Imperial College London

Oil Spill Remediation Using Waste Feathers as a Natural Sorbent

A thesis Submitted in Fulfilment of the Requirements of the Degree of

Doctor of Philosophy

By

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Declaration

I, **Kaine Bene Chinwah,** affirm that this thesis, submitted for the degree of Doctor of Philosophy of Imperial College London, is my own original work. Contributions from other researchers have been specifically acknowledged and a list of references is given. This work has not been presented for another qualification elsewhere.

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Kaine Bene Chinwah

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Abstract

Oil spills threaten the aquatic ecosystem and are a critical global concern due to their adverse social, economic, and environmental impact. This research thoroughly examined the viability of waste chicken feathers as low-cost biosorbents for oil spill remediation in the Niger Delta region of Nigeria. The developed biosorbents also provide a sustainable waste management option for agro-waste. In this research, waste chicken feathers were processed into oil sorbent pillows and water sorption, oil sorption capacity, reusability, and oil recovery percentage of the chicken feather pillow sorbent were determined. These sample properties were also compared with two reference sorbent materials, polypropylene pad a commercial synthetic sorbent, and chicken feather fibre mat a natural sorbent obtained from Imperial College London, UK.

The oil sorption capacities of the chicken feather pillow, chicken feather fibre mat and polypropylene pad for engine oil were 8.8g/g, 12.7g/g and 13.0g/g, respectively. The result of vegetable oil in the same order was 8.0g/g, 11.2g/g and 12.5g/g. The polypropylene pads and chicken feather fibre mat recorded the highest amounts of oil sorption for engine and vegetable oil. All sorbents were reusable, and the percentage of oil recovery for all three sorbents was above 60%. Further trial tests were performed at four oil spill locations: a diesel oil site, palm oil, weathered crude oil and a fresh crude oil site. The results strongly implied that waste chicken feather is a good sorbent and could be a practical solution to the problem of oil spills for the oil and gas, shipping, manufacturing, and chemical industries, who can maximise the economic gain in the reduction of oil spill management costs to ensure a sustainable environment. in the Niger Delta region of Nigeria. Further work assessed the commercialisation and barriers to developing a circular economy for chicken feather pillows.

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I am grateful and humbled for the transformation and growth I have experienced over the past five years. This thesis is the culmination of my doctoral path and is pretty much the same as scaling a tall mountain step by step with faith, motivation, difficulty, and frustration. I have had so much to learn about oil spill remediation, sorption science, and all related branches of this core topic. I have developed patience, matured in interpersonal relationships, and become more diligent in work. I often felt overwhelmed, but keeping my eyes on the goal kept me going. This is a big step towards a more fulfilling academic career and a great route to further widening my research on profitable commercial solutions for oil spill remediation in developing countries. Earning a doctorate and writing a dissertation is a lengthy, demanding, cooperative, and collaborative effort.

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Conferences

The following presentations were made at these conferences, as a result of work pertaining to this thesis:

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2. International conference on new views in Engineering and Technology, RSU, 27th October 2021. Waste chicken feathers as sorbents for hydrocarbon and Non-hydrocarbon Spills.
3. Groundwater making the Invisible visible Host: Dangote Cement PLC/ Lagos Business School Sustainability Centre. Tuesday 22nd, March 2022. Tackling Groundwater pollution in the Extractive Industry.

Glossary Of Terms

List of Abbreviations

ACEA	-	Africa Circular Economy Alliance
ACEF	-	Africa Circular Economy Faculty
AHP	-	Analytical Hierarchical Process
ASTM	-	American Society for Testing and Materials
BET	-	Brunauer-Emmett-Teller
BMC	-	Business Model Canvas
CA	-	Contact Angle
CAGR	-	Compound Annual Growth Rate
CBA	-	Cost Benefit Analysis
CF	-	Chicken Feather
CFM	-	Chicken Feathers Mat
CFP	-	Chicken Feathers Pillow
CFU	-	Colory Forming Unit
CFW	-	Chicken Feather Wates
CRL	-	Commercial Readiness Levels
Ct	-	Carat
DC	-	Developing Countries
DVS	-	Dynamic Vapor Sorption
EBITDA	-	Earnings Before Interest, Taxes, Depreciation and Amortization
ECCE	-	European Commission Circular Economy
EGASPIN	-	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria
EIA	-	Environmental Impact Assessment

EU	-	European Union
FBK	-	Feather Beta – Keratins
GDP	-	Gross Domestic Product
H&S	-	Healthy and Safety
HR	-	Human Resources
HYPREP	-	Hydrocarbon Pollution Remediation Project
IGC	-	Inverse Gas Chromatography
ITOPFL	-	International Tanker Owners Pollution Federation Limited
MPL	-	Market Readiness Levels
MVP	-	Minimum Viable Product
NCDMB	-	Nigeria Content Development and Monitoring Board
NCEP	-	Nigeria Circular Economy Programme
NCEWG	-	Nigeria Circular Economy Working Group
NDDC	-	Niger Delta Development Commission
NESREA	-	National Environmental Standards and Regulations Enforcement Agency
NGO	-	Non-Governmental Organisation
NOSDRA	-	National Oil Spil Detection and Response Agency
NRF	-	National Research Fund
NUPRC	-	Nigeria Upstream Petroleum Regulatory Commission
PP	-	Polypropylene
PSH	-	Poultry Slaughterhouses
R&D	-	Research and Development
SEM	-	Scanning Electron Microscopy
SNS	-	Surface Measurement System

