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Waste Chicken Feathers as Sorbents for Hydrocarbon and Non-Hydrocarbon Spills

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ABSTRACT
The freshwater habitat of the Niger Delta region of Nigeria currently faces oil spill challenges which arise not only from Crude oil and its refined products but also animal fats, vegetable oils as well as other non-petroleum oils. The harmful effect of Spilled Petroleum and non-petroleum oil on the environment stems from their similar chemical and physical properties, which produce harmful effects on the environment. Oil spill remediation is achieved using chemical, biological, or physical processes to sorb oil from the surface of contaminated water. This study investigates the use of waste chicken feathers as sorbents for oil clean-up which is a physical process. The sorption capacity of waste chicken feathers was experimented on water contaminated with vegetable oil, peanut oil and engine oil. The experimental results showed that waste chicken feather have a high oil sorption capacity of 20.59g for Vegetable oil/g of sorbent and low water sorption capacity of 0.98g of water/g of sorbent and are highly oleophilic and hydrophobic. Waste chicken feathers when used for oil spill clean-up, only interacts with the oil at the surface of oil/water mixture, it does not sink or mix with the water below and is not prone to degrading in the water when left for a long period.

KEYWORDS: Waste Chicken feathers, Sorbents, Oil spill remediation, Oleophilic, Hydrophobic.

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1. INTRODUCTION

The exploration and production of crude oil activities provide great revenue for the global economy, but the negative impact of oil spill remains a major concern for the oil and gas industry (Ifelebuegu & Chinonyere, 2016). Numerous spills have occurred in recent years. In November 2011, nearly 6,000 litres of oil were leaked into Campos Bay, Brazil, and this polluted an area of 163 km^2 and required a massive clean-up operation (Silva *et al.*, 2014). In the same year, the Bonga oil field spilled 1.1 million litres of crude oil (35,000 barrels) and contaminated a coastal strip of nearly 200km at the Nigerian coast (Sam & Prpich, 2017).

Oil spills can occur from non-hydrocarbon geographical settings like natural disasters, households, and manufacturing or production companies. These equally have negative impact on the marine ecosystem and the environment. In some developing countries, oil spillage in water or on land leads to a progressive change in the physical and chemical properties of oil. The spilled oil is responsible for an undesirable taste and odor in drinking water and causes severe environmental damage (Nwadiogbu *et al.,* 2016). It was observed that local palm oil processing companies are sited close to water bodies (Olaleye & Adedeji, 2004). Most times, Palm oil plantation will have agricultural runoff into surrounding water bodies that can lead to bioaccumulation and toxic blooms, which could have an adverse effect in the aquatic ecosystem and reduce the drinking water quality for surrounding communities (Ng, 2017).

Oil spreads when spilled, whether on land or water. The critical and urgent nature of Oil spills is on account of the fact that the occurrence is sudden and results in colossal damage to the aquatic environment and marine life.

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Hence, their containment and control require rapid response in order to avert a long-term disaster (Luciano *et al.,* 2018).

To control its spreading from polluting the environment, there is the need for containment and recovery. Containment of an oil spill refers to the process of confining the oil to stop it from spreading to other areas. That is, to redirect the oil to an area where it can be treated or recovered. Recovery is a major step in removing oil from the environment. In the removal of oily contaminants from water, several methods are used; they include solidification of the oils, bioremediation, gravity separation, electro flotation and physical techniques such as natural recovery, skimmers, and sorbents (Tesfaye *et al.,* 2018).

Sorbents recover oil through either adsorption or absorption. Sorbents over the years, for oil spill clean-up are grouped into three classes: natural organic, inorganic sorbents and synthetic organic sorbents (Lim & Huang, 2007). Studies reveal that the removal of oil by sorption is one of the most effective techniques for the complete removal of spilled oil under ambient conditions (Hussein *et al.*, 2008). Organic materials such as feathers are inherently hydrophobic (water repelling) and oleophilic (oil attracting) thus, they absorb oil. Absorbents which are oleophilic and hydrophobic in nature, have often given an outcome that shows them as good controls of oil spills.

