Journal of Agriculture and Ecology Research International

21(3): 43-53, 2020; Article no.JAERI.55160
ISSN: 2394-1073

The Use of Chicken Feather Waste as an Adsorbent for Crude Oil Clean Up from Polluted Water

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Authors' contributions

This work was carried out in collaboration among all authors. Author AAO designed the experiment, wrote the protocol, interpreted the data and coordinated the writing of the manuscript. Author NOO performed the experiments, performed the statistical analysis and wrote the first draft of the manuscript. Author ABA contributed reagents and interpreted the data. Author OOO analysed and interpreted the data, manage the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2020/v21i330136
Editor(s):
(1) Dr. Ozdal Gokdal, Aydın Adnan Menderes University, Turkey.
Reviewers:
(1) Julian Cruz-Olivares, Autonomous University of State of Mexico, Mexico.
(2) Pucci Graciela Natalia, Universidad Nacional de la Patagonia San Juan Bosco, Argentina.
Complete Peer review History: http://www.sdiarticle4.com/review-history/55160

Original Research Article

Received 20 December 2019
Accepted 28 February 2020
Published 30 April 2020

ABSTRACT

The present study aims to evaluate the use of chicken feather waste (CFW) as an absorbent for the removal of crude oil from crude oil polluted water (CPW) in comparison with commercial activated carbon (CAC)) in Nigeria. Oil pollution, can be as a result of natural disaster like earthquake, volcanic eruption, hurricane etc., or as a result of man's interference for example terrorism, oil bunkering, tanker and oil rig accidents. CAC have been use as adsorbent for crude oil removal from the water environment but very expensive, hence the need to develop cheaper and environment friendly adsorbents from some agricultural waste which could constitute nuisance in the environment. The pulverized chicken feathers were characterized using Rutherford Backscattering Spectrometer (RBS) and Scanning Electron Microscope (SEM) for elemental composition and the determination of surface morphology, respectively. The agricultural wastes used for this study was chicken feathers. The CFW was sourced from a local market at Ile-Ife, Osun State Nigeria, while commercial activated carbon was purchased from Uche-El Water Limited Company. The pulverized CFW was characterized using Scanning Electron Microscopy (SEM) and

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Particle-induced X-ray Emission (PIXE). Elemental composition of the CFW showed the presence of Na, Mg, Al, P, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Sr, Zr, Cd, Sn, Pb and Si within the range 12.8 - 22566.3 ppm with agglomeration of particle. The results of the scanning electron microscope clearly showed the surface texture and morphological characteristics of CFW. The efficiencies of adsorption increased with increasing initial concentration for the two adsorbents except initial concentration of 20/30 which decreased in the case of CAC. The adsorption efficiencies for all the initial concentrations for the adsorbents is significantly different (F=16.114; P=0.000) at confidence interval of 0.05. CFW showed greater adsorption efficiency of 99.95%, followed by CAC which showed an adsorption potential of 95.08% (P=0.577 > C.I=0.05). The adsorption efficiencies obtained for the chicken feather compare very well with the activated carbon and even better as the dosages of the chicken feather increased. The result of the study shows that chicken feathers is an efficient sorbent for the mopping of crude oil spill in water.

Keywords: Crude oil; chicken feather waste; oil pollution; adsorption, Nigeria.

1. INTRODUCTION

The WHO [1] reported that as a result of high population growth in Africa and growing income, the demand for eggs and poultry meat, in recent year, has significantly increased across most parts of the continent. According to the USAID (United States Agency for International Development) estimates, this trend is likely to continue over the next few years. As a result, the consumption of poultry and eggs will increase by 200% between 2010 and 2020 for at least some countries in sub-Saharan Africa as reported by Obi [2] and USDA [3]. Nigeria is an African country where this trend can clearly be seen. Nigeria is one of the largest and most populous country in Africa, with a total geographical area of 923,768 square kilometers [4]. Its estimated population was 174.5 million people in 2013, and its population growth rate is 3% per annum [3]. Nigerian economic statistics reveal annual economic growth rates that averaged over 7% in recent decades, making Nigeria one of the fastest growing economies in the world [2]. Nonetheless, this growth has not reduced poverty or created much needed jobs. According to African Economic Outlook [5], unemployment is still very high, and more than 60% of the population lives below the poverty line.

