Investigating the use of plastic waste to clear up oil spills

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Abstract

Oil spills and plastic pollution are serious issues with severe environmental impacts. Current oil spill cleanup methods include burning, using dispersants bioremediation, which are often limited in effectiveness and expensive. This study proposes the use of two types of plastic waste (expanded polystyrene and expanded polyethylene) in clearing up oil spills. The effect of stearic acid coating on the plastic wastes' hydrophobicity and oil absorption capacity in both pure oil and oil-seawater environment was investigated. Stearic acid coating improved the hydrophobicity of both plastic wastes but not their oil absorption capacity. However the plastic wastes without modification have high oil absorption capacity and outperformed several other oil sorbents such as feather and wheat straw. Expanded polyethylene which has higher oil absorption capacity than expanded polystyrene shows promise to be used as an absorbent to clear up oil spills.

1.   Introduction

In this modern age, fossil fuels are the most widely used energy source. As much as 10 million tonnes of petroleum products and derivatives are consumed daily worldwide (Abdullah, Rahmah, & Man, 2010). Owing to the large demand for oil, enormous amounts of it are drilled out of the ground and transported around the world to where it is wanted, often by ship. During this transportation or during the extraction process, accidents may occur, spilling large amounts of the oil into the ocean. Approximately 1000 tonnes of oil was spilled into the ocean in 2019 (ITOPF, 2019). It is undeniable that these oil spills cause a large impact on the environment. The oil coats the plumage of seabirds, rendering the creatures unable to take flight and float, causing them to starve or drown. The oil also affects the insulation ability of their feathers, causing many more to die from hypothermia (Nasar & Jones, 2012). Oil spills also cause significant harm to animals under the surface. Toxic oil compounds can poison the small and vulnerable young of the fish, either killing them immediately or causing all kinds of devastating effects as they grow up, having long-term effects on the fish population (Langangen et al, 2017).

Three of the currently used methods of dealing with oil spills include: in-situ burning, oil dispersants and bioremediation. However, bioremediation takes very long (Dave & Ghaly, 2011), in-situ burning releases harmful pollutants, such as carbon monoxide, sulfur dioxide, nitrogen dioxide and particulate matter (Fritt-Rasmussen, Brandvik, & Villumsen, 2012),

and the use of dispersants are expensive and not environmentally friendly (Page, Bonner, McDonald, & Autenrieth, 2002).

Plastics are one of the many products produced from petroleum. First invented in 1862, there are now a wide variety of types, with numerous different uses such as packaging, construction and textiles, and as components in electronics (Gilbert, 2017). One of the types of plastic products are plastic foams. By heating and blowing air into plastic resin, foams of thin cells filled and surrounded with many air spaces can be produced (Altan, 2018). Due to the many air spaces, they have low-densities and reduced thermal conductivity and yet are reasonably strong (Altan, 2018). Therefore, they are popular for purposes like thermal insulation, fireproofing, and for packaging (Altan, 2018). Familiar sights such as the expanded polystyrene foam used in packaging electronic products and for keeping drinks and ice cream cool, the extruded polystyrene foam (styrofoam) used for packing food and even the expanded polyethylene nets used to protect fruits and wine bottles from damage demonstrate how widely used they are. As much as 8.3 billion tonnes of plastics had been produced globally by 2015. However, between 1950 and 2015, only 9% of plastic waste was recycled, 12% was incinerated, and a shocking 79% has accumulated in landfills and the environment (Geyer, Jambeck, & Law, 2017). The discarded plastic items result in land and marine pollution, accumulating on sandy beaches and the seabed, as well as in mangrove forests, and coral reefs (NOAA, 2016). The chemical structure of most plastics renders them resistant to degradation, and as a result, they are slow to degrade. Moreover, low price and durability resulted in a high level of production of plastics. Together, these two features have brought about a high prominence of plastic pollution in the environment.

In an attempt to alleviate both issues at once, studies have started to investigate the secondary use of plastic foam waste as an oil sorbent material for cleaning up oil spills (Patil et al, 2018; Yu et al, 2019). Because plastic foams are organic polymers made from petroleum, they are by nature hydrophobic and oleophilic (Patil et al, 2018). This allows them to absorb less water and more oil, wasting less space and rendering them more effective in cleaning up oil spills on water. Furthermore, since they are highly porous, they can absorb large amounts of spilled oil per unit mass.

