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ECO-FRIENDLY CHICKEN FEATHERS AS A SORBENT MATERIAL FOR OIL SPILLS POLLUTING SEAWATER

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ABSTRACT

This research aims to explore the potential of chicken feathers as a sustainable and eco-friendly solution for the pollution cleanup of oil spills in seawater. Baladi chicken feather was used as a biosorbent material and motor oil as a sorbate and the feathers characterization was applied. The oil sorption efficiency of 98% at 20 ml oil and 85.3% at 80 ml oil per 1 g feather. 5-6 g feather powder was needed per 20 ml of oil and this quantity was six times the unpowdered feather. The body and down feathers were the optimum for the oil sorption efficiency at 98% instantaneously. Chemically modified feathers showed higher effective sorption activity than unchemically treated feathers due to lipid coating on the surface, with a maximum efficiency of 99% and a minimum efficiency of 95.5% at 20 and 80 ml of oil per 1 g of feather, respectively. The oil sorption efficiency decreases as the initial oil volume increases, with a maximum sorption capacity not exceeds 120 ml (105 g) oil per 1 g feather. Finally, Baladi feathers are a promising biosorbent material for environmental pollution remediation due to their ability to effectively sorb a large amount of oil per unit weight, making them a promising alternative to synthetic sorbents.

KEYWORDS: Chicken feathers, Oil spill, Pollution, Chemical modification, Sorption.

استخدام ريش الدجاج كمادة ماصة صديقة للبيئة للإنسكابات النفطية الملوثة لمياه البحر

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الملخص

يهدف هذا البحث إلى استكشاف إمكانات ريش الدجاج كحل مستدام وصديق للبيئة لتنظيف التلوث الناجم عن الانسكابات النفطية في مياه البحر. تم استخدام ريش الدجاج البلدي كمادة ماصة حيوية وزيت المحرك كمادة ممتصة وتم توصيف الريش. بلغت كفاءة امتصاص الزيت لكل ١ جرام من الريش ٩٨٪ عند استخدام ٢٠ مل زيت و ٨٥,٣٪ عند ٨٠ مل زيت. كان هناك حاجة إلى ٥-٦ جرام من الريش المطحون لكل ٢٠ مل من الزيت وهذه الكمية تساوي ستة أضعاف الريش غير المطحون. الريش الملتصق بالجسم والجزء السفلي هو الأمثل لكفاءة امتصاص الزيت بنسبة ٩٨٪ لحظيا. أظهر الريش المعدل كيميائيا فاعلية في الإمتصاص أعلى من الريش الغيرمعالج كيميائيا بسبب طبقة الدهون الموجودة على سطح الريش، مع كفاءة قصوى تبلغ ٩٩٪ وأقل كفاءة ٩٥,٥٪ عند ٢٠ و ٨٠ مل من الزيت لكل ١ جرام من الريش، على التوالي. تنخفض كفاءة امتصاص الزيت مع زيادة كمية الزيت المستخدمة، مع قدرة امتصاص قصوى لا تتجاوز ١٢٠ مل (١٠٥ جم) زيت لكل ١ جم من الريش. وأخيرًا، يعد الريش البلدي مادة ماصة حيوية واعدة لمعالجة التلوث البيئي نظرًا لقدرته على امتصاص كمية كبيرة من الزيت لكل وحدة وزن بشكل فعال، مما يجعله بديلاً واعدًا للمواد الماصة الاصطناعية.
الكلمات المفتاحية : ريش الدجاج، تسرب النفط، التلوث، التعديل الكيميائي، الامتصاص.

1. Introduction

Oil spills are a major source of marine pollution, causing great damage to affected areas of the aquatic ecosystem due to the development of large-scale off-shore petroleum industry, oil runoff, accidental spills, fuel discharges from land-based sources, oil drilling accidents, and an increase in marine oil transportation, or leakages from pipelines or vessels [1-3]. Large quantities of oils discharged into the ecosystem can cause serious environmental problems, such as adverse effects on water quality and aquatic biota, clogging of sewage treatment plants, increased chemical oxygen demand, and increased biochemical oxygen demand [4-6]. Oil contaminants enter the water from natural gas seeps, drilling, oil extraction and transportation facilities, and land and marine navigation. They are composed of aliphatic, naphthenic, and aromatic hydrocarbons [7].

Treatment of oil spills in affected waters results in improved water quality, oil recovery, protection of aquatic biota, and environmental protection [8]. Spills of crude oil, diesel or kerosene have detrimental effects on the environment [9]. Oils can be toxic to microorganisms responsible for biodegradation in conventional sewage processes [10]. So, efforts have been made to reduce the frequency and extent of oil spills near or on navigable waters. Clean-up should be done using an efficient, cheaper, and environmentally friendly material [9].

The ideal cleanup approach is one that promptly eliminates most of the transportable oil, and this is frequently determined by time [11]. Oil spills are frequently removed using a variety of techniques: Chemical, physical, and biological methods. Their choice depends on the size of the spill, the nature of the water, and the weather [12, 13].

Chemical methods of oil removal from water are successful but expensive and can harm zooplankton, a vital food source in the marine food chain. Because treated oil cannot be recovered, it is dangerous to humans and animals [14, 15].

The use of sorbents (natural and organic materials) is one of the physical methods and has been applied in the industry recently [16, 17]. Sorption is believed to be one of the most effective methods used for treating water from impurities [18].

Feather waste has been reported as a petroleum sorbent, and attempts have been made to evaluate its potential for higher-added-value applications [19, 20]. Worldwide, 24 billion chickens are killed annually, and 8.5 billion tonnes are produced [9, 21]. The chicken feather fiber is highly hydrophobic and partially hygroscopic due to its amino acid content and the efficient application of sorbent requires knowledge of sorbent sorption capacity and an understanding of the sorption mechanism [22].

