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Comparative Characterization of Broiler and Old-Layer Chicken Feather Species for Oil Sorption

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Abstract- This study characterizes chicken feather-based sorbents and assesses their effectiveness for cleaning up oil spills. Proximate analysis and X-ray fluorescence (XRF) were utilized to measured moisture content, fixed carbon, and elemental make-up in broiler and old-layer species. Findings showed that both feathers have the chemical stability and structure needed to trap pollutants. Broiler feathers were found to have better absorption capabilities, having lower initial moisture and higher fixed carbon content compared to old-layer feathers. XRF analysis showed the occurrence of mineral oxides that help stabilize the keratin structure. The findings suggest that both feather types are biodegradable options compared to commercial polypropylene (PP) pad for oil spill cleanup. Broiler feathers showed a competitive sorption capacity of 15.7 g/g, these results indicate that both broiler and old-layer feathers are practical, low-cost, and biodegradable materials suitable for oil recovery.

Index terms- Oil Sorption, Chicken Feather Sorbent, Polypropylene Pad, Oil Spill Remediation, Agricultural Waste Valorization

I. INTRODUCTION

The global poultry industry produces approximately 8 to 9 million tonnes of feather waste each year. This waste is mainly composed of around 90% keratin by weight [1]. Although this large industrial waste stream is problematic for environmental management and disposal, it also provides a chance to turn waste into a resource for addressing global oil pollution. Oil pollution is still a major environmental problem, especially in areas with active petroleum exploration and transport operations [2]. Among remediation techniques for dealing with oil spills, the use of sorbent materials that possess a high preference of oil while repelling water are widely utilized [3]. To achieve this, high oil sorption capacity, hydrophobicity, oleophilicity, buoyancy, and reusability are characteristics of ideal sorbents. Due to their hydrophobic and oleophilic nature, synthetic sorbents like polypropylene pads are frequently utilised [4]. Despite their widespread use, synthetic sorbents present non-biodegradable and costly environmental challenges [5], and scalability challenges often limit their widespread application [6], [7].

In response to these constraints, recent research centre on the creation of sustainable and biodegradable sorbents made from natural and agricultural waste materials. The development of biodegradable sorbents made from agricultural wastes has therefore received more research attention [8]. Because of their large surface area and capacity for adsorption, natural materials like fibrous biomass and agricultural residues have demonstrated their feasibility [9], [6]. Natural fibrous sorbents and biosorbent materials have been well reserved and have proven to be successful in successful eliminating oil pollutants from water systems [10], [7]. Because of their effectiveness and minimal environmental impact, biosorption processes have also been extensively investigated as sustainable alternatives for pollutant removal [11], this materials effectiveness is governed by physicochemical interactions such as adsorption, absorption, and capillary action [12].

Chicken feathers have become a viable option among these substitutes largely due to their physiochemical characteristics. One of the most common types of poultry waste produced worldwide is chicken feathers. Millions of tonnes of feather waste are produced annually by the poultry industry worldwide, posing problems for environmental management and disposal. The conversion of this waste into useful sorbent materials is in line with waste-to-resource and circular economy concepts. In addition to being economically feasible and easily accessible, chicken feathers are also good for the environment [8]. Keratin, a fibrous structural protein with a complex hierarchical structure, low density, and intrinsic hydrophobicity, makes up the majority of chicken feathers [13]. Feathers' keratin-rich structure creates a hydrophobic, lightweight, porous matrix that may be able to absorb hydrocarbons [13]. Hydrocarbons can be efficiently trapped and retained by this keratinous structure's network of barbs and barbules, which creates a highly porous and fibrous matrix. A number of variables, such as surface morphology, porosity, fibre arrangement, and physicochemical composition, affect how well feathers absorb oil. Their oil sorption performance may differ depending on the arrangement, porosity, and surface area of the fibres when processed into various structural forms, such as feather pillows or fibre mats [3]. Additionally, their sorption efficiency can be improved by processing techniques like grinding, mat formation, or chemical modification [3].

