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Research article

Comparative effectiveness of natural by-products and synthetic sorbents in oil spill booms

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ABSTRACT

Sorbent booms are considered a 'first line of defence' technology used for containing and minimizing the impacts of crude oil spills. Booms containing human hair waste as sorbent were compared to other natural sorbents, including cotton by-product, recycled cellulose, as well as booms containing synthetic polypropylene, in order to evaluate their effectiveness in adsorbing petroleum crude oil pollution, remaining buoyant, and adsorbing seawater. A series of oceanic mesocosm experiments were used to simulate oil spill pollution events and to test sorbent effectiveness. Hair by-product was found to be significantly better at adsorbing crude oil on average (i.e. 0.84 g of crude oil per 1 g of sorbent) than all other materials, although it had wider variation in adsorbency likely associated with the non-homogeneous nature of mixed human hair. Hair sorbent was also observed to be less naturally buoyant than other materials, potentially due to low surface tension or increased porosity.

1. Introduction

Crude form petroleum oils are complex mixes of hydrocarbons and organic compounds that vary in density and composition (Rogowska and Namiesnik, 2010). Polycyclic aromatic hydrocarbons (PAHs) are one constituent of crude oils known to have negative effects on the natural environment (Allan et al., 2012; Webby and Ling, 2016), with a wealth of scientific research that attributes human exposure to crude oil pollution with acute illness, injury, and mortality (Williams et al., 2011). Exposure to crude oil also causes chronic health effects for marine organisms, such as alteration of metabolic and cardiac function (Tissier et al., 2015), impeded growth and development (Stefansson et al., 2016) and reduced species richness and abundance (Finlayson et al., 2015). Compounds derived from petroleum may continue to persist in the environment well after the initial spill has visibly cleared and it is possible that complete removal of crude oil residues from the environment may never fully occur (Allan et al., 2012; Li and Boufadel, 2010). Therefore, when crude oils are released, or unintentionally spilled, they pose a serious pollution threat to the immediate environment and require an immediate and appropriate emergency response (AMSA, 2014).

Accidents with crude oil containment vessels and pipelines are often unpredictable and occur on a regular basis, despite increased industry-wide safety and containment protocols. Ecosystems located in areas of crude oil extraction, processing, shipping and distribution of crude oil are most susceptible to the direct and indirect impacts of these activities (Rogowska and Namiesnik, 2010). Large-scale oil spills (i.e. > 10,000 barrels lost) from shipping vessels worldwide were recorded 301 times between 1974 and 2014, although the frequency of larger spill incidents has been decreasing due to improvements in shipping regulations (BOEM, 2016). Smaller, localised spill incidents (i.e. < 1000 barrels lost) are extremely common, with 844 marine pollution events reported to Maritime Safety Queensland from 2002 to 2016 (QLD Government, 2016). This equates to approximately one marine pollution event every week. While larger events have been historically less common in Australia, 27 major oil spills occurred from 1903 to 2012 in or near Australian waters alone, ranging in size from a mere 4 tonnes spilled at Great Keppel Island near Queensland to 17,280 tonnes spilled in Western Australia (AMSA, 2016).

Environmental remediation encompasses the broad range of activities undertaken to remove contaminants from polluted environments (Wagner et al., 2015). When oil spills of any size occur, the aims of environmental remediation are to contain, disperse, and remove the oil contaminant from the affected vicinity (Wagner et al., 2015). Response time is of crucial importance to ensure that remediation activities are effective in mitigating further ecological damage (Hospital et al., 2015) and effective oil spill remediation technologies are required to minimise impact (Wagner et al., 2015). Under Australian maritime law, the responsibility for oil spill prevention, risk management, monitoring and response lies with the titleholder, owner or operator of the polluting

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facility (AMSA, 2014). Each state government is also responsible for ensuring their emergency response equipment stockpiles are located within a 24 h road transport distance of high-risk areas (AMSA, 2014). Whilst the equipment and/or techniques used vary regionally and are dependent on local environmental conditions and regulatory approval (Kirby and Law, 2008), emergency stockpiles often contain sorbent materials as a first line of defence.

