Abstract

Oil spills pose a threat to the environment, and if one occurs, it can be very disruptive to entire ecosystems as well as individual organisms and populations. The purpose of this project was to develop a method of removing the spilled oil from the polluted area after a spill in a manner that is both efficient and nonhazardous to the area. Feathers are known to have a high capacity for adsorbing oil, and they introduce neither synthetic materials nor foreign bacteria that can cause even more harm when they are used to remove oil from water. After the adsorbency capacities of peacock, pheasant, rooster, ostrich, duck, and turkey feathers were tested, it was determined that ostrich feathers were the most adsorbent. Thus ostrich feathers were used to construct the device. Prototypes of two different designs were tested. One contained feathers that were enclosed by a mesh fabric, but the feathers were loose within the confines of the fabric, and the other was similar, but the feathers were sewn in place. Three of each design were tested using motor oil and distilled water, and three of each type was tested using motor oil and distilled water with sea salt added. The adsorbency of each design in both cases was compared to that of the other, and after considering criteria such as how easy they were to make and how adsorbent they were, a decision was made as to which design to choose.

Introduction

Crude oil and petroleum products have numerous modern applications; however, they are often a problematic source of water pollution. Ships and boats can spill the oil into the ocean, which is harmful to the ecosystems in the polluted area. When the oil enters the water, it spreads out on the surface. Some of the oil evaporates, and some of it emulsifies with the water. One major oil spill occurred in 1989 when 42 million liters of crude oil were inadvertently dumped into the Prince William Sound. Approximately thirty percent of the oil evaporated, leaving behind a viscous fluid. As a result of this spill, 2,800 sea otters, 300 harper seals, and 250,000 seabirds were estimated to have died from oil-related causes (Lin & Tjeerdema, 2008, p. 803).

Oil is harmful to marine organisms, especially mammals and birds. The fumes from the oil are toxic, and the inhalation of the vapors can be fatal. The oil can cause other severe health problems in animals, including hypothermia, blood congestion, skin irritation, and digestion of oil (Goethe, 1968, p. 371). These conditions can be caused by the oil adhering to and by being adsorbed by the fur and feathers of animals. Plankton and benthic invertebrates can also be adversely affected by the oil.

The existing methods for removing oil spills are insufficient. These include bioremediation, sorption, and skimming. Even when these methods are employed, the oil still remains in the water for a long enough time to cause harm to the environment. The solution may lie in the problem: feathers are highly capable of adsorbing oil, and they could be used to remove the pollution from the water.

Literature Review

Oil and Oil Spills

When petroleum products are spilled, they spread out into on the surface of the water, forming a layer that is a few millimeters thick. Some of its volatile components evaporate into the air; potentially half of crude oil, three quarters of refined petroleum products, and a tenth of residual fuel oils can evaporate. Also, some components are oxidized by ultraviolet radiation. This process, known as both photolysis and photooxidation, can make the oil more toxic than it previously was (Lin & Tjeerdema, 2008, p. 800). Although less than one percent of the oil becomes dissolved in the water, some water is dispersed in the water. Dispersion is the process through which oil is made into small droplets in the water, where it remains until it is biodegraded, or broken down by bacteria (Kingston, 2002, p. 54). If there are sand or clay particles near the surface, they can adsorb some of the oil. When this happens, the particles sink to the seafloor, along with the oil, where they are biodegraded. In addition, mousse, the viscous material formed by the emulsification of water in oil, can be formed when sea conditions are rough, and it makes the pollution more persistent (Kingston, 2002, p. 55).

The chemical properties of the oil, the location of the spill, and the weather in the area determine what happens to the oil when it enters the environment. The horizontal movement of the oil is dependent on such factors as gravity, surface tension, inertia, and viscosity. How these factors affect the distribution and flow of the oil is not well documented in the article by C. Lin and R. Tjeerdema (2008). In addition, wind, waves, and currents cause the oil to spread out over a larger area. Surprisingly, the oil is not evenly distributed on the surface of the water; ninety percent of it occupies ten percent of its area (Lin & Tjeerdema, 2008, p. 799).

