Design & Development of a Textile Based Structure Made From Discarded Polyester Textured Yarns for Oil-Water Separation

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I. INTRODUCTION

Filtration textiles are not simply appropriate for oil spills since they need to collect polluted water before separating the oil. To overcome the identified problem, a sorbent textile structure is developed in this project. A textile-based structure is developed using discarded Polyester textured yarn waste to remove spilled oil from the surface of water and reduce the environmental damage occurred by oil spill accidents. Reusing waste polyester yarn from yarn processing mills for a practical solution is an environmentally friendly strategy. Due to the lack of structural integrity of yarn waste, it was decided to use the polyester textured yarns as a filling material by using the outer netting material as polypropylene (PP) leno mesh which are used as packing materials (generally referred as onion bags). In order to make the sorbent hydrophobic, few approaches were chosen. The effectiveness of the final prototype sorbent was assessed by conducting tests on oil sorption and oil-water selectivity.

II. LITERATURE REVIEW

Conventional methods such as skimmers, chemical dispersants, mechanical collection, chemical decomposition, and situ burn were some methods used in oil spill cleanup [1]. However, those techniques can be expensive, environmentally unfriendly, and time-consuming [1]. Usage of filterable materials cannot be easily applied for oil spills since they can only filter the oil by gathering polluted water first [2]. Considering those factors, usage of sorbents is more economical to remove and extract large amounts of spilled oil from the water surface [1]. Natural materials such as cotton [3] and kapok [4], synthetic materials such as polypropylene, polyester [5], polyurethane [6], and blended materials [7] have been used in the forms of fabrics, sponges [6], [1], nonwovens [4], [8], composites [9], and fabric bags [2] etc. Sorbents mostly possess both oil and water sorption. Therefore, various treatments have been used in past research in order to make the sorbent superhydrophobic and oleophilic. Wet chemical methods (coating micro/nanoparticles [5], as-grown inorganic metal oxides) and dry physical methods (Vapor deposition, plasma etching, atomic layer deposition) are the two main categories that can be used to categorize the most popular ways for creating superhydrophobic coatings on fabrics [4]. Those approaches have different drawbacks when using those in large scale fabrication due to their high cost, complicated fabrication process, low flexibility, low stability, poor selectivity, and recyclability [5]. This study aims to develop an oil sorbent that can selectively adsorb oil from water surfaces using recycled polyester textured yarn waste obtained from a yarn processing mill as the primary raw material. The choice of this material is driven by its potential to be repurposed and contribute to waste reduction while providing a practical solution for oil spill cleanup.

III. C. *MATERIALS AND METHODS*

A. Initial Testing

Initial tests were conducted using textile waste from a yarn processing mill to assess discarded Polyester textured yarn waste. The study compared the properties of draw-textured polyester yarns and regular polyester yarns by examining them under an Optical Microscope. Additionally, the availability of void spaces for improved oil sorption was evaluated. The oil sorption rate and capacity of draw textured yarns were experimentally determined within 5-minute intervals using an oil bath, following ASTM F726-12 [10] standards.

The nature of the extracted yarns are highly entangled yarns without structural integrity. Based on the nature of extracted yarns and since it is a waste, it was decided to be used without further processing to achieve a low manufacturing cost. Considering the above, a flat rope like structure as shown in *Figure 1* was selected as a convenient option. Due to the lack of structural integrity of yarn waste, it was decided to use the polyester textured yarns as a filling by using the outer netting material as polypropylene (PP) leno mesh which are used as packing materials (generally referred as onion bags) with 5 × 5 per cm^2 which is also hydrophobic in nature. It has several advantages such as durability, lightweight, flexibility and reusability.