1.1. Oil spill sorbents

Among the oil spill remediation techniques approved for use in Australia by the AMSA National Plan Register of Oil Spill Control Agents (AMSA, 2015), sorbents have been used extensively to remediate accidents involving crude oils, particularly in marine environments. Sorbents are often applied directly to surface oil as loose material, or are deployed as booms. Booms are long rolls of buoyant, adsorbent materials placed around a vessel, or oil patch, to prevent further spread of oil, while also adsorbing the contained oil. Oils are primarily adsorbed by booms, as opposed to absorbed, as the liquids adhere to the surface of the materials and are not chemically integrated within them. The primary considerations for sorbent effectiveness are the hydrophobic and oleophilic properties of the material. Their efficiency can also be judged on secondary criteria that include (1) amount of oil adsorbed per unit weight of sorbent; (2) retention of the adsorbed oil; (3) buoyancy of boom materials (Adebajo et al., 2003). There is generally not a 'one size fits all' approach to sorbent use, with different materials performing at varying levels of effectiveness when subjected to changing environmental conditions such as waves, currents, wind or combinations of these variables (Castro et al., 2010). Absorption of water can limit effectiveness, therefore synthetic sorbents have generally been a preferred option as they can be easily engineered to be both super-hydrophobic and super-oleophilic (Zhu et al., 2011).

Recent research suggests that the oil adsorption capacities of sorbents made from natural materials may be comparable to that of popular and widely used synthetic sorbents, showing strong oleophilic (i.e. oil-attracting) and hydrophobic (i.e. water-repelling) properties. In addition, natural sorbents may offer an advantage in that they are also more readily biodegradable than synthetic sorbents. Examples of this include human hair (Ifelebuegu et al., 2015), wool (Radetic et al., 2008), cotton (Carmody et al., 2007; Wang et al., 2013), kapok (Hori et al., 2000; Lim and Huang, 2007) and silk (Patowary et al., 2016). Human hair by-product in particular has strong potential for use as a natural sorbent for both crude oil (Ifelebuegu et al., 2015) and other contaminants (An-Na and Yun-Fei, 2011), providing an innovative new use for an unusual resource material that is continually generated by the human populace, yet otherwise considered as low value waste by-product. It has been shown that hair's sorbent capacity may vary according to hair type (e.g., ethnicity) ranging from 2010 mg/g for hair of European origin, up to 5450 mg/g for hair of African origin (Ifelebuegu et al., 2015). This is likely due to the differing microstructures and morphology of hair, which result in differing hydrophobicity (Ifelebuegu et al., 2015). However, little is known about the potential of human hair to act as a sorbent material within booms designed to remediate oil spills. In addition, there is a paucity of comparative quantitative information on the oil adsorbency capacities of natural and synthetic oil spill sorbents in their commercially-available forms, and there are no published studies to date that have experimentally tested oil adsorbency capacities of different booms within a uniform comparative framework.

In the present study, the effectiveness of human hair by-product as an oil spill sorbent was compared with the performance of several other widely-used commercial sorbents, including cotton (i.e. by-product from the cotton milling process), K-Sorb (i.e. recycled cellulose), and polypropylene booms. Importantly, a consistent, comparative framework was used to examine the viability of using human hair for crude oil spill remediation. The framework uses an oceanic mesocosm approach to test the seawater and oil adsorbency capabilities of oil spill booms using international ASTM guidelines as the basis for performance. This study examines the efficacy of a human hair boom prototype compared to three mainstream and commercially available sorbent booms intended for use in oil spill pollution clean-up. If human hair is to be identified as an efficient product for adsorbing crude oil, then relative to the other products human hair will (i) adsorb more crude oil, (ii) adsorb less water, (iii) exhibit buoyancy for at least 90% of test units (as per international ASTM requirements), and (iv) remain structurally intact when immersed in water.

2. Materials and methods

2.1. Experimental system: a mesocosm approach for simulating oil spills

The safety and efficacy of the sorbent booms were evaluated in an artificial marine mesocosm with medium weight crude oil. ASTM F726-12 (ASTM, 2012) requires that test cells are "large enough to enable the adsorbent sample to float freely". The standard also recommends that larger samples, such as the whole booms used in this experiment, are tested in a 53 cm by 56 cm plastic sink (laundry tub or equivalent). To meet this criteria as close as possible, plastic storage tubs measuring 55 cm × 79 cm (with a depth of 37 cm) were sourced from Bunnings (Ezy Storage Ultimate 110L Storage Tub - UV Protected, lead and BPA free Polypropylene). Testing for oil adsorbency was conducted in a similar manner to the method outlined in ASTM F726. Variations to this method included testing in a well-ventilated, outdoor area of the University of Technology Sydney (UTS) rooftop glasshouses, and the meaning of 'triplicated' was interpreted as being that three booms were contained within one test cell.