However, the Nigerian poultry industry in particular as reported by USDA [3] and Adene and Oguntade [6] has been rapidly expanding in recent years and is therefore one of the most commercialized (capitalized) subsectors of Nigerian agriculture. Hence, the popularity of poultry production can be as result of the fact that poultry has many merits over other livestock. Poultry birds better converters feed into useable protein inform meat and eggs. The production cost per unit is relatively low, and the return on investment is high. Therefore, farmers need a comparatively small capital to start a poultry farm. Furthermore, poultry meat is very tender and acceptability to consumers is high, regardless of their religious beliefs. Also, capital is not tied up over a long period because the production cycle is quite short. Finally, eggs which are one of the major products of poultry production are relatively affordable for the common person than other sources of animal protein [7,8].

On the other hand, oil pollution, can be as a result of natural disaster like earthquake, volcanic eruption, hurricane etc., or as a result of man's interference for example terrorism, oil bunkering, tanker and oil rig accidents, to mention but a few. It is a prominent occurrence in oil producing countries like Nigeria which therefore result to a concern on how to attend to the challenges of oil pollution in the environment. This is because of the various impacts it has on the aquatic and terrestrial environment. Different methods have been developed such as adsorption, absorption, ion exchange, coagulation etc for the removal of different contaminants such as spent engine oil, urban storm water runoff, bacteria, virus and fungi from different sewage pipes etc, but not without limitations. The commercial activated carbon (CAC) have been in use as adsorbent for crude oil removal from the water environment but very expensive, hence the need to develop cheaper and environment friendly adsorbents from some agricultural waste which could constitute nuisance in the environment. Many researchers have developed such agricultural wastes as adsorbents for solving oil pollution problems. Behnood et al. [9] reported that several natural organic sorbents have been studied for the removal of oil spill, for example raw sugar cane bagasse [10,11,12] raw and fatty-acid grafted sawdust for oil [13] and other pollutants [14] black and white rice husk ash [15] barley straw [16] banana trunk fibers [17] acetylated sugarcane bagasse [18,19] carbonized peat bagasse [16] *Dialium guineense* seed husk [20], and hydrophobic aerogels for emulsified oil [21, 22].

Adsorption is a surface phenomenon which involves the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface [23]. Despite the report of several studies carried out on the use of agricultural waste as adsorbent, there is paucity of information on the use of chicken feather waste (CFW) for removal of crude oil from crude oil polluted water (CPW), hence this study.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The agricultural wastes used for this study was chicken feathers. The CFW was sourced from a local market at Ile-Ife, Osun State Nigeria, while commercial activated carbon (Calgon Activated Carbon) was purchased from Uche-El Water Limited Company. The CFW was washed in detergent-containing tap water to remove stains, oil and grease, and then rinsed with the tap water. The chicken feathers were rinsed with distilled water to remove any detergent left and sun-dried to constant weight. After that, chicken feathers were pulverized (plate 1) with ROCKLABS Ring mill pulverizer Model CRC3E; Serial no 1288 at the Center for Energy and Research Development (CERD), Obafemi Awolowo University, Nigeria. The pulverized feathers were used directly because it could not be passed through the sieves due to its fibrous nature.

2.2 Characterization of Chicken Feather

The pulverized CFW was characterized using Scanning Electron Microscopy (SEM) and Particle-induced X-ray Emission (PIXE) (equipment model) from Centre for Energy Research and Development (CERD).

