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Up-and-coming oil-sorbing green fibers: A text mining study

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Abstract: Oil is a crucial raw material, preferably transported by sea. Thus, spills frequently take place in the ocean. Several alternatives have already been investigated to combat these disasters. This paper discusses the possibility of using lignocellulosic fibers for environmental recovery via the sorption of oil spilled in accidents. The data search was performed using Google Scholar. The obtained results allowed the choice of four fibers: coconut, sisal, peat, and kapok. The retrieved reference numbers were 8.360, 6.360, 6.360, and 2.380 for coconut, sisal, peat, and kapok fibers. There was no period restriction. Ten papers with significant results were chosen, and their main results are presented here. All fibers are renewable, besides presenting low cost and excellent sorption capability compared to polypropylene (commercial material) equal to 6 to 10 g/g of oil per gram of the sorber.

Keywords: Lignocellulosic fibers, Oil spill, Sorbent fibers, data mining, Experimental design, Data analysis, green fibers, oil spill clean up.

Adherence to the BJEDIS' scope: This review used data mining for the analysis of the articles and subsequent writing of this review.

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1.INTRODUCTION

Polymers are vital materials for Humankind and have been widely researched, aiming to develop green materials for a myriad of uses (1–112), including Environment recovery applications. This short review is focused on vegetable fibers used as sorbing oil materials over the last decades. Data mining was chosen for the analysis of the articles and subsequent writing of this review. The present work contributes to the dissemination of Applied Statistical knowledge. The collected data allowed us to analyze which fiber would work better for sorbing oil. The data search was performed using Google Scholar. The obtained results allowed the choice of four fibers: coconut, sisal, peat, and kapok. The retrieved reference numbers were 8.360, 6.360, 6.360, and 2.380 for coconut, sisal, peat, and kapok fibers. There was no period restriction.

The aquatic ecosystem is under constant threat and can be contaminated by oils from different sources. Among the possible acute sources of contamination, the wreckage of ships and oil tankers is worth mentioning. On the other hand, a slow and constant contribution comes from industrial effluents or from the leakage of oil from machinery and pipelines that eventually reach rivers and other underground water systems (113).

Since the 20^{th} century, there has been an increasing oil demand (114). However, billions of tons of oil have already been spilled into the oceans when transported, affecting the marine ecosystem and human health (115). The challenge of recovering the impacted environments is enormous and deserves attention (116).

If the oil falls into the water, it is essential to collect it from the surface as soon as possible. Only one ton of oil can cover up to 12 km^2 of water surfaces, creating a layer of oil inducing all physical and chemical problems, such as increasing the surface temperature, changing color, pH and creating odors (117).

There are several techniques for removing oil from the ocean, such as natural dispersion, containment, skimming, burning in situ, use of sorbents, bioremediation, detergents, and dispersants, all generating some negative impact (118). Among these alternatives, sorption polymers deserve to be highlighted. Among them, cellulose has a high potential for water treatment. In addition to mechanical properties, cellulose is biodegradable and has a low production cost (119).

Biosorbents have emerged as an alternative for removing organic contaminants, natural products with high availability, low cost, renewable, and good sorption capability. Fibers are materials that could be being improperly discarded in nature (120). As population growth occurs, the fiber production amount is more significant, and its waste disposal increases (121). So, the use of these wasted fibers as oil sorbents is advantageous.

The fibers' waste can be avoided if these substracts present exciting properties, such as high oil absorption capability, high selectivity, low density, and excellent recyclability. It is still a challenge to increase the water-repellent property and the oil sorption capability for practical application (122).

Polypropylene is a typical commercial material used for oil sorption in spill accidents. It is a thermoplastic polymer that can be recycled and is non-toxic, but it is not renewable like natural fibers, which is a disadvantage. Polypropylene has an oil sorption capability of 6 to 10 g/g (115), and other materials that can replace it will be presented. This work aims to present and discuss four lignocellulosic fibers and their performance as oil sorbents to remove spills from the oceans. These fibers were chosen through data mining performed into the Google Scholar platform.

