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Article

From trash to treasure: A sustainable approach to oil spill clean-up

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SUMMARY

Oil spill clean-up is a colossal and pressing problem in our world today. About 1.5 million gallons of oil are spilled each year and millions of dollars are spent to clean-up the spilled oil. These spills also harm marine animals and pollute drinking water. Due to these detrimental environmental effects, cleaning up oil spill is imperative. Finding an effective method to combat these oil spills will greatly reduce the amount of damage and the cost of oil spill clean-up. We examined the ability of two plant-based biodegradable sorbents, water spangle leaves (*Salvinia minima*) and milkweed fibers (*Asclepias syriaca*) to retain oil in fresh and salt water conditions. We hypothesized that milkweed fibers would be more effective than water spangle leaves for oil spill clean-up due to its hydrophobic, oleophilic nature and its tubular structure. In addition, we assessed milkweed fibers for their recovery and reusability by recovering the absorbed oil using a vacuum filter unit. Our results indicate that milkweed fibers are a more effective sorbent than water spangle leaves and could be reused multiple times. Interestingly, we also found that milkweed fibers were able to absorb oil up to 40 times of its weight. The results from this study will help find an eco-friendly and cost-effective solution for oil spill clean-up using natural, biodegradable sorbents.

INTRODUCTION

Oil spills cause far-reaching environmental damage and are a major threat to our world today (1). In 2016, the Center of Documentation, Research and Experimentation on Accidental Water Pollution reported the weight of oil spilled ranged between 10 and 100 tons globally (2). The largest spill to-date happened between August 1990 and February 1991, when 460 million gallons of oil were spilled in the Persian Gulf, extending for 65 kilometers across the coastline and 49 square kilometers in the Kuwait desert (3). Gasoline and diesel oil are destructive and harmful to water and marine animals, and they have a wider impact on the public health and community (4).

Oil spill clean-up is a major challenge and an expensive, labor-intensive process. The common clean-up methods are burning, skimmers, dispersants, biological agents, booms and synthetic polymers. Burning causes toxic gas and environmental pollution (5). Skimmers are a variety of mechanical equipment that physically remove floating spills from the water surface. They are effective, but are yet to be tested properly (6). Dispersants breakup the oil layer into tiny droplets that can be removed via water columns; however, dispersants are detrimental to marine life as they spread the oil out across a larger surface area (7). Biological agents are environmentally friendly but highly unpredictable and hard to control (8). Booms are used to contain and control the spread of oil but are not effective to clean up oil spills (5,6). Use of synthetic polymers (e.g., polypropylene) are ideal for oil spill cleanup due to their low density, low water uptake and preferred chemical and physical resistance (9). However, these sorbents are not renewable or biodegradable (10).

Using natural sorbents is a more beneficial, ecofriendly, effective, and economical method over other common clean-up methods. Aquatic floating weeds, such as water spangle leaves (*Salvinia minima*), are very efficient in absorbing oil due to their superhydrophobic trichome-covered (highly water repelling hair-like) surface (11). Depending on the physical properties of the oil, water spangle leaves can absorb oil within seconds (12). Another natural oil sorbent, milkweed fibers (*Asclepias syriaca*) has been proven to have the highest oil absorption capacity against crude oil when compared to cotton or wool (13). The surface of these fibers is hydrophobic-lyophilic, demonstrating superior water repellency and oil absorbency (14). Depending on the oil properties, milkweed fibers can absorb oil up to 40 times its weight (14).

In this study, we compared the efficiency of water spangle leaves and milkweed fibers in oil absorption under different temperatures using two different oils in fresh water and saltwater conditions. In addition, we investigated the reusability of milkweed fibers to propose an environmentally friendly solution to remove, recover and reuse oil from a spill.

RESULTS

Oil Removal by Water Spangle Leaves and Milkweed Fibers – Time Optimization Experiment

Oil spills happen in both fresh water and saltwater bodies. We tested effectiveness of oil removal in both fresh water and saltwater conditions. Since this experiment was performed for optimization purposes, considering the environmental reasons, only vegetable oil was used.

To determine the optimal time needed to absorb oil by water spangle leaves and milkweed fibers, we placed these natural sorbents in a water-oil mixture for 1, 15, 25, 45 and 60 minutes.