Oil Spills and the Environment

Large quantities of oil, such as those resulting from an oil spill, are very hazardous to marine environments. For example, the fumes from oil evaporation can cause disorientation and brain lesions in marine animals (Lin & Tjeerdema, 2008, p. 803). Because marine birds and mammals require air to survive, they are frequently in contact with the surface of the water. It is for this reason that the oil that floats on top of the water causes a problem. When oil touches the fur or feathers of animals, it adheres to them. This process, know as adsorption, is purely a surface phenomenon (Professor J. Bergendahl, personal communication).

Oiled feathers and fur often result in several serious health issues. For example, drowning and smothering may occur as a result (Lin & Tjeerdema, 2008, p. 803). The oil also impairs the ability of a bird to regulate body temperature because air is removed from between the feathers when they become contaminated with oil. Hypothermia, blood congestion, and the inability to absorb nutrients from food are the results of the inability to regulate boy temperature. In addition, oiled birds preen constantly. Not only is this damaging to the birds, but it can lead to digestion of oil, which is irritating to the skin and digestive tract of birds. Oil also interferes with flying capability. However, in his article, F. Goethe explains neither how the feathers and fur adsorb the oil, nor how the oil causes problems such as drowning, digestive tract irritation, and poor nutrient absorption (Goethe, 1968, p. 371).

Feather Structure

There are six basic types of feathers. Contour feathers smooth the exterior layer of feathers to form a streamline when the bird is flying or swimming. Down feathers, which have plumaceous barbs that lack the hooked cilia that hold the vanes together, help maintain the body temperature of the bird. Also, down is heavier in water birds than in other birds (Proctor & Lynch, 1998, p. 92). Semiplumes also have plumaceous barbs, but unlike down feathers, they have a central rachis which is longer than any of the barbs (Proctor & Lynch, 1998, p. 94). Bristle feathers are hairlike, and they are used to protect the eyes. Filoplumes are located throughout the plumage. They have sensory functions, giving the bird a sense of touch in the plumage. They also aid the bird in finding the location of flight feathers and in determining its flight speed (Proctor & Lynch, 1998, p. 92). Powder feathers, also called powder down, are feathers in which the barbs deteriorate into a fine powder. The exact function this powder is not well understood, but it is hypothesized that they help with both grooming and waterproofing (Proctor & Lynch, 1998, p. 96).

A contour feather comprises several components. There is a central shaft, called the rachis, that has vanes on either side of it. The rachis is almost square, and grooves give it more strength in bending. The bare part of the shaft located at the end of the feather is called the calamus or quill. In a mature feather, this hollow tube has a small opening at the end called the inferior umbilicus. The calamus connects the inferior umbilicus to the superior umbilicus, which is the remainder of the end of the epithelial tube from the early development of the feather. On either side of the rachis are the vanes. The soft, downy part of the vanes is considered plumaceous, and the firm, bladelike part of the vane is considered pennaceous (Proctor & Lynch, 1998, p. 82). Each vane is composed of barbs, which have barbules with cilia on them. The cilia of pennaceous barbules have hooks that hold the barbs to each other, but the plumaceous barbules do not have hooked cilia; therefore, plumaceous barbs do not connect the way that pennaceous barbs do (Proctor & Lynch, 1998, p. 85). In flight feathers, the vanes are asymmetrical. The anterior vane is narrower than the posterior vane, giving the feather an airfoil shape, which aids the bird in flight (Proctor & Lynch, 1998, p. 82).