2.3 Physicochemical Properties of Crude Oil

The physical properties of crude oils are the quantitatively measurable parameters of crude oils. They depend upon the composition of the oil, the relative abundance of the groups of hydrocarbons, and essentially depend on reservoir temperatures and pressures. Crude oil consists of liquid paraffin hydrocarbon compounds such as pentane to pentadecane (C5 – C15). These hydrocarbon compounds are made of various groups like the normal paraffins, iso-paraffins (branched chain paraffins), alkyl paraffins, naphthenes (or cycloparaffins), alkylbenzene and nuclear aromatics. The normal paraffins are the saturated, low molecular weight hydrocarbons. The related gaseous phases are within this group. The naphthenes (or cycloparaffins) are extensively bonded, high molecular weight hydrocarbons. All crude oils contain some notable amount of the naphthene compounds, (10% by composition). Crude oils also contain a substantial variety of heteroatomic chemical constituents, including sulphur, oxygen, carbondioxide, nitrogen and trace metals. Nitrogen varies from 0.01 to 2% as dissolved gas in the crude oil [24,25]. Oxygen occurs in different forms in oxygen-bearing resinous substances.

2.4 Simulation of Crude Oil Polluted Water

The CPW was prepared in the laboratory by mixing 20 ml of crude oil with 30 ml deionized water in a 250 ml beaker and shaken with a digital orbital shaker (JINOTECH INSTRUMENTS), for a period of 20 mins at a constant speed of 300 rpm. The CPW was then used for the adsorption experiment using different adsorbent dosages, contact times, initial concentrations, pH.

2.5 Batch Adsorption of Crude Oil using the Chicken Feather Waster

Twenty grams of each of the adsorbents (pulverized CFW and CAC) was added to the crude oil polluted water (20 ml) in a beaker in turns. The beakers and its contents were placed on a digital orbital shaker (JINOTECH INSTRUMENTS), and shaken at 300 rpm for 20 mins. The contents of the beakers were then filtered to separate the wetted adsorbent from the filtrate. The weight of the wetted adsorbent was recorded and the weight of the filtrate (oil and water) as well as the separated water from the filtrate was recorded separately. Adsorbed oil content was determined by subtracting the water content and the initial adsorbent weight from the total wetted sorbent. The weight of the oil adsorbed was then recorded as gg^{-1} (gram of oil/gram of adsorbent).

Plate 1. Pulverized chicken feathers

Batch adsorption experiments were carried out twice, and the mean recorded for the different adsorbent dosages, contact time, pH and concentration. The data obtained were subjected to One-way ANOVA. One-way ANOVA was used to analyze the distribution of one factor among several independent groups or means.

The percentage of oil adsorbed was calculated using the equation (1).

$$\frac{w_f - w_i}{w_i} \times 100 \qquad (1)$$

Where:

w_i is the initial weight of crude oil (ml/ml) before adsorption
w_f is the final weight of crude oil (ml/ml) in the filtrate after adsorption.

3. RESULTS AND DISCUSSION

3.1 Characterization of the Adsorbents

The results for the characterization of pulverized CFW are presented below:

Elemental composition of the adsorbent: The presence of these elements (Na, Mg, Al, Si, P, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Sr, Zr, Cd, Sn, Pb) characterized using Rutherford Backscattering Spectrometer (RBS) as shown in Table 1 in the CFW can enhance adsorption through the following mechanism: biosorption, ion exchange, chelation, co-ordination and complexation reactions. Elements like Al, K, Na, Ca and Mg could have influence on the adsorption mechanism through biosorption and ion exchange interaction, that is, by exchanging with metal ions present in the aqueous solution [26], while the presence of such elements as P and Si according to Miessler and Tarr [27] and Lancashire [28] could influence adsorption through the chelation, coordination and complexation.

Surface Morphology of Chicken feathers: In the results of Scanning Electron Microscopy, Fig. 1 compared the surface morphology before (a) and after (b) adsorption process of the CFW respectively.

Furthermore, the results of the scanning electron microscope clearly showed the surface texture and morphological characteristics of CFW. The magnification was optimized at a display magnification of more than 2000 times. Agglomeration of particles of CFW (as shown in Fig. 1a and 1b) and the distinctive irregular material which is in line with the works of Okoya et al. [29], Selvaraju and Bakar [30] is said to enhance adsorption.