With water spangle leaves in both saltwater and fresh water, the oil absorption remained a plateau between 25 and 45 minutes and started decreasing afterwards (**Figure 1**). Thus 25 minutes was optimal for water spangle leaves to absorb vegetable oil from saltwater or fresh water. Milkweed fibers in both salt and fresh water absorbed oil the most optimally at 25 minutes remained in a plateau up to 60 minutes (**Figure 2**). Thus 25 minutes was optimal for milkweed fibers to absorb vegetable oil from saltwater or fresh water. Unlike water spangle leaves, oil absorption did not decrease with

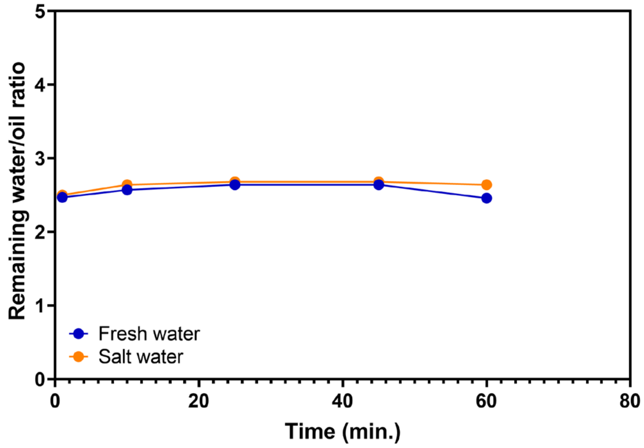

Figure 1. Optimal time for efficient sorbent oil recovery for vegetable oil using water spangle leaves. Water/oil ratio remaining was recorded at 0 min, 10 min, 25 min, 45 min, and 60 min in saltwater (orange circles) and fresh water (blue circles). Optimal oil absorption occurred at 25 minutes and started to decline after 45 minutes.

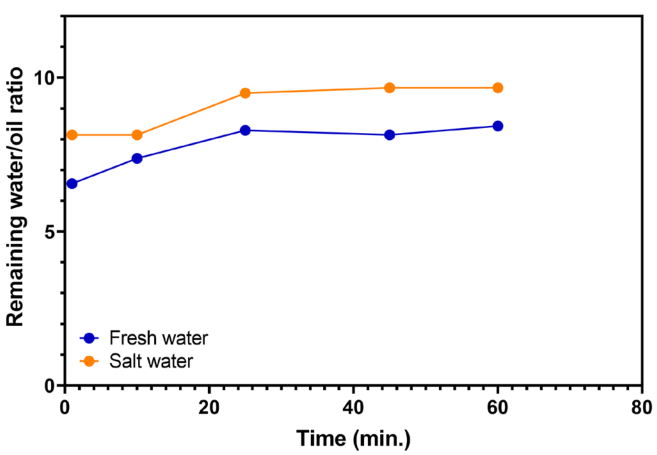

Figure 2. Optimal time for efficient vegetable oil removal using milkweed. Water/oil ratio remaining was recorded at 0 min, 10 min, 25 min, 45 min, and 60 min in saltwater (orange circles) and fresh water (blue circles). Optimal oil absorption occurred at 25 minutes and remained in a plateau up to 60 minutes. Oil absorption was more pronounced in saltwater conditions.

milkweed fibers. In addition, the magnitude of oil removed by milkweed fibers were approximately three to four times higher than that of water spangle leaves.

Effect of Temperature and Oil Type on Absorption

To further analyze the efficacy of the sorbents in removing oil, we tested two kinds of oil (vegetable and motor) at three different temperatures (5°C, 20°C, and 38°C) (**Table 1**). Absorption of vegetable oil by water spangle leaves was comparable in fresh water and saltwater at all temperatures (**Figure 3A-B**). Water spangle leaves were marginally more effective at removing motor oil from saltwater than fresh water at all temperatures (**Figure 3C-D**). Oil absorption by milkweed fibers was more pronounced in saltwater than fresh water (**Figure 3C-D**). Milkweed fibers were more effective in removing motor oil compared to removing vegetable oil