Objectives and Hypotheses

This study proposes the secondary use of two types of plastic foam wastes (expanded polyethylene and expanded polystyrene) as oil absorbents. The oil absorption capacity of the plastic wastes in pure oil and oil-seawater environments were investigated. They were also physically coated with stearic acid in an attempt to enhance their hydrophobicity and oil absorption capacities.

It is hypothesised that both types of plastic foam waste are hydrophobic with water contact angle exceeding 90°. Both types of plastic foam waste are effective at absorbing diesel oil in a pure-oil and an oil-seawater environment. Coating the plastic foam waste with stearic acid was also expected to enhance its hydrophobicity and improve its oil absorption capacity.

2.   Materials and methods

2.1   Materials

Expanded polystyrene (EPS) was obtained as leftover packaging material (e.g. for appliances), and expanded polyethylene (EPE) nets were collected from fruit stalls. Stearic acid was procured from GCE Chemicals. Diesel was purchased from the petrol kiosk.

2.2   Preparation of waste plastic samples

0.2g of plastic waste was used in each sample. The EPE (expanded polyethylene) nets were cut into diamond shapes (figure 1), and 0.2g of the diamond-shaped EPE were weighed out per sample. The EPS (expanded polystyrene) was broken into 3 cubes of similar dimensions per sample, with a total mass of 0.2g. Each cube had a length of approximately 1.3cm (Figure 2).

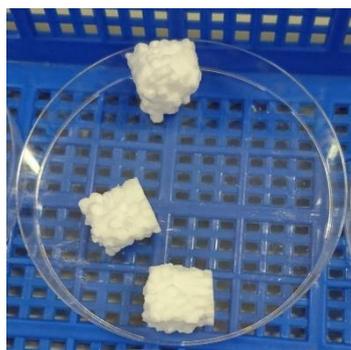Figure 1. An example of a diamond-shaped of EPE

Figure 2. EPS being cut into pieces of similar dimensions

2.3   Characterization

The plastic wastes were characterized using a Scanning Electron Microscope (SEM) to understand their morphology.

2.4   Modification of plastic waste via stearic acid coating:

0.2 g of each plastic waste was cut into similar dimensions and added to stearic acid solution (2.5 g in 50 ml ethanol). As the plastic waste tended to float, a smaller beaker was used to keep the plastic waste fully immersed in the stearic acid solution (Figure 3).
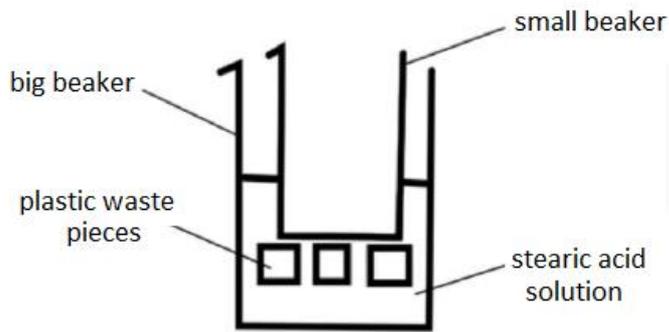
Figure 3. Set up for coating of stearic acid onto the plastic waste

The plastic waste pieces were soaked in stearic acid solution for 1 day, after which they were dried in the oven. Final mass of plastic waste pieces was measured to determine the amount of stearic acid coated.

2.5 Measurement of water contact angle

The water contact angle of the plastic foam wastes were measured to evaluate their hydrophobicity. A small piece of plastic waste/stearic acid coated plastic waste was placed on a glass slide. A drop of deionised water was dripped onto the plastic before a image was captured with a USB digital microscope camera. The software *DinoCapture* was then used to measure the water contact angle as shown.

Figure 4. How water contact angle is measured

2.6 Water absorption test

As a further test of hydrophobicity, the water absorption capacities of the plastic foam waste was evaluated. 50ml of deionised water was measured using a measuring cylinder and transferred into a beaker, and a sample of plastic waste (0.2 g) was placed inside. Because the porous plastic foam floated, a smaller beaker was placed into the larger one over the plastic waste, keeping it fully immersed in the water. The set-up was similar to the one illustrated in Figure 3. The set-ups were then left for 1 hour, after which the smaller beaker was removed, and the plastic foam waste pieces were sieved to drain off the excess oil before weighing them on an analytical balance. Triplicates were conducted for EPE, EPS, stearic acid coated EPE, and stearic acid coated EPS.