A range of oils of varying viscosity and density are specified under ASTM F726-12. For this experiment, petroleum crude oil of medium weight (i.e. 0.8–1 g per cm^3 in density) was sourced from Chem-Supply Pty Ltd. The ASTM F726-12 protocol does not specify which type of water must be used for testing. As marine oil spills were the focus of this investigation, tapped seawater from Sydney Harbour was used for all experimentation.

2.2. Australian maritime safety authority (AMSA) criteria for testing oil spill boom performance

A mixture of shoreline and marine toxicity tests are required to seek approval for use of any oil spill control agent (OSCA) within Australia (AMSA, 2015, Table 1). These requirements are addressed across multiple mesocosm simulation experiments, examining both the outer socking material as well as the inner sorbent material. Each of the

Table 1
AMSA Oil Spill Control Agent test requirements for oil spill booms.

AMSA OSCA Test Requirements		
Test Requirement	Intended Application	Applicability to Sorbents
Efficacy	Marine and Shoreline	Required - Efficacy test is independent of test medium.
Toxicity	Marine and Shoreline	Discretionary to AMSA, depending on the nature of the proposed sorbent product.
Degradation	Marine Only	Required for synthetic material; discretionary for natural organic material; and not required for natural mineral material.

Table 2
Oil spill booms used in experimentation.

Boom Type	Description of Materials
Cotton	Commercially available booms made from organic cotton by-product.
Human Hair	Prototype organic hair booms: Mixed human hair by-product from salon waste as inner sorbent, encased in plumber's socking material.
K-Sorb	Commercially available, recycled cellulose booms.
Spaghetti	Commercially available, 'spaghetti'-type polypropylene booms.

following methods is an adaptation of the OSCA testing procedures prescribed for Type IIIb adsorbent booms in ASTM F726 Standard Test Method for Sorbent Performance of Adsorbents (ASTM, 2012).

2.3. Selection of sorbent booms

Synthetic sorbents were chosen due to their widespread use and international availability. Organic sorbents were chosen due to their potential similarity to human hair. Mineral sorbents were excluded from this experiment due to reported low performance in comparison to both synthetic and natural sorbent products (Adebajo et al., 2003). This experiment compared three types of current commercially-available oil spill sorbent booms (i.e. two organic-type sorbents, one synthetic-type sorbent) with a human hair waste boom prototype (Table 2).

Each of the products used in the experiments meets the ASTM F726-12 definition for a Type IIIb adsorbent boom, such that the insoluble inner material is: "Contained by an outer fabric or netting that is permeable to oil but with openings sufficiently small so as to substantially retain the sorbent material within the fabric or netting. The lengthwise dimension substantially exceeds other dimensions and with strength members running parallel with length." The 'strength members' are assumed to be the nylon rope and/or lengthways stitching present on the commercially manufactures booms (i.e. cellulose, polypropylene, and cotton). It should be noted that there is no such strengthening item present in the hair booms.

2.4. Pre-experimental conditioning of booms

Conditioning was conducted in a similar manner to the method required by ASTM F726-12. Variations to this method included Glasshouse testing; It was expected that testing conducted in Glasshouse conditions would vary substantially from controlled laboratory room temperatures, but this variation was likely more akin to the real-world conditions expected during transportation and deployment of booms, in the event of an oil spill. Sorbent booms were conditioned by removing all product packaging and allowing booms to remain fully exposed whilst contained in the test mesocosms for 24 h.

2.5. Dynamic degradation testing

Dynamic degradation testing is designed to quantify water uptake, and to determine the hydrophilic and oleophilic properties of an adsorbent sample under dynamic environmental conditions (ASTM, 2012). As per ASTM F726-12, both the outer material and the filler material were tested independently. The pass/fail performance criteria are the ASTM Standard test requirements for sinking (i.e. no more than 10% by volume sinking completely below the water's surface).

2.6. Testing inner 'sorbent' material and outer 'socking' material

Testing was conducted in a similar manner to the method outlined in ASTM F726, with sorbent materials tested separately to outer socking. Variations to this method included the use of a 5 g sub-sample of inner sorbent sample, a sample jar of 2 L volume, and the shaker device (Fritsch international Analysette) frequency was unable to be adjusted. Shaking was kept at 2.5 mm amplitude for 15 min with the shaker operating continuously.