The natural organic sorbents such as cotton and kapok samples exhibited a high value of oil sorption capacity 9.77 and 11.53 g a Lubricant Motor Oil per unit mass and 8.86 and 10.19 g a diesel fuel per unit mass compared to the synthetic sorbents such as polyester fiber sorb 6.6 a Lubricant Motor Oil and 5.74 diesel fuel per unit mass [23]. Moreover, Sorption capacity is attributed to Chicken feather (natural organic sorbents) which sorbed per unit mass 13.77 g/g of crude oil, 11.99 g/g of diesel fuel and 10.61 g/g of kerosene [9].

The purpose of this paper was to investigate the usage of waste chicken feathers in the cleanup of oil spills from contaminated waters as a physical treatment to replace the currently utilized standard synthetic adsorbents. Therefore, this research was done to develop and measure the sorption efficiency of the cheapest organic sorbent materials for Baladi chicken feathers. Sodium Dodecyl Sulphate (SDS) has been used to remove lipids from feathers surfaces which decreases the effectiveness of sorption. In addition, this research aimed to determine the sorption capacity and efficiency of the feathers before and after chemically modified and for feathers in the same structure and as a powder.

2. Materials and Methods

2.1 Materials

Egyptian Baladi chicken feathers were used as a sorbent material and obtained from a local poultry slaughterhouse. The preparation process for the feather samples involves cleaning to remove any external contaminants and preserving them to prevent degradation. Firstly, feathers are typically immersed in a detergent solution, then washed and rinsed thoroughly with tap water to remove the detergent, then soaked in distilled water. After that, they were dried in an oven dryer at 105 ºC for 24 hours and then stored at room temperature in closed containers and used for experiments. Dried chicken feathers were pulverized into powder using a mechanical blender Ball Mill Machine.

A technical oil, Super Stan SAE 50 from a cooperation petroleum company (CPC), which is used as a motor oil for lubricating engines, has been used as a sorbate material in a sorption process.

According to the test done, a sample of water from the Mediterranean Sea has the following physical properties: Salinity is 34789.1 mg/l; alkalinity is 218.6 mg/l, specific gravity is 1.0335, and pH at 25 °C is 7.70. The water sample is highly saline and slightly alkaline based on the given values. The specific gravity indicates that it is denser than pure water, and most aquatic organisms' pH falls within the neutral range.

Sodium dodecyl sulphate (SDS) was obtained from El-Gomhoria Company for Chemical Industries, Cairo, Egypt. SDS is a sulphate surfactant that is less poisonous and more soluble in water in pellet form than in powder form [24, 25]. It is used in laundry detergents with a variety of cleaning uses due to its ability to form foam, cut through grease, and suspend dirt particles. It is an efficient surfactant used in any operation involving the removal of greasy stains and residues [26]. Lipid content of feather was determined using a Soxhlet apparatus according to ASTM D1574. The optimum concentration of SDS treatment can be determined by implementing the laboratory experiments needed. At maximum removal efficiency, the optimum concentration of chemical modifications for lipid removal from feathers was 1.5 g per 1 liter of water [27].

2.2 Methods

2.1.1. Moisture content

The moisture evolution temperature of chicken feathers is 100-110 °C, and oven-dried samples were dried at 110 °C +5 °C until there was no change in weight according to (ASTM D1576-90). This information is important for understanding the thermal behavior of chicken feathers and for the accurate characterization of materials' properties [28].

To achieve a constant mass, the Baladi feather samples were dried at 105 °C. The moisture content was calculated by using equation (1) which was expressed on a dry basis [29].

Moisture content, % = $\frac{W1-W2}{W1} \times 100$ (1)

Where:
W1= Original mass in gram
W2= Oven dry mass in gram

2.1.2. Characterization of feathers

SEM analysis, IR spectroscopy, and XRD analysis were used to examine the properties of feathers. SEM analysis was used to determine the texture of the sorbent and its surface morphology. Chicken feathers have hollow structures of knots and hooks [1, 30]. The effects of decontamination and chemical treatments on the morphology and elemental composition of feathers were studied using energy dispersive spectroscopy (EDX) [31].

The functional groups in chicken feathers were detected using FTIR spectrophotometer with the wavenumber range of 400–4000 cm^{-1} [32]. The FTIR spectrum was taken in transmittance mode. The scanning range can be set from 4,000 to 650 cm^{-1}, with a precision of 0.8 cm^{-1} [33].

The scanning region of the diffraction angle (2Θ) was from 4° to 90° [34]. Crystallinity refers to the degree of structural order in a solid and the amorphous regions give the polymer toughness, that is, the ability to bend without breaking and the crystallinity index (Ic) was determined using equation (2) [35].

$$\text{Crystallinity index, \%} = \frac{I_{9^o} - I_{14^o}}{I_{9^o}} \times 100 \quad (2)$$

Where:
I_{9^o}= Maximum diffraction intensity with 2θ at 9°
I_{14^o} = Minimum diffraction intensity with 2θ at 14°

2.1.3. Sorption Capacity and Efficiency

Different parameters affecting the sorption process were studied for optimization. Two different volumes of precleaned beakers (parameter 1), 250 ml, and 1 liter were used. A constant volume of seawater for each beaker volume and variable quantities of oil (sorbate) per ml unit (parameter 2) were put in the beaker. A certain weight in grams of a chicken feather (sorbent) (parameter 3) was added to the beaker, and the feather structure of the different parts of the chicken (parameter 4) was used as is, or powder (parameter 5). A range of contact times was allowed (parameter 6); also, a treated chicken feather (a chemically modified sorbent) was used (parameter 7).

A sample holder was used to withdraw the feathers from the oil water media after the sorption process, and some associated water droplets after gathering were extracted by pulling them with a syringe, as the amount of water associated is very small and does not exceed, in the maximum case, 1 ml.

The sorption capacity of the sorbents is referred to as a mass of liquid sorbed per the mass of sorbent. Hence in this study, the sorption capacity is considered to as the amount of oil in ml of oil sorbed per a gram of the sorbent material (feather) [9]. Sorption efficiency can be calculated as the rate of the volume of oil sorbed to the original oil volume as follows: Volumetric sorption efficiency of the sorbents are considered here to study the amount of sorbate removed by the sorbents [23].

