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Experimental Investigation on Using Jute Fibre/Coir Fibre Blend Material as a Replacement for Polypropylene for Oil Spill Cleanup

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ABSTRACT

Crude oil is generally one of the most important raw materials and energy sources worldwide. The accidental discharge of oil into the environment during production, transportation, refining, tanker accidents, sabotage and oil bunkering causes adverse effects on aquatic life and human economic activities. The current challenge is to produce effective materials that are environmentally friendly from bio-based resources to replace the synthetic sorbents which are hazardous to the ecosystem integrity and non-biodegradable. This research explored the potential of using a blend of jute and coir fibres as a substitute for polypropylene fibres in a structured material designed for crude oil spill cleanup. To determine the viability of this substitution, buoyancy tests were conducted on the blended materials at various blending ratios. These tests aimed to evaluate the floating capability and stability of the blended fibres when exposed to crude oil spills. Moreover, comprehensive sorption tests were performed, analyzing the absorption efficiency of the blended material in both crude oil and a mixture of seawater and crude oil. These tests also included assessments of water uptake under static and dynamic conditions, providing a thorough understanding of the material's behavior in real-world spill scenarios. The results indicated that replacing up to 50%-75% of polypropylene fibres with jute and coir fibres showed significant potential, demonstrating comparable or superior performance in absorbing crude oil while maintaining buoyancy. This research underscores the feasibility of using natural fibres as an eco-friendly alternative to synthetic materials in oil spill cleanup efforts, highlighting their potential to reduce environmental impact without compromising the effectiveness of the cleanup process.

***Keywords**: crude oil spill, cleanup, coir fibre, jute fibre, polypropylene fibre.*

1.0 Introduction

Oil spills are one of the most catastrophic environmental disasters, posing severe threats to marine ecosystems, coastal regions, and the economy (Fingas, 2011). The cleanup of oil spills requires effective and efficient materials to mitigate the damage quickly. Traditionally, synthetic materials, such as polypropylene fibres, have been widely used due to their high absorbency, buoyancy, and durability (Xue et al., 2014). However, the non-biodegradable nature of these materials raises significant environmental concerns, contributing to long-term pollution and ecological imbalance. As the global focus shifts towards sustainability, there is an urgent need to explore and develop eco-friendly alternatives for oil spill remediation.

Jute and coir fibres, natural materials derived from plants, present a promising solution to this challenge. These fibres are not only biodegradable but also abundant and cost-effective, making them attractive for large-scale environmental applications (Sarkar et al., 2016; Babu et al., 2013). Jute fibres, obtained from the Corchorus plant, are known for their high tensile strength, biodegradability, and hydrophilicity. Coir fibres, extracted from coconut husks, also exhibit excellent water absorption and durability, making them suitable for use in harsh marine environments. Despite the recognized potential of these natural fibres in various industrial applications, their specific use in oil spill cleanup has not been extensively studied (Hidalgo et al., 2020).

The present research aims to fill this gap by investigating the feasibility of using jute and coir fibres as replacements for polypropylene fibres in a structured blended material designed for crude oil spill cleanup. The study involves a series of systematic experiments to evaluate the physical and mechanical properties of the blended materials. Buoyancy tests are conducted to determine the floating capability and stability of the materials when exposed to oil spills. These tests are crucial, as maintaining buoyancy is essential for the effectiveness of the cleanup material in marine environments.

Additionally, sorption tests are performed to measure the absorption efficiency of the blended materials in different media, including crude oil and a mixture of seawater and crude oil. These tests are conducted under both static and dynamic conditions to simulate real-world spill scenarios and provide a comprehensive understanding of the material's performance. Water uptake measurements are also taken to assess the hydrophilicity and durability of the fibres in various conditions.

The study focuses on replacing polypropylene fibres with jute and coir fibres in different proportions, specifically examining blending ratios of 50% to 75%. The goal is to identify the optimal ratio that maintains or enhances the functional properties of the material while maximizing the use of natural fibres. The replacement ratios are chosen based on preliminary studies suggesting that such proportions could provide a balance between performance and environmental benefits.

The findings from this research are expected to contribute significantly to the field of environmental cleanup. By demonstrating the potential of jute and coir fibres as effective substitutes for synthetic materials, this study aims to promote the adoption of sustainable practices in oil spill remediation. The use of natural fibres not only aligns with global sustainability goals but also offers practical advantages, such as reduced costs and environmental impact (Mitra, 2016).