2. METHOD

The four fibers covered in the present study were selected from a text mining carried out on the Google Scholar website. A combination of words was performed: "oil spill clean up" plus the respective fiber's name under analysis. During the research process, there was no time restriction. Figure 1 shows the number of results obtained for the research and the produced amount of each fiber. The four vegetable fibers were chosen because they have a high production globally, besides having low cost and being renewable.

The first ten and most relevant pages of the survey were analyzed, resulting in 100 articles gathered. The ten most relevant articles were chosen among the ones where the fibers underwent little chemical treatment or were tested in natura and present exciting results in the sorption tests compared to the polypropylene.

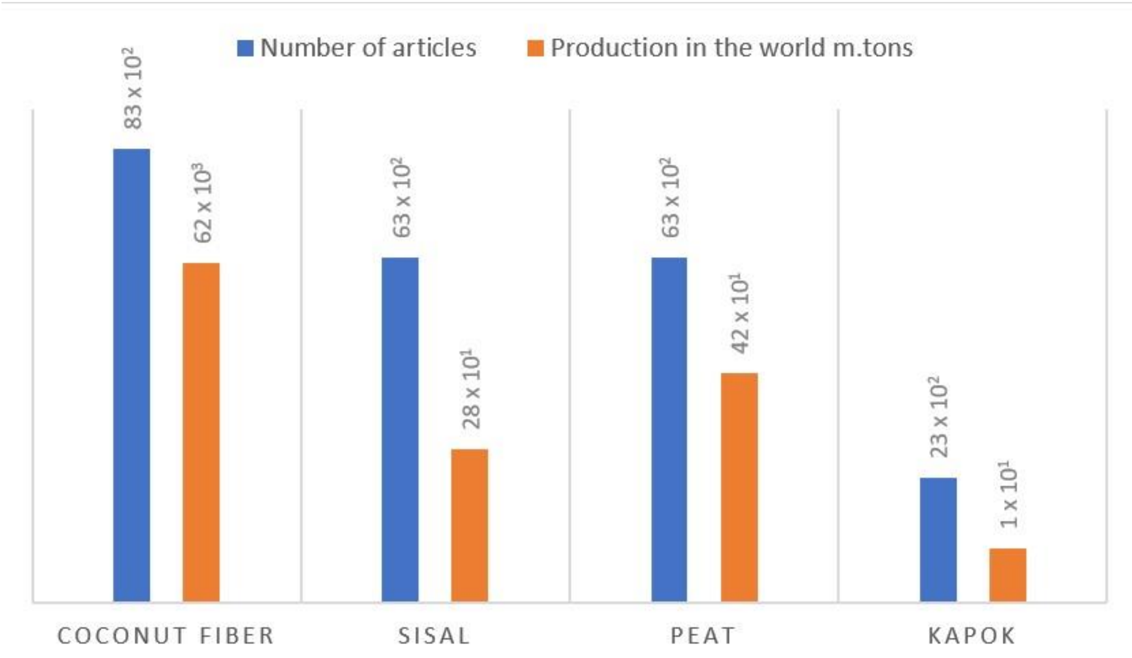

Figure 1: Results obtained for the research carried out on the Google Scholar website for coconut, sisal, peat and kapok fibers and also their global production. Source: Elaborated by the author, 2020.

3. RESULTS

3.1 Coconut Fiber

Coconut is the fruit of the coconut tree (*Cocos nucifera L*), and Brazil has a large-scale production, from which 80% of the gross weight is discarded as waste in landfills, generating various environmental and sanitary issues. The amount of waste generated is about seven thousand tons per year. A thousand coconuts produce approximately 10 kg of fiber (123). Coconut fiber has several uses in favor of environmental issues. It is odorless, undergoes microbial decomposition, can be used as a charge and has a hydrophilic nature, has low density, is cheap, easily obtained, resistant to heat, moisture, and saltwater (124). Coconut fibers can float on the water's surface for a long time, making it proper to collect the spilled oil (125).