A Sorption Capacity and efficiency were determined in the following equations:

$$Q = \frac{V1}{W1} \quad (3)$$

Where:
Q= Sorption Capacity, ml of oil/weight in a gram of feather

V1= Volume of oil sorbed, ml
W1= weight of sorbent, grams

$$\eta = \frac{V1}{V2} \times 100 \qquad (4)$$

Where:
η= Sorption Efficiency, %
V1= Volume of oil sorbed, ml
V2= Initial Volume of oil added to the beaker, ml

3. Results and Discussion

3.1. Moisture Content

The moisture content of Baladi was at 7.6% which is very low, indicating that the sample was homogeneous. The ability of chicken feathers and fractions to absorb moisture from the environment has important implications.

However, the average moisture content of the Baladi chicken feathers did not exceed 8%, indicating that chicken feathers are hygroscopic.

3.2. Baladi Chicken Feathers Characterization

The results of the scanning electron microscope clearly showed the Morphological structures of feathers with elemental profiles for each tested sample (EDX); the FTIR spectrophotometer investigated the functional groups; and the XRD diffractometer recorded the intensity peaks.

SEM was applied for the powder sample that had been pulverized with a ball mill machine. Figures 1 and 2 display SEM-EDX data for baladi feathers before and after cleaning and washing with distilled water, respectively. In Figure 1, there are some impurities of unwanted elements such as magnesium, aluminium, and sulphur as compared to the data shown in Figure 2, in which the elements of magnesium and aluminium were totally removed, and the sulphur element percentage was slightly decreased.

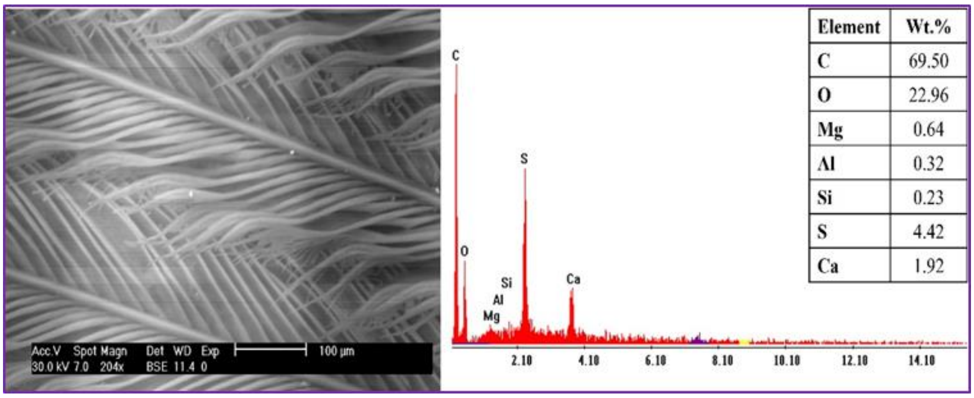
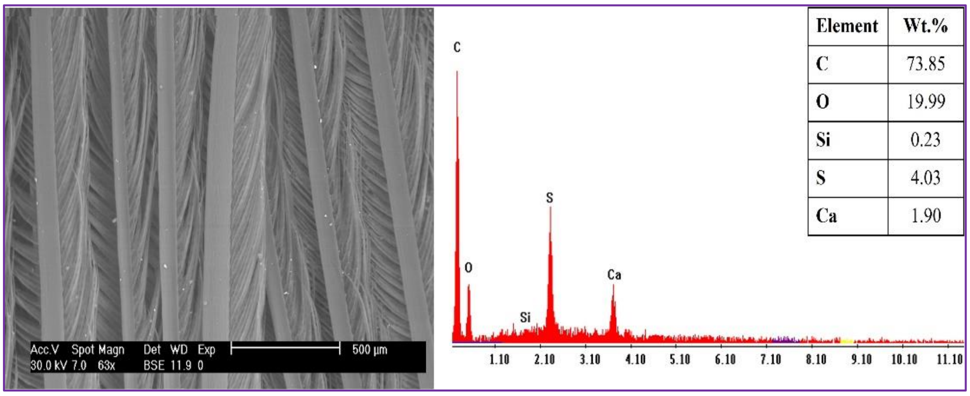


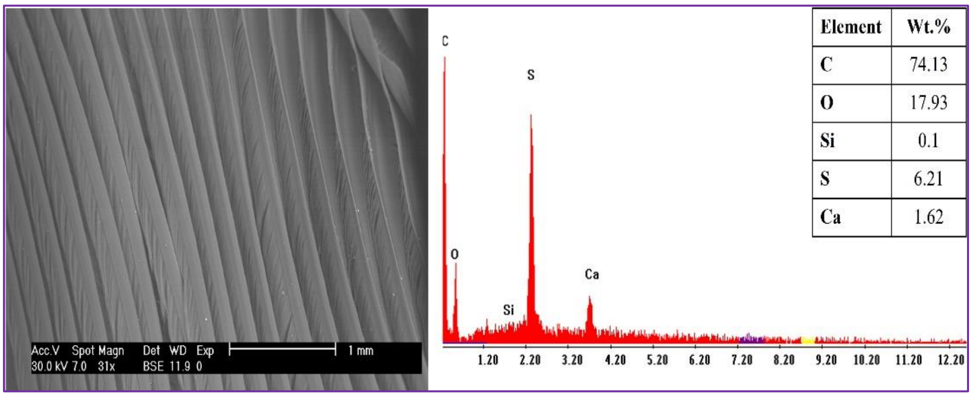
Fig. 1 SEM-EDX images and elemental profiles for undistilled Baladi chicken feathers



Element	Wt.%
C	73.85
O	19.99
Si	0.23
S	4.03
Ca	1.90

Fig. 2 SEM-EDX images and elemental profiles for distilled Baladi chicken feathers