SPDC	-	Shell Petroleum Development Company
SSA	-	Specific Surface Area
TETFUND	-	Tertiary Education Trust Fund
TRL	-	Technology Readiness Levels
WRAP	-	Waste Resources Action Programme
XRF	-	Xray Fluorescence

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List of Symbols

P	Pressure
K	Constant
T	Temperature
n	Adsorbed Gas Amount
n_m	Monolayer Adsorbed Gas Amount
C	BET (or Sorption) Constant
N_A	Avogadro's Number
a	Adsorption Cross Section Adsorption Species
γs^D	Dispersive Component of Surface Energy of solid
γs^T	Total Surface Energy
γs^{AB}	Specific Component of Surface Energy
V_N	Retention Volume
P_D	Molar Deformation Polarization of Probes
MW	Molar Mass of Probe
r	Reflective Index of Probes
D	probes LIQUID Density
W_C	Work of Cohesion
W_A	Work of Adhesion
W_d	Dispersive Component of Work of Adhesion
Wp	Polar Component of Work of Adhesion
W_h	Hydrogen Bonding Component of Work of Adhesion
ΔG_{SP}	Gibbs Free Energy of Adsorption
K_A	Gutmann's Acid Constant
K_B	Gutmann's Base Constant
S_O	Initial Dry Sorbent Weight
S_{wt}	Weight of the Sorbent Sample at the end of the test
S_w	Net Water Sorbed.
Q	Sorption Capacity
S_t	Total Mass of Sorbed Samples
S_o	Initial Mass of Sorbed Material
G	Gibbs Free Energy
MC_i	Initial Mass of Chicken Feather Before Drying

MC_f	Final Mass of Chicken Feather After Drying
M	Molarity
S	Volume of Thiosulphate
V	Volume
W_S	Weight of Sample

Chapter 1 – Introduction

1.1. Background

An oil spill is a global challenge that occurs due to the release of oil into the environment. The population of the world and increased industrialisation have increased the growing oil demand (Senanurakwarkul and Chavarnakul, 2012). The causes of oil spills can be human error, deliberate acts of vandalism, war, or natural disasters such as hurricanes or earthquakes (T. Lim and Huang, 2007).

The Niger Delta region of Nigeria contains one of the largest wetlands in the world, with an extensive freshwater swamp that provides a habitat for many endangered species. It covers a land area of 70,000 square kilometres and is (crisscrossed by many rivers, rivulets, streams, canals, and creeks (NDES, 1997). The region is known for oil production and has an estimated spillage incident of over 7,000 over 50 years (UNDP,2006). There is also the problem of the sewers with mineral oil carried from the streets by rain and water polluted with cooking oil from homes and restaurants (Deschamp et al.,2003). Some of the problems associated with oil spills in the region include contamination of water bodies, threatened aquatic life, destruction of farmlands, and loss of lives (Nwilo and Badejo, 2008). Due to the impact of oil spills on marine resources over the past years, there has been increased public and government awareness of the need to protect the marine environment (Nordvik, 1999). The different methods for oil spill cleanup have been categorised into three main groups: mechanical methods, such as booms, skimmers, and adsorbents; chemical methods, such as dispersion and in-situ burning; and finally, biological methods (Bayat et al., 2005). Considering the various options available for oil spill remediation, much attention is being given to the use of natural sorbents such as rice straw, corn cob, cotton, milkweed floss, kenaf, and wool fibres (Choi and Cloud, 1992; Ghalambor, 1995; Rowell and Stout, 1998). The major advantage of natural sorbents of agrarian waste origin is that they are readily available, renewable, and easy to maintain (Kumar et al., 2020). Hydrophobicity and oleophilicity are the major factors for a good sorbent, as well as the retention over time, recovery of oil from sorbents, the amount of oil sorbed per unit weight of sorbent, the reusability and the biodegradability (J. W. Doerffer, 1992). Feathers, an abundant agricultural waste product, has been researched to have oil sorption characteristics (Ijeoma and Prisca, 2015).

1.2. Problem Statement

Poultry consumption is on the increase globally due to the rapid growth rate of chickens and the relatively low costs associated with poultry farming. In 1960, poultry accounted for only 12% of global meat production, but by 2013, its share had approximately tripled to around 35% (FAO, 2019). Countries like China and India that traditionally had vegetarian diets are consuming more protein-rich diets, and this current trend in meat consumption is unsustainable and capital-intensive (Schmidhuber and Shetty,2005). It has been reported that there are currently around 4.5 billion kilograms of feather products generated annually worldwide (Acda, 2010).



Figure 1.1: Kobis Farm (60,000 Bird Capacity) in Cross Rivers State

The Nigerian poultry industry is a highly commercialised subsector of the agricultural sector. Figure 1.1 is an example of a commercialised farm located in Nigeria. With the large population of the country, growing at a rate of 3% per annum, the trend can certainly be sustained. Nigeria is reported to consume 1.5 million tonnes of chicken, with about 30% locally reared and projected to increase annually (Kelle and Eboatu, 2018). Currently, the major methods of disposal of feathers are the use of open dumpsites and incineration, which is a waste of resources (Xia et al., 2012). This method also gives rise to environmental challenges through the generation of greenhouse gases (Xia et al.,2008; Borioni et al., 2012).