2.7. Statistical analysis

To compare the mass of crude oil adsorbed by each boom type when immersed in water with water logging, an oil adsorbency ratio was calculated for each boom type, correcting for both dry weight and the mass of uncontaminated water.

$$Oil\ adsorbency\ ratio = \frac{Mass\ of\ boom\ in\ oiled\ water - Boom\ dry\ mass}{Mass\ of\ boom\ in\ water - Boom\ dry\ mass}$$

Differences in oil adsorbed by the different boom types were compared using Analysis of Variance (ANOVA) followed by Tukey's Post Hoc test to determine where significant differences lay between pairs of sorbent types. In the ANOVA, mass of oil or water adsorbed (grams) was the response variable, boom type was a categorical explanatory variable, and grams of material (i.e. of the inner sorbent or outer socking) were included as a control variable to examine the effect of boom type over and above any effect of material quantity. Intact booms or deconstructed parts of booms were treated as the replicates. Differences in water or oil adsorbtion between sorbent types, socking types, and boom types were examined using separate ANOVA tests followed by Tukey's Post Hoc tests in the same manner as above. All statistical analyses were performed in SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY), graphed using R Studio (R Studio Team, 2015), and significant differences were reported at the level of $P < 0.05$.

3. Results

3.1. Crude oil adsorbed per standardised gram of boom

There was a significant effect of boom type on adsorption of crude oil (ANOVA: $F_{3,67} = 22.02$, $P < 0.001$). Hair booms showed the highest average adsorption ratio of crude oil compared with all other boom types (Fig. 1) (Tukey's Post Hoc tests: hair vs cotton $P < 0.001$; hair vs cellulose $P < 0.001$; hair vs synthetic $P < 0.001$; Fig. 1).

The greatest range within the average adsorbency ratios was found in hair booms, followed by K-Sorb, cotton booms, and spaghetti booms (Fig. 1). This would indicate that the results obtained for synthetic booms are the most consistent due to the small range, whereas hair booms have a large range of results. The adsorbency ratios compared across cotton, K-Sorb, and spaghetti booms types were statistically insignificant (Tukey's Post Hoc tests: cotton vs K-Sorb $P = 1.0$; K-Sorb vs spaghetti $P = 1.0$; spaghetti vs cotton $P = 0.759$), and therefore these boom types were similar in their oil adsorbency capacity. This is a positive indication that synthetic sorbents could reasonably be replaced with natural adsorbents and perform equally well.

3.2. Total volumetric oil adsorption of crude oil within booms

Spaghetti booms had the greatest mean volumetric oil adsorption (Fig. 2), accounting for the original density of the sorbent within the booms (ANOVA: $F_{3,67} = 2.851$, $P < 0.001$). This indicates that synthetic spaghetti booms are the most efficient type of sorbent in the present commercially-available form, adsorbing the greatest volume of oil per cubic centimetre of all booms. K-Sorb and hair booms also had statistically similar mean volumetric adsorption to the synthetic booms ($P = 0.08$), as did K-Sorb and cotton boom ($P = 0.24$), although hair booms performed significantly better in direct comparison to cotton ($P < 0.001$). Hair had wider overall variation in oil adsorbency that was associated with variation in boom sorbent densities. Cotton booms had the lowest volumetric oil adsorption ratio of all four boom types

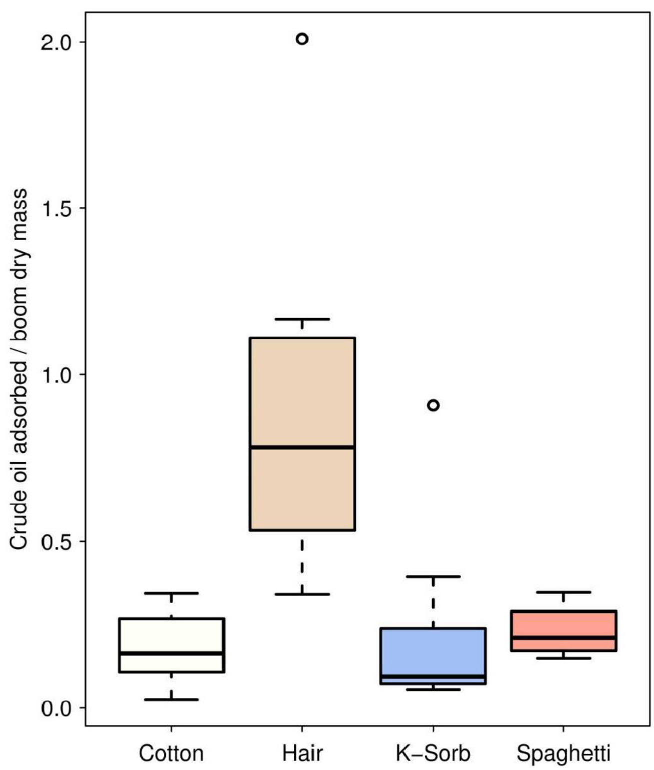

Fig. 1. Crude oil adsorbed (per gram of sorbent) compared across boom types.