Zarate *et al.* (2018) studied the sorption of benzene, toluene, and naphthalene in water using three different materials: coconut shell, coconut fiber, and the fiber-associated shell. The effect of the solution's pH dissolved organic matter. The coconut fiber showed the highest sorption capability for the oils due to several factors, such as the large surface area, functional groups, and material morphology. The shell's micrograph showed a smooth surface with few pores, while the fiber had a hollow tubular structure, generating a larger surface. Another possibility analyzed is that there is a high concentration of phenolic groups in coconut fiber, which, when associated with the structure of lignin, there is a consequent increase in the adsorption of aromatic hydrocarbons. The fiber sorption order was 222 mg/g, 96 mg/g, and 5.85 mg/g for benzene, toluene, and naphthol, respectively. Other analyses were performed in two solutions: deionized water and natural water from the San Jose aquifer. Benzene was the one that obtained the best sorption result. Besides that, the sorption in natural water was higher than in deionized water, possibly due to dissolved organic matter, which acted as a sorbent for hydrophobic compounds, such as aromatic carbides. After that, an analysis of the waste combustion heat with soluble hydrocarbons was performed, which showed an increase in the heat generation capability, which can be considered residual biomass with high added value (126).

Teli, Valia, and Mifta (2016) studied the coconut fiber's oil sorption capability (obtained as waste). Fibers were functionalized with butyl acrylate to increase their hydrophobicity and may be able to absorb more oil. There was a 275% increase in the sorption capability after treatment, starting to drink 13.45 g/g. A simple compression can also release the absorbed material so that the fiber can be reused, showing that it can be reused three times before and be discarded. The compression method is more economical and practical. The work shows that modified coconut fibers can be used as an oil spill cleanup tool (127).

Osamor and Momoh (2015) investigated coconut fiber's sorption capability and modified it with human hair. The fiber's sorption capability was equal to 7,231 mg/g and 6,350 mg/g for vegetable oil and diesel oil, respectively. However, the material's water sorption was equal to 6,540 mg/g, so this material in oil spill cleanup applications in the ocean is problematic. After that, the blend of coconut fiber with human hair was prepared in proportion 3:1. This material presented an increase in the sorption capability. However, in the proportion 1:1, the best result for diesel sorption (7,916 mg/g) and vegetable oil (8,814 mg/g) was obtained. Besides, water sorption decreased by up to 22%. After that, a temperature analysis was performed at 18°C, 28°C, 38°C, and 48°C. The results allowed inferring that the higher the temperature, the lower the sorption capability. The sorption kinetics followed a pseudo-second-order model, adjusted to the Freundlich adsorption isotherm model. This work demonstrated that through the use of appropriate modifications, as in this case, the addition of human hair can improve coconut fiber's hydrophobicity, it may be an excellent low-cost ecological sorter for cleaning up oil spills in oily wate (128).

3.2 Sisal

The sisal fiber is extracted from the sisal plant's leaves (*Agave sisalana*). Sisal is widely used because of its abundant availability, lower cost, good thermal and acoustic insulation, resistance to traction and abrasion, and high tenacity (129). Besides that, sisal is a renewable and low-density resource, making the fiber even more attractive (130). The sisal fiber has a high percentage of cellulose (approximately 65%), which is one factor responsible for increasing the tensile properties and not absorbing moisture quickly (129).

Zhang *et al*. (2019) prepared nanoporous hierarchical superhydrophobic aerogels (SHPC) based on low-cost natural premna microphylla (PM) leaves and sisal. Five different aerogels were prepared using different sisal amounts in the PM (0%, 50%, 100%, 200%, and 300%). The authors reported that hydrophobicity increased as the proportion of sisal was increased in the blend. In this case, the maximum superhydrophobicity was obtained to the SHPC - 200, filled with 200% of sisal. So, SHPC - 200 was used as a sorber of model substances (toluene, n-hexane, tetrahydrofuran, acetonitrile, diesel oil, dimethylformamide, dimethyl sulfoxide, soy oil, carbon tetrachloride, and automotive oil). The best performance was for tetrachloride, which presented sorption of 147.3 g/g. This sorption was the same during ten cycles of reuse. The material presents a low cost. Besides that, it is biodegradable, has excellent elasticity and superhydrophobicity, and can be used in oil recovery in spill accidents (131).