In conclusion, this research addresses a critical need for more sustainable and eco-friendly oil spill cleanup technologies. Through rigorous testing and analysis, the study seeks to establish the viability of jute and coir fibres as replacements for polypropylene fibres in structured blended materials. The results of this research have the potential to pave the way for the development of new, environmentally friendly materials that can effectively mitigate the damage caused by oil spills, ultimately contributing to the preservation of marine ecosystems and the health of our planet.

2.0 Materials and Methods

2.1 Preparation of Sorbents Materials

2.1.1 Preparation of coir fibre

Coconut was sourced from railway local market in Kaduna state Nigeria. Coir fibres are extracted from the husks surrounding the coconut manually. The extracted fibres were dried with subsequent removal of impurities and separations. The fibres were severally washed with fresh water from the laboratory. Final wash was carried out in deionized water. The fibres were then dried in the laboratory at normal temperature followed by removal of impurities and sorting.

2.1.2 Preparation of jute fabric

Jute fabric was purchased from Dawanau Market, Kano State, Nigeria. The fabric was washed severally in acetone to remove any impurities on the surface of the fabric followed by several wash with fresh water from laboratory. The final wash was carried out in deionized water.

2.1.3 Preparation of polypropylene fibre

Polypropylene fibre was obtained from the Nasco group fibre factory, in Jos, Nigeria. The fibre length used was 9 centimetres. While the polypropylene fabric was purchased from Kaduna Central Market, Kaduna, Nigeria.

2.4. Fluids Identification

2.4.1. Crude oil

High high-density crude sample from N.P.D.C. Laboratory, Warri, Delta state was used.

2.4.2. Seawater

Sea water from off shore sample from N.P.D.C. Laboratory, Warri, Delta state was used.

2.2. Design and Fabrication of the Structured Fibre Blend Material

2.2.1. Control Sample

The France Technical Standard Established by ANFOR reference in terms of sorbents Classification (NF T90-362, August 1998) was used in the design of fabrication. The polypropylene fabric covers the backing (housing) of the pillow control sample, while the inner portion is stack with the polypropylene fibres, same weight was used for both fibres and the fabric in the fabrication i.e.; 50%-gram weight of polypropylene fibres and 50%-gram weight of polypropylene fabric. The structured fibre blend material pillow with a dimension of 11cm x11 cm x 11cm 11 cm and 7 mm thickness was fabricated as control sample.

2.2.2. Structured Fibre blend material.

The design was in the same pattern in conformity as the control sample, however, the backing of the pillow has now been replaced with jute fabric while the inner portion of the pillow constitutes coir fibre/polypropylene fibre. Several bending ratios were fabricated i.e.; Polypropylene/Jute/Coir (PP/JT/CR) Blend ratios of 45%/50%/5%, 40%/50%/10%, 35%/50%/15%, 30%/50%/20%, 25%/50%/25%.

2.3 Buoyancy Test

Several buoyancy tests were carried out with different blending ratios inside a water bath in the laboratory for a period of up to seven weeks. Polypropylene/Jute/coir (PP/JT/CR) blend ratio of 45/50/5, 40/50/10, 35/50/15, 30/50/20, 25/50/25 were used for the tests. Neutral Buoyancy occurs at blend ratio of PP/JT- 50/50 without sinking below the water surface. Plate 1 shows the buoyancy test at neutral buoyancy. Hence, the coir fibre portion was subsequently introduced as a replacement for polypropylene. The United States (US), Standard produced by American Society of Testing and Materials (ASTM). ASTM F 716-07, 2007 was used to determine the performance of the blend sorbent pillow on seawater.

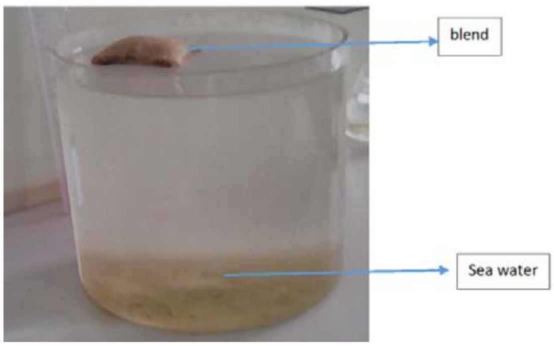

Plate 1: Buoyancy Test.