Sorbent	Oil Type	Water Type	Temperature (°C)	Remaining water to oil ratio* after 25 minutes
Water spangle leaves	Vegetable	Fresh	5	2.55
			20	2.64
			38	2.39
		Salt	5	2.48
			20	2.68
			38	2.30
Water spangle leaves	Motor	Fresh	5	2.55
			20	2.48
			38	2.39
		Salt	5	2.89
			20	2.64
			38	2.67
Milkweed fibers	Vegetable	Fresh	5	7.71
			20	8.29
			38	6.22
		Salt	5	9.00
			20	9.50
			38	7.43
Milkweed fibers	Motor	Fresh	5	11.20
			20	13.25
			38	10.40
		Salt	5	26.00
			20	27.00
			38	26.50

Table 1. Effect of Temperature on Oil Removal. *To rule out any errors associated with water absorbed by the sorbents, a water:oil ratio is utilized.

(**Figure 3B-D**). Overall, in all conditions, milkweed fibers were more effective (approximately 3 to 10 times) in oil removal compared to water spangle leaves.

Oil Recovery and Reusability Test

The experiments performed thus far have shown milkweed fibers to be superior to water spangle leaves in oil removal. Therefore, we also tested oil recovery and reusability of milkweed fibers. For environmental reasons, vegetable oil was used in the oil recovery and reusability experiment. We found milkweed fibers could be reused more than 12 times in fresh water (**Figure 4**) and 15 times in saltwater (**Figure 5**) before the oil recovery was reduced to 50%. During the reusability test, the amount of vegetable oil recovered ranged from 46% to 86% for fresh water and 54% to 94% for saltwater (**Figure 6**). Overall, average oil recovery after 15 uses was 59.7% in fresh water and 72.5% in saltwater (**Figure 6**).

DISCUSSION

Oil spills can damage environment and the clean-up is an expensive, labor-intensive process. Natural sorbents, such as water spangle and milkweed fibers, can be ecofriendly, effective, and economical method for oil spill cleanup. Water spangle leaves are very efficient at absorbing oil due to their superhydrophobic trichome-covered surface, and milkweed fibers have been proven to have the highest oil absorption capacity due to hydrophobic-lyophilic properties (11,14). In this study, we compared the efficiency of water spangle leaves and milkweed fibers in oil absorption under different temperatures using two different oils in fresh water and saltwater conditions.

In both fresh water and saltwater conditions, 25 minutes was optimal for water spangle leaves to absorb oil. The oil absorption plateaued at 45 minutes and started to decline (**Figure 1**). Results for oil absorption were similar with milkweed fibers in that both fresh water and saltwater conditions, 25 minutes was optimal to absorb oil, and oil removal was more pronounced in saltwater conditions. However, the oil absorption remained in plateau for up to 60 minutes with no decline (**Figure 2**). The

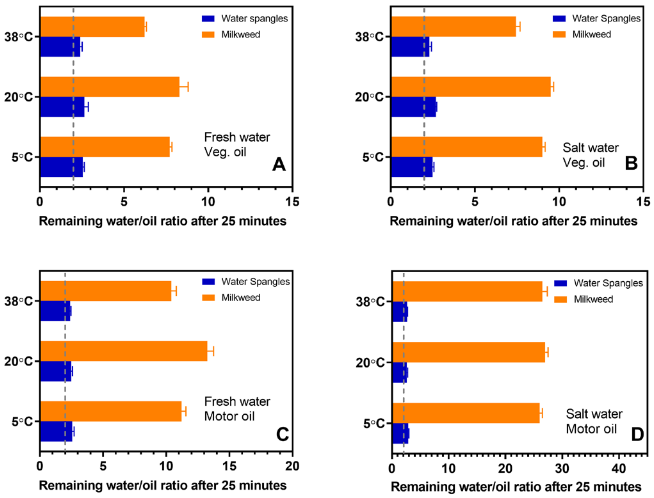

Figure 3. Comparison of sorbent properties at various temperatures. Water/oil ratio remaining after absorption by water spangle leaves or milkweed fibers at various temperatures (5°C, 20°C, and 38°C). **A)** Vegetable oil removal from fresh water by the sorbents**. B)** Vegetable oil removal from saltwater by the sorbents**. C)** Motor oil removal from fresh water by the sorbents. **D)** Motor oil removal from saltwater by the sorbents. Dotted lines indicate the initial water/oil ratio. In all conditions tested above, milkweed fibers absorbed oil more efficiently when compared to water spangle leaves. All experiments were performed in triplicates.

results suggest that the milkweed fibers were 3 to 10 times superior in oil removal (as measured by the remaining water/oil ratio) when compared to water spangle leaves at all tested temperatures (5°C, 20°C, and 38°C) (**Figure 3**).