There is still little comparative research assessing the effectiveness of various chicken feather types, especially between broiler and old-layer species, in comparison to traditional synthetic sorbents, despite the growing interest in feather-based sorbents. Feathers' composition, age, and structure can all have a big impact on their sorption properties, but little is known about this. To address this gap, this study investigated the physicochemical and sorption properties of chicken feather-based sorbents. Comparative analysis with conventional PP pads was conducted to evaluate the feasibility of utilizing waste chicken feathers as sustainable sorbents for oil spill remediation [5], [8].

Thus, the purpose of this study is to compare the physicochemical characteristics and oil sorption capacity of locally sourced chicken feather materials (old-layer and broiler) with a traditional polypropylene pad. The materials' elemental composition was evaluated using X-ray fluorescence (XRF). Engine oil and vegetable oil were used to represent various oil types in oil sorption experiments carried out in compliance with ASTM F726–17 standards. The viability of using poultry waste as a substitute sorbent material for oil spill remediation is thoroughly assessed in this study. The study supports the development of low-cost, biodegradable solutions for oil pollution management and advances sustainable environmental remediation technologies by comparing natural and synthetic sorbents under controlled conditions.

II. MATERIALS AND METHOD

A. Materials

1.Chicken Feathers

The primary sorbent materials used in this study were local chicken feathers sourced from a slaughterhouse facility in Port Harcourt, Nigeria. The feathers were categorized into two groups based on the Chickedn species: white feathers obtained from broiler chickens and brown feathers from old-layer chickens. These species are differentiated by their commercial utility and growth characteristics. Old layers are egg-laying poultry that remain relatively small, while broilers are fast-growing birds bred for meat production that possess deeper muscle tissue. For all subsequent characterization and sorption experiments, we processed these raw materials into a shredded form.

Fig 1a: Old Layer Chicken Feather (Brown)

Fig 1b: Broiler Chicken Feather (White)

2. Polypropylene Pad

A commercial 3M-HP static-resistant petroleum sorbent pad, made of polypropylene and polyester, served as the benchmark control [5], [4]. These synthetic pads were obtained from a local supplier in Nigeria. The physical properties of the 3M polypropylene pad are shown in Table 1.

Table 1 Properties of 3Mtm Polypropylene sorbents

Properties	Polypropylene
Manufacturer/ Code	3M
Thickness (cm)	0.6
Length (cm)	48.1
Width (cm)	40
Nominal Density (g/cm^3)	0.032
Buoyancy	Floats in water
Colour	Off White
Sorption	Hydrophobic/Oleophilic

B. Testing Oil

Before the sorption experiments, the physical and chemical properties of the oils were measured to establish their basic characteristics. According to ASTM D445-04 standards, kinematic viscosity was assessed using a Stanhope-Seta 5E1A Kinematic Viscometer, and density was measured with an Anton Paar DMA 35 Densimeter. Engine oil and vegetable oil were chosen to represent petroleum-based and plant-based spills, respectively. The engine oil showed a kinematic viscosity of 3.06 cm^2/s and a density of 0.8989 g/cm^3. In comparison, the vegetable oil had a much lower viscosity of 0.57 cm^2/s and a higher density of 0.9387 g/cm^3. These differences in viscosity and density between the two oils allow for an assessment of how the structural variations in chicken feather types affect the absorption of fluids with different flow resistances.

C. Proximate Analysis

1. Moisture Content

The moisture content was determined gravimetrically, following standardized protocols [14], [15]. Samples (5.0 g) were oven-dried at 105 °C until they reached a constant weight. We calculated moisture content on both dry and wet bases using Equations 1 and 2.