This quantity is considered favourably and conveniently sufficient to supply any industrial application of waste chicken feathers, including taking advantage of the unique natural properties of Waste feathers and their abundance by developing a circular economy, which is

a sustainable alternative to the current and linear disposal methods. The use of waste chicken feathers for oil spill remediation is significant, considering the increasing world population and the challenge posed by unsustainable levels of resource extraction, materials production, and waste generation.

1.3. Research Question and Scope

1.3.1. Research Question

The main question generated by this research is;

Can waste feathers be locally designed in Nigeria into an oil sorbent and also used locally for oil spill remediation?

This thesis follows through some key hypotheses, which were generated from the findings of a previous M.Sc. thesis project. The initial study concluded the following;

- Waste feathers have unique properties of high buoyancy, hydrophobic, and oil sorption properties that can be used as a sorbent.
- Waste feathers are available in abundance in Nigeria and can be accessed
- Waste feathers can be used to develop a waste-to-wealth initiative in Nigeria

The thesis research is focused on investigating the potential of substituting conventional sorbents used in Nigeria with sorbents produced from waste feathers, thereby enabling a circular economy through the following;

- Identifying a simple method of converting waste feathers into a fibre material and packaging for use in oil spill cleanup.
- Investigate the potential of commercialising developed products.
- Investigate the barriers to adopting this product to enable a circular economy model.

1.3.2. Research Scope

This thesis focuses on the development of a natural sorbent from waste feathers to be used in the Niger Delta region of Nigeria. Evaluating its oil sorption performance compared to existing commercial sorbents, the suitability for commercialisation to promote a circular economy for waste feathers will also be assessed. This covers the following;

- Compare the physico-chemical properties of chicken feathers with standard conventional sorbents. Are there some similarities? Or major differences?
- What key properties of sorbents and sorbates affect the oil sorption performance
- Design a biosorbent from chicken feathers.
- Compare the sorption capacity, oil recovery, and reusability of the prepared chicken feather pillow with the two standard sorbents.
- Assess the viability of a circular economy business model for chicken feather pillow.

The scope does not include the determination of which properties of local chicken feathers or commercial sorbents had the most effect on the sorption capacity or an extensive analysis of which other properties of the oil or factors like temperature of surrounding, humidity, or viscosity can affect the oil sorption process the most.

1.4. Aim and Objectives

This research aimed to actualise synthesising biosorbents from chicken feathers and identify local applications for the use of chicken feathers as sorbents in Nigeria by understanding the sorption process, providing basic characterisation data for chicken feather materials and an overview of the route to commercialisation for the use of waste feathers as a sustainable technology for oil spill remediation.

The aim of this research was achieved by meeting the following Objectives.

- Understanding the fundamental science controlling the waste chicken feather sorption process.
- Evaluating its sorption potential and confirming it can conveniently replace other conventional sorbents for oil spill remediation in developing countries.
- Developing waste chicken feather sorbent for application in local communities and manufacturing companies in Nigeria.
- Assessing the possibility of achieving a circular economy using waste chicken feathers as a sorbent in Nigeria.

1.5. Research Design

The research design of this thesis into four work packages is presented in Figure 1.4, where work package one is the research clarification. This contains chapters one and two. A detailed literature review is done to review information available on oil spills, sorbent types, sorbent properties, and the use of chicken feathers as sorbents. Objective one of the thesis was achieved in this first stage.

In work package two, experiments were done to characterise sorbents of chicken feathers and standard sorbents used for comparison. Experiments for feather characterisation are carried out to discover potential raw materials needed for the production of sorbents. Chapters 3 and 4 focus on empirical data analysis to assess the results and information collected in Work Package 1, thus achieving the second objective of my research work, which is to evaluate chicken feather sorption potential and confirm that it can conveniently replace other conventional sorbents for oil spill remediation in developing countries.