Ideally, a natural sorbent used for oil spill cleanup should have high hydrophobicity, oleophilicity, uptake capacity, and retention. Sorbent construction (fiber diameter and porosity) can also play an important role in oil retention (15). Aquatic floating weeds such as water spangle leaves are effective in oil absorption due to their superhydrophobic trichome covered leaf surface (16). These leaves are water-repellent and are selective in absorbing oil from oil-water mixtures (17). Trichome height and architecture play a role in oil absorption capacity (12). Even though water spangle leaves have been shown to possess superhydophobic properties, their oil retention has not been demonstrated.

On the other hand, milkweed fibers have been shown to be superior in oil spill cleanup due to their oil sorption, capacity, oil/water selectivity, reusability and oil retaining ability (18). Milkweed fibers are ligno-cellulose fibers containing hollow tubular interior with a wax-coated surface. It has also been shown that oil can penetrate the hollow interior due to the capillary pressure (14). Furthermore, greater than 90% of the total volume of the milkweed fiber is empty lumen, providing more void volume to absorb oil (14). Surprisingly, 1 gram of milkweed fiber can absorb 40 grams of crude oil (19).

Milkweed fibers tended to absorb more oil from saltwater than fresh water, likely due to the presence of salts and ions, which may reduce electrostatic repulsion (20,21). Furthermore, the solubility of organic compounds may be reduced in salt solutions due to 'salting-out' effect, leading to more absorption of oil by the sorbent (22,23). The sorbents were more effective in removing motor oil than vegetable oil, possibly due to the higher viscosity of motor oil which increases the adherence of oil to sorbents (24,25).

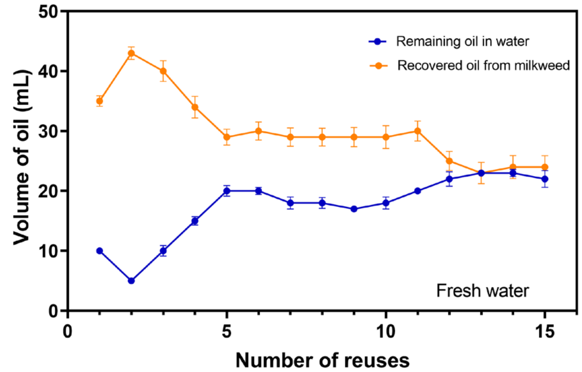

Figure 4. Oil Recovery by and reusability of milkweed in fresh water. Volume of oil remaining in fresh water, and the volume of vegetable oil recovered from milkweed fibers, versus its number of uses (n=3). Milkweed fibers could be reused more than 12 times in fresh water before the oil recovery was reduced to 50%.

In this study, we also considered sorbent reusability. A sorbent is considered reusable if the absorbed oil can be effectively removed by compressing or squeezing the sorbent, after which the sorbent regains its original size and shape (13). About 89% of the oil absorbed by milkweed fibers from the saltwater-oil mixture and about 70% of the oil absorbed by milkweed fibers from the fresh water-oil mixture was recovered by simple mechanical action using a Buchner funnel kit (**Figure 6**). Even with 15 uses, we recovered an average of 72.5% of absorbed oil from the saltwater-oil mixture and 59.7% of the absorbed oil from the fresh water-oil mixture, further highlighting the value of using milkweed fibers as an oil sorbent (**Figure 6**). Oil recovered by vacuum filtration and this method allows reusability of oil from the spill and milkweed fibers from the clean-up.

Natural milkweed fibers have great potential to replace synthetic oil sorbents as they are eco-friendly and cost-effective for oil spill clean-up. The characterization of sorbents with and without oil should be performed using scanning electron microscopy; which would enable us to understand the morphology of the sorbent and understand the absorption mechanism. Similarly, Fourier transform infrared (FTIR) analysis would enable to understand the mechanism of absorption at the molecular level.