2.7 Oil absorption (pure oil environment)

In a similar manner to the water absorption test, 50ml of diesel was measured using a measuring cylinder and transferred to a beaker. A sample of plastic waste (0.2 g) was added into the beaker containing the diesel and a smaller beaker was used to keep the plastic waste

in full contact with the diesel. After 1 hour, the plastic pieces were removed and their mass was measured using an analytical balance.

2.8 Oil absorption (oil-seawater environment)

This experiment was conducted to evaluate the effectiveness of the plastic waste in a simulated oil spill. Firstly, artificial seawater was prepared by dissolving 56g of sodium chloride, 17g of magnesium chloride, 8.19g of magnesium sulfate, 2.5g of calcium sulfate 2g of potassium chloride in 2 litres of deionised water (Thio et al, 2012).

100ml of seawater and 10ml of diesel were combined in a conical flask, then a sample of plastic waste (0.2g) was added (Figure 5), and the flask was sealed with parafilm. To simulate the waves on the ocean, the flasks were shaken on an orbital shaker at 150rpm for 1 hour. The plastic waste and the remaining seawater and diesel were transferred into a separating funnel. 50ml of n-hexane was added into the separating funnel. The separating funnel was capped and shaken, inverted and the tap opened to release hexane fumes. The separating funnel was then placed back upon the retort stand and left for the contents to settle (Figure 6). The diesel-hexane mixture was drained into a beaker. The hexane extraction process was repeated again. Anhydrous sodium sulfate powder was added into the beaker containing the hexane-diesel mixture to remove remaining traces of seawater. The mixture was decanted into a round-bottomed flask. Using a rotary evaporator, the hexane was removed from the round-bottomed flask. The mass of the remaining diesel was monitored until it became constant (indicating that all traces of hexane had evaporated). The mass of the diesel was recorded and used to calculate the amount of diesel removed by the plastic waste. This experiment was conducted for at least 5 times for each type of plastic foam waste, due to the larger error margin of this test. A negative control with no plastic foam waste involved was also conducted to help determine how much diesel was naturally lost in the extraction process.
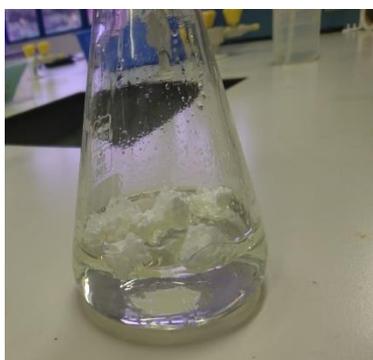

Figure 5. Plastic waste added to oil-seawater mixture

Figure 6. Extraction of remaining diesel using hexane and a separating funnel

2.9 Calculation of water/oil absorption capacities

To calculate the oil or water absorption capacities of the plastic waste, the amount of diesel or water absorbed by the plastic waste was divided by the initial mass of the plastic foam waste sample (0.2g), as shown by the formula below.

$$Q_t = \frac{m_w - m_d}{m_d}$$

Where Q_t is the absorption capacity in g/g, M_w is the mass of the plastic waste in g after the experiment, and m_d is the initial mass of the plastic waste in g.

3. Results and Discussion

3.1 Characterisation using Scanning Electron Microscopy (SEM)

EPS was observed to have a smoother surface (Figure 7) whereas EPE had a rougher surface with numerous fibrils (Figure 8).
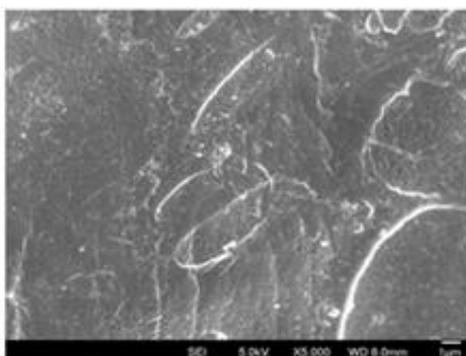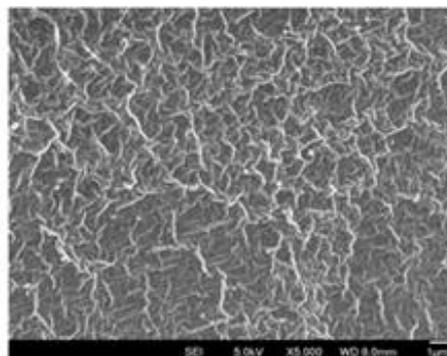