Feathers have a hollow structure and contain barbs and barbules, responsible for a high surface area. The oil retention on feathers is influenced by the intermolecular bonds between the hydrocarbons in oil and feather keratin (Kelle & Eboatu, 2018). Oil sorption is determined by the surface chemistry and microstructure of feathers.

The presence of disulfide crosslinks from cysteine and predominant non-hydrophilic amino acids in the chain sequence give chicken feather keratin a hydrophobic character (Mendez-Hernandez *et al.,* 2018). Keratin fibers are strictly non-abrasive, low density, biodegradable, renewable, eco-friendly, insoluble in organic solvents, hydrophobic behavior, warmth retention and cost effective too (Bansal *et al.,* 2017).

Chicken feathers are agricultural waste that is available in most countries with a high consumption of poultry. The consumption of poultry is increasing globally due to the rapid growth rate of chickens and the relatively cheap costs associated with poultry farming. Europe consumes ~14,013,000 tonnes of poultry yearly (AHDB, 2018). By 2023, there is an expected increase in Global poultry consumption to ~14.9 kg/person/year (Mottet & Tempio, 2017). Waste feathers have limited applications compared to other natural fibres such as wool, hemp and sisal. In the UK, Waste poultry feathers processed by autoclaving to form feather-meal, a low-value, low-grade, protein-rich animal feed currently exported to Eastern Europe and Russia (Meeker & Meisinger, 2015). In Nigeria, however, chicken feathers constitute a major agricultural waste. They are usually disposed of in uncontrolled dumpsites, landfilled or burned.

The utilization of this agricultural waste can provide an effective, low cost, abundant and environmentally friendly oil sorbent with performance that is comparable to conventional sorbents. This research assesses the potential for chicken feathers to be used as a sorbent for the removal of oil spills of both hydrocarbon and non -hydrocarbon origin from contaminated waters. The most common materials used as oil sorbents in recent times are commercial polypropylene which has good oil sorption capacities of 15-25g.g-1 and good oil/water selectivity because of their oleophilic -hydrophobic properties (Wu *et al.,* 2014). A comparison of the performance of the chicken feather to commercially available polypropylene is done by investigating the microstructures, oil sorption capacity, water sorption capacity and oil recovery potential.

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The barriers to their commercial development are also highlighted and recommendations proposed.
The objectives of the study is to further validate previous research work that Chicken Feathers can be used as an oil sorbent for oil spill remediation of both hydrocarbon and non-hydrocarbon spills.

2. MATERIALS AND METHODS

2.1 Materials

Shredded chicken feather, polypropylene pads, and three different oils: engine oil, vegetable oil and peanut oil were the materials used in the study.

2.1.1 Whole Chicken Feather

Chicken feathers (see Figure 1) obtained from a major UK poultry facility were washed using a 5% hydrogen peroxide solution containing an industrial scouring agent (M-SCOUR EF-5, Regency FCB). The sample was treated with 1% disinfectant solution (Dupont Virkon S), and washed twice using industrial feather cleaning soap.

Figure 1: Waste Chicken Feathers

A Rapid 2040 granulator with a 5mm mesh was used to shred dried feathers in batches, after they had been cleaned and dried using a tumble dryer.

2.1.2 Polypropylene Pads

The Polypropylene pad used in this study was sourced from Darcy Co. U.K. This material is oleophilic and hydrophobic with a high oil absorbency and it is usually used as a suitable oil absorbent for domestic and industrial use.

2.1.3 Oil

Three types of oil representing hydrocarbon origin and non-hydrocarbon origin were used.

to evaluate the oil sorption potential of waste chicken feather. The viscosity and density ranges of the different oils are given in Table 1.

Table 1: Viscosity and Density Values for Engine, Vegetable and Peanut Oil

Type of Oil	Viscosity (m.Pa.s)	Density (g/cm^3) at 20^{o}C
Engine	60	0.885
Vegetable	40	0.918
Peanut	40	0.912

(Oil Data extracted from Burkle GmbH, 2021)

The three oils, engine oil, vegetable oil and peanut oil were bought from TOTAL company, Lidl, and Morrison stores respectively in the United Kingdom.