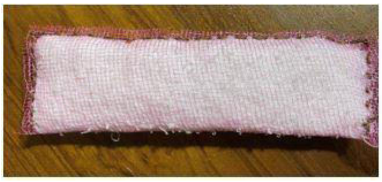

Figure 1: Rope-like Structure

An additional treatment was necessary to make the textile structure hydrophobic since only 59% of the capacity of the sorbent was utilized by oil. As the hydrophobic treatment, three approaches were done. First the sorbents were dip coated with PDMS (Polydimethyl siloxane). As the next approach, yarn filling was coated with Silver nanoparticles. The final approach was to treat the yarn filling of the sorbent with Dimethicone.

B. *Trial Sample Testing*

Trial sample testing was conducted to determine the optimal parameters. Motor oil 5W-30 was used for testing, as it is a suitable alternative to crude oil. To prevent submersion due to water absorption, rigifoam balls were added to provide buoyancy to the untreated samples. The oil sorption capacity was found to be 25.88 g/g. However, real-world scenario involves oil-water mixtures, so testing was conducted in an oil-water bath for 20 minutes with a 10-minute dripping time. Samples were then oven-dried at 100^0 C to eliminate water content, assuming no oil evaporation at temperatures lower than 300^0 C. Effect of below rope parameters on the oil sorption capacity of the sorbent was evaluated using trial sample testing in order to find the optimum parameters.

1) Shape

Sorbents were prepared in the shapes of cylindrical, thick rope and thin rope with same volume and same sorbent weight.

2) Shredding intervals of yarn filling

The same amount of yarn filling was shredded into 1cm, 1.5cm, 2cm, 2.5cm, 3cm to check the effect on oil sorption capacity.

3) Packing Density

To check the effect of packing density, weight of the sorbent was changed as 2g, 4g, 6g, 7g, 8g, 10g, 14g and filled in to ropes which have same volume.

4) Thickness

Optimum thickness was decided by checking the effect of thickness by changing the thickness in to 0.5cm, 1cm, 2cm. It was filled according to the optimum packing density which was decided before and length and width were kept constant.

5) Width

Width was changed as 3cm, 4cm, 7cm, 10cm, 12cm to check the optimum width. It was filled according to the optimum packing density which was decided before and length and thickness was kept as the same.

6) Construction of the Leno mesh

Three mesh constructions 4 × 4 per cm^2, 5 × 5 per cm^2, 6 × 6 per cm^2 were tested, and their oil water sorption capacities were compared.

By trial sample testing, the effect of parameters was observed and according to those results, optimum parameters of the rope were decided.

C. *Final Testing*

Prepared samples were tested to analyze the effectiveness of the developed prototype.

1) Oil Sorption Capacity

The sorption test involved weighing dry sorbent, immersing it in an oil-water mixture with a 1 mm oil layer, and leaving it for 20 minutes. Afterward, the sorbent was removed, drained for 10 minutes, and reweighed. Subsequently, the sorbents were dried at 100°C until a constant weight was achieved to eliminate water content. This process was conducted for three Dimethicone treated samples and three untreated samples to calculate the oil sorption capacity.

2) Oil-water selectivity test

In this test, a material sample was placed in a container with a known volume of oil and water, creating a 1 mm thick oil layer. After mixing and settling for 5 minutes, the sorbent was immersed in the mixture for 20 minutes, drained, and weighed. The sorbents were then oven-dried at 100°C to remove water. The test determined the oil-water selectivity by calculating the separated amounts of oil and water. Three Dimethicone treated and three untreated samples underwent this procedure.