Moisture Content (Dry Base):

$$MC_{db}=\frac{M_i-M_f}{M_f}\times 100 \tag{1}$$

Moisture Content (Wet Base)

$$MC_{wb}=\frac{M_i-M_f}{M_i}\times 100 \tag{2}$$

Where:

- M_i= Initial mass of sample before drying (g)
- M_f= Final mass of sample after drying (g)

2.Volatile Matter

To quantify volatile matter, procedure followed ASTM D3175-02 [16]. Samples (2.0 g) were subjected to thermal degradation in covered crucibles at 450 °C until they reached a constant weight. The percentage of volatile matter was then calculated using Equation 3.

Volatile Matter:

$$VM=\frac{W_2-W_1}{W_2-W_0}\times 100 \tag{3}$$

Where:

- W_0= Weight of empty preheated container (g)
- W_2= Weight of sample before heating (pre-combustion) + container (g)
- W_1= Weight of sample after heating + container (g)

3. Ash Content

Ash content was assessed according to standard procedures [14]. Samples (10 g) where combusted in a muffle furnace at 550 °C for 4 hours to obtain a consistent ash residue. Ash percentage was obtained using Equation 4

$$Ash=\frac{W_1-W_0}{W_2-W_0}\times 100 \tag{4}$$

Where:

- W_0= Weight of empty crucible (g)
- W_2= Weight of crucible + sample before ashing (g)

- W_1= Weight of crucible + ash after combustion (g)

4. Fixed Carbon

Fixed carbon (FC) represents the solid combustible residue remaining after the removal of moisture, volatile matter, and ash. This parameter was calculated by difference using Equation 5.

$$FC=100-(MC+VM+Ash) \quad (5)$$

Where:

- MC= Moisture Content (%)
- VM= Volatile Matter (%)
- Ash= Ash Content (%)

D. X-ray Fluorescence (XRF) Analysis

Elemental composition was determined using a Xenematics Genius IF X-ray fluorescence spectrometer. Before analysis, we ashed the feather matrices at 550 °C, oven-dried them at 105 °C for 24 hours, and passed them through a 75 µm mesh screen to ensure uniform particle size. We compressed the processed ash into pellets with boric acid as a binder. Certified reference materials were used alongside a calibrated benchtop XRF spectrometer. To ensure accuracy, we executed all measurements in triplicate.

E.Sorption Experiments

1. Oil Sorption Capacity (OSC)

The sorption capacity was evaluated following ASTM F726–17 guidelines for loose sorbents. Sorbent samples (4.0 g) were introduced into prepared oil-water mixtures and allowed them to reach saturation. The saturated matrices using a stainless-steel mesh and drained them to remove unbound fluid. The final oil sorption capacity was calculated gravimetrically using Equation 6.

$$Q=(W_f-W_i)/S_i \quad (6)$$

Where:

- Q = Sorption Capacity
- Wf = Final weight of samples
- Wi = Initial weight of samples
- Si = Initial mass of the sorbed samples

2. Oil Recovery (Experimental Procedure)

Fluid recovery after saturation through mechanical extraction was assessed. The absorbed was expelled oil from the drained sorbents using consistent mechanical pressure. The extracted volume was quantified gravimetrically and recovery efficiency using calculated Equation 7. This procedure was repeated for all sorbent types (broiler chicken feathers, old-layer chicken feathers, and polypropylene pad) for both engine oil and vegetable oil under the same conditions to ensure comparability.

$$OR=W_r/W_s \times 100 \quad (7)$$

Where:

- OR= Oil Recovery (%)
- W_r= Weight of oil recovered from the sorbent (g)
- W_s= Weight of oil originally sorbed (g)

3. Oil Retention

The stability of the sorbents was tested by cycling oil sorption and desorption through multiple phases. After squeezing the oil out of the sorbents, they were reused for the next tests without any extra treatment. This cycling process was repeated three times to measure the oil retention capacity and to see how each material's performance changed over time. The same experimental conditions, such as the mass of sorbent, volume of oil, and contact time, were kept consistent for each cycle.