Table 1. Elemental composition of Chicken feathers

Element	Conc. (ppm)	Conc. Error
Na	376.3	±22.11
Mg	795.8	±43.53
Al	699.6	±40.11
Si	1858.1	±57.07
P	7546.7	±101.50
K	1104.7	±70.46
Ca	22566.2	±81.64
Ti	376.0	±12.23
Cr	564.0	±30.12
Mn	291.9	±31.44
Fe	18363.0	±26.36
Cu	5373.6	±24.38
Zn	4139.4	±18.51
Sr	17.5	±3.31
Zr	84.8	±11.20
Cd	77.3	±10.38
Sn	91.0	±11.32
Pb	12.8	±4.0

Fig. 1a and 1b shows the agglomeration of particles and the non-availability of toxic element in the composition of the sorbent materials which in turn support their uses for effluent treatments as reported by Alayande et al. [31].

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4. ADSORPTION STUDIES ON CRUDE OIL USING CFW AND CAC

The parameters affecting the adsorption were studied by comparing the adsorbents. Effects of these parameters are presented below:

4.1 Effect of Adsorbent Dosage on Adsorption of Crude Oil from Crude Oil Polluted Water

The result of the experiment for the adsorption of crude oil using CFW from crude oil polluted water is presented in Fig. 2. The adsorption efficiencies ranged from 72.55 to 99.33% and from 41.75 to 82.63% for CFW and CAC respectively with varying dosages of 5, 10 15 20 and 25 g. The mean percentage (85.4±4.81%) of crude oil adsorbed with CFW is significantly higher than that of CAC (59.1± 8.02%) for all the parameters optimized (Figs. 2, 3, 4 and 5), but more pronounced for the increased adsorbent dosage (Fig. 2). The adsorption efficiencies increased with increase in adsorbent dosage for both CFW and CAC. This implies that CFW and CAC can be used effectively for crude oil adsorption. The increase in efficiency with increase in adsorbent dosage for the CFW could be due to greater availability of exchangeable sites and increase in surface area at higher dose of the adsorbents respectively. These observations are in line with the findings of previous studies on many other adsorbents [32,33,9,34].

4.2 Effect of Contact Time on Adsorption of Crude Oil from Crude Oil Polluted Water

The effect of contact time on the removal efficiency of crude oil from CPW is shown in Fig. 3. The adsorption efficiencies ranged from 73.15 to 99.80 and from 68.34 to 92.79 for CFW and CAC respectively with varying contact time (10, 20, 30, 40, 50 minutes). The mean percentage (85.59±4.95%) of crude oil adsorbed with CFW is significantly higher ((F=17.073; P=0.000) at confidence interval of 0.05) than that of CAC (83.76± 4.23%).

The adsorption efficiencies increased as the time increases for both CFW and CAC. It shows that the adsorption of crude oil increases with time and then reaches a constant value beyond which no more oil was further removed from the polluted water. This may be due to the availability of a large number of vacant sites at the beginning of the adsorption experiment. This agrees with work of Kanyal and Bhatt [35] and

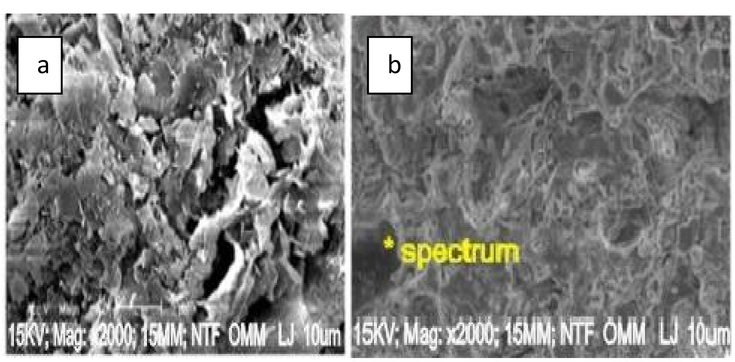

Fig. 1. SEM images of chicken feathers (a) before adsorption and (b) after adsorption