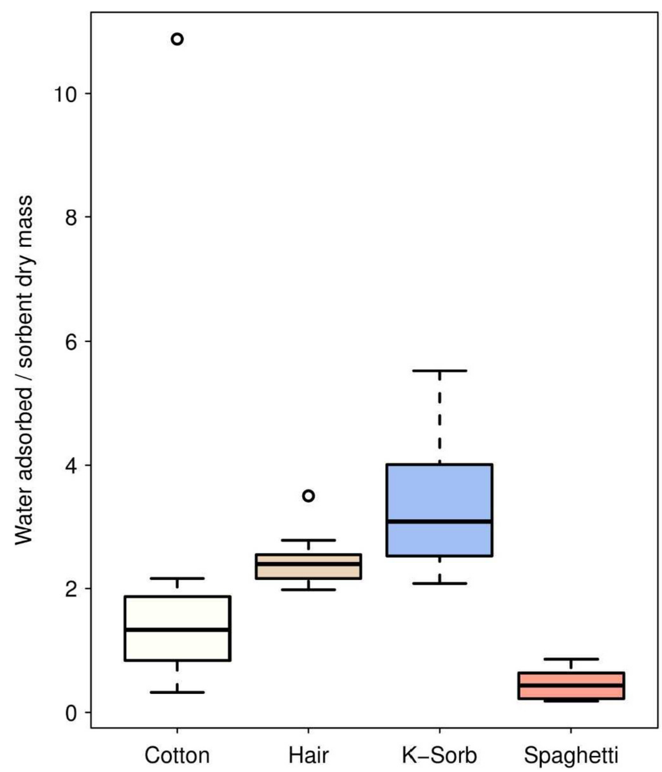

Fig. 3. Water adsorbency ratio compared across inner sorbents.

tested (Fig. 2), indicating that this boom type were the least efficient means of adsorbing oil.

3.3. Inner sorbents: water adsorbency and buoyancy

Water adsorbency differed significantly among the sorbent types (ANOVA: $F_{3,48} = 7.393$, $P < 0.001$). Synthetic spaghetti sorbents had the lowest average water adsorbency ratio (Fig. 3), showing this product to be the strongest performer in this context. Conversely, K-Sorb and hair had statistically similar high water adsorbency ($P = 0.164$) indicating these booms did not repel water as well as other sorbent materials, and that this may affect the efficiency of the materials to adsorb oil.

The greatest range within the water adsorbency ratio was found in cotton booms, followed by K-Sorb, hair, and spaghetti booms (Fig. 3). This would indicate that the results obtained for synthetic booms are the most consistent across replicates, whereas the natural booms have a larger range of results and are less consistent.

During testing, it was observed that all hair samples failed to meet the minimum ASTM acceptability criteria for buoyancy (i.e. less than 10% sinking) and are therefore not considered to be a buoyant sorbent

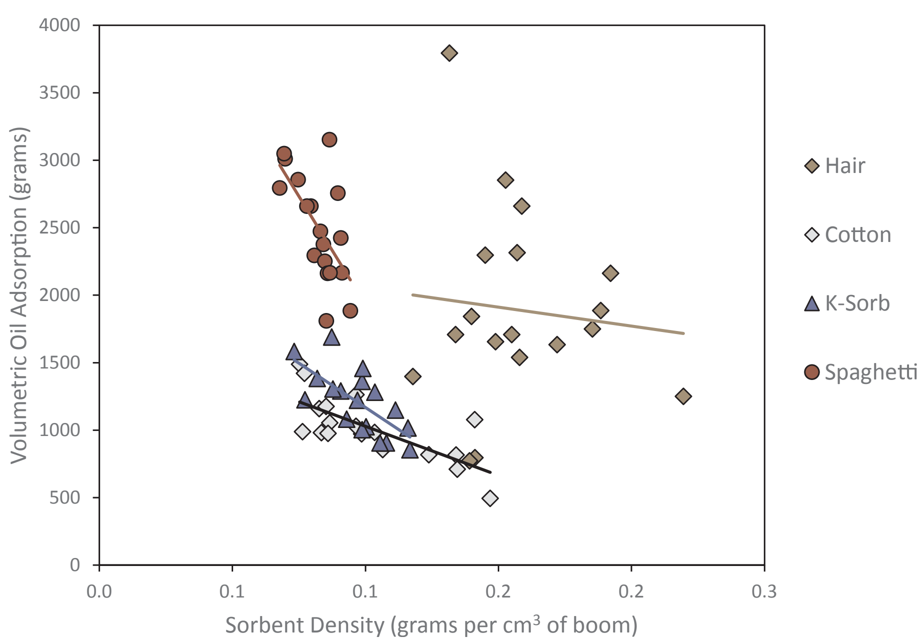

Fig. 2. Volumetric crude oil adsorbency compared to density of booms.