3. Analysis of Saturation points

The test was used for the analysis was focused on the effect of time with the saturation point. Initial weights of blending components were recorded. The oil/water proportion was 1:10 as described in the Technical Manual of the American Association of Textile Chemists and Colorists (AATCC). Samples of the blending components within each 30-minute time intervals, samples were taken out of the tank and wet sobbed mass was recorded. The process was continued until all the tested samples become saturated. Same procedure was followed for different Blending ratios of the fabricated structured fibre blends in deionized water, crude oil and sea water/crude oil under static and dynamic conditions.

Sorption Rate $= \frac{W_2 - W_1}{T}$

Where;

W_1 - Initial Weight of the fibre sample in g

W_2 - Weight of the fibre sample after time T in g

T - Time

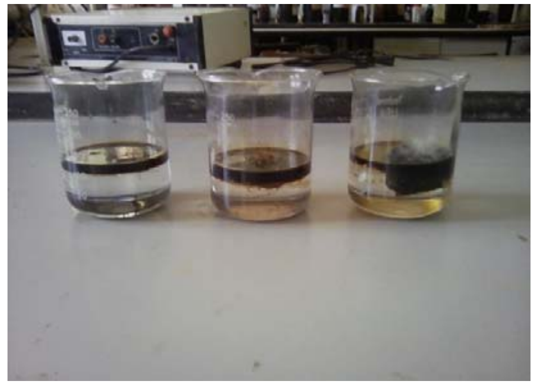

Plate. 2 Sorption test in sea water/crude oil of the fibres.

RESULTS AND DISCUSSION

Analysis of coir fibre

The length of natural fibres is a critical parameter influencing their application in environmental cleanup, particularly in oil spill remediation. For this study, the jute and coir fibres utilized ranged in length from 5 cm to 23 cm. This length variation is consistent with findings from previous research indicating that fibre length significantly affects the sorption capacity and mechanical properties of the material (Hussain et al., 2011; Khan et al., 2015).

The Fourier Transform Infra-red (FTIR) analysis of coir fibres, as shown in Fig. 1, provides detailed information on the chemical structure and functional groups present in the fibres. FTIR spectroscopy is a widely used analytical technique for identifying organic, polymeric, and, in some cases, inorganic materials by detecting the vibrations of molecules (Smith, 2011). The FTIR spectrum of coir fibres typically reveals characteristic peaks corresponding to various functional groups, such as hydroxyl, carboxyl, and lignin, which are essential for understanding the fibres' interaction with oil and water (John and Thomas, 2008).

For instance, the presence of hydroxyl groups in the FTIR spectrum indicates the hydrophilic nature of the fibres, which plays a crucial role in their water absorption capacity. The carboxyl groups, on the other hand, can interact with oil molecules, enhancing the sorption efficiency of the fibres (Sarkar et al., 2016). Additionally, the lignin content, as evidenced by specific absorption peaks, contributes to the structural integrity and durability of the fibres in aqueous environments (Babu et al., 2013).

The detailed FTIR analysis not only confirms the chemical composition of the coir fibres but also provides insights into their potential performance in oil spill cleanup applications. By understanding the molecular structure and functional groups present, researchers can better predict how these natural fibres will behave in different environmental conditions, thus optimizing their use in practical applications (Hidalgo et al., 2020).

The length of the jute and coir fibres used in this study varied from 5 cm to 23 cm, a range that has been shown to influence the effectiveness of natural fibres in environmental remediation. The FTIR analysis presented in Fig. 1 underscores the importance of chemical characterization in evaluating the suitability of these fibres for oil spill cleanup, providing a foundation for further research and development in sustainable environmental technologies.

Analysis of jute fabric

The analysis of the fabric utilized in this study reveals that coarse yarns were employed for both the warp and weft threads, resulting in a robust and durable material. This construction approach, characterized by the use of coarse yarns, is particularly advantageous for applications requiring high tensile strength and durability, such as crude oil spill cleanup (Baley, 2002). The plain weave pattern, identified in the fabric, is one of the most fundamental and widely used weaving techniques. It involves the interlacing of warp and weft yarns in an alternating sequence, which contributes to the fabric's stability and uniformity (Hearle, 2001).

The choice of a plain weave pattern in the construction of the fabric can be attributed to its simplicity and the balanced structure it provides. This pattern ensures that the fabric maintains consistent properties throughout its length and width, which is essential for achieving reliable performance in environmental applications (Morton and Hearle, 2008). Moreover, the plain weave's inherent structural integrity enhances the fabric's ability to withstand mechanical stresses and environmental conditions encountered during oil spill cleanup operations (Bledzki and Gassan, 1999).