III. RESULTS AND DISCUSSION

A. Proximate Analysis

The proximate composition plays a crucial role in determining the structural stability and available adsorption sites within the sorbent matrices (Figure 2a-d). When we compared the biological sorbents, broiler feathers showed a better physicochemical profile for oil entrapment. The moisture content in broiler samples was 1.5%, lower than the 1.9% found in old-layer feathers. Higher moisture means that water molecules occupy some active sorption sites, reducing the effective surface area available for oil uptake [17]. The lower initial moisture in the broiler matrix minimizes this site competition, improving its affinity for oil compared to both the old-layer variant and the commercial polypropylene benchmark (2.4%).

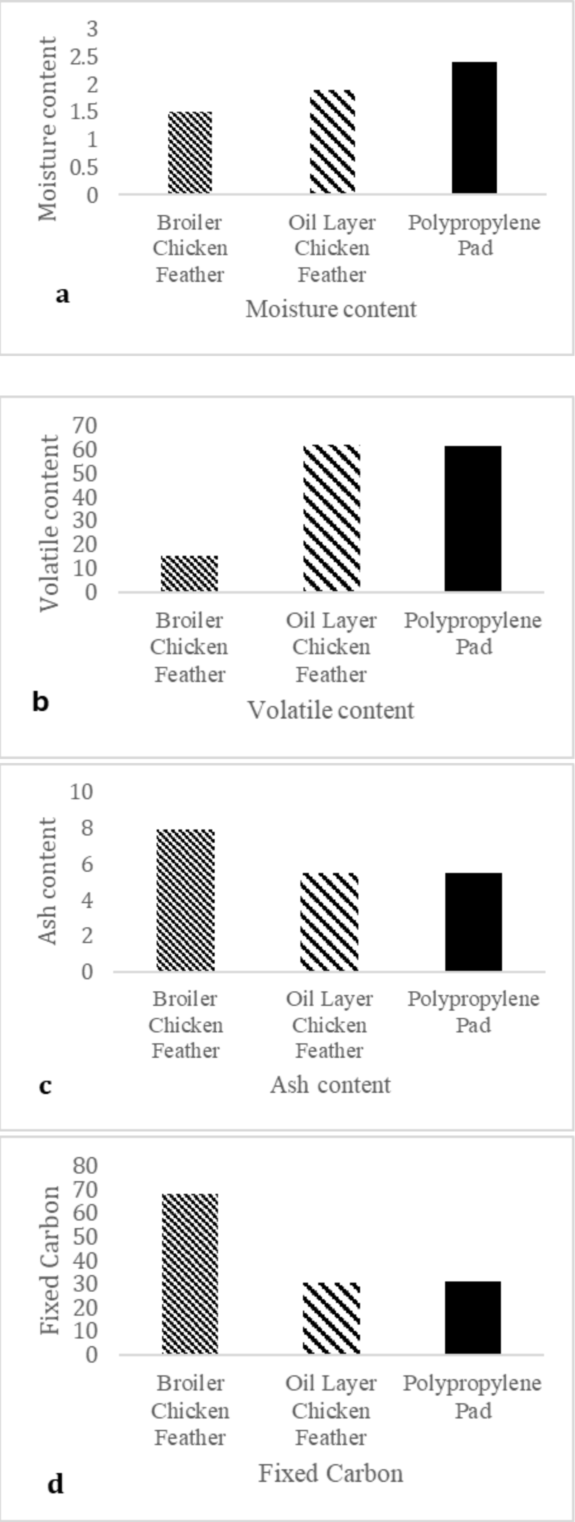

Fig 2a-d: Mean Proximate Analysis results for Broiler CF, Old Layer CF and PP Pad

A difference in volatile matter between the two types of feathers was observed. Old-layer feathers contain 62.1% volatile matter, which is indicative of an unstable organic structure prone to degradation, limiting the longevity of the adsorption sites. Broiler feathers, in contrast, maintain stability by only having 15.5% volatile matter. The fixed carbon content of broiler feathers reached 68%, exceeding that of old-layer feathers (30.8%) and the synthetic pad (31%). Sorbents with high fixed carbon generally show better sorption capacities because they have larger carbon surfaces that facilitate oil adsorption [18].