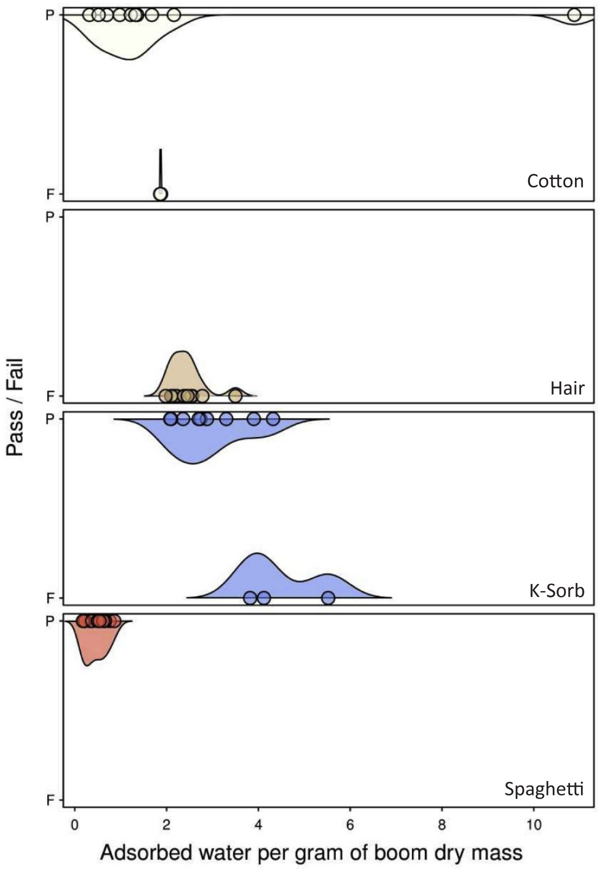

Fig. 4. Pass or fail buoyancy response of boom types vs boom dry mass.

material (Fig. 4). For cotton, 17% of samples failed this criterion. It was therefore expected that hair would have the highest water adsorbency ratio, which was intriguingly not the case. It was also observed that 25% of K-Sorb cellulose samples did not meet the minimum acceptability criteria for buoyancy (i.e., less than 10% sinking), which likely contributed to a wider range in water adsorbency.

3.4. Outer socking material: water adsorbency

From the analysis, socks covering spaghetti booms had the greatest average water adsorbtion ratio (Fig. 5.), followed by socks covering hair booms (ANOVA: $F_{3,48} = 34.307$, $P < 0.001$). This result was expected as it was observed that all outer materials for hair booms and synthetic booms failed to meet minimum acceptability criteria for buoyancy (less than 10% sinking). The outer socking on K-Sorb and cotton booms had statistically similar average water adsorbency ratios ($P = 0.073$), whereas hair boom socking adsorbed less water than cotton ($P < 0.001$). The sock materials for cotton and cellulose booms generally meet minimum acceptability criteria for buoyancy (less than 10% sinking), with the exception of only a few outliers. The dry weight of outer materials recorded for cotton booms were often similar to cellulose booms and these materials were seen to have performed similarly. The greatest range within the water adsorbency ratio was found in spaghetti boom socking material, followed by K-Sorb, cotton, and then hair boom socking (Fig. 5). This would indicate that the outer material for hair booms have the most consistent performance in this water adsorbency test.