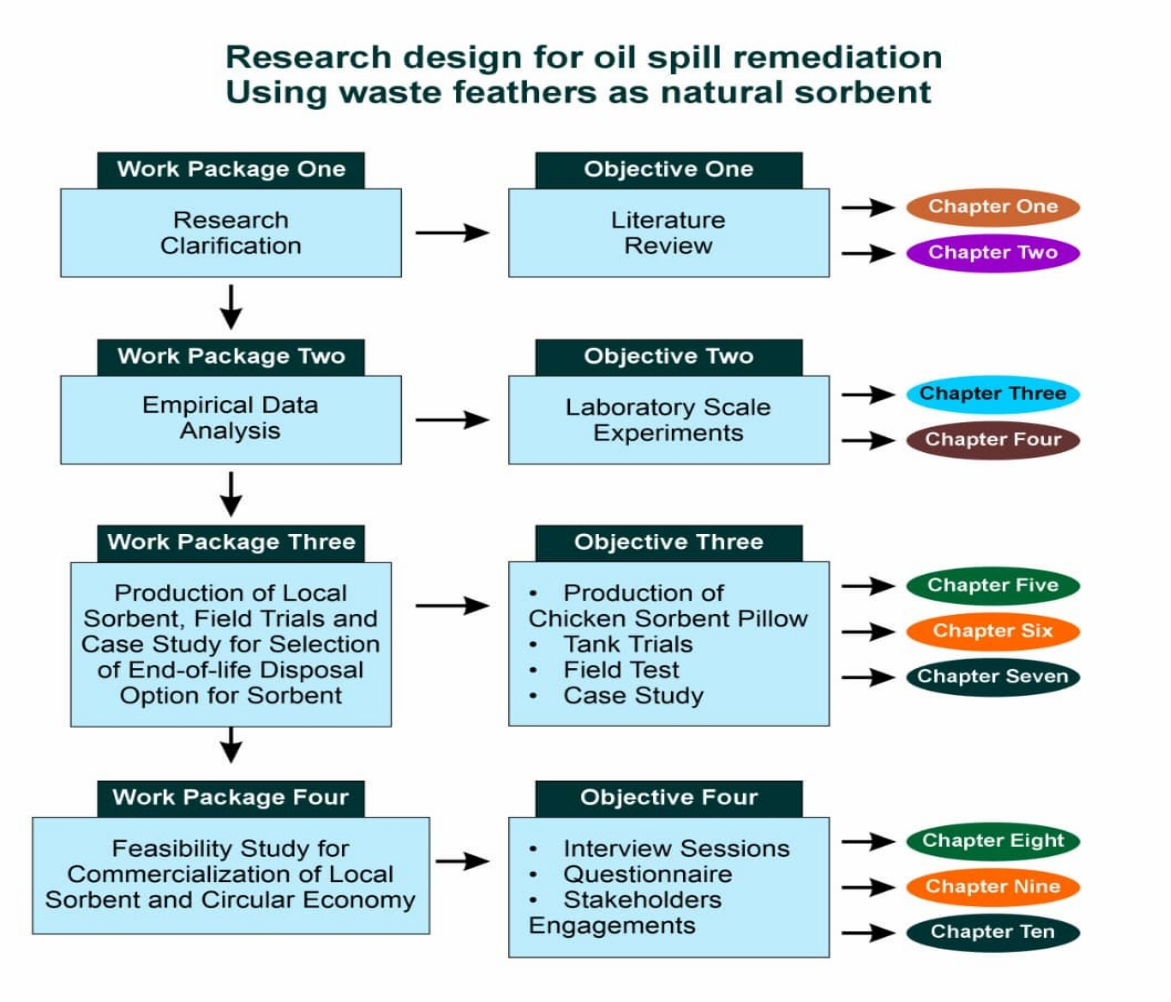


Figure 1.2: Research Design for oil spill remediation using waste feathers as natural sorbents.

Work package 3 involves the development of the Chicken Feather Pillow. Feather sorbent net was first developed, and then the design progressed to the Chicken Feather Pillow. The third objective was achieved in stage 3, which was to develop waste chicken feather sorbent for application in local communities and companies in Nigeria. A case study for the selection of the end-of-life disposal option for Chicken Feather Pillow was also conducted.

Finally, in work package 4, two feasibility studies were embarked on to get knowledge on the economic visibility of commercialisation and circular economy potential as a viable solution to the oil spill challenge experienced in the region. The final objective of my research was to assess the possibility of achieving a circular economy using waste chicken feathers as a sorbent in Nigeria.

1.6. Significance of Research

Organic sorbents are gaining popularity and acceptance globally for oil spill remediation. However, there are very limited real-life applications in developing countries. As a sorbent, chicken feather pillows will impact the environment and economy positively in developing countries. The research findings contribute to the development of simple, cost-effective production of chicken feather sorbent that can compete favourably with other conventional products in use. The chicken feather pillow has been patented in Nigeria with NG/PT/NC/2023/6929 patent number, and an acceptance for product presentation in the first quarter of 2024 has been approved by the Nigerian Content Development and Monitoring Board (NCDMB), a Government Agency that promotes local content development.

One paper from this research has been published, a second has been accepted and under review, and two other papers are in the advanced stages of preparation for submission. The Ph.D. research established international collaborations between Imperial College London and Rivers State University, a Science and Technology university in Rivers State. Partnerships were also initiated between Rivers State University and two Government agencies - the Hydrocarbon Pollution Remediation Project (HYPREP) and the National Oil Spill Detection and Response Agency (NOSDRA) to get technical support for Research.

Overall, the research is a positive contribution in both the short and long term to the sustainable use of chicken feather waste for environmental and economic impact.

1.7. Thesis Outline

Chapter One: This is the general introduction, which highlights the background, statement of the problem, research question, and definition, research scope and design, significance of research, and aims and objectives.

Chapter Two: This chapter reviews oil spill sources and globally recognised methods of remediation. The use of Sorbents for oil spill remediation, types of sorbents, the global market for sorbents, and the use of chicken feather waste as a sorbent were researched. The concept of the circular economy and practice in Nigeria was reviewed. The research gaps were identified, and this guided the development of the experimental procedure and feasibility study methodology adapted for this Ph.D. research.

Chapter Three: This chapter discusses the experimental laboratory procedures for the characterisation and oil sorbency performance of chicken feather sorbent materials and other conventional products sourced in the United Kingdom.

Chapter Four: This chapter discussed the experimental laboratory procedures for the characterisation and oil sorbency of local chicken feather materials and polypropylene pads sourced in Rivers State, Nigeria.

Chapter Five: This chapter reports on the production process of oil sorbent developed locally - Chicken Feather Pillow. This included the collection of chicken feathers, washing, drying, shredding, and packaging. The production cost was also evaluated.

Chapter Six: This chapter reports on the three practical field testing of the oil sorbency performance of chicken feather pillows. The first field trial test was performed in 1500-litre tanks at Rivers State University. The second was in four different spill locations in Rivers State: weathered oil spill, engine oil spill, palm oil spill, and crude oil. The final test was performed in a wastewater discharge from Accugas blending plant.