IV. RESULTS AND DISCUSSION

Table 1: Finalized parameters of the sorbent

Parameter	Optimum value
Shape of the sorbent	Flat-thin
Shredded/unshredded yarn filling	Shredded
Shredding interval of yarn filling	2 cm
Packing density of yarn filling	0.0604 g/cm^3
Thickness of the sorbent	0.5 cm
Width of the sorbent	7 cm
Construction of Leno mesh	5 × 5 per cm^2

Different parameters of the rope-like structure were tested in an oil-water bath to assess their impact on oil sorption capacity. The flat-thin shape outperformed cylindrical shapes, attributed to improved contact and wicking ability. Shredded yarns were more effective than unshredded ones due to increased surface area and capillary forces in the open spaces between the shredded fibers, aiding oil adsorption. The study also considered the impact of shredding intervals on oil sorption capacity per unit length. 2 cm interval was found to strike the right balance between surface area and accessibility, offering effective oil adsorption without premature saturation. Furthermore, the investigation into packing density of the sorbent material showed that initially, increasing sorbent weight improved sorption capacity per cm due to increased surface area and attachment sites. However, beyond 6 g, sorption capacity plateaued or slightly decreased, indicating a saturation point where additional filling did not significantly enhance oil adsorption.

Reducing sorbent thickness from 1 cm to 0.5 cm increases sorption capacity per cm due to improved oil penetration and adsorption space. However, manual preparation limits thickness reduction below 0.5 cm, so it was considered the optimum value. Wider sorbents (7 cm) offer higher sorption capacities per cm by providing more surface area for oil attachment, but some oil may escape upon reaching saturation. The Leno mesh construction showed minimal impact on sorption capacity, suggesting its limited influence on sorbent performance.

The PDMS coating resulted in a hydrophobic surface, preventing oil penetration into the sorbent. In the case of in-situ silver nanoparticle formation, there was no significant difference in oil sorption capacity between coated and uncoated samples. The initial yellow coloration suggested successful nanoparticle generation, but issues like agglomeration or inadequate adhesion during drying may have led to loss of hydrophobic properties. Dimethicone treatment substantially increased the oil sorption capacity of shredded polyester textured yarns, with treated samples reaching 78% compared to 59% in untreated ones. This hydrophobic treatment effectively prevented the sorbent material from absorbing water or aqueous liquids, thereby enhancing its affinity for oil. This hydrophobic nature improved oil adsorption and retention, boosting overall oil sorption capacity.

Figure 2: Untreated sample after adsorption

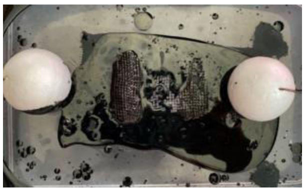

Figure 3: Dimethicone treated sample after adsorption

The Dimethicone treatment significantly improved the sorption capacity of yarns in an oil-water mixture by 31%, reaching 1.64 g g^{-1}/cm compared to the untreated sample's 1.25 g g^{-1}/cm. The treated sample adsorbed 77% of oil, equivalent to 23 times its weight in an oil-water bath. The hydrophobic coating enabled selective oil adsorption, enhancing oil capacity utilization. This research informs textile-based sorbent development for more effective and eco-friendly oil spill solutions, focusing on maximizing sorption capacity and minimizing environmental impact.

V. Conclusion

This study focuses on creating an environmentally friendly textile-based sorbent from discarded polyester textured yarn waste to mitigate the impact of oil spills. It repurposes waste yarn from processing mills. The effectiveness of the final prototype sorbent is evaluated through tests on oil sorption capacity and oil-water selectivity. To ensure structural integrity, the polyester textured yarns are used as filling material within a polypropylene (PP) leno mesh, known for its durability, lightweight nature, flexibility, and affordability. Trial sample testing was conducted using motor oil 5W – 30 to determine the impact of various parameters, including the shape of the sorbent, shredding intervals of yarn filling, packing density, width and thickness of the sorbent, and mesh construction, on the oil sorption capacity. Dimethicone treatment to filling yarns to enhance their hydrophobic properties, resulting in an overall increase in oil sorption capacity from 59% (untreated) to 77% (treated). The treated prototype sorbent exhibits impressive oil sorption capabilities, with the ability to adsorb approximately 23 times of its own weight in an oil-water bath. The oil sorbent is recommended for usage in oil spills occurring in inland waterways with calm flow rates. This research showcases the potential of utilizing waste materials for effective oil spill cleanup.

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