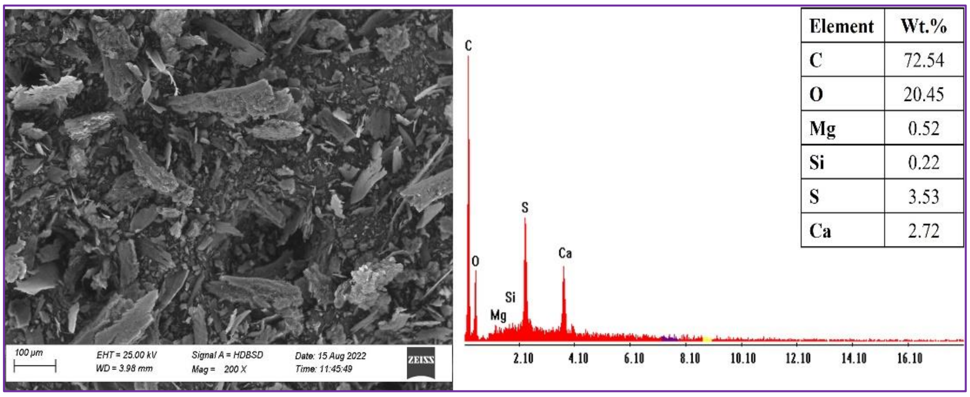
Figure 3 shows the SEM-EDX structure of chemically modified Baladi chicken feathers treated with sodium dodecyl sulphate (SDS). There were no significant differences, and no damage was created after chemical treatment.



Element	Wt.%
C	74.13
O	17.93
Si	0.1
S	6.21
Ca	1.62

Fig. 3 SEM-EDX images and elemental profiles for chemically modified Baladi feathers treated with sodium dodecyl sulphate

The additional SEM micrograph and EDX spectrum obtained for a powder sample of Baladi feathers, as shown in Figure 4, reveal the surface morphology structure of different grin sizes found and elemental composition approximately like the previous analysis of the feather before being powdered.



Element	Wt.%
C	72.54
O	20.45
Mg	0.52
Si	0.22
S	3.53
Ca	2.72

Fig. 4 SEM-EDX images and elemental profiles for powder Baladi chicken feathers

Figure 5 illustrates the functional groups that resulted from the infrared spectroscopy test for Egyptian baladi feathers. The peak at 3296 cm^{-1} for the N-H single bond and the signals at 3080 and 2962 cm^{-1} correspond to the ordered regions of the -CH group of alkanes, at 2932 and 2876 cm^{-1} are related to the asymmetry vibration of the $-CH_3$ group of alkyls; and for the main groups assigned at 1657 and 1532 cm^{-1} peaks from the chicken feather keratin are amide I and amide II bands, respectively. These signals can be attributed to groups of amino acids and lipids [36].

The peak at 1451 cm^{-1} is attributed to a plane bending of the $-CH_3$ group, 1393 cm^{-1} is assigned to vibrations of the C─C group, and 1235 cm^{-1} corresponds to the bending of the OH group. The presence of C-O and N-H bonds, which were confirmed at wavelengths of 1078 and 685 cm^{-1}, indicates that carboxyl and amino groups and the contents of amino acids were presented, so it is confirmed that protein is present.

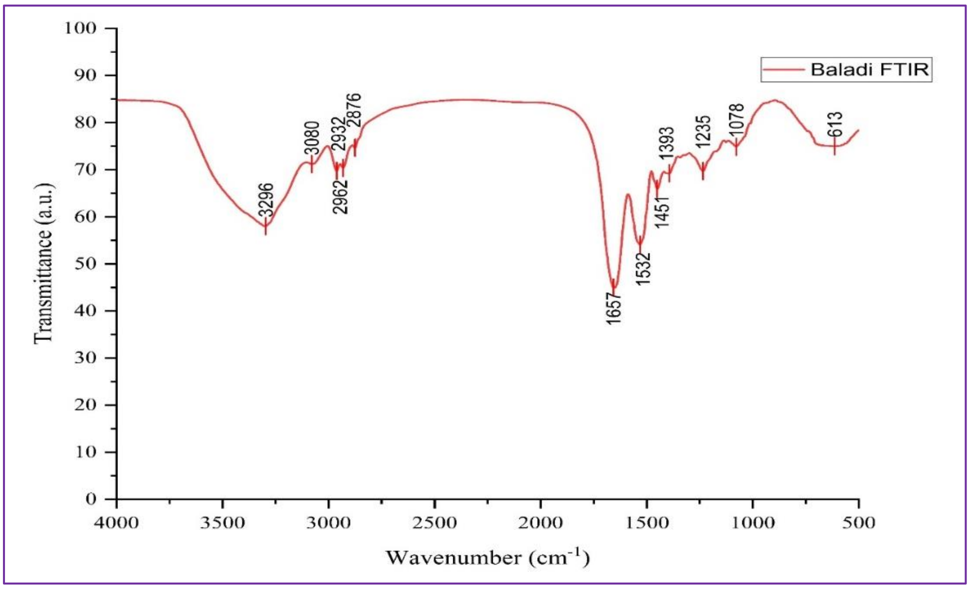


Fig. 5 FTIR spectra of Baladi chicken feathers

The XRD pattern of the Baladi chicken feathers is shown in Figure 6. The XRD test result confirmed that the Baladi chicken feathers reveal a single broad peak at 29° which is the most intense in the crystalline pattern; however, the graph appeared amorphous or semi-crystalline. It was observed that Baladi feathers had low intensity and keratin is semi-crystalline and naturally macromolecular [37].

Crystallinity also plays an important role in the high strength and stiffness of feather keratins [38, 39]. The crystallinity index of a Baladi chicken feather, according to the previously mentioned equation, is 38%, and a lower value in crystallinity could improve the extraction and dissolubility of the feather keratins.