Chapter Seven: This chapter reports on a case study for the end-of-life options for chicken feather pillow.

Chapter Eight: This chapter discussed the findings of the feasibility study on the commercialisation of chicken feather pillows. The market size, SWOT analysis, and income potential were assessed.

Chapter Nine: This chapter reports on the barriers to developing a circular economy for chicken feathers in the Niger Delta region of Nigeria using a barrier assessment framework.

Chapter Ten: This chapter discusses the conclusions, challenges, and recommendations for future work.

Chapter 2 - Literature Review

2.1. Oil Contamination

Oil spills are categorised into four main types in terms of the quantity of oil discharged into the land, coastal or offshore wasters, and they are minor spills, medium spills, major spills, and disaster (Nwilo, P.C and Badejo, O.T.,2001). In the Niger Delta region of Nigeria, oil was discovered in the 1950s, and subsequent extraction activities in the area have had varying undesirable effects on the ecology. The rapid population growth and industrialisation of the Niger Delta region, along with the discovery of new crude oil resources, have resulted in environmental degradation (Nwilo and Badejo, 2004).

Reports show that approximately 5334 crude oil spills occurred between 1976 and 1997, which culminated in an estimated oil spill of 2.8 million barrels into Nigerian estuaries, inland and coastal waters, land, and swamps (Dublin-Green et al., 1998). It is estimated that between 9 and 13 million barrels of oil spillages have occurred in the last 53 years, averaging about 50 times more than the Exxon Valdez Oil Spill in 1989 in Alaska (Weiner A et al., 1997). Over 70% of the oil spilled between 1976 and 2001 was not recovered (UNDP, 2006). Reports reveal that three million barrels of oil were lost in about 7000 oil spill incidents at a damaged Nigerian Liquefied Natural Gas pipeline connecting Kala-Akama and Okrika mangrove forest; the pipeline was eventually set ablaze in 2004 (Fentiman and Zabbey, 2015).

The factors causing oil spills in Africa and Nigeria include sabotage of oil facilities, vandalism of crude oil pipelines, oil theft, poor maintenance practices at oil facilities, corrosion of oil pipelines, and accidental release of petroleum from tankers during logistical processes. Others include poverty, marginalisation, bad governance, and intervention (Akpoghelie et al., 2021).

2.2. Impact of Oil Spill

Oil spills occur over the seas, water bodies, and land surfaces as a result of operation and equipment failures, accidents, and natural disasters in the course of production, transportation, storage, and use of oil (Praba Karan et al., 2011). These oil spill incidents pose a major challenge to the environment (Husseien et al., 2009; Madkour, 2014; Radetic et al., 2008). Over the years, activities from the oil and gas industry have impacted the ecosystem due to leaks, spills, offshore production, transportation, industrial waste discharge, and urban runoff in large quantities (Asif et al., 2022; Walker et al., 2019; Zhang et al., 2018). The impacts on living

organisms vary from minimal to severe depending on the magnitude and scale of the spill (Thakur and Koul, 2022). The size of the receiving body forms part of the basis for predicting the environmental effects of the release of a given quantity of oil since large spills may be more disastrous on small receptors. Because of the environmental processes acting on the released hydrocarbon, it is important to consider the type of hydrocarbon released as well as the risk it poses to the organisms (Kadafa and Ayuba, 2012).

2.2.1. Environmental, Ecological and Economic Impacts

Damages caused by oil pollution to ecosystems, food chains, and life-sustaining resources like controlled waters are very severe (Ajai, 2010). The damage to the ecosystem has made oil spills the worst nightmare for host communities (Chinweze et al., 2012), causing the extinction of ecosystem services, including timber, fish breeding grounds, and mangrove forests (Kadafa and Ayuba, 2012), as well as other long-term, irreversible effects like cancer (Adepoju and Olawuyi, 2012). In addition, the oil spill has had an impact on seabed biodiversity and the marine ecosystem. The macro-fauna in offshore sediments, such as benthic fauna and detritivores, are deposited while feeding on organic particles in the ocean or seabed (Ritchie, 1995).

When oil compounds dissolve in water, coral reefs are exposed to harmful chemicals and other substances (IPIECA, 2000). The ecosystems have now become unsuitable for species and biodiversity as a result of the damaging effects of oil spills on mangrove forests and freshwater wetlands (Chinweze et al., 2012). For example, the oil spill resulting from the Funiwa-5 oil well rupture of 1980 led to 836 acres of mangrove and the defoliation of mangrove seedlings (Raji and Abejide, 2013). The oil rupture incident also had a significant effect on the coastal mangroves, which served as a nursery for fish and other aquatic life (Kadafa and Ayuba, 2012). Consequently, fishing resources are dwindling.

A typical example of the harm oil spills cause to the environment is that sea birds swimming and diving for food are most likely to become oiled. The nesting grounds of entire species are also being destroyed. For instance, the long-term environmental effects of the 2010 BP Deepwater Horizon offshore oil spill in the Gulf of Mexico will not be known for years. The spill occurred at a time of peak mating and nesting for many birds and marine species (Quintana-Rizzo et al., 2015). Birds are not able to fly because of oil, which also contributes to the destruction of their natural waterproofing and insulation, making them susceptible to

hypothermia or overheating (Mathewson et al., 2018). Birds may often swallow the oil as they frantically preen their feathers in a bid to regain their natural defences, which is critically harmful to their internal organs and may cause death (King et al., 2021). The Exxon Valdez oil spill is estimated to have caused the death of 250,000 seabirds (Rice et al., 2001). A decline in the rate of reproduction arises from oil spill contamination. For instance, it also causes physiological changes when the habitats of birds and mammals are contaminated (Briggs et al., 1996a). In addition, natural aeration is hindered by oil film floating on the surface of the water reducing the ability of rivers to support marine life, and often, this leads to the death of aquatic organisms, especially lucrative fish species; fishermen would lose their jobs.