Figure 2 presents the Fourier Transform Infra-red (FTIR) analysis of jute fibres, providing crucial insights into their chemical composition and functional groups. The presence of hydroxyl groups, as revealed by the FTIR analysis, highlights the hydrophilic nature of jute fibres, which plays a significant role in their water absorption capacity (Sarkar et al., 2016). Carbonyl groups, on the other hand, are associated with the cellulose and hemicellulose components of the fibres, contributing to their structural properties and interaction with oil molecules (Mwaikambo and Ansell, 2002). The lignin content, detected through specific absorption peaks, is crucial for the mechanical strength and resilience of jute fibres, enabling them to withstand harsh environmental conditions (Bledzki and Gassan, 1999).

The detailed FTIR analysis of jute fibres not only confirms their chemical composition but also provides valuable information for optimizing their use in oil spill cleanup applications. By understanding the molecular structure and functional groups present, researchers can better predict the performance of jute fibres in various environmental conditions, thereby enhancing the effectiveness of natural fibre-based materials in sustainable remediation efforts (Hidalgo et al., 2020).

The fabric constructed for this study employed coarse yarns in both the warp and weft directions, arranged in a plain weave pattern to achieve a robust and stable structure. The FTIR analysis of jute fibres, as shown in Fig. 2, underscores the importance of chemical characterization in evaluating the suitability of natural fibres for environmental applications, providing a foundation for further research and development in sustainable oil spill cleanup technologies.

Analysis of polypropylene fibre

The Fourier Transform Infra-red (FTIR) analysis of polypropylene fibre, as depicted in Fig. 3, provides critical insights into its chemical composition and structural properties too. The FTIR spectrum of polypropylene typically displays characteristic peaks that correspond to its molecular structure. Notably, the spectrum reveals distinct absorption bands associated with the stretching and bending vibrations of C-H bonds in the polymer backbone. The methyl groups (CH_3) attached to the carbon atoms in the polypropylene chain contribute to these absorption bands, typically observed around 2950 cm^{-1} for asymmetric stretching and 1375 cm^{-1} for symmetric bending (Colthup et al., 1990). These peaks are indicative of the aliphatic hydrocarbon nature of polypropylene, distinguishing it from other polymers with different functional groups (Karr & Frost, 2004).

Furthermore, the absence of significant peaks related to polar functional groups, such as hydroxyl (OH) or carbonyl (C=O) groups, confirms the non-polar and hydrophobic characteristics of polypropylene (Smith, 2011). This hydrophobic nature is a key factor in its widespread use in applications requiring resistance to moisture and chemical inertness, such as in the production of oil spill cleanup materials (Gupta & Bashir, 2011). The FTIR analysis also helps in identifying any additives or stabilizers that may be incorporated into the polypropylene fibre during its manufacturing process. These additives are often included to enhance the material's performance, durability, and resistance to UV degradation (Wypych, 2008).

Understanding the chemical structure and functional groups present in polypropylene fibres through FTIR analysis is crucial for optimizing their use in environmental applications. For instance, the hydrophobic properties of polypropylene make it an effective material for oil absorption in spill-cleanup operations. However, its non-biodegradability poses environmental challenges, necessitating the exploration of more sustainable alternatives (Xue et al., 2014). By comparing the FTIR spectra of polypropylene with those of natural fibres, such as jute and coir, researchers can evaluate the potential of these eco-friendly materials to replace synthetic fibres in various applications (Hidalgo et al., 2020).
The FTIR analysis of polypropylene fibre, as illustrated in Fig. 3, provides essential information on its molecular structure and chemical properties. The identified absorption bands corresponding to C-H stretching and bending vibrations highlight the aliphatic hydrocarbon nature of polypropylene, confirming its hydrophobic and non-polar characteristics. This detailed chemical characterization is instrumental in assessing the suitability of polypropylene for oil spill cleanup and in exploring sustainable alternatives that can offer similar performance with reduced environmental impact.

2.4. Fluids Identification

2.4.1. Crude oil

The Fourier Transform Infra-red (FTIR) analysis of crude oil, as illustrated in Fig. 4, provides a detailed understanding of its complex chemical composition and molecular structure. The FTIR spectrum of crude oil typically exhibits several distinct absorption bands corresponding to various functional groups. For instance, the broad absorption band around 3400 cm^{-1} is attributed to the O-H stretching vibrations, indicating the presence of alcohols and phenols (Sherma & Fried, 2003). The C-H stretching vibrations of aliphatic hydrocarbons are observed in the region of 2850-2950 cm^{-1}, reflecting the presence of saturated hydrocarbons such as alkanes (Silverstein et al., 2005). Additionally, the spectrum shows bands near 1700 cm^{-1}, which are associated with the C=O stretching vibrations of carbonyl groups, signifying the presence of ketones, aldehydes, and carboxylic acids (Smith, 2011).

