighed again and their new weights, along with the percent decrease in weight, were calculated.

4 Results and Discussion

The most absorbent materials were polypropylene fiber and cotton. Polypropylene is hydrophobic and oleophilic. It absorbs up to five times its own weight in oil and

found in all of the lab experiments were cotton and polypropylene fiber. Other materials that were
tested include 1M pulled white string, polypropylene straws, sol-gel with NaCl, sol-gel with Ammonia, sol-gel with CoCl, and microporous hollow fiber.

4.1 First Trial
In the first trial, all of the materials absorbed at least 20% of their own weight; however, the polypropylene fiber which absorbed 600% of its own weight in oil (from 0.1g to 0.7g) and the microporous hollow fiber which absorbed 300% of its own weight in oil (from 0.1g to 0.4g) were the most successful. Although the polypropylene fibers absorbed a significant amount of oil, they had a greater uptake in water than in oil. The polypropylene straws also absorbed over 100% of its weight in oil (from 1.1g to 2.3g). The ammonia and NaCl sol-gel samples, which were expected to be hydrophobic, turned out to be more oleophobic when they absorbed more water than oil. All the samples from the first trial were weighed with a triple beam balance with ±0.05 grams of accuracy, which left room for possible human error.

4.2 Second Trial
In the second trial, a digital scale was used with an accuracy of ±0.001 grams. The polypropylene fibers that were retested proved to be significantly more hydrophobic than previously observed; the fibers uptook 503% their own weight when immersed in oil, but only 172% their own weight when immersed in water. (This may be due to the larger sample that was used which yielded more accurate results.) However, the polypropylene straws that were retested did not show a significant change in absorbency results from the first trial and the polypropylene straw and fiber combination proved less effective than expected.

Cotton proved to be highly absorbent, holding at least 16 times its own weight in each liquid (water, oil, and the water-oil mixture). Although cotton appears to be just as oleophilic as it is hydrophilic, it may still prove to be highly useful in creating designs for oil absorption as shown in Figure 2.
with the polypropylene fibers in the water-oil mixture.

Although the emulsification process only caused the polypropylene fibers to decrease in weight from 1.278 g to 0.948 g and 1.554 g to 1.094 g as shown in Figure 4.

<table>
<thead>
<tr>
<th>Changes in Polypropylene Fiber Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
</tr>
<tr>
<td>Oil</td>
</tr>
<tr>
<td>Mixture</td>
</tr>
</tbody>
</table>

Figure 4: This table shows the weights of the polypropylene fibers before being placed in the water-detergent solution, after removal from the water-detergent solution, and after re-immersion in an oil or water-oil mixture.

This small change may be because only a small amount of diluted detergent was used. In addition, the detergent on the samples may have only removed the oil from the exterior of the fibers, and not the interior of the fibers, leaving little room for the reabsorption of oil. A simple solution may be to use a larger amount of dishwashing detergent or more concentrated detergent. To further improve the cleaning process, the materials could be placed in an environment with a higher temperature to decrease the viscosity of the oil, making it easier to absorb.

5 Approach to Future Work

Based on the research and data, we have proposed a design involving the use of certain porous materials that are attached to the perimeter of boats in the Gulf of Mexico oil spill. The design is representative of a pillow case. A thick polypropylene sheet or woven fiber cloth which acts as the pillow case will surround cotton balls which act as the pillow. This material will act as rigid wings attached to the side of boats and will be submerged in the seawater. This is so that as the front of the boat separates the water and pushes the waves toward the side of the boat, the polypropylene material will catch the contaminated water. The material will have an opening for easy access to the cotton ball core. The purpose of the opening is so that the cotton can be taken out, strained, and recycled for further use. The polypropylene sheet can then be washed with detergent to remove the oil for reuse.

This design works on the basis of two principles: the hydrophobic quality of the outer sheath, made of the polypropylene sheet; and the high absorbency of the inner core, made of regular, mass-produced cotton. The porous polypropylene sheet will act as the oil-water filter. Its hydrophobicity will repel the seawater while letting in the crude oil into its pores. As a result, the cotton core of the polypropylene sheet will act as the main absorbing mechanism of the device. The high uptake capacity and uptake rate of the cotton make it effective at absorbing oil. The idea of the polypropylene sheet is to ensure that little to no water will be absorbed by the cotton.

6 Conclusions

Currently, the methods used to clean up oil spills have not fully explored materials science. Our research delved into this field by experimenting with porous materials and their absorbency. The results of the first trial concluded that the sol-gels, materials thought to be highly absorbent and oleophilic, were less effective than other materials, since they absorbed more water than oil. In addition, the sol-gels did not absorb more than their own weight in oil. Since the sol-gels were less effective in the first trial, the focus was switched to polypropylene and cotton balls. Polypropylene was tested in the first and second trial and showed promising results both times. In the first trial, Polypropylene absorbed six times its own weight in oil and in the second trial, it absorbed five times its own weight in oil. However, cotton performed the best overall in absorbency, absorbing twenty times its weight in oil and sixteen times its weight in the mixture. Polypropylene fibers, along with cotton balls, proved to be the best examples of porous materials which can be applied effectively toward oil spills. By adopting our proposal, we can clean up the current Gulf oil spill along with future oil spills more efficiently and effectively, creating a cleaner, healthier environment.

7 Acknowledgements

Without the support of the Governors School of Engineering and Technology, this paper would not have been possible. We would like to thank our mentor Professor Lisa Klein, director of the Rutgers Sol-Gel Group, for providing us with guidance and materials. We would like to thank Liz Neubauer, junior in Materials Science and Engineering at Rutgers University; Phiorella Gamboa, senior in Chemical Engineering at Rutgers University; and Lou Gambino, senior in Materials Science Engineering at Rutgers University for their lab demonstrations and advice. We would also like to sincerely thank
our RTA mentor Monal Agrawal for her dedication and encouragement to our research.

We would like to thank Blase E. Ur, GSET Program Coordinator; Ilene Rosen, GSET Program Director; Kristin Frank, Head RTA; Jameslevi Schmidt, Research RTA; Marguerite Beadseley, Chair of the Governor’s School Board of Overseers; and Laura Overdeck, Vice Chair of the Governor’s School Board of Overseers. We would also like to thank the sponsors of the New Jersey Governor’s School of Engineering and Technology for 2010: Rutgers University, the Rutgers University School of Engineering, Morgan Stanley, the State of New Jersey, Lockheed Martin, PSEG, the Tomasetta family, the Provident Bank NJ Foundation, Silver Line Building Products, and the families of Governor’s School alumni for their support in the continuation of the program.

References