Liu *et al*. (2018) prepared ultralight, elastic, superhydrophobic, and durable carbon fiber aerogels from sisal (CFAs). These materials were prepared through simple alkalinization, bleaching, lyophilization, and carbonization. They were tested for sorption of various oils and organic solvents (toluene, trichloromethane, carbon tetrachloride, ethanol, methanol, diesel, and soy oil). The material was developed to absorb oil both in spills and in water and oil separation with different density levels. CFAs have superhydrophobic and superoleophilic properties, showing that they have a high water-oil separation capability. Its three-dimensional network structure facilitates oil sorption in spills. The sorption capability reached between 90 to 188 times its weight, and that it can be recycled more than ten times by squeezing or burning the material. Besides, the most absorbed material was trichloromethane, and the one with the lowest sorption was ethanol. Also, it can be concluded that the sorption capability is not significantly modified after the ten washes test. CFAs also have advantages such as buoyancy, selectivity, renewable and non-toxic. This material has an excellent ability to be used in accidents with spills of oils and solvents in water (132).

3.3 Peat

Peat is known to be a super sorbent. Besides, it is biodegradable, has a low cost, and excellent sipping capability (133). Peat is formed from the partial decomposition of mosses and other living materials such as grasses, shrubs, reeds, or even trees under flooding conditions (134). Peat is found on approximately 1-2% of the Earth's surface (135). Two main points of this excellent sorption capability are the large number of pores that provide large surface areas for molecules to adsorb to the walls and the large number of capillary spaces that allow the absorption and retention of hydrocarbons (136). However, the peat's hydrophobicity is low, leading to more excellent water absorption when applied to an oil spill. However, this increase in hydrophobicity can be done through chemical modification and temperature treatment (137). Due to its high buoyancy and high adsorption rate, its recovery on the water surface is straightforward (138).

The authors Cojocaru, Macoveanu, and Cretescu (2011) carried out research focusing on three peat-based sorbents for diesel oil, light liquid fuel, and automotive oil petroleum. The three samples were dried, cut, and treated with temperature. The difference between them was the depth of their collections from the soil. The peat - 1 (PT - 1) material was collected from a depth of 0.05 m, peat - 2 (PT - 2) from 1 m, while the peat - 3 (PT - 3) was removed from a depth of 3 m. With these samples, three analyzes were performed, SI (30s drainage), SR (specific retention capability in 30 min), and SC (residual retention capability after centrifugation). According to the results, the peat - 1 material had the highest oil sorption capability, sip 12 to 16 times its weight in oil. The material that was best absorbed was automotive oil. After this analysis, an artificial neural network model was developed to make reliable predictions about the percentage of oil stain removal from the water surface, and the best conditions lead to obtaining an oil removal efficiency of 99.21% (139).

AlAmeri *et al*. (2019) conducted a study to evaluate peat-derived biochar use as a biosorbent to act in oil spills to sip it out of water. The experiments were designed to determine the effect of four operational factors (time of contact with oil, the dosage of biochar, dosage of oil, and temperature), this evaluating two performance indicators (sorption capability and efficiency of oil removal). Thus, linear, bidirectional, and quadratic interaction regression models were used to predict the indicators. To obtain the most effective sorption (32.5 g of oil/g of sorbent) with 91.2% efficiency in removing oil, the conditions under analysis were 70 minutes of exposure at 45°C. Besides, the material was reused three times to sip, maintaining its performance. In addition to the material having excellent performance, it can be concluded that it still has a higher sorption capability than commercial activated carbon (140).

3.4 Kapok

Kapok is obtained from the fruits of the *Ceiba speciosa* and is native to the tropical and subtropical regions of South America. It is the plume that surrounds the seed that would be the kapok itself (141). Kapok requires little water for its growth. Besides, kapok does not need fertilizer or pesticides (142). It is a low-density fiber, non-allergenic, non-toxic, resistant, and odorless (143). The kapok has a low cost, is renewable and has hydrophobic properties, and a high sorption capability. Its composition is prepared up of lignin, polysaccharide, and cellulose, in addition to several acetic groups (141).

Kapok has a low hydrophilic content and a high oleophilic content. Kapok can slowly absorb water because it has a natural wax on its surface. It is a more ecological solution because it comes from a tree that begins to bear fruit in the third year of life and continues to produce for several decades (142). Besides, the material can be reused (144).