Figure 7. SEM of EPS at 5000x magnification

Figure 8. SEM of EPE at 5000x magnification

3.2 Water contact angle

The water contact angle measures the hydrophobicity of the plastic waste. When the contact angle is more than 90°, the material is hydrophobic (Förch, Schönherr & Jenkins, 2009). The unmodified forms of the plastic waste were found to be hydrophobic, with water contact angle exceeding 90°. The water contact angle of unmodified EPS was slightly higher than that of the EPE, having an average of 95.5° versus an average of 92.8° for the unmodified EPE. Both types of plastic foam waste were naturally hydrophobic, likely owing to the non-polar nature of the hydrocarbon polymers they are made of.

After modification, the water contact angle of both types of plastic foam rose to an average of 106.8° and 114.5° for EPS and EPE respectively (Figure 9), with the stearic acid coating having a more prominent effect on the EPE, likely due to the greater surface area of

EPE as supported by the SEM image (Figure 8) which reveals the presence of numerous fibrils while EPS had a plain flat surface (Figure 7). These results were further reinforced by the observation that EPE samples typically had more stearic acid coated on them than EPS samples, inferred through the end mass of samples after treatment.

As shown in Figure 10, stearic acid is a saturated fatty acid with an 18-carbon backbone. When coated onto the plastic wastes, the non-polar long chain carbon atoms enhance the plastics' hydrophobicity, which in turn results in larger water contact angles.
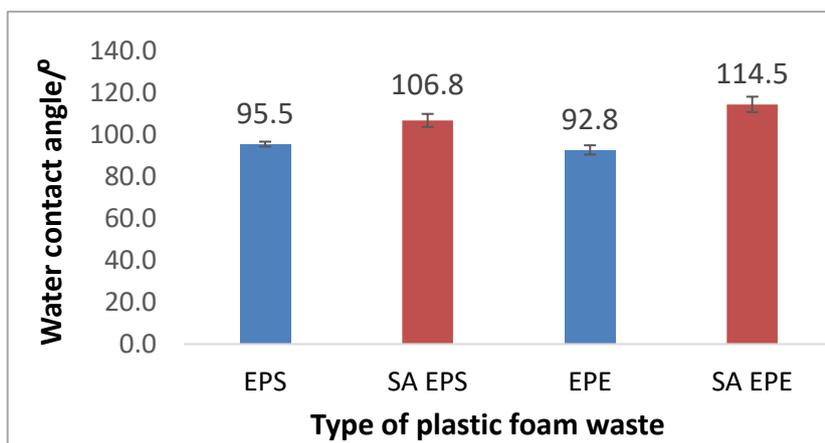

Figure 10. Chemical structure of stearic acid

Figure 9. Effect of stearic acid coating on water contact angle of plastic wastes. SA denotes "stearic acid coated"

3.3   Water absorption

Water absorption is another indicator of hydrophobicity. EPS had on average water absorption capacity of 2.9 g/g, while EPE absorbed more water per unit mass, with a water absorption capacity of 3.6 g/g on average. After modification, the water absorption capacities of both types of plastic foam waste dropped to 1.9 g/g and 1.3 g/g for EPS and EPE respectively, suggesting that the stearic acid coating has enhanced the hydrophobicity of both types of plastic waste. The stearic acid coating again had a more prominent effect on EPE.
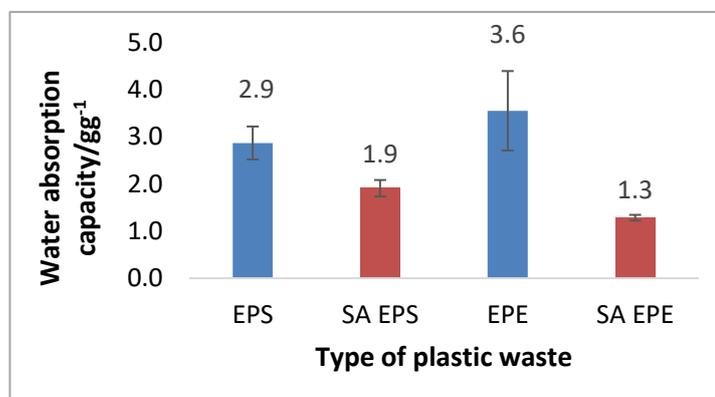