The high mobility and persistence of contaminants potentially change the chemical composition of the soil, water, and other ecological components and cause groundwater contamination (Fentiman and Zabbey, 2015). For instance, many rural communities rely on surface water as their primary source of drinking water (Brassington et al., 2007). Additionally, the soil is made inimical to microbial and enzymatic activities because chemical characteristics present in petroleum hydrocarbons interfere with soil functionalities (Alrumman et al., 2015; Labud et al., 2007). The soil becomes infertile because of a reduction in soil nutrients and increased toxicity, culminating in unsuitable conditions for plant growth. This has an impact on the general soil ecology and the microbial activity in the soil (Alrumman et al., 2015).

Moreover, oil spill has a major impact on the food security and eco-toxicology of the region. The local food chain may become contaminated by bio-accumulating hazardous hydrocarbon components in root crops and other agricultural products, which can be harmful to human health when consumed (Fent, 2004).

In Nigeria, attention is constantly being drawn to the observable increase in soil and water pollution, which affects food safety (Omemu and Aderoju, 2008). Sources of food contamination include chemical pollution and excessive pesticide and fertiliser use on the soil. Consequently, the rising oil spill contamination in the Niger Delta creates serious threats to the ability of the region to produce safe food. Furthermore, the reliance of the local population on farming to earn a living has been eliminated, leaving them without a viable option (UNEP, 2011). Arable land has become less available as pollution levels rise (Orubu et al., 2004; Umukoro, 2012). As farmers move to other communities in search of farmland, the demand for scarce fertile land increases, generating communal clashes resulting from land disputes (Oluseye and Oluwasanjo, 2012).

As employment options diminish, taking up arms and engaging in social vices in the local community becomes imminent (Watts, 2007). The human, economic, and environmental consequences of an oil spill are enormous. Oil spills destroy the beauty or aesthetics of the ecological environment (Clinton et al., 2009). It can cause gross biological damage, physiological effects on plants and animals, and ecological changes (Briggs et al., 1996b).

Petroleum hydrocarbons can set off modifications in many organisms at all levels, including ecosystems, organisms, and cells. The consequences on aquatic organisms vary from toxicity, specifically for mild oils, to smothering (Rim-Rukeh and Agbozu, 2013). Poisonous or hazardous elements do not always lead to mortality but may result in transient consequences like tainting tissues and narcosis, which generally subside over time. Environmental effects of oil spills include scarcity of easy water for cooling in industries sited close to water bodies, limitations in the use of water bodies such as streams, rivers, and lakes for recreational purposes, and disruption of usual harbour activities such as ferry services (Ajayi and Osibanjo, 1981). Furthermore, when oil spills on water bodies, the water quality is changed, making it unsuitable for human consumption. One barrel of crude oil can make one million barrels of water unfit for portable use (Uzoekwe and Achudume, 2011).

Mangrove swamps are crucial nursery grounds in tropical climes and offer an incredibly diverse and rich ecology that protects coastal shorelines. Oil spills have a significant impact on breathing roots (NDES, 2018).

There are immediate risks and environmental effects of water contamination and threats when oil is spilled over water bodies and land surfaces. The oil spill is usually harmful as it spreads most times to the seashores as a result of wind and other environmental factors, and the slick formed is usually harmful to animals and humans (Brody et al., 2012). Even in very small concentrations, oils can be extremely dangerous to the microorganisms that normally carry out the biodegradation process in traditional sewage systems (Rengasamy et al., 2011a).

The effects of oil spills also include the extinction of marine life and the occurrence of fires. The impact of oil pollution raises serious questions about the government's commitment to protecting marine resources and controlling oil contamination. Oil spills have a significant negative economic impact on fisheries, marine culture, tourism, and energy. They also harm the marine, coastal, and terrestrial environments (Hussein et al., 2008a; Rengasamy et al., 2011b). Aquatic and terrestrial species' cell membranes are significantly impacted by oil in both structure and function, which reduces growth and reproduction (Rufino et al., 2014).

Additional effects include the drastic collapse of the food chain (Silva et al., 2014), as well as the suppression of light and energy transmission (Roques and Aurelle, 1991).

2.2.2. Social and Public Health Impacts

Oil spills have been reported to affect people in three ways: by directly affecting ecological processes, such as the health effects of eating seafood with bio-accumulated oil toxins; by changing intermediary processes, such as the economic effects of an oil spill on fishers; and by directly affecting people, such as the health effects of breathing oil vapour (Webler and Lord, 2010).

In terms of physical health, direct or indirect exposure to crude oil can have harmful effects that range from nausea to certain types of cancer and problems with the central nervous system (Davidson et al., 2005; Herrington et al., 2006; Munro Jensen, 1996; Rodriguez-Trigo et al., 2007; Whitford, 2008).