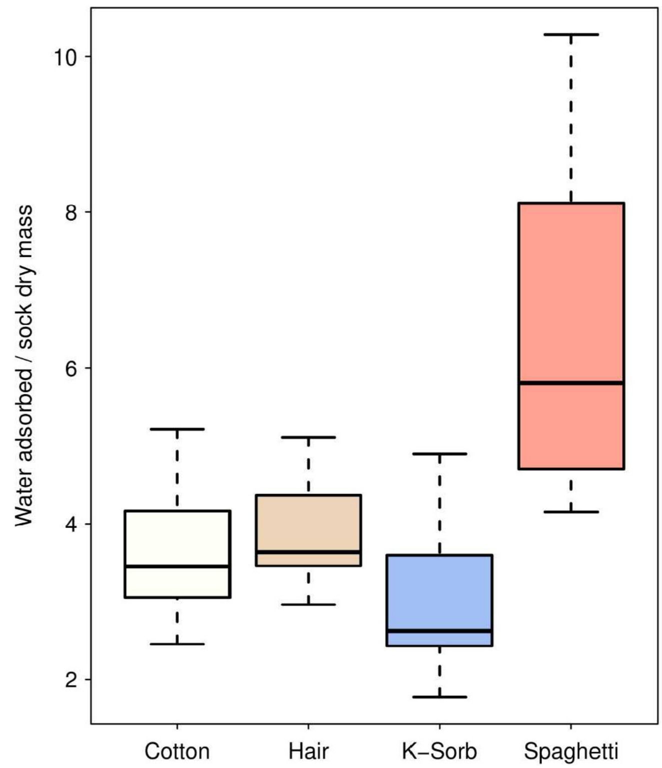

Fig. 5. Water adsorbency ratio compared across external socking types.

4. Discussion

Natural sorbents have been previously criticised for having poor buoyancy, low oil sorption capacity and low hydrophobicity (Adebajo et al., 2003). All of the natural sorbent materials tested, including hair by-product, were indeed observed to have poor buoyancy and greater water adsorption ratio than the polypropylene sorbent. It is possible that buoyancy of hair booms could be artificially enhanced by changing the outer material to one which is more hydrophobic and buoyant, or through the addition of floatation devices. Mat-type hair adsorbents may also provide a promising future solution for increasing hair buoyancy by modifying the surface of the sorbent to become more uniform and increase water displacement (Matter of Trust, 2017). The capacity for oil sorption in hair was found to be higher than other natural sorbent booms tested in this experiment, indicating that hair would be a suitable material to use in the adsorption of crude oil. In addition, the volumetric oil adsorption ratio of hair booms is relatively high compared to the other boom types tested, indicating that not only is hair capable of adsorbing oil at high rates, but that hair is also relatively more efficient at adsorbing oil than other materials.

Synthetic sorbents are currently the most commonly used products in environmental remediation due to being highly oleophilic and hydrophobic (Adebajo et al., 2003). As was expected, the synthetic sorbents tested in this experiment showed consistently high oil adsorbency and significantly lower water adsorbency than the other boom types tested. This can be attributed to the synthetic sorbent having being artificially manufactured/treated to be significantly more hydrophobic than other sorbents (Wei et al., 2003). A disadvantage of synthetic sorbents, which was observed at all stages of the experiment, is the ease of which small non-woven polypropylene fibres can escape or be sheared off from the booms. Whilst the boom must meet ASTM F726-12 criteria for “substantial retention” of the sorbent material to be used, smaller fibres are not adequately contained by the netting used as an outer covering on this product. This poses a risk to the environment as it is highly likely that synthetic fibres contaminated with crude oil would remain behind following any remediation efforts. Furthermore, this oil could be released back into the environment due to the poor oil retention observed in polypropylene sorbents (Choi and Cloud, 1992; Wei et al., 2003).

Due to the small volume of oil used and short test period, it is unlikely that the sorbents reached peak saturation during this experiment. It would be well worth exploring the volume of oil required to saturate all booms, as it has been shown that while polypropylene sorbents initially adsorb more oil, their ability to retain oil is poor (Choi and Cloud, 1992; Wei et al., 2003). Peak saturation of crude oil has recently been explored using sheep wool, revealing a saturation point of 8.23 g of crude oil per 1 g of wool after 20 min in still water, with exposure up to 60 min not yielding any further significant uptake of oil (Sulyman et al., 2017). Leaching post-saturation point of sorbents is also important, as this information has implications for potential re-contamination of water bodies. Leaching of oil from synthetic sorbents has been observed after 5 h of continuous use, indicating that this is the maximum time sorbents could be used before saturation is reached (Khan et al., 2004).

Throughout this experiment, it was found that the performance of cellulose booms was similar to the other natural sorbents. This is consistent with the findings of (Suni et al., 2006) who found that the performance of cellulose adsorbents alone did not surpass the performance of synthetic or other natural sorbents. The exact composition of the cellulose booms is not stated in the MSDS, nor was it provided by the manufacturer, though through observation was assumed to be a heterogeneous mix of cellulose fibres. It is possible that mixtures of cellulose with other materials, such as peat, may improve boom performance (Suni et al., 2006). It would be of interest to test whether mixtures of the natural materials used in this experiment enhance sorbent boom performance in comparison to synthetic booms. The main advantage was that the outer material used to cover cellulose sorbents was deemed highly suitable for use in aquatic environments. This was due to the cellulose socks having a low water adsorption ratio and one of only two types to display adequate buoyancy. It is possible that the outer sock of hair booms could be changed to a material similar to that used for Cellulose booms to improve the buoyancy performance of the overall boom.