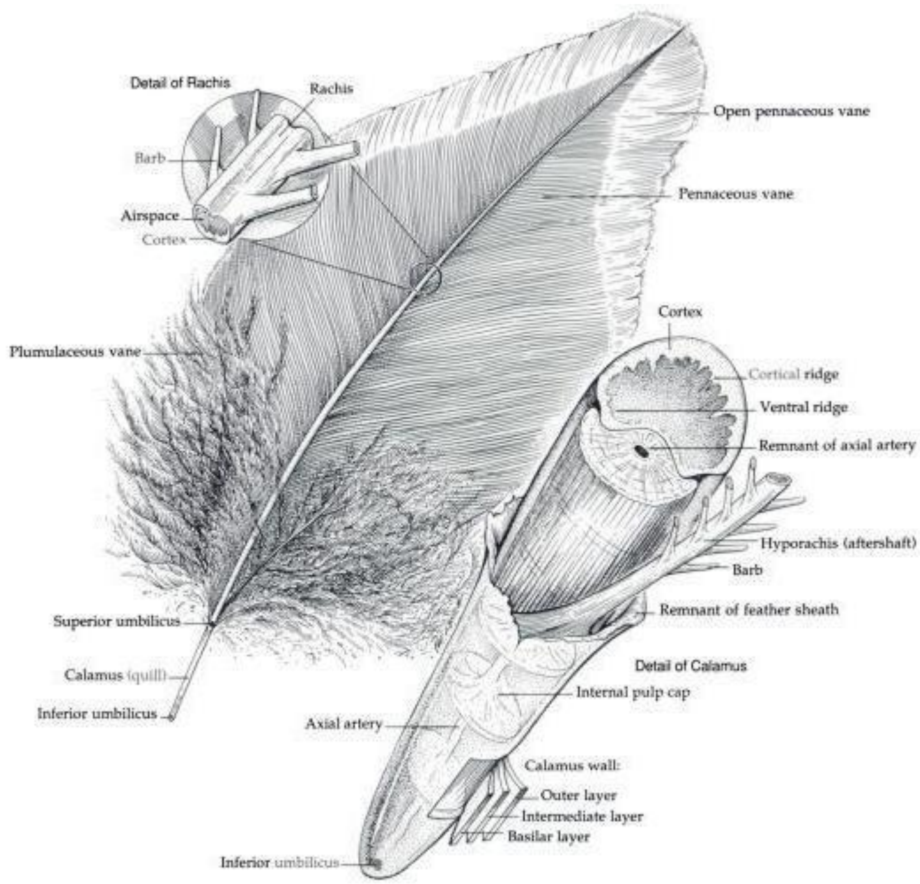

Figure 1. Morphology and Anatomy of a Contour Feather. This diagram shows the structure of a typical contour feather (Proctor & Lynch, 1998, p. 83.

Current Methods of Oil Removal

There are several existing methods for removing oil from water after an oil spill. One common device is known as a boom, which is used as a barrier to contain the oil and to prevent it from spreading out further along the surface of the water. Also, bioremediation is the use of bacteria to break down the oil that pollutes the water. Another method involves skimming the top of the polluted area to reclaim the spilled oil. The sorption of the polluting oil is one more method, where the oil is absorbed or adsorbed by another material (Birkland, 2007, Responding to Oil Spills section, para. 1).

William T. Lafay and William F. Meistrell (patent #4,919,820, 1990) described a new device for containing and removing oil. Their device is a boom that utilizes waterfowl feathers, which are contained by a material that allows the oil to pass through and be adsorbed by the feathers. Their boom plays two roles: it prevents the water from spreading, and it helps to remove the oil from the water. The patent stated that feathers were used because they are highly capable of adsorbing oil; however, the patent did not explain why the feathers have this capability.

Gaps in Technology

Although there are several methods available for the removal of oil, the current processes are not very effective. For example, in the Exxon-Valdez spill, 3,500 dead birds washed ashore (Kingston, 2002, p. 56). If the oil from this spill had been cleaned up faster, there would not have been as many avian deaths. In addition, there are methods for cleaning and saving oiled animals. These techniques, which include washing the animals, do nothing to retrieve the spilled oil.