Research on the Prestige oil spill in Spain (Suárez et al., 2005). reveals that exposure to hydrocarbons has a detrimental effect on people's health. Human cancer and respiratory problems have been related to acute aromatic hydrocarbon exposure. The data implies that chromosomal and lung abnormalities may occur in hydrocarbon-exposed individuals. Moreover, Polycyclic Aromatic Hydrocarbons (PAH) can cause skin cancer, bronchial sickness in vulnerable individuals, including children, and skin damage (Rodriguez-Trigo et al., 2007).

The Deepwater Horizon oil platform explosion, commonly known as the Gulf of Mexico Oil Spill or the BP Oil Leak, occurred on April 20, 2010, roughly 50 miles southeast of the Mississippi River delta (Cutler, 2010). Its economic effects first appeared in the localised areas that were impacted before spreading to the entire nation. In 2008, commercial fishermen in the gulf hauled in more than 1 billion pounds of fish and shellfish. In the Gulf of Mexico, around 5.7 million recreational anglers made about 25 million fishing excursions in 2008. The immediate repercussions of the spills were felt by fishermen in prohibited fishing regions as well as by hotels, eateries, and other Gulf Coast enterprises engaged in tourism, conferences, and leisure pursuits.

Growing hydrocarbon pollution in the Niger Delta is a major factor in the growing carcinogenic health statistics of the region. Due to several continuous spills, the region is among the most

severely damaged deltas in the world. These factors have had a significant influence on the local economy, agricultural land, and surface and groundwater quality (Zabbey and Uyi, 2014).

In a study of 130 disasters in the United States, oil spills were shown to be more emotionally challenging than natural catastrophes (Picou et al., 2004). Threatened livelihoods and fresh influxes of recovery funds have been connected to various forms of stress and societal collapse. After the Exon Valdez disaster, domestic violence and general crime rates rose, and high rates of alcohol and drug use were associated with recovery occupations, particularly in Indigenous communities. As a result, there was an increase in demand for clinics, mental health services, and rehabilitation programs (Palinkas *et al.,* 1993). Due to decreased productivity and a shorter life span, these not only entail immediate financial costs in the form of medical bills and other expenditures but also far-reaching societal costs (Loureiro and Lotade, 2005).

Oil spills may affect society and the economy. It may have detrimental effects on the way of life, culture, traditions, norms, values, local economy, and the environment of local communities (Pegg and Zabbey, 2013). Means of subsistence are lost due to the disaster, resulting in widespread unemployment. This is a more likely outcome than an improvement in social and economic conditions as a result of petroleum production (Albert et al., 2018). Most of the negative social effects of oil spills are associated with conflict and violence, which have historically had a detrimental effect on the tourist and hospitality sectors (Okonkwo, n.d.). There is also a rise in the cost of living.

2.2.3. Treatment of Oil Spill

The environment must be cleaned up quickly to limit and lessen the effects of oil pollution and contamination. An oil-in-water emulsion or floating film is created when oil and water are combined, which must be expunged before it is released into the environment. So, after an oil leak, cleaning of the water and land is needed. Over the years, cleaning oil spills, also known as oil spill remediation, has become a serious concern due to the effects on the environment and human life, beneficial microorganisms and plants, and their ecosystem survival requirements. This has led to the development of several clean-up techniques to reduce and manage the environmental effects of oil spills (Rengasamy et al., 2011a). Treatment techniques for oil spills, as shown in Figure 2.1, can be categorised as chemical, biological, mechanical, or physical (EPA, 2017).

Oil can be removed chemically via in-situ burning, dispersion, and solidifiers (Madkour, 2014). When using in-situ burning, the oil is often carefully ignited at or near the spill spot on the surface of the water or in a marsh (Mullin and and Champ, 2003). For oil to be ignited and burning sustained, the oil needs to be confined to achieve at least 3mm thickness. When used appropriately, in-situ burning may quickly and efficiently remove substantial volumes of oil with minimal effort. In-situ burning can minimise the amount of oil that seeps into sensitive near-shore and coastal ecosystems, such as mangroves, and reduce the effect on species at the water's surface (Yender, 2002). The risk of burning is decreased by the volatile components of the oil, evaporating as soon as the spill occurs. Oil does not become more dangerous when burnt as it is intended to be in fuels. Nevertheless, burning oil pollutes the air and leaves behind unburned particles, making it harmful to the environment (Christodoulou and Panias, 2002).

Oil spill clean-up using chemicals is effective but typically costly and suppresses zooplankton, which might disrupt the marine food cycle (Tesfaye et al., 2018). Some of the chemical methods employed include dispersants, sinking agents, demulsifiers, gelling agents, and neutralising agents. Chemical dispersants are compounds that are introduced to oiled water to encourage the formation of small oil droplets that mix with the water column and are dispersed by currents. Oil spills are decomposed by dispersants into little particles of varied sizes that bacteria may swiftly destroy (L. Sun et al., 2010). When dispersants are introduced to an oil slick, the molecules stick to the oil and split it up into tiny oil droplets.

Biological techniques involve the use of nutrients, Oxygen, and microorganisms to encourage the growth of bacteria that act on the oil spill and break it down (Azubuike et al., 2016). Biological methods have fallen out of favour recently because of the limitations of physiochemical approaches (Das and Chandran, 2011).

Oil may be effectively treated by bioremediation, which converts it to Carbon(iv)oxide and fatty acids. However, this procedure takes time and is influenced by elements including temperature, oxygen concentration, and organic oil moieties (T. Lim and Huang, 2006).