Cotton sorbents were found to have a higher water adsorption ratio, with large variation within the results. Although the water adsorbency was found to be significantly different to synthetic sorbents, it was not significantly different to other natural sorbents. This result was unexpected, as previous works have found cotton to be completely hydrophobic and deemed cotton to be the most suitable of all-natural sorbents (Carmody et al., 2007; Wang et al., 2013). In addition, cotton booms were found to have a low oil adsorbency ratio and low volumetric oil adsorption ratio, indicating that this boom type had the least favourable performance and were the least efficient means of adsorbing oil. Again, this was an unexpected result due to previous works having found cotton to be oleophilic (Carmody et al., 2007) and the oil sorption of cotton fibers to be significantly high in comparison to synthetic sorbents (Adebajo et al., 2003; Choi and Cloud, 1992; Singh et al., 2013). As with cellulose booms, the main advantage was that the outer material used to cover cotton booms sorbents was deemed the most suitable for use in aquatic environments. This was due to the cotton boom socks having the lowest water adsorption ratio and one of only two types to display adequate buoyancy. However, given the unexpected results above, it could be possible that the socks are inhibiting the performance of cotton sorbents by preventing adequate oil uptake. Further investigation would be required to determine whether this is the case.

This experiment measured the water and oil absorbency of natural and synthetic booms by ratio and volumetric analyses. An important continuation of this work would be to determine the optimum structure of sorbent booms in order to improve the efficiency and efficacy during oil spill clean-up. Such structural changes may include change in boom density, change in size of booms and change in composition, for example, cutting and/or grinding hairs to a smaller, more uniform size.

It is highly likely that hair will need to be washed and dried prior to the manufacture of sorbent booms to prevent leaching of dyes and other chemicals into waterways. A hot water treatment, in combination with other pre-treatments may either improve or hinder the performance of hair booms (Wong et al., 2016). For example, hair given an alkaline treatment of Sodium Hydroxide (NaOH) has resulted in an increased adsorption of uranium when compared to untreated samples (Saini and Melo, 2015). Other pre-treatments may include the adhesion of silica nanoparticles to enhance the hydrophobic properties of natural materials (Wang et al., 2015). Contrary to this, Choi and Cloud (1992) showed that pre-treating cotton to remove the surface wax decreased oil sorption capacity. In addition, the pre-treatment increased water sorption, causing the fibre to be more hydrophilic (Choi and Cloud, 1992). It is thought that surface wax present on cotton-cellulose sorbents facilitates the uptake of crude oil by creating a hydrophobic surface on cotton fibres (Carmody et al., 2007). Due to a similarity in structure, it could be expected that hair may react to pre-treatment in a similar manner.

A disadvantage of synthetic sorbents is that they are not readily disposable in comparison to natural sorbents, as they require landfilling or incineration (Adebajo et al., 2003). It is possible that natural sorbents could be instead disposed of through commercial-grade composting facilities. Suni et al. (2006) showed that oil adsorbed to biodegradable cellulose fabric was readily degraded when incubated in either sand or soil for a 12-week period. It is thought that some water adsorption is necessary to facilitate biodegradation of oil and the high hydrophobicity of synthetic sorbents inhibits this process (Suni et al., 2006). The addition of bacterial cultures may also facilitate the degradation process of crude oil contaminated natural sorbents (Lin et al., 2014).

At present, contaminated adsorbent materials of any type (synthetic, natural, or mineral) can only be sent to Australian landfills that are licensed to receive such hazardous wastes and may be subject to additional state government regulations (e.g. NSW EPA, 1999; VIC EPA, 2007). Further investigation into the ability of contaminated natural sorbents be commercially composted will likely require the prior approval of state government authorities to conduct such experiments.

5. Conclusions

Hair waste was found to be significantly better at adsorbing crude oil on average than other sorbent materials including polypropylene, cotton by-product and recycled cellulose. Booms made with hair sorbent had wider variation in oil adsorbency compared to other products which is likely associated with the non-homogeneous nature of mixed human hair. Hair sorbent was also observed to be significantly less buoyant in seawater than other materials, potentially due to low surface tension or increased porosity. Polypropylene booms had the most consistent high buoyancy performance in seawater, followed by cotton by-product, recycled cellulose, then hair waste.

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