While broiler feathers had a slightly higher ash content (7.9%) than old-layer variants (5.5%), which can sometimes limit porosity and overall capacity [19], the greater advantage in fixed carbon outweighs this limitation. Low moisture, minimal volatile content, and a strong carbon framework position broiler feathers as the superior structural material for biosorbent formulation.

B. X-ray Fluorescence (XRF) Analysis

Figure 3a-b shows the elemental profiles of the evaluated sorbents. The polypropylene pad has an active surface area due to a dense quartz (silica oxide) concentration of 28.15%. This feature helps retain surface micropores [20], [21]. In contrast, the matrices of the chicken feathers use a different chemical approach for adsorption [22].

Both feathers have higher concentrations of SO3, CaO, MgO, and K2O compared to the polypropylene pad, this difference comes from the complex organic composition of the keratin fibre [23]. The high SO3 fraction in the biological materials is especially important, this is because it helps trap oil through processes like biosorption, ion exchange, and surface complexation [24]. Even though both feather types have this mineral profile, the broiler's better structural stability and larger fixed carbon network, shown in the proximate analysis offer a more resilient physical framework. This stable structure lets the broiler matrix use these active complexation sites avoiding the breakdown that affects old-layer feathers.

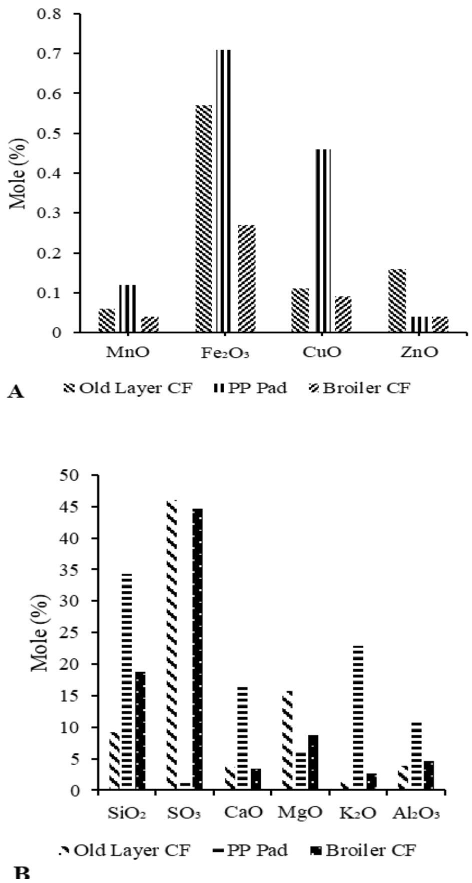

Fig 3a-b: XRF analysis results for sample

C. Oil Sorption Capacity

The physicochemical properties of the test fluids (Table 2) directly influence how the sorbent interacts with them. Figure 4 shows that the sorption capacities for biological matrices were consistently higher in engine oil than in vegetable oil. The higher kinematic viscosity of engine oil (3.06 cm²/s) encourages stronger surface adhesion and reduces fluid drainage during extraction [25], [26]. The synthetic polypropylene pad set the performance standard in all trials, achieving 17.6 g/g in engine oil and 21.0 g/g in the lower-viscosity vegetable oil. Its highly uniform hydrophobic pore structure contributed to this performance. When evaluating the biological alternatives, broiler feathers decisively outperformed the old-layer variants across both fluid environments. In the highly viscous engine oil, broiler feathers achieved a sorption capacity of 15.7 g/g, substantially exceeding the 10.4 g/g recorded for old-layer feathers (Figure 4). A parallel performance gap emerged in vegetable oil, where broiler matrices absorbed 12.6 g/g compared to the old-layer's 9.5 g/g.