Figure 11. Effect of stearic acid on water absorption capacity of plastic wastes. SA denotes "stearic acid coated"

3.4 Oil absorption (pure oil environment)

Both EPS and EPE in their unmodified forms performed well at absorbing diesel in a pure oil environment, with oil absorption capacities of an average of 12.8 g/g and 8.3 g/g respectively. Counterintuitively, the stearic acid coating did not improve their oil absorption capacities, instead lowering it for both types of plastic waste. The oil absorption capacity of EPS dropped all the way to 4.5 g/g on average, while the oil absorption capacity of modified EPE dropped to an average of 4.7 g/g. This is shown in Figure 12 below.
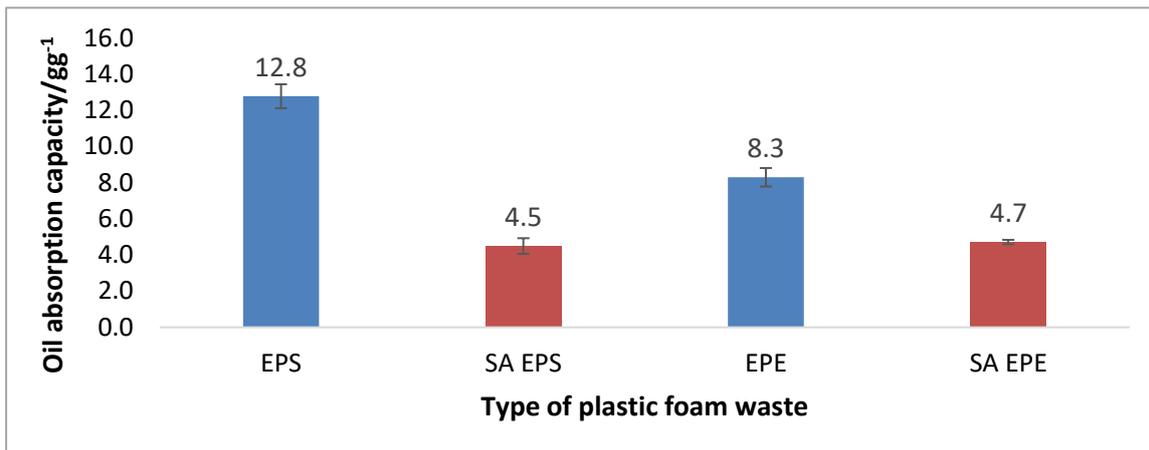

Figure 12. Oil absorption capacity of plastic wastes in pure oil environment. SA denotes "stearic acid coated"

3.5 Oil absorption (oil-seawater environment)

In the simulated oil spill environment, the oil absorption capacity of unmodified EPS dropped all the way to 6.0 g/g on average, whereas that of EPE was higher at 10.8 g/g on average. The stearic acid coating continued to reduce oil absorption capacity, though this was to a lesser extent in the oil seawater study, with modified EPS having on average of oil absorption capacity of 4.9 g/g, while coated EPE had an oil absorption capacity of 8.7 g/g on average. These results are depicted in Figure 13.
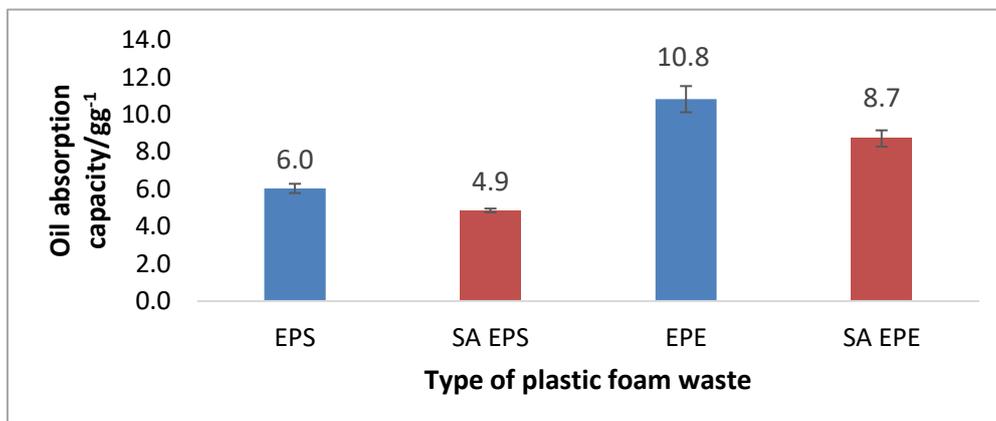