2.2 Methods

2.2.1 SEM Analysis

The Physical characteristics, morphological and chemical characteristics were investigated. The appearance and surface of waste chicken feathers and polypropylene mat was evaluated using scanning electron microscopy (SEM). The images were taken with Hitachi TM4000Plus. The samples were dried at 40^{o}c for about 12 hours; and then vacuumed for 5 – 10 minutes before starting the analysis.

2.2.2 Water Contact Angle

Whole Chicken feather and polypropylene pads were the samples used to determine water contact angle, which provides useful data about the wettability of the material.

A Kruss drop shop Analyzer (model DSA 100S) was used at a temperature of approximately 20ºC. 5 µl deionized water was dropped onto the sample surface during every test. It was necessary to flatten the surface of the samples as much as possible in order to get the required clear result from the analysis. Hence, the samples were compressed with a 2.3kg cement block for 24 hours to get as much flatness of sample surface as possible.

2.2.3 Dynamic Water-Sorption Test

Water-sorption test was carried out to determine water up-take and the oleophilic properties of waste chicken feathers and polypropylene pads under dynamic conditions. Samples of the sorbent are cut into squares, weighed and then placed in 1 litre jars filled with water and sealed. This is then mounted on a shaker table and set to a frequency of 150 cycles per minute at duration of 15 minutes. After 15 minutes, the content is allowed to settle, and observations recorded for them to determine the condition of the absorbent and the water. The water sorption capacity is calculated according to equation (ASTM, 2018).

$$Water\ Sorption\ Capacity\ \left(\frac{g}{g}\right) = \frac{Net\ Water\ Sorbed\ (Sw)}{Initial\ Mass\ of\ Sorbent\ (So)} \quad (1)$$

So = Initial Dry Sorbent weight
Swt = Weight of the sorbent sample at the end of the test
Sw = (Swt-So)
Sw = Net water Sorbed

2.2.4 Oil Sorption Study

To study the oil sorption capacity, the procedures followed were the ASTM F 726-06 method for both the short test and long test. The sorption experiments were conducted in a static system at room temperature of about 20 ± 4^{O}C

Short test: This test was carried out by pouring 30 ml of Engine oil into a one-liter glass beaker containing 700ml tap water, to obtain oil films of about 3ml thickness on the water surface. This process was repeated for the other two oils used and this was done in triplicates. The sorption material was cut, weighed and placed in the beaker for 15 minutes. Subsequently, after 15 minutes, the sorbents were removed from the beaker with a sieve and drained for two minutes.

Long test: 30 ml of Engine oil was poured into a one-liter glass beaker containing 700ml tap water, to obtain oil films of about 3ml thickness on the water surface. This procedure was repeated for the other oil, and this was done in triplicates. The sorption material was cut, weighed, and placed in the beaker for 24 hours. Subsequently, after 24 hours, the sorbents were removed from the beaker with a sieve and drained for two minutes.

After draining the sorbents, its new weight was measured and recorded. The amount of oil retained was determined by subtracting the final weight of sorbent from its initial weight. The equation used for evaluating the oil sorption capacity was:

$$Oil\ Sorption\ Capacity\ (Q) = \frac{Net\ Oil\ Retained\ (Sn)}{Initial\ Mass\ of\ Sorbent\ (So)} \quad (2)$$

Q= Sorption Capacity
St = Total mass of the sorbed samples
So= Initial mass of the sorbed materials
Sn = Net oil retained = St - So

2.2.5 Saturation Time

The saturation time was observed for the three oils using the ASTM F-726-06 method for the short test. However, it was ensured that the sorbent was removed from the beaker and left to drain every one minute which added up to a contact time of fifteen minutes. A record of the weight was noted after each two-minute interval and the sorption capacity calculated to model the saturation curve.