A review of the literature revealed that the procedures for the extraction and containment of oil are insufficient. For example, bioremediation inserts bacteria into the polluted area, which are difficult to retrieve from the water after they have been introduced. Booms, which are used to contain the oil, do not aid in the removal of the bulk of the oil. Even the booms that contain feathers for oil adsorption only come into contact with the edges of the spill. Thus they are unable to play a large role in the removal of the oil. Skimming the surface of the spill requires much more energy from the people cleaning the spill because they are required to operate the devices. From several of these methods, the oil cannot be retrieved and reclaimed.

Research Proposal

The effect of feathers as a sorbent on the amount of oil in water after an oil spill will be examined. Following an oil spill, water is polluted with oil, which is harmful to the organisms that inhabit the polluted area, and the current methods of removing the oil are insufficient. The goal of this project is to develop a medium to remove the oil and then to test the effectiveness of the new method.

First, the properties of feathers from different species of birds will be studied. They will be examined under a microscope, and their capacity for oil adsorption will be tested. Predetermined volumes of water and oil will be massed using an electronic balance. To simulate the conditions of an oil spill, the measured distilled water and oil will be added to an empty graduated cylinder. A feather and a glass dish will be massed together. Then the feather will be added to the oil-water mixture. After a set period of time, the feather will be removed from the mixture, and the remaining volumes of both the oil and water will be measured. When the feather is removed from the mixture, it will be placed on the dish. Once it dries and the water has evaporated, the tared mass of the oil that was adsorbed by the feather will be taken. This process will be repeated for feathers from several different species of birds. Then the feathers that adsorb the most oil will be tested once more, using the same method, but for a longer period of time. The most adsorbent type of feather, along with sheets of a mesh fabric will then be used in the device. Two sheets of the mesh will be sewn together to make a pocket. The feathers will be inserted into the pocket, which will then be sewn shut. These flat pockets filled with feathers can then be used to adsorb oil by placing them in the polluted area. The prototype will be tested using the previously described method, but with a couple of changes. Because the device will be larger than a single feather, it will be tested in a glass beaker, which can also be used to measure volume. Several trials will be conducted, each of which will have a different duration. After the trials, the data collected will be analyzed, and any necessary changes to the device will be made. Throughout all the trials, the temperature will be kept constant, and the water will remain stationary.

Methodology

The materials used were untreated feathers: (peacock [Genus: *Pavo*] sword, rooster [*Gallus domesticus*], duck [Family: *Anatidae*] pointer, turkey [Genus: *Meleagris*] quill, pheasant [Family: *Phasianidae*] golden redtops, and ostrich [*Struthio camelus*] drab), motor oil (Castrol brand, GTX Drive Hard, SAE 10W-40; Mobil brand, Drive Clean Oil, SAE 10W-30), distilled water, thread, four mesh laundry bags (American Plastics brand, Style # 6151), twelve clear plastic Petri dishes, twelve paper plates (Dixie brand, 21.91 cm), twelve plastic weighing boats, and twelve foil baking pans (Handi-Foil Bake America brand, Ultimates Cake Pans, 20.3 cm x 20.3 cm x 3.7 cm). The equipment used was a 210 g electronic balance (Flinn Scientific, Inc Brand, model OB2088), a sewing machine (Kenmore brand, model 385.15212, obtained from Sears, Roebuck, and Co.), a plastic ruler, a pair of scissors, and four 250 mL graduated cylinder.