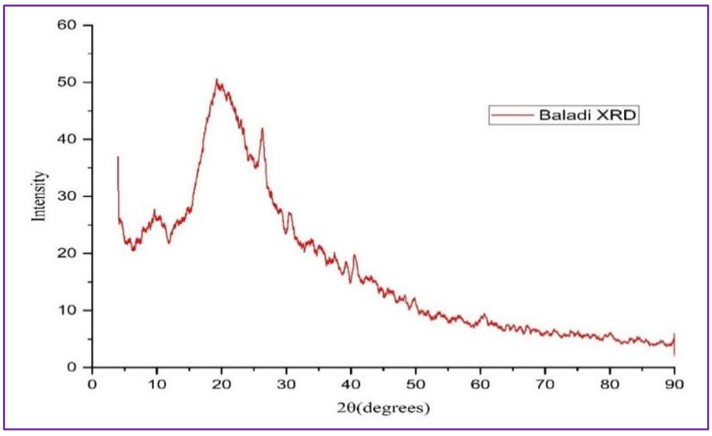


Fig. 6 XRD Patterns of Baladi Chicken Feathers

3.3. Oil Sorption Processes Using Feathers as a Sorbent

Chicken feathers were mostly divided into two categories: wing and tail feathers and body, semi-plume, and down feathers as shown in Figure 7, which were analyzed to select the most effective one in the sorption processes that oil sorption process in the laboratory are revealed in Figure 8. As previously discussed, several parameters influenced the sorption, so these factors were optimized and featured in the sorption experiments successively.

Fig. 7 Baladi Chicken Feathers categories: (a) Wing and tail; (b) Body, semi-plume, and down feathers

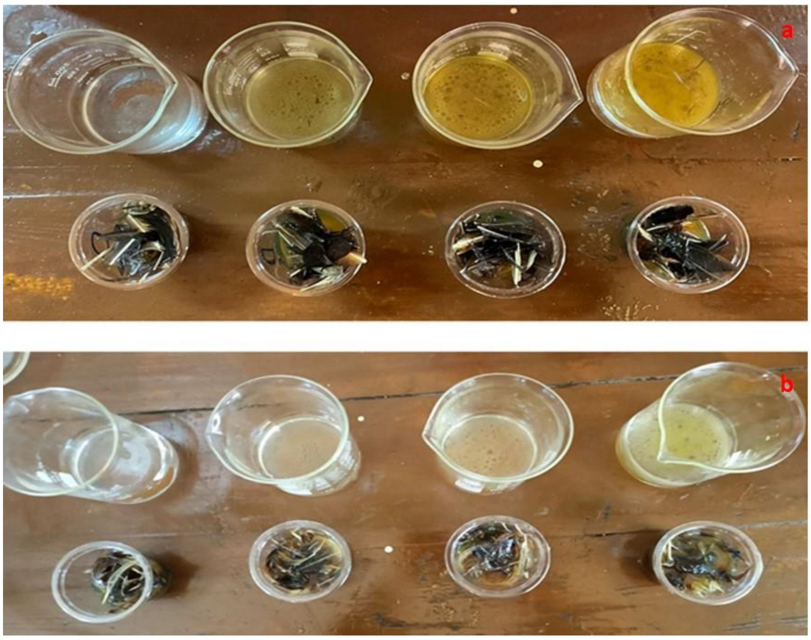


Fig. 8 Oil sorption process by Baladi Chicken Feathers: (a) Wing and tail; (b) Body, semi-plume, and down feathers

The optimum contact time for "body, semi-plume, and down feathers" in the sorption process was determined by conducting experiments with two different quantities of feathers (0.5 g and 1 g). As shown in Figure 9, the values of sorption efficiency for 1g were greater than 0.5g, and sorption efficiency increased with increasing contact time; this increase was large for 0.5g, but for 1 g, it was small, so 1g was a sorbent quantity optimum.

The difference between the values from the instantaneous time up to 10 minutes was a slight difference, as the difference in the values between the instantaneous sorption efficiency and at 10 minutes was 1.5%, so it was useless to stay for 10 minutes for this slight difference, especially since the prolongation of the period has a negative impact on marine life and the environment. Therefore, one gram of body, semi-plume, and down feathers with instantaneous time was optimum at a sorption efficiency of 98%.

Different oil quantities and two beaker sizes (250 and 1000 ml) were screened. As illustrated in Figure 10, the sorption efficiency of 1 g of body, semi-plume, and down feathers decreased for both beakers as the oil volume increased, with a maximum efficiency of 98% at a minimum oil volume of 20 ml, and an initial oil volume of 80 ml, the efficiency was 85.3% (62.2 ml of oil). This was for the beaker's 250 ml, which was higher than 1000 ml.

It was implied that at constant oil volume, the oil thickness increased, and the oil surface area decreased with the beaker size decreasing, hence the oil sorption capacity had a higher activity. Therefore, selecting the optimum point at maximum sorption efficiency of 98% at 20 ml oil and a minimum beaker size of 250 ml as compared to 11.64 ml of lubricating oil for natural organic sorbent and 7.54 ml of lubricating oil for synthetic sorbent [23].

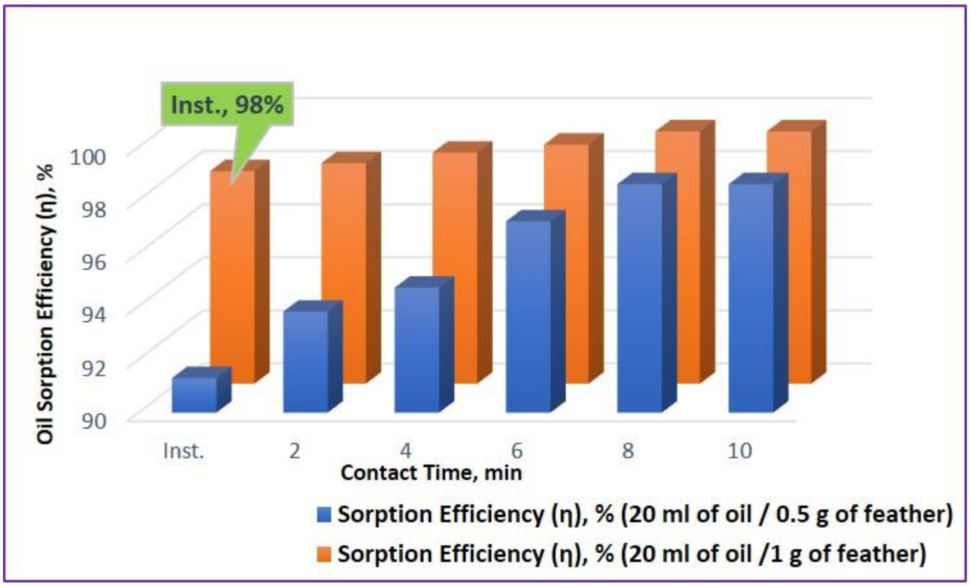


Fig. 9 Optimization of sorption efficiency and contact Time for "body, semi-plume and down feathers"