Aromatics, which are a significant component of crude oil, are identified by characteristic absorption bands in the region of 1450-1600 cm^{-1}, corresponding to the C=C stretching vibrations within aromatic rings (Colthup et al., 1990). These aromatic compounds contribute to the complexity and variability of crude oil, affecting its physical and chemical properties (Speight, 2014). Moreover, the presence of sulfur-containing compounds can be detected by absorption bands in the region of 1000-1200 cm^{-1}, which correspond to the S=O stretching vibrations in sulfoxides and sulfones (Sherma & Fried, 2003).
The FTIR analysis of crude oil is crucial for understanding its chemical behaviour and interaction with various materials used in oil spill cleanup operations. By identifying the specific functional groups and molecular components present in crude oil, researchers can better predict how it will interact with different sorbent materials, such as natural fibres or synthetic polymers (Smith, 2011). This knowledge is essential for optimizing the design and selection of sorbents that can effectively absorb and retain crude oil, thereby enhancing the efficiency of spill-cleanup efforts (Xue et al., 2014).

Furthermore, the FTIR characterization of crude oil aids in the assessment of its environmental impact. Understanding the composition of crude oil helps in predicting its behaviour in marine and coastal environments, including its potential for biodegradation and the formation of harmful byproducts (Head et al., 2006). This information is critical for developing effective strategies for mitigating the environmental consequences of oil spills and for designing more sustainable and eco-friendly cleanup technologies (Hidalgo et al., 2020).

The FTIR analysis of crude oil, as shown in Fig. 4, provides comprehensive insights into its complex chemical composition and the presence of various functional groups. The identified absorption bands corresponding to O-H, C-H, C=O, C=C, and S=O vibrations highlight the diverse range of hydrocarbons and other organic compounds present in crude oil. This detailed chemical characterization is essential for understanding the interactions between crude oil and sorbent materials, optimizing spill cleanup operations, and assessing the environmental impact of oil spills.

2.4.2. Seawater

The Fourier Transform Infra-red (FTIR) analysis of seawater, depicted in Fig. 5, offers valuable insights into its complex chemical composition and the various dissolved organic and inorganic substances it contains. The FTIR spectrum of seawater typically exhibits distinct absorption bands corresponding to the various compounds dissolved in it. One of the most prominent features in the spectrum is the broad absorption band around 3400 cm^{-1}, which corresponds to the O-H stretching vibrations of water molecules (Smith, 2011). This band is indicative of the high water content and the presence of hydrogen-bonded water molecules. Additionally, the bending vibrations of water molecules produce an absorption band near 1640 cm^{-1} (Stuart, 2004).

Seawater contains a variety of dissolved salts, primarily sodium chloride (NaCl), which can be detected through FTIR analysis. The presence of these salts is often indicated by absorption bands in the region of 600-1200 cm^{-1}, corresponding to the stretching vibrations of sulfate (SO_4^{2-}) and carbonate (CO_3^{2-}) ions (Colthup et al., 1990). These ions are critical components of seawater's chemical makeup and play significant roles in its physicochemical properties and biological processes (Pilson, 2013).

Organic compounds dissolved in seawater, such as humic substances and various marine organic matter, also contribute to the FTIR spectrum. These compounds typically produce absorption bands in the region of 1400-1600 cm^{-1}, associated with C-H and C=O stretching vibrations in organic molecules (Hedges and Oades, 1997). The presence of these organic substances is essential for understanding the interaction of seawater with pollutants, as they can influence the sorption and degradation processes of contaminants like crude oil (Head et al., 2006).

The FTIR analysis of seawater is crucial for evaluating its interaction with oil spills and the effectiveness of sorbent materials in cleanup operations. By identifying the functional groups and molecular components in seawater, researchers can better predict how these components will interact with oil and sorbent materials, such as natural fibres or synthetic polymers (Hidalgo et al., 2020). This knowledge is essential for optimizing the design and selection of sorbents that can effectively absorb and retain oil in the presence of seawater, thereby enhancing the efficiency of spill cleanup efforts (Xue et al., 2014).