MATERIALS AND METHODS

Creating Water-Oil Mixtures

To make the saltwater stock, 50 grams of Supremo Italiano sea salt was mixed in 3 liters of Poland Springs natural spring water. The fresh water stock consisted of 3 liters of Poland Spring water. To make the water-oil mixtures, a test tube (36 mL capacity) was filled with 14 mL water and either 7 mL Mazola corn oil or 7 mL Pennzoil SAE 10W-30 fully synthetic motor oil. The initial water and oil levels, as well as the initial total fluid level were recorded (in cm).

Oil Absorption by Sorbents

For the oil absorption assays, 0.1 g of live water spangle leaves (Amazon) or dry milkweed fibers (eBay) were added to the water oil mixture and incubated at room temperature (20˚C) for the indicated amount of time. At the desired timepoints (one tube per each timepoint), the sorbent was removed from the

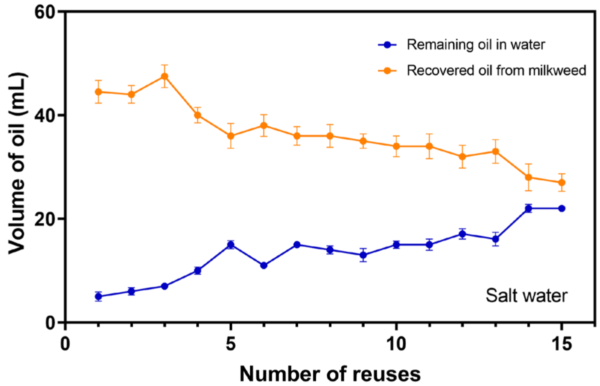

Figure 5. Oil Recovery by and reusability of milkweed in saltwater. Volume of oil remaining in saltwater, and the volume of vegetable oil recovered from milkweed fibers, versus its number of uses (n=3). Milkweed fibers could be reused more than 15 times in saltwater before the oil recovery was reduced to 50%.

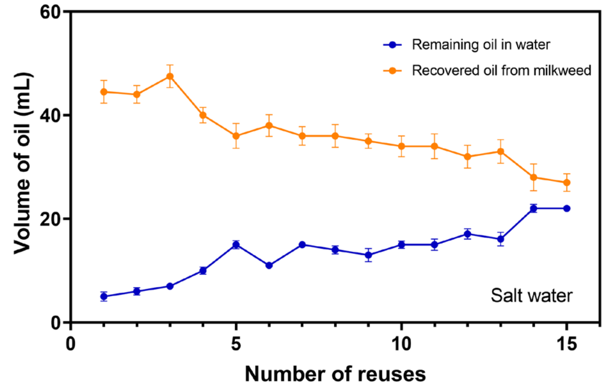

Figure 6. Comparison of oil recovery by and reusability of milkweed in fresh water and saltwater. Percentage of vegetable oil recovered from saltwater and fresh water using milkweed fibers versus its number of reuses. This experiment was performed in triplicates. The amount of vegetable oil recovered ranged from 46% to 86% for fresh water and 54% to 94% for saltwater. Overall, average oil recovery after 15 uses was 72.5% in saltwater and 59.7% in fresh water.

test tube using a tweezer. The remaining water level (in cm) (A) and the remaining oil level (in cm) (B) were recorded. The remaining water to oil ratio was calculated as (A/B). Where indicated, the temperature was modified by performing the experiment in a refrigerator (5˚C) or in a conventional oven (38˚C). All experiments were performed in triplicate.

Recovery and Reusability Tests

For recovery and reusability tests, 9 oz plastic clear cups were filled with 50 mL vegetable oil and 100 mL water and oil levels were recorded. 0.7 g of milkweed fibers was then added to water-oil mixture and incubated at room temperature for 25 minutes. Oil was extracted out of the milkweed fibers using a Buchner funnel kit and a vacuum pump. The oil removed and recovered was measured (using graduated cylinder) and weighed (in a weighing scale). A new cup was used each time to minimize the errors associated with the oil remaining in the cup with reuse. This step was repeated 15 times to test the reusability of milkweed fibers. All the experiments were performed in triplicate.

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