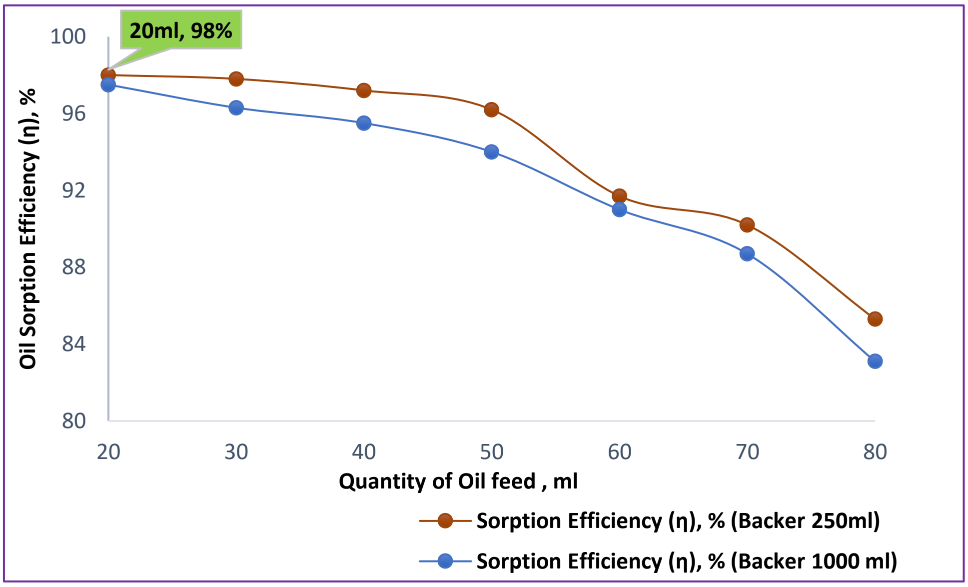


Fig. 10 Oil sorption efficiency for 1g of "body, semi plume, and down feathers" at two different surface areas

Figure 11 revealed that the instantaneous oil-water contact time and the 1 g sorbent quantity of wing and tail feathers at 93% sorption efficiency were the optimum conditions, similar to the body, semi-plume, and down feathers represented in Figure 9.

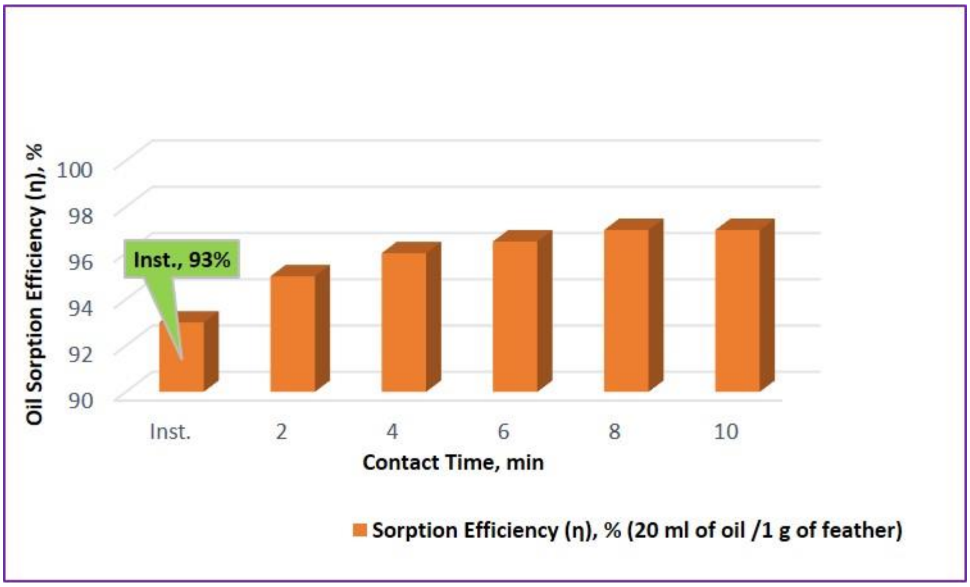


Fig. 11 Optimization of sorption efficiency and Contact Time of "wing and tail feathers"

The optimized case with maximum oil sorption efficiency of 93% at 20 ml oil volume and 250 ml beaker size for wing and tail feathers, as shown in Figure 12, was like the optimum factors for the body, semi-plume, and down feathers represented in Figure 10.

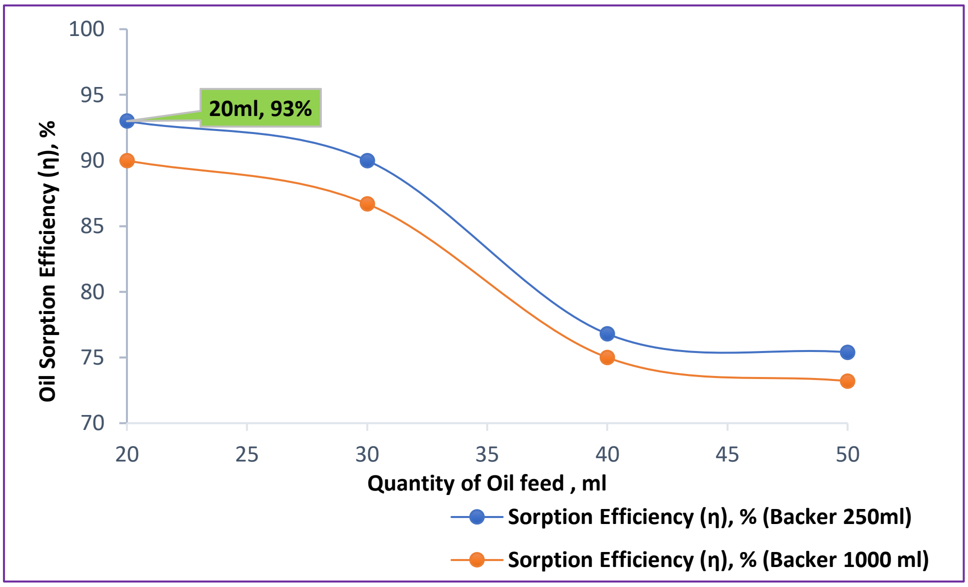


Fig. 12 Oil sorption efficiency for 1g of "wing and tail feathers" at two different surface areas