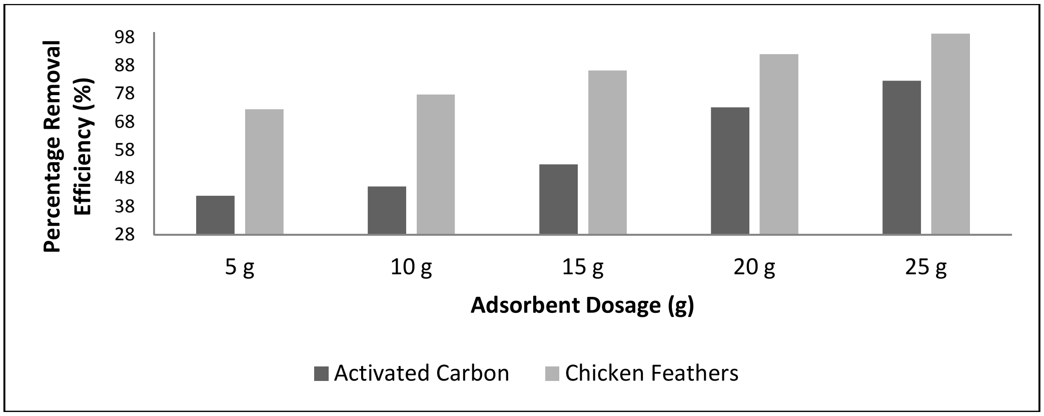

Fig. 2. Effect of adsorbent dosage on adsorption of crude oil from crude oil polluted water

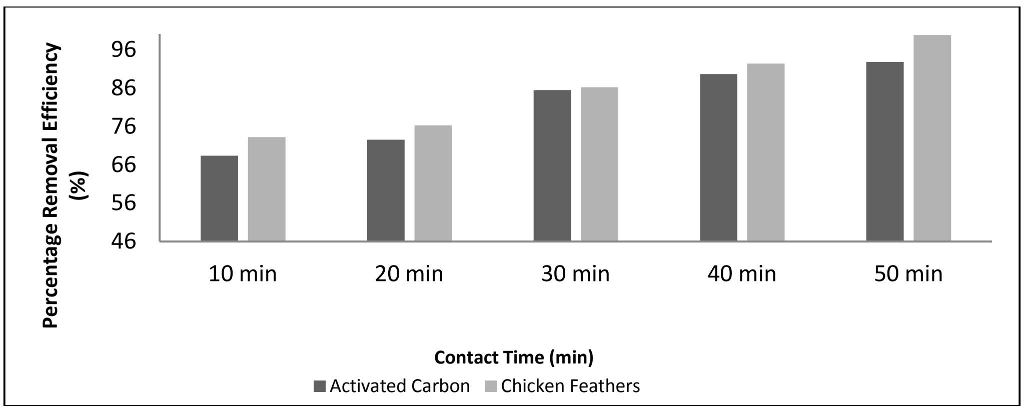

Fig. 3. Effect of contact time on adsorption of crude oil from crude oil polluted water

Mateen et al. [36] who reported that the percentage removal of the adsorbent increase with contact time and constant with increase in contact time. Since all the adsorbent sites exist in the exterior of the adsorbent, it is easy for the adsorbate to access these active sites, resulting in rapid approach of equilibrium Mastral et al. [37]. Also Ansari and Mosayebzadeh [38] reported that the rate of removal of dye increased with an increase in contact time to a certain extent and further increase in contact time does not increase the uptake due to deposition of dyes on the available adsorption site on adsorbent material.

4.3 Effect of Initial Concentration on Adsorption of Crude Oil from Crude Oil Polluted Water

The results of the investigation of the adsorption of crude oil on the adsorbents with varied initial concentration are presented in Fig. 4. Fig. 4 presents the adsorption efficiencies of CAC and CFW with varied initial concentrations (10/30, 20/30, 30/30, 40/30, and 50/30 ml/ml) for the two adsorbents, while all other conditions (adsorbent dosage, contact time, and pH) were kept constant. The efficiencies of adsorption increased with increasing initial concentration for the two adsorbents except initial concentration of 20/30 which decreased in the case of CAC. For the two adsorbents, the initial concentration which showed the optimum amount of crude oil adsorbed (99.95% for CFW) from the CPW was 80 ml (50/30 ml/ml). The adsorption efficiencies for all the initial concentrations for the adsorbents is significantly different ($F=16.114$; $P=0.000$) at confidence interval of 0.05. CFW showed greater adsorption efficiency of 99.95%, followed by CAC which showed an adsorption potential of 95.08% ($P=0.577 > C.I=0.05$). This is in agreement with [39] who reported that initial oil concentration affects removal of oil from wastewater as the initial concentration of oil influences the oil adsorption kinetics and inhibits hydraulic conductivity. In a study by Ahmad et al. [39] on the removal of oil from palm oil mill effluent (POME) by chitosan, it was discover that chitosan was able to give high oil removal efficiency in POME with low oil concentration compared with POME of higher oil concentration. It may be that, at high oil concentration, oil occupies the surface of sorbent thus saturation is reached quickly and high amount of unattached oil is left. In terms of filtration mechanism, this phenomenon can be explained by the occupation of spaces between sorbent particles (macropores) by oil, thereby hindering more oil to infiltrate into the sorbent micropores as reported by Huang et al. [40].