A turkey feather was cut 5 cm from the dorsal end of the rachis twice, and the two 5 cm segments were put aside. Two pheasant feathers were cut 5 cm from the end of the rachis twice, and a third pheasant feather was cut 5 cm from the dorsal end of the rachis once. These five pieces were also put aside. Next, three 5 cm segments were cut from the dorsal end of a duck feather and were set aside. A peacock feather was also cut twice 5 cm from the dorsal end of the rachis, and the segments were put to the side. The same procedure was then with an ostrich feather. Afterward, two rooster feathers were each cut 5 cm from the dorsal end of the rachis twice. The tared mass of the segments of turkey feathers was taken, as was the tared mass of 20 mL of distilled water and 15 mL of oil. The liquids were then added to a weighing boat. These feathers were added to the oil-water mixture. After five minutes, the feathers were removed from the mixture. The tared masses of both the mixture and the oil-soaked feathers were taken. The tared mass of the oil absorbed by the feather was taken. This process (starting with taking the tared mass of the feather segments) was repeated with each of the other types of feathers. The entire process was repeated with new feathers, using the same method, to confirm the results, and also without the oil to determine how much water the feathers adsorbed in the same amount of time. Four 20 cm by 20 cm squares were cut from the laundry bag so that each square was made of two layers of mesh joined at least one side. Two of the squares were then turned inside out and sewn around the outside, beginning with the side that was already sewn or folded and leaving an eight centimeter opening on one of the disconnected sides. The pockets were then turned back the right way, and five ostrich feathers were inserted into the pockets, which were then sewn closed. Five feathers were arranged between the two layers of each of the other two squares, and then the perimeter was sewn closed so that the feathers were secured in place by the stitching. This was repeated with three more laundry bags, to make a total of twelve of each design. Then, three of each design were tested in distilled water. For each trial, 200 mL of distilled water and 75 mL of the Mobil motor oil were added to an empty baking tin. A different type of oil was used because the supply of the Castrol motor oil was depleted. The tared mass of the liquid mixture and the tared mass of the device that was being tested were taken. The device was then placed on the surface of the mixture, and after five minutes, it was removed from the mixture and placed on a paper plate. The tared mass of the oil soaked device was taken. After this was done for three of each design, it was done once more with the remaining three prototypes of each type. However, in each of these six trials, 7 g of sea salt was added to the 200 mL of water before anything else was done. The data collected was then analyzed and a choice was made regarding the design.

Results, Data, and Discussion

Table 1 and Figure 2 refer to the preliminary testing that was done to determine which type of feather should be used in the device.

Feather Type	Duck	Turkey	Ostrich	Pheasant	Peacock	Rooster
Feather Mass (g)	0.15	0.15	0.10	0.10	0.10	0.10
Mass of Oil Adsorbed (g)	2.40	2.30	6.05	1.50	2.20	2.05
Oil Adsorbed per Gram of Feather (g)	18.25	17.00	60.50	15.00	22.00	20.50

Table 1. Average Oil Adsorption of Different Feathers. This table displays the average mass of the feathers used in testing, the average mass of the oil adsorbed, and the average ratio of the mass of the oil adsorbed to the mass of the feathers.