As shown in Figures 13 and 14, the oil sorption efficiency of the body, semi-plume, and down feathers was higher than for the wing and tail feathers with increments of oil-water contact time and, likewise, with oil quantity increments, so the body, semi-plume, and down feathers were the optimum category of chicken feathers for the oil sorption processes.

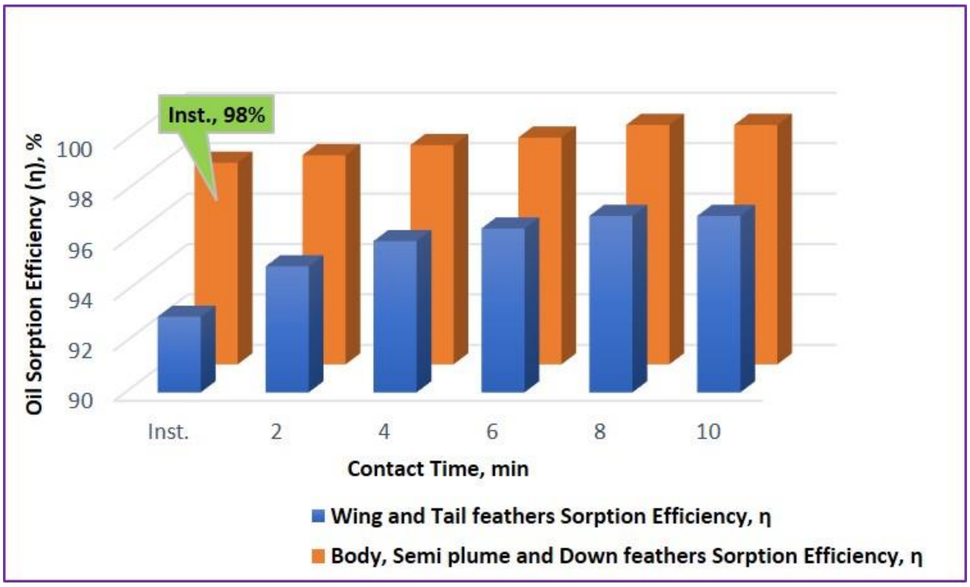


Fig. 13 Determination of oil sorption efficiency vs. contact time for two categories of chicken feathers

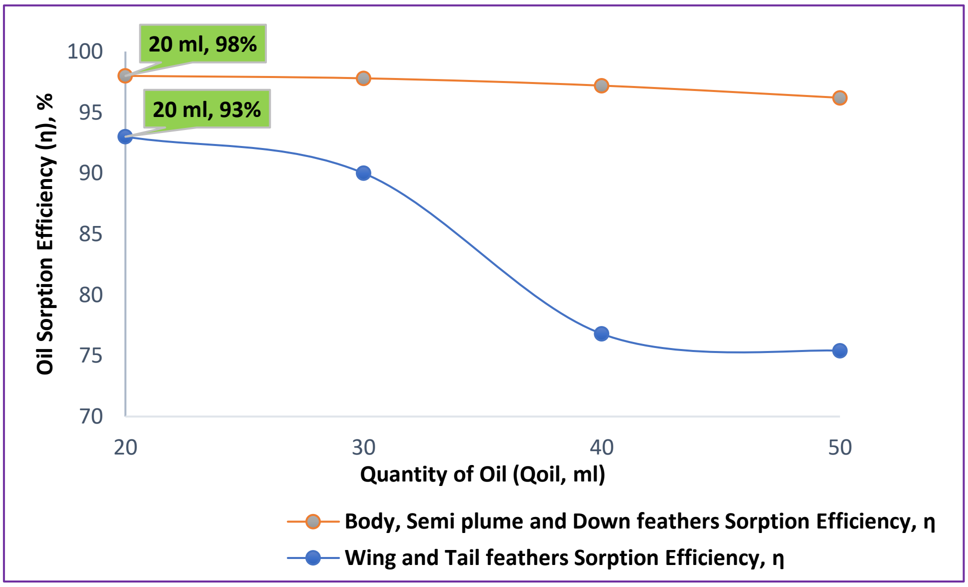


Fig. 14 Determination of oil sorption efficiency vs. oil quantity for the two categories of chicken feathers

Use the least quantity of feather powder as a sorbent material in the oil as a sorbate, as the powders dispersed rapidly and the oil viscosity increased slightly, but it was difficult at that time to recover any amount of sorbed material due to the absence of any, so it is the dividing point at which the sorbed oil was easily extracted. 5–6 g of feather powder sorbed the entire amount of 20 ml of oil due to the formation of sludge and recovered all the oil completely [27].

SDS chemical agent was applied to treat the body, semi-plume, and down feathers, and these feather parts had the most effective sorption. Figure 15 showed that the sorption capacity of 0.5 g and 1 g of SDS chemically modified body, semi-plume, and down feathers was higher than for unchemically treated feathers, with a sorption efficiency of 94.5 and 99%, respectively, compared to 93 and 98% for 0.5 g and 1 g of unchemically treated feathers.

As shown in Figure 16, the oil sorption capacity for 1 g of chemically modified body, semi-plume, and down feathers was detected at original oil volume of 80 ml with a sorption efficiency of 95.5% as compared to 83% of untreated feathers at the same conditions. The reasons for that are that SDS chemical agents remove any residual grease or lipids capsulated and coated on the surface of feathers and obstruct and negatively affect the sorption efficiency.