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2.2.6 Oil Recovery

The oil recovery % is given by Equation (3)

$$Oil\ Recovery\ (\%) = \frac{Oil\ Recovery\ (g)}{Oil\ Retained\ (g)} \cdot 100\ \%$$

The oil recovery for waste chicken feathers and polypropylene pads was investigated. After the sorbent was saturated with oil, the weight was noted. Subsequently, the sorbent was compressed in a container using a 2.3kg cement block and weighed again. The difference between the weight of the saturated sorbent and the weight after compression is the mass of oil that could be recovered (oil recovery in grams). The percentage of oil recovery was calculated according to equation *(3)*.

3. RESULTS AND DISCUSSION

3.1 SEM Analysis of Sorbents

Morphological structures of Chicken feather fractions: From the SEM image we see more clearly that chicken feathers comprise of three distinct and separate units, the rachis, the central shaft of the feather; the barbs and tertiary smaller structures and the barbules. These indicated a large surface area and a rough surface with hollow microstructure (or lumen) as seen in Fig 3. hollow structures observed in the chicken feathers enable the binding of the feather mats to the oil surface. Rough morphology of sorbent materials and entangled pore structure contribute to oil retention (Wahi *et al.,* 2013). The dense surfaces and small gaps in the structure are said to increase their hydrophobicity (Tesfaye *et al*., 2018).

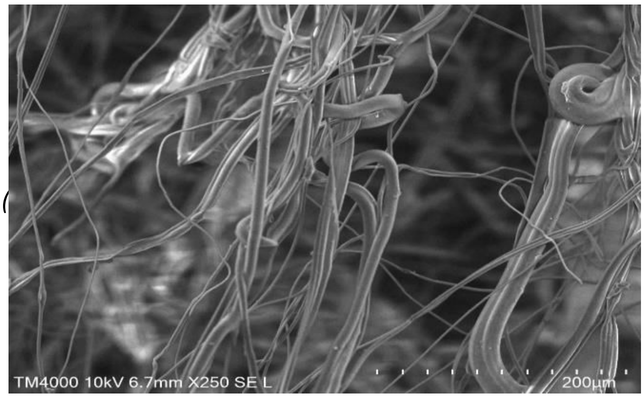

Figure 2. SEM image of polypropylene pad

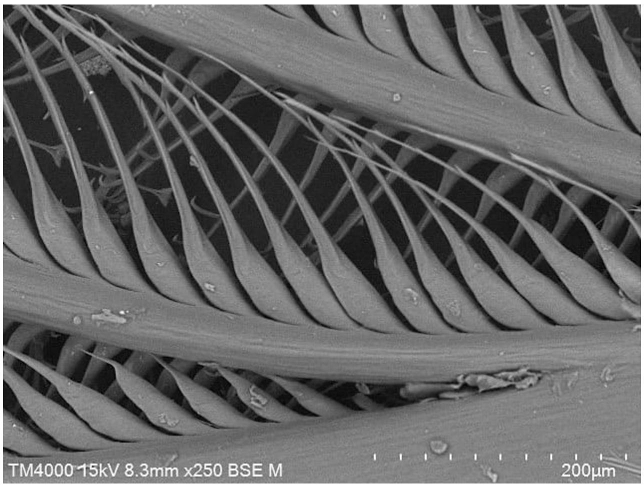

Figure 3 SEM image of a whole chicken feather with barbs, barbules and hooks shown, branching out from the rachis.

As stated in Radetic *et al.* (2008), the most important qualities to consider when selecting oil sorbents include high sorption capacity, good buoyancy, sufficient oil retention and reusability. The hydrophobicity and oleophilic properties of feathers result from high keratin content with disulphide bonds.

3.2 Water Contact Angle

Contact angle results show hydrophobicity and oleophilicity for the whole chicken feathers and the polypropylene pads (see Table 2). When the contact angle is above 90 degrees, the solid is said to have a poor wetting potential and is termed hydrophobic.

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Table 2: Contact Angle for Polypropylene Pads and Chicken Feather

Sample	Water Contact Angle
Polypropylene Pads	136°
Chicken feathers	119°

Earlier reports have shown that the wettability of a solid surface depends on factors such as the topographical microstructure and the surface chemical composition (Neinhuis & Barthlott, 1997; Zhang *et al.,* 2013).