4.4 Effect of pH on Adsorption of Crude Oil from Crude Oil Polluted Water

The pH of effluent can undoubtedly affect the adsorption potential of the adsorbent. The results of the investigation of the adsorption of crude oil on the adsorbents with varied pH of 2.0, 4.0, 10.0 and 12.0 while other conditions (adsorbent dosage, contact time and initial concentration) were kept constant, are presented in Fig. 5.

Fig. 5 shows the effect of pH on the adsorption efficiencies of the adsorbents for the adsorption of crude oil from crude oil polluted water. The range of the adsorption efficiencies for the varying pH values (2, 4, 10, 12) is 72.95 – 84.70 and 85.64 – 98.20 for CAC and CFW respectively. The mean adsorption efficiencies are 79.64±2.74 and 92.29±2.73 for CAC and CFW respectively. The adsorption efficiencies of crude oil at different pH for the adsorbents is significantly different for the adsorbents (F=11.019; P=0.001) at confidence level of 0.05. The efficiency for CFW is significantly higher (98.20%) than the CAC (84.70%) and also higher than the results of using other adsorbents for crude oil removal as in Table 2. The result of the laboratory experiment showed that the pH 12.0 was the best pH favouring the maximum

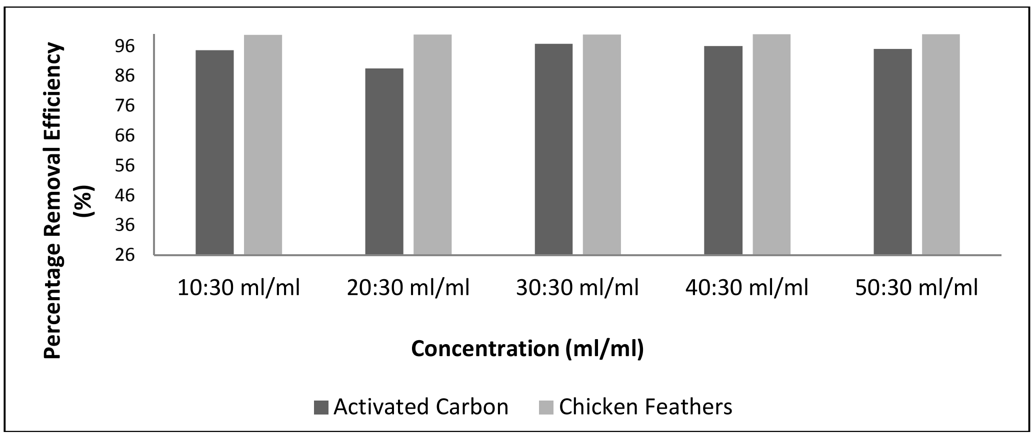

Fig. 4. Effect of initial concentration on adsorption of crude oil from crude oil polluted water