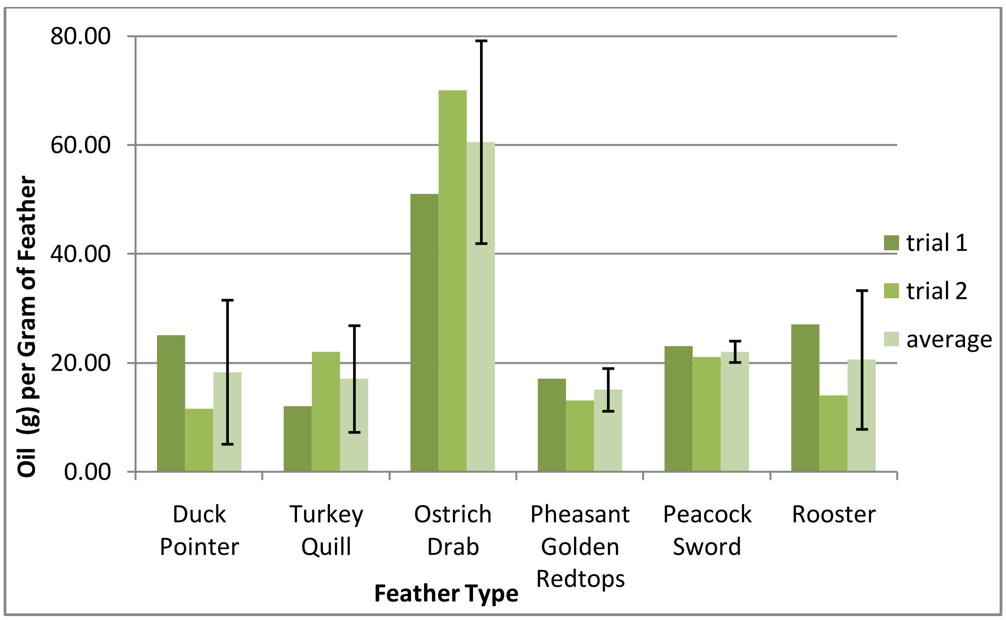

Figure 2. Ratio of Mass of Oil Adsorbed to Mass of Feather. This graph shows the ratio of the mass of the oil adsorbed by the feather to the mass of the feather itself for two trials and for the average of the two.

As clearly indicated by Table 1 and Figure 2, ostrich feathers have a much greater affinity for oil than the other feather types that were tested. The average mass of oil adsorbed per gram of feather is 60.50 g. The next greatest value was 22.00 g of oil for a peacock feather. When the ninety five percent confidence intervals are considered, the minimum value of that for the ostrich feathers is 41.88 grams of oil per gram of feather, while the maximum values of that for the other feathers range from

18.00 to 33.24 grams of oil per gram of feather; this shows that the ostrich feathers are consistently more adsorbent than the other feathers. Because the ratio for the ostrich feathers was so much greater than that for other feather types, the feathers used in the device were ostrich feathers.

	Distilled Water						Salt Water					
	trial 1	trial 2	trial 3	avg	st dev	95% CI	trial 1	trial 2	trial 3	avg	st dev	95% CI
sewn: mass (g)	3.80	3.80	4.80	4.13	0.58	0.65	4.10	4.40	4.10	4.20	0.17	0.20
sewn: mass after (g)	32.80	38.80	39.80	37.13	3.79	4.28	63.30	61.70	54.40	59.80	4.74	5.37
sewn: oil adsorbed (g)	29.00	35.00	35.00	33.00	3.46	3.92	59.20	57.30	50.30	55.60	4.69	5.30
loose: mass (g)	4.10	3.80	4.00	3.97	0.15	0.17	4.00	4.40	4.00	4.13	0.23	0.26
loose: mass after (g)	33.80	38.80	53.80	42.13	10.41	11.78	49.70	51.10	51.70	50.83	1.03	1.16
loose: oil adsorbed (g)	29.70	35.00	49.80	38.17	10.42	11.79	45.70	46.70	47.70	46.70	1.00	1.13

Table 2. Oil Adsorption of Each Design. This table displays data from the three trials performed using distilled water, the three trials using salt water, and the averages from each test. The mass of the prototypes before and after the trial and the mass of the oil adsorbed were all measured.