As 200 ml of oil and one gram of feathers were used to find out the maximum sorption capacity of the Baladi feathers. The result anyway was a sorption capacity not exceeds 120 ml (105 g) which is compared to natural organic sorbents that sorbed per unit mass. 13.77 g/g of crude oil, 11.99 g/g of diesel fuel, and 10.61 g/g of kerosene, since there is no comparison [9]. This quantity was applied instantaneously with 1 g of the body, semi-plume, and down feathers and had a priority as a renewable organic material in the sorption process as compared to all the other categories of sorbent materials.

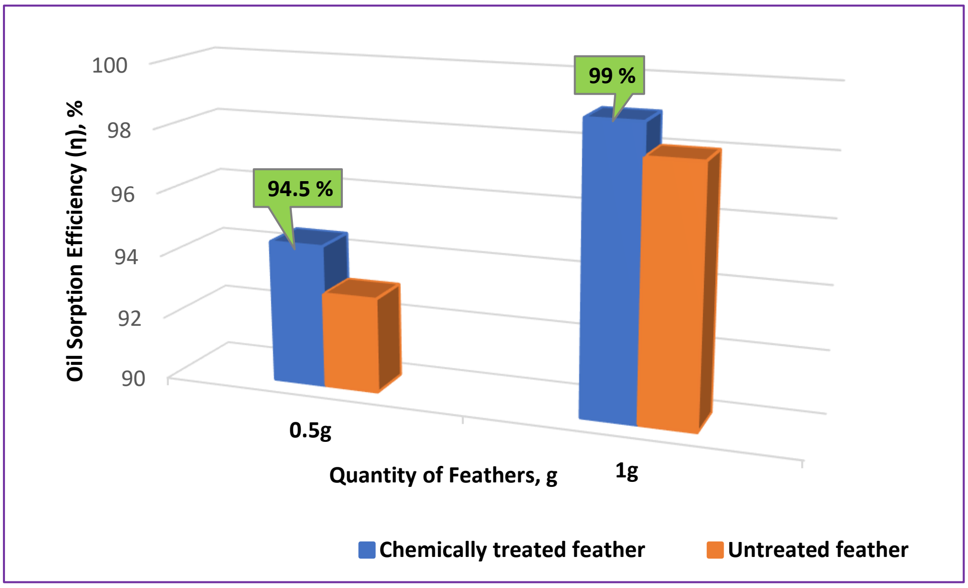


Fig. 15 Oil sorption efficiency for 0.5 g and 1 g of chemically treated and untreated chicken feathers at 20ml oil

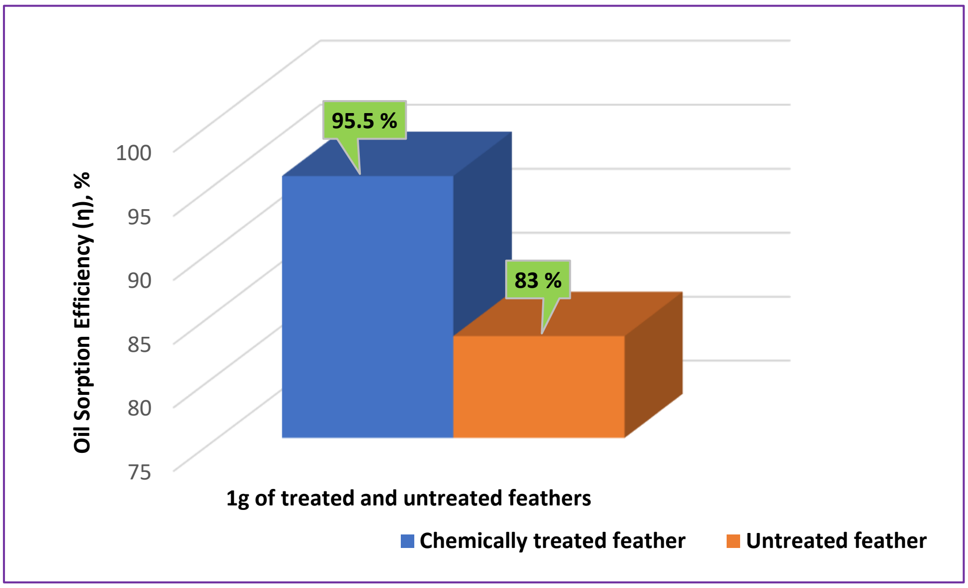


Fig.16 Oil sorption efficiency for 1 g of chemically treated and untreated chicken feathers at 80ml oil.

4. Conclusions

Clean feathers with distilled water and dispose of waste to maintain product quality. SEM-EDX and FTIR spectroscopy confirm protein presence, while XRD shows a 38% crystallinity index in Baladi chicken feather, improving keratin extraction and dissolubility.

Feathers are an effective renewable resource for oil spill removal, with a maximum sorption efficiency of 98% at 20 ml of oil and a minimum efficiency of 85.3% at 80 ml. The body, semi-plume, and down feathers are the most effective for oil sorption efficiency at 98% instantaneously, with the wing and tail feathers showing less effectiveness. The optimum feather category for oil sorption efficiency is the body, semi-plume, and down.

The feather powder sorbed the oil, creating a sludge that was easy to remove without leaving any residue. The use of feathers without grinding was more effective than the powder, as sorption is a physical process that requires volume. Chemically modified feathers improved sorption efficiency. The study utilized 200 ml of oil and one gram of Baladi feathers to determine their maximum sorption capacity, resulting in a 60% sorption efficiency with an sorption capacity of 120 ml, prioritizing these feathers as renewable organic materials.

Abbreviations

SDS: Sodium Dodecyl Sulphate
CPC: Cooperation Petroleum Company
SEM: Scanning Electron Microscope
EDX: Energy Dispersive Spectroscopy
FTIR: Fourier Transform Infrared Spectroscopy
XRD: X-ray Diffraction
Ɵ: Diffraction Angle
Ic: Crystallinity Index

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