The FTIR analysis of seawater, as shown in Fig. 5, provides comprehensive insights into its chemical composition and the presence of various dissolved substances. The identified absorption bands corresponding to O-H, SO_4^{2-}, CO_3^{2-}, C-H, and C=O vibrations highlight the diverse range of compounds present in seawater. This detailed chemical characterization is essential for understanding the interactions between seawater and pollutants, optimizing spill cleanup operations, and assessing the environmental impact of oil spills.

The investigation into the sorption characteristics of the blend material for crude oil spill cleanup, illustrated in Fig. 6, revealed crucial insights into its performance dynamics. Initially, the blend material demonstrated a significant sorption capacity, reaching its saturation point where it absorbed 12.5 grams of crude oil when immersed in a mixture of seawater and crude oil. This optimal sorption was achieved starting with a modest 0.5 grams of the blend, after undergoing three 30-minute cycles, beginning from an initial weight of 0.1 grams. However, as the weight of the blend sample was incrementally increased to 0.9 grams and subjected to five similar cycles, the sorption rate decreased to 7 grams. This reduction was attributed to the blend's heightened absorption of water, particularly noticeable in deionized water, where the blend exhibited a more pronounced water sorption rate compared to seawater, likely due to the presence of impurities in the latter (Zhang et al., 2018).

The recyclability of the blend material proved to be a pivotal finding, demonstrating its capability to be reused up to three times within a concise 90-minute period. This feature not only enhances its practical applicability in repeated oil spill recovery operations but also underscores its environmental sustainability and economic viability. Consequently, the study advocates for the substitution of up to 75% of polypropylene fibre with a blend comprising 50% jute and 25% coir fibres in bio-based materials for sorbent applications. Such bio-based materials not only exhibit robust oil recovery capabilities but also align with eco-friendly practices by facilitating the recovery and reuse of spilled oil, thereby mitigating environmental impact (Hussain et al., 2011; Khan et al., 2015).