This consistent performance supports the findings of the proximate analysis. The broiler feathers have unique physicochemical advantages, like low moisture interference and a strong fixed carbon framework that creates a highly oleophilic matrix. This structural strength allows the broiler material to compete with synthetic polypropylene, making it a promising, biodegradable option for industrial oil spill cleanup [27], [28].

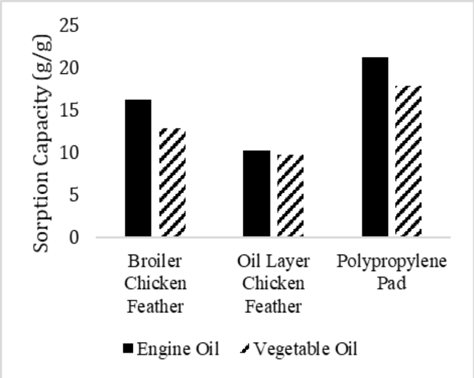

Fig 4. Mean oil sorption capacities of broiler chicken feathers, old-layer chicken feathers, and polypropylene pad in engine and vegetable oil.

The sorption capacity of the broiler chicken feather and old layer chicken feather in vegetable oil was 12.6g/g and 9.5g/g, respectively as shown in Figure 4. The sorption capacity in engine oil was 15.7g/g and 10.4g/g. Given the same conditions, the polypropylene had a sorption capacity of 17.60g/g for engine Oil and 21.0g/g for vegetable oil

D. Oil Recovery

The effectiveness of biosorbents in oil spill cleanup is based on their mechanical extraction capabilities. Figure 5 shows the average recovery percentages after the initial saturation. The commercial polypropylene pad set the highest recovery levels, capturing 73.3% of vegetable oil and 69.8% of engine oil. Its uniform, synthetic structure resists compression fatigue, enabling easier fluid evacuation from the macro-pores [28].

When evaluated broiler feathers performed better than the old-layer feathers in both fluid environments. Broiler samples recovered 58.9% of the absorbed engine oil and 55.6% of the vegetable oil, while the old-layer feathers yielded lower extraction efficiencies, recovering only 56.3% and 53.5%, respectively. This difference in performance is linked to the feathers difference in composition identified in the proximate analysis. The high volatile matter of the old-layer feathers indicates a degraded internal structure that breaks down under mechanical pressure, which leads to the fluid been trapped within compromised void spaces. In contrast, fixed carbon framework of the broiler feathers provides the structural resilience necessary to withstand mechanical squeezing and expel the sorbed fluid efficiently.

Interestingly, the biological sorbents had higher recovery rates for engine oil than for vegetable oil. The lower viscosity of vegetable oil allows it to penetrate more deeply into the keratin micropores of the feathers, this deep penetration makes it harder to extract manually. In contrast, the more viscous engine oil mainly adheres to the macro-surface of the carbonaceous network, making it easier to release during compression [26], [25]. Even though the broiler feather matrix retains a significant amount of fluid, it still shows competitive extraction efficiencies. This supports its structural suitability for creating durable Oil Pillows.

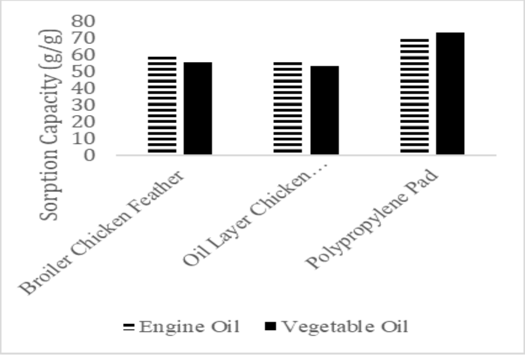

Fig 5: Mean oil recovery for chicken feather materials and polypropylene pad.