Figure 13. Oil absorption capacity of plastic wastes in oil-seawater environment. SA denotes "stearic acid coated"

Both types of plastic waste, in their unmodified forms, performed well under pure oil conditions. In oil-seawater tests, unmodified EPS performed poorly, perhaps due to absorption of unnecessary water, resulting in a loss of space for the diesel.

The stearic acid coating unexpectedly reduced the oil absorption capacities of both types of plastic waste. This could be due to the stearic acid clogging up some of the air spaces in the plastic waste, thereby reducing available space for the diesel. Under oil-seawater conditions, this strange trend was also observed, though to a lesser extent. It is likely attributed to the hydrophobic stearic acid coating which reduces absorption of unnecessary water, freeing up some space for diesel, although this effect was not enough to compensate for the loss in space caused by the stearic acid clogging up the pores. Figure 14 illustrates how stearic acid could have possibly caused a net drop in the oil absorption capacity of the plastic wastes under oil seawater conditions.
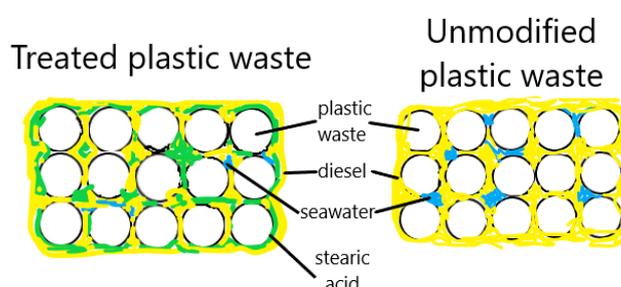

Figure 14. How stearic acid affects oil absorption capacity of plastic waste

3.6   Comparison with other oil absorbents

In comparison with some other oil absorbents made from waste products, the unmodified forms of both types of plastic waste performed well, having higher oil absorption capacities than other absorbents, as summarised in Table 1.

Table 1. Comparing the oil absorption capacity of plastic wastes with other oil absorbents

Type of sorbent	Oil sorption capacity/(g/g)	Reference
Expanded polystyrene (EPS)	6.04	This study
Expanded polyethylene (EPE)	10.8	This study
Chicken feathers	4.10	Osamor & Chinonyere, 2016
Wheat Straw	5.00	Konstantinou & Sidiras, 2014
Kenaf Fibre	3.95	Lee, Han & Rowell, 1999

4. Conclusion and Future Work

Both types of plastic waste (EPE and EPS) are hydrophobic and have rough surface as revealed by SEM. Both types of plastic wastes had high oil absorption capacities in their unmodified forms and were effective in absorbing diesel. Coating both kinds of plastic wastes with stearic acid resulted in an increase in hydrophobicity, but did not improve their oil absorption capacities. The oil capacities of EPS and EPE in oil-seawater environment were determined to be 6.04 and 10.8 gg^{-1} respectively. EPE nets are recommended to be used in oil spill cleanup, since it outperformed EPS in simulated oil spill environment and was comparable to other oil absorbents derived from waste. Plastic pollution is one of the greatest threats to marine ecosystems worldwide. With skyrocketing plastic production, low levels of recycling, and poor waste management, between 4 and 12 million metric tonnes of plastic enter the ocean. By reusing plastic waste as an oil absorbent, this study proposes a way to reduce plastic waste, which could potentially mitigate the impact of plastic pollution.

To expand the scope of this study, further research can be conducted on other types of plastic foam waste, such as polyurethane foam. Methods of making plastic foam waste into a usable prototype, such as packaging them in a boom (Figure 15) to clean up oil spills can also be investigated. Other types of modification methods can also be attempted, such as the deposition of silicon dioxide particles.

Figure 15. Oil booms used in cleaning up of oil spills

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