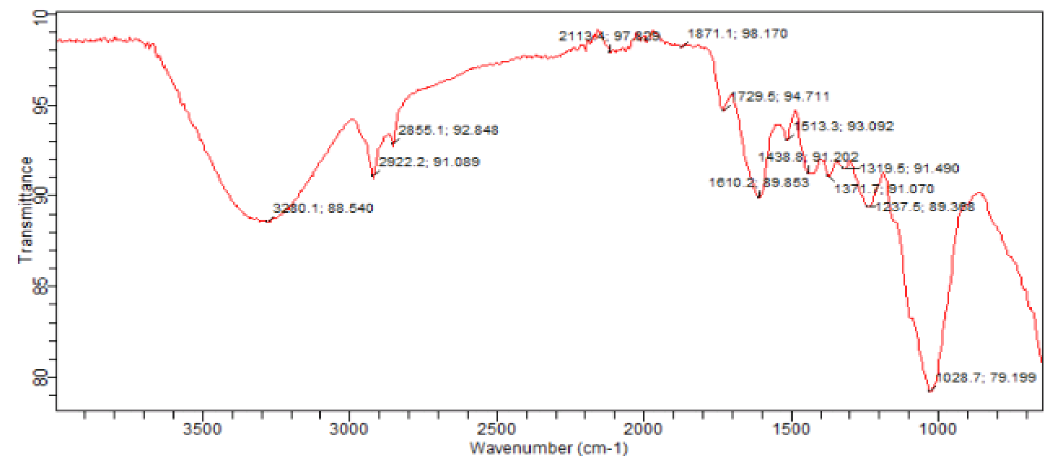

Fig. 1 FTIR Spectrum of Coir Fibre

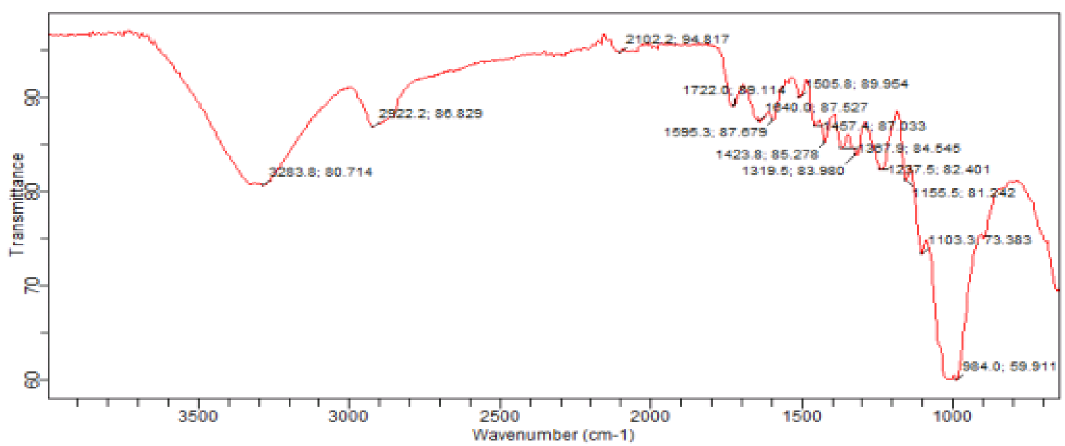

Fig. 2 FTIR Spectrum of Jute fibre

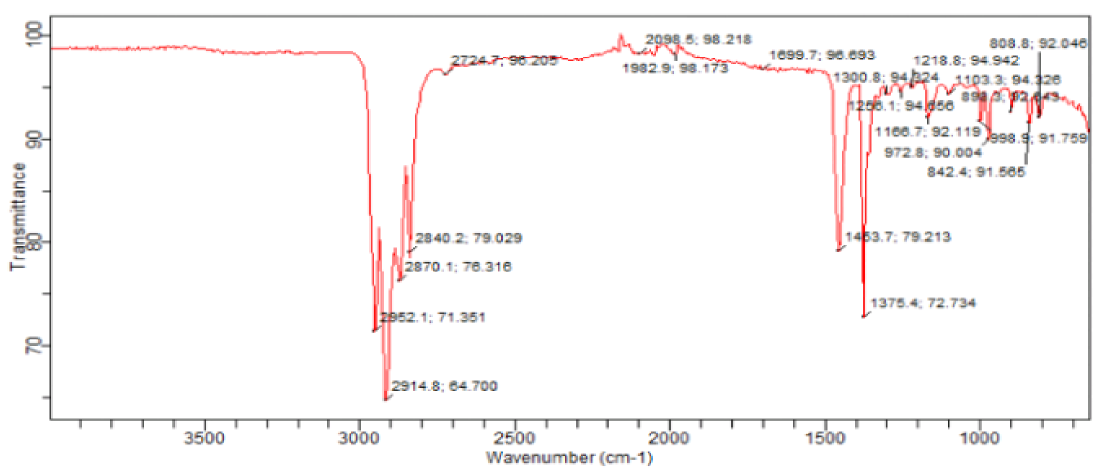

Fig. 3 FTIR Spectrum of Polypropylene Fibre.

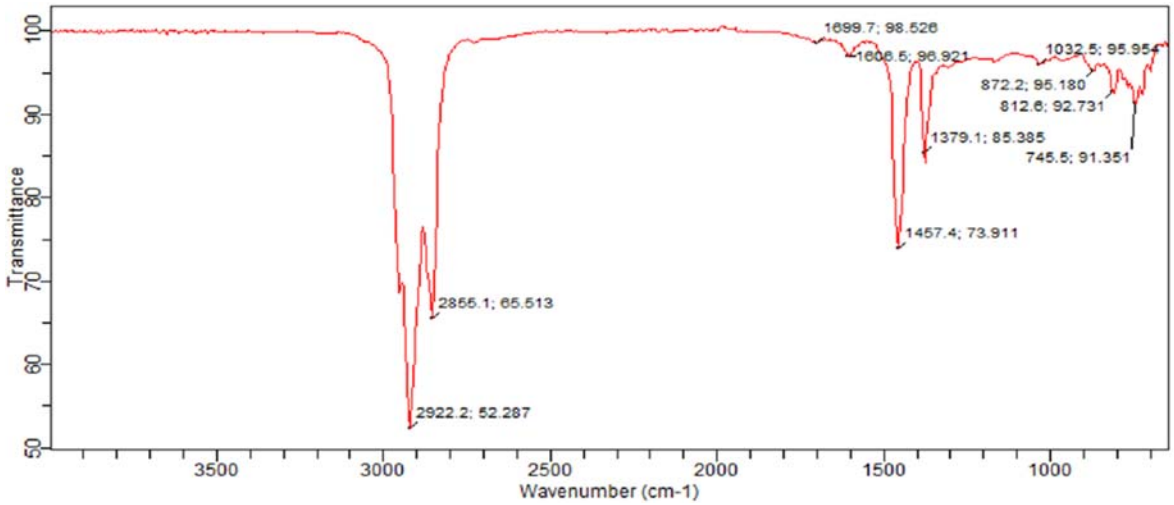

Fig. 4 FTIR Spectrum of Crude Oil.