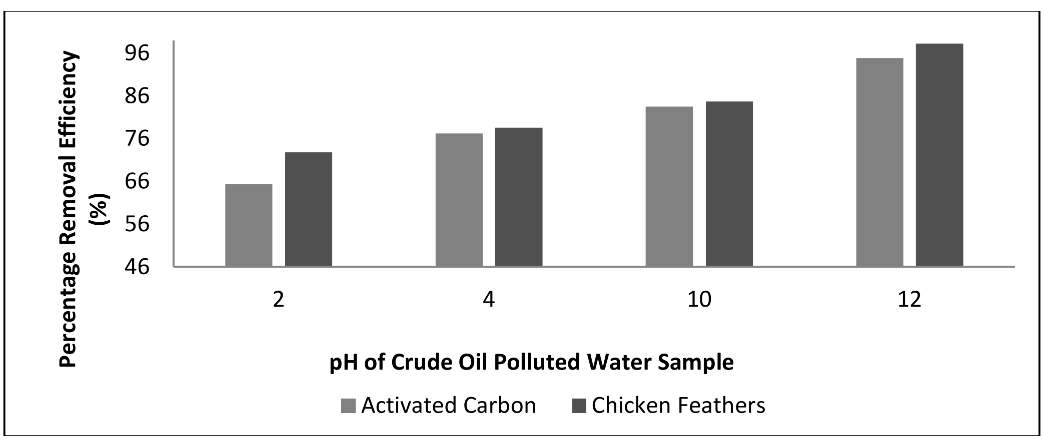

Fig. 5. Effect of pH on adsorption of crude oil from crude oil polluted water

Table 2. Comparison of adsorption of efficiencies of different adsorbents for crude oil removal

S/N	Materials of plants origin	Adsorption capacity	References	Materials of animal origin	Adsorption efficiency	References
1.	barley straw	87%	[45]	Chicken Feather	84%	[47]
2.	Date bits	80%	[45]	Cow Bone	97.8%	[48]
3.	Sphagnum	57.7%	[46]	-	-	-
4.	Peat	55.2%	[46]	-	-	-
5.	Charcoal	60.0%	[46]	Chicken Feather	99.95	This Study

adsorption of crude oil. Also, according to Osu and Okereke [41], the pH of a solution, in fact determines the chemistry, degree of ionization and speciation of metal ions and also affects the surface charge of the adsorbent. In this study, the adsorption behaviour of crude oil were studied at different pH values. This is because the pH change affects the surface properties and sorbent binding sites [42] and emulsion breaking [43]. A number of studies reported the increase of oil removal in acidic and basic medium. Ahmad et al. [39] and Sokker et al. [43] reported in their studies on chitosans that palm oil and crude oil removal efficiency was increases at strongly acidic and basic pH. According to Ahmad et al. [39], saponification process is associated to high removal efficiency at strong basic condition whereby hydrolysis of oil in sorbate occurs.

Several studies demonstrated an increase in oil removal efficiency as the sorbate pH increases. For example, motor oil removal using natural wool fibre revealed high removal efficiency at pH 10, and low removal efficiency at pH 5 [44]. In addition, the use of surfactant-modified barley straw showed the lowest removal efficiency for canola oil and mineral oil at strongly acidic condition (pH 2), with an increase in removal efficiency in parallel to increasing pH as reported by Reddy et al. [49]. Ibrahim et al. [42] reported that low oil adsorption at extremely low pH was suggested to occur due to ionisation of the sorbate, which caused lower favourability of oil adsorption.

5. CONCLUSION

This study determined the adsorption potential of chicken feathers for the removal of crude oil in crude oil polluted water. It compared the efficiencies of chicken feathers with commercial activated carbon. Best adsorption conditions for chicken feathers are 50:30 initial concentrations; 25 g dose; pH 12.0; and 50 min contact time for adsorption of crude oil from crude oil polluted water. The adsorption efficiencies obtained for the chicken feather compare very well with the activated carbon and even better as the dosages of the chicken feather increased. The result of the study shows that chicken feathers is an efficient sorbent for the mopping of crude oil spill in water.

6. RECOMMENDATION

Treatment of crude oil polluted water with agricultural wastes should complement the conventional treatment for efficient removal of crude oil from the polluted water. Government and industries should take advantage of adsorption technologies by developing these natural adsorbents for household purposes.

DISCLAIMER

A preliminary version of the manuscript has been published in the following link: https://www.psychosocial.com/article/PR201024/11488/

ACKNOWLEDGEMENT

The authors acknowledge with gratitude SwWECh Laboratory, Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife, Nigeria where most of the field and laboratory analyses were carried out.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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