E. Oil Reusability

The cost-effectiveness of Oil Pillows for industrial oil spill cleanup depends on their overall durability. Figures 6a and 6b show the performance of the sorptive matrices across three cycles of sorption and desorption. All materials tested remained structurally sound, they absorbing oil beyond a single application without critical failure. The biological sorbents kept their shape under repeated mechanical compression, showing their potential for extended field use [29], [30].

Sorption capacity decreased across all media after the first application. Mechanical extraction does not fully remove the absorbed fluid, leaving some oil trapped in the internal voids and blocking capillary pathways. As a result, the effective surface area available for more oil capture decreases gradually. In addition, the disjointed state of the shredded feathers also leads to some material loss, contributing to this overall reduction.

Despite the decrease in sorption, performance varied noticeably between the species. Old-layer feathers showed better mechanical strength and stability during cyclic sorption and desorption compared to the broiler feathers. By the third cycle, the old-layer species achieved a capacity of 1.1 g/g in engine oil, while the broiler feathers dropped to 0.5 g/g. This extended use connects directly to the physicochemical framework confirmed in the proximate analysis. The structure of the old-layer feathers withstands repeated mechanical stress well. In contrast, the internal microstructure of the broiler feathers is more likely to collapse under compression. The stable composition of the old-layer matrix results in a longer lifespan and greater recovery during multi-cycle oil spill cleanup.

Broiler feathers outperformed the old-layer varieties due to key compositional differences. Proximate analysis revealed that broiler samples had less initial moisture. This is important, less moisture means there is reduced competition within the keratin matrix for oil uptake. The broiler feathers also had higher fixed carbon, providing more active sites for adsorption. The performance gaps in both the engine and vegetable oil trials is linked directly to these structural benefits.

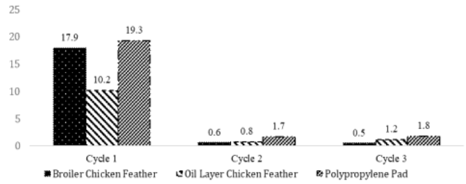

Fig 6a: Mean sorption capacities of reused samples in engine oil over 3 cycles

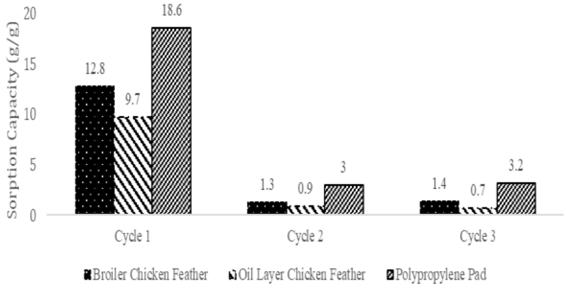

Fig 6b: Mean sorption capacities of reused samples in vegetable oil over 3 cycles

IV. CONCLUSION

This study confirms that chicken feather waste, can be a practical and biodegradable substitute for synthetic polypropylene in oil spill cleanup. While polypropylene pads had the highest absorption rates, broiler feathers' performance of 15.7 g/g suggests they could be effectively used on a large scale, comparative data highlights that feather type influences the effectiveness. Broiler feathers displayed better performance than old-layer feathers because of their advantageous physical and chemical properties, which included higher fixed carbon and lower moisture content. XRF characterization further supported the presence of stabilizing mineral oxides in the keratin matrix, helping the material maintain its structure during repeated absorption and recovery. Although all materials lost some effectiveness over time, chicken feather sorbents still had enough capacity to make them suitable for local spill management.

Turning chicken feathers, which are waste streams from poultry, into usable sorbents aligns with circular economy and waste Valorisation practices. By using agricultural leftovers that would otherwise be discarded, this research presents a sustainable and cost-effective approach to environmental protection. Future work should prioritize enhanced mechanical processing of these fibres in order to augment their strength and preparedness for oil spill remediation.

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