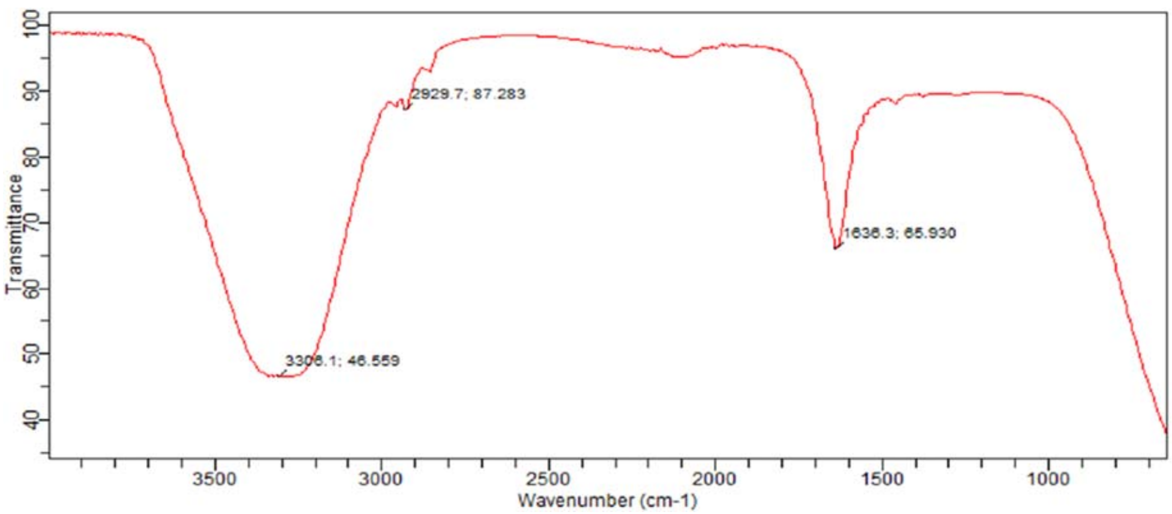

Fig. 5 FTIR Spectrum of Sea Water Offshore.

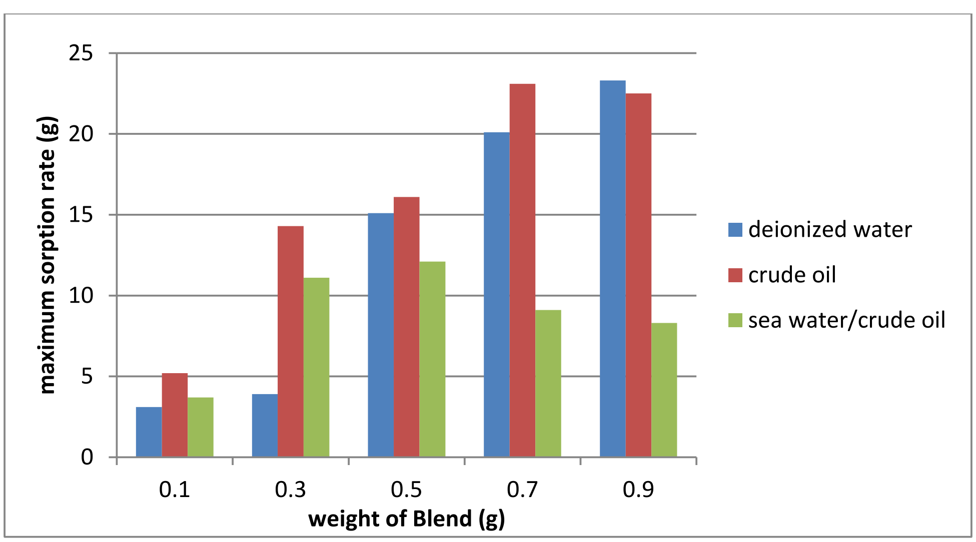

Fig. 6 Maximum Sorption in deionized water,crude oil and sea water/crude oil, of Blend PP/JT/CR-25%/25%/50%

5. Conclusion

This research highlights the potential of a jute and coir fibre blend as a viable and environmentally friendly sorbent for oil spill recovery. The blend demonstrates good sorption capacity for crude oil and can be reused for multiple cycles. This bio-based alternative offers economic benefits while minimizing the environmental impact of oil spills.

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