3.3 Dynamic Water Sorption Capacity

The experimental results show that waste chicken feather mats have a very low water sorption capacity of 0.98g of water/g of sorbent even though polypropylene pads absorb less water of 0.40g of water/g of the sorbent (See Fig 4).

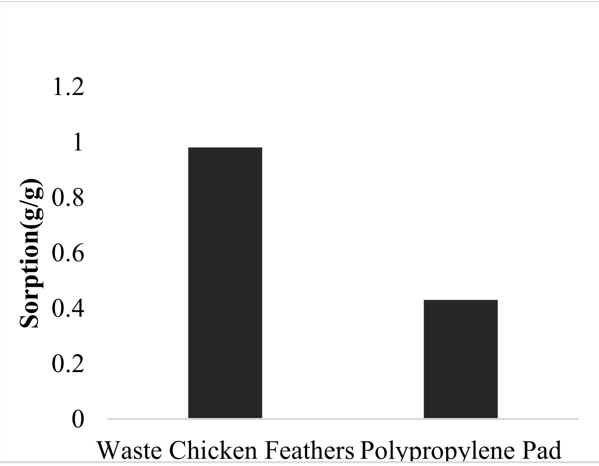

Figure 4 Water Sorption capacity of waste chicken feather and polypropylene pad

The result revealed that they are both highly hydrophobic and an important characteristic when selecting good sorbents.

This will mean that the waste chicken feathers when used for oil spill cleaning, will only interact with the oil at the surface of oil/water mixture, it would not sink and mix with the water below and will not be prone to degrading in the water when left for a long period

3.4 Oil Sorption Capacity

The sorption capacities of waste chicken feathers for vegetable oil, peanut oil and engine oil under static conditions after 15 minutes are presented in Fig 4(a). It was observed that there is no major difference between the 15 minutes sorption time and the 24 hours because the saturation time was reached in less than 20 minutes and the waste chicken feather has higher sorption than polypropylene pads for all the different oils. The sequence from the highest to the lowest was vegetable oil, peanut oil and Engine oil. The sorption capacity for peanut oil was 20.59g/g about one and a half times greater than the polypropylene pads which was

13.04g/g. The results confirmed the report that Chicken feathers have an oil sorption capacity of about 16.2g/g (Tesfaye *et al.,* 2018). Consequently, waste chicken feathers and polypropylene pads provide feasible advantages for introduction to and extraction from oil spills.

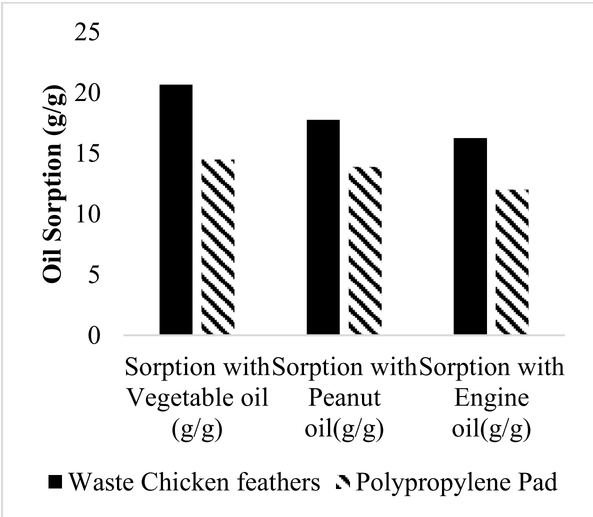

Figure 5 Sorption capacities of waste chicken feather and polypropylene using vegetable oil, peanut oil and engine oil

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3.5 Saturation Time

Figure 6 illustrates the sorption time increase from 60s to 720s. After 720s, a maximum vegetable oil sorption capacity of 20.66 (g/g) was attained for chicken feathers. For all the three oils, it was observed that the initial two minutes were very rapid and then the rate of sorption reduced. The initial fast adsorption suggests the initial adsorption onto the surface of the material followed subsequently by penetration into the microscopic voids. The slow uptake in the later stages may be indicative of the fact that available sites for active sorption are less. This may be due to the oleophilic and hydrophilic nature of the chicken feather. This observation relates to the trend reported in Osamor and Momoh (2015) research on the use of coconut coir as a sorbent to remove vegetable oil and diesel oil from saltwater.