Wang, Zheng, and Whang (2012) carried out a study with the kapok to analyze its sorption capability with toluene, chloroform, n-hexane, and xylene. Through the tests, it is possible to correlate the density and viscosity of the material absorbed with the kapok's sorption capability. Two samples were prepared, one with the raw fiber and the other that underwent treatments with different solvents (water, HCl, NaOH, $NaClO_2$, and chloroform), totaling 24 samples. The treated fibers obtained a better result than those not treated in oil sorption, except for chloroform. However, the difference in treatment also interfered with the sorption capability. $NaClO_2$ lead to the best result: an increase of 19.8% (35.5 g/g), 30.0% (51.8 g/g), 21.5% (34.8 g/g) and 24.1% (25.2 g/g) for toluene, chloroform, n-hexane and xylene, respectively. The removal of vegetable wax did not affect the oils' sorption capability under analysis because the wax did not influence the sorption of low-density oils, but it affects the high-density oils engine diesel. So, after treatment, fibers presented a superior sorption result, being an excellent option for oil spills (144).

Dong, Wang, and Xu (2015) studied the sorption capability of kapok fibers in the following oils were analyzed: diesel, motor oil, used motor oil, and cooking oil through a drainage method. Each oil had a distinct sorption capability, 14.68 g/g, 13.42 g/g, 12.85 g/g, and 12.53 g/g for cooking oil, engine oil, used engine oil diesel, respectively. After that, there were two treatments with chloroform (1h at 80°C and 8h at 25°C), both generated a significant increase in the sorption coefficient of the four oils but a minor increase in the sorption capability. The treatment that deserves to be highlighted with the best results was 8h. Diesel was spread like a film covering a single fiber of kapok, while the other three oils formed symmetrical cylindrical shell shapes. Besides, it was with him that a higher sorption coefficient was obtained, even though it had the lowest result for sorption capability. This treatment prepared the surface, previously smooth of the kapok, highly rough, which provides a greater driving force for the oil's sorption in question. There was no increase in the sorption capability, but there was an increase in the speed of 76.74%, 141.68%, 126.47%, and 100% for diesel, cooking oil, used engine oil, and engine respectively. Hydrophobicity, the wax on its surface, and the lumen are some of the main factors for the fiber's high performance as a sorbent (145).

Senanurakwarkul *et al*. (2013) carried out a study to investigate the use of mixtures of recycled rayon (artificial silk) - kapok (RRWK) residues as an oil sorbent for the removal of diesel, engine oil, and large ships (oil marine fuel). The proportions 100: 0, 75:25, 50:50, 25:75, and 0: 100 were used to mix kapok and rayon. Also, tests were carried out parallel with these same proportions but with a sodium sulfate treatment. The materials were tested in two cases: short tests of 15 minutes of exposure and 24 hours of exposure. The most useful tests were long-term tests in all cases. Through the analyzes, it can be observed that the sorbents had a higher oil sorption capability than commercial polypropylene. The presence of paw fibers in RRWK increases hydrophobicity and oil sorption capability, while rayon fibers' presence improves the sorbents' resistance. The two mixtures of 100:0 (kapok: rayon) achieved the best results. However, the most effective sample was achieved through treatment with sodium sulfate. The addition of sodium sulfate during the material's preparation increases the surface area and the pores' size, causing an improvement in sorption. Besides, the higher the viscosity, the greater the retention, and, therefore, ship oil was the one that had the best result, followed by engine oil and diesel. The work concludes that a low-cost, environmentally friendly oil sorbent was developed, which uses materials that would be discarded and performance comparable to commercial products (146).

4. CONCLUSIONS

The oil spill cleanup area is continually developing more effective absorbers. In this work, the fibers of coconut, sisal, peat, and kapok were presented with an emphasis on oil sorption to be used in accidental spills in the ocean, and it was shown that they have excellent applications in this area. Some works were carried out based on raw fiber, and others with treatment to increase its sorption capability. The fibers of coconut, sisal, peat, and kapok were tested for sorption of different substances, showing equal or more significant results than the commercial absorbers. Finally, the highlighted points are that all fibers presented are renewable, have low cost, and have a high capability for sorption of oils and organic solvents. Another advantage of using these plant fibers is the mitigation of adverse environmental impacts generated by their possible improper disposal, helping in a new cycle of use, avoiding the early discard of these materials.

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