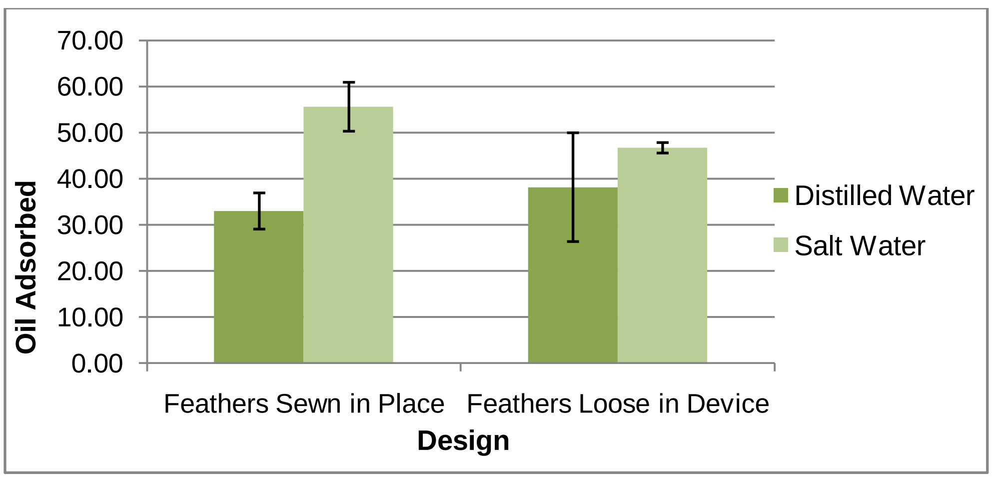

Figure 3. Average Oil Adsorbed by Each Prototype. The average amount of oil adsorbed by each design of the prototype in both distilled water and salt water tests is represented in this graph.

Table 2 and Figure 3 both show the amount of oil adsorbed in the trials performed in distilled water and in salt water. The tests in distilled water revealed that the design with loose feathers contained by the mesh fabric was more efficient at removing the oil, but the tests in salt water showed the opposite result. The difference in the amount of oil adsorbed was greater in the trials conducted in salt water than those done in distilled water. The most probable cause is that the salt increased the density of the water, and that this caused more of the oil to remain on the surface of the water. Because there was more oil on the surface, it spread out to cover a larger area. The arrangement of the feathers in the design in which they are sewn in place allowed the feathers to span a greater area on the surface of the liquid. Also, the prototypes were all made with the same amount of fabric, but the ones with the loose feathers were constructed like a pillow, meaning that they were sewn inside out and then turned the right way. This gives them shorter side lengths and also less surface area in contact with the oil than the other prototypes. This would not have caused as much of a problem in distilled water because the area of the oil on the surface was much less than in salt water. The results suggest that the design with the feathers sewn into place would be more efficient as a means for removing oil in the event of a real spill.

Conclusions

The environmental and ecological hazards of an oil spill can be prevented by removing the oil as soon as possible. This experiment has shown that feathers can be used to do this. Of the feathers that were tested, the most adsorbent were the ostrich feathers. The engineering goal was to develop a method to remove the oil using the feathers, and it was met in the course of the project. Two solutions were designed, constructed, and tested. The efficiencies of the design were similar, but the one with the feathers sewn in place was slightly more adsorbent in salt water and easier to construct. These two criteria were used to decide on a final design: two pieces of mesh fabric with feathers sewn in place between the two sheets.

Limitations and Assumptions

This project had numerous limitations. Time and space was a great restraint, limiting the construction and testing of a full size prototype under realistic conditions. In order for the device to be useful in an actual spill, it is necessary for it to be much larger than the prototypes constructed. To accommodate this problem, the twenty centimeters by twenty centimeters devices can be joined to each other to produce a larger, more useful prototype. Also, the testing was done with motor oil rather than with crude oil, and the crude oil may interact differently with the feathers; however, crude oil is much harder to obtain and much more expensive than motor oil. In addition, there was not enough time to test several variations of the design or to test whether they are washable and reusable.

Several assumptions were made as well. For example, it was assumed that feathers would have a comparable affinity for the sorption of motor oil as they do for crude oil and other types of oil. Another was that all feathers have the same basic exterior chemistry, and that the β-keratins of all feathers are similar. Also, the presumption that the salt would affect all feathers in the same manner was made. A final assumption was that the relative adsorption capacity for each design would be the same if the size of the device were increased.

Applications and Further Experiments

The project lends itself to many possible further experiments. For instance, the device can be tested in a solution in which the water is moving to simulate waves. This would show the effects of rough waters on the efficiency of the device. Another would be to test the amount of time it requires to adsorb the maximum amount of oil. Also, the size of device and the number of feathers used can be varied, and their relationship with the amount of oil adsorbed can be investigated. Another extension would be to determine whether the device can be reused if it is cleaned between uses.

The project can be used in the real world in the case of an oil spill. In fact, the device was designed specifically for this application. Larger models and models attached to each other can be used to adsorb the bulk of the oil that is spilled into any body of water. When a spill occurs, it is important to remove the oil as soon as possible, and this device allows for that to happen.

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