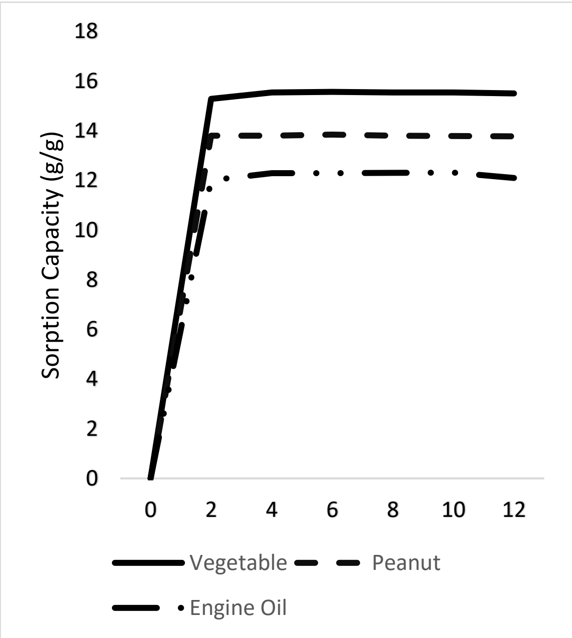

Figure 6 Saturation curve of waste chicken feathers in vegetable, peanut and engine oil showing that the waste chicken feathers were saturated within the first two minutes of being exposed to oil.

3.6 Oil Recovery

Waste Chicken feather showed oil recoveries of over 48.62% for vegetable oil at a pressure of about 2,000 $N.m^{-2}$ as seen in Fig 7. Some higher values of up to 95 % have been revealed in previous studies from the literature (Tesfaye *et al.*, 2018).

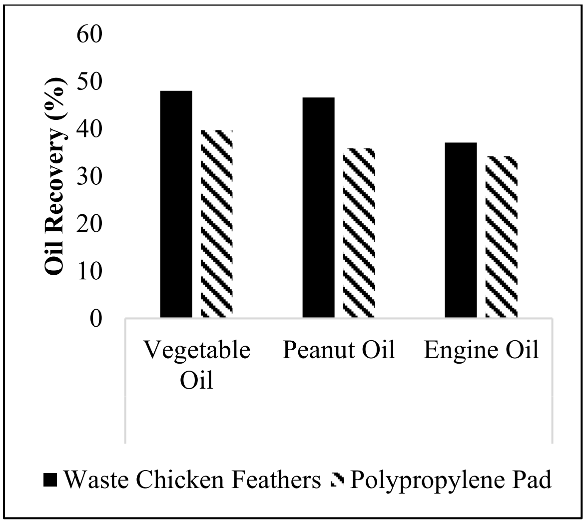

Figure 7 Oil recovery in percent for waste chicken feathers and polypropylene pads

It was observed that the oil recovery of waste chicken feather was higher for polypropylene pads. The porous structure of waste chicken feathers enables the oil to be retained in voids, this contributes greatly to the high oil recovery and this oil is therefore easier to recover by using pressure.

4. CONCLUSION

The potential of chicken feather waste to be used as a good and effective sorbent to clean up oil spills arising from vegetable oil, peanut oil and engine oil was confirmed by this study. It studied the science of sorption and its applicability in the cleanup of oil spills. Chicken feathers are a local abundant resource, and their use is a cheaper, practical solution to address problematic oil spills in Niger Delta Communities in Nigeria. Factors such as converting feathers to mats or commercial packaging for clean-up should be considered because this will impact the likelihood of local manufacturing of chicken feather sorbents.

After use, the oil loaded feathers can be used to generate biogas because it has biochemical methane potential. This will also solve the waste management challenge of this agricultural waste because waste chicken feathers have limited disposal options thereby establishing a circular economy for this agricultural waste.

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