Physical/mechanical recovery is the process of transporting oil from the water's surface to a mobile container for short-term storage. Booms may be used to confine or redirect oil, skimmers, or solvents to remove or recover it from the water surface, hoses, and pumps. Booms and skimmers are used to contain and collect oil spilled on the water during many spill clean-up operations (Yender, 2002). Booms and skimmers are rapid and simple, making them still the main method for controlling marine oil spills (Mullin and and Champ, 2003). However,

research indicates that wide-ranging spills offshore are generally not best handled by mechanical recovery systems. Weather, sea conditions, the kind of oil, and other factors might reduce the overall efficiency of mechanical recovery (Y. Sun et al., 2004).

Booms are stationary objects that float on the water's surface and use physical/mechanical ways to stop the oil slick from spreading (Doshi et al., 2018a). Hydrophobic meshes that repel water are also stationary objects. They can be used in skimmers for improved oil recovery because they reject water yet let oil through (Banat, 1995).

However, choosing sorbent materials has traditionally been based on the nature of oil spills. The treatment procedure will determine how quickly oil spills can be cleaned up or handled in open waters. Environmental variables can also affect how well the treatment procedures work. Some of these variables include wind, currents, waves, oil viscosity, and susceptibility to debris. The price of different oil spill clean-up techniques varies greatly. In order of increasing cost (i.e., from least to most costly): In-situ burning, dispersants, mechanical recovery, and manual clean-up (Mullin and and Champ, 2003).

Oil spills in aquatic environments are typically handled using physical containment and recovery solutions. They do not alter the physical or chemical characteristics of the oil; instead, they act as a barrier to stop it from spreading.

The sorption technique, which makes use of sorbents, is one extremely cost-effective and efficient method of handling oil spills. Because of the significant negative effects on the environment, there has been much research and technological development to establish acceptable remediation of oil spills (Y. Sun et al., 2004; Ventikos et al., 2004).

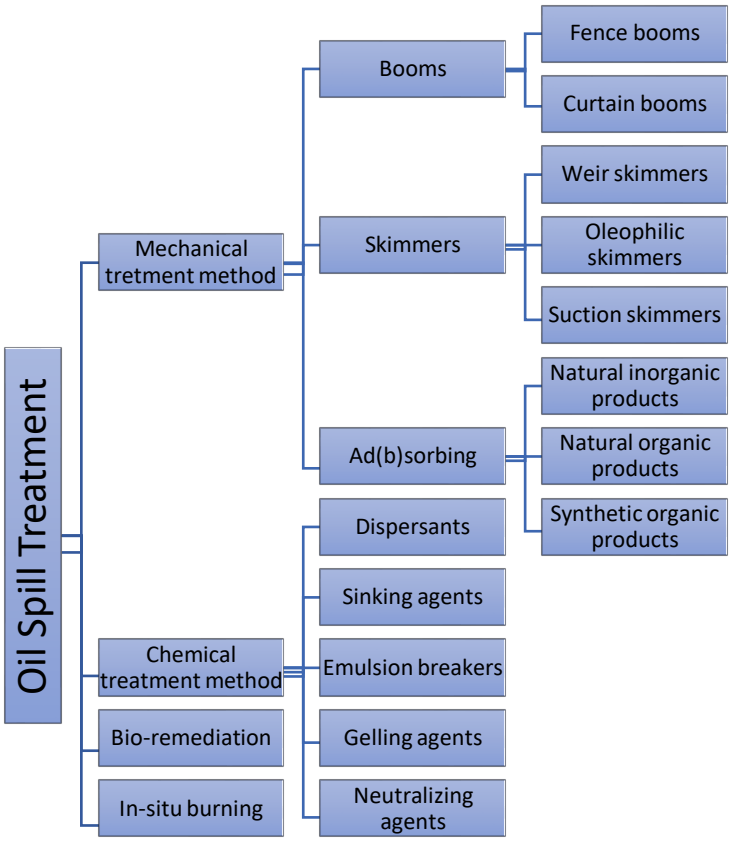


Figure 2.1: Oil spill treatment techniques (Sun et al., 2004)

2.3. Sorbents

Sorbents are materials that can absorb liquids. One of the most effective and economical ways to clean up hydrocarbon spills on land and in water is by the use of sorbents (Carmody et al., 2007b). There are several advantages to employing sorbents to clean up oil spills, one of which is the straightforward method and affordable supplies (Chung et al., 2008). The use of various sorbents has been the focus of recent research due to growing concerns about groundwater contamination by organic pollutants. Once a sorbent is placed in the affected wetland, it absorbs the contaminated oil. It keeps the oil in place long enough for the local bacteria to degrade the hydrocarbons under aerobic conditions (Chung et al., 2008). By adsorption, absorption, or both, they can be utilised to recover oil (Aboul-Gheit et al., 2006). Oil is collected in sorbents, which function like sponges, through capillary action or suction. They rely on chemical elements, including porosity, molecular structure, volume changes, a chemical affinity for oil spills, and other properties.

Research and practice show that sorbents are among the most efficient techniques to clean up hydrocarbon spills on the shoreline (Adebajo et al., 2003; Carmody et al.). Oleophilic and hydrophobic sorbents are required for the clean-up of oil spills. Hydrophobicity and oleophilicity, high oil absorption capacity and rate, buoyancy and retention over time, durability under aquatic conditions, reusability, biodegradability, and oil recovery are the qualities of an effective sorbent material for cleaning up oil spills (Tanobe et al., 2009; Wei et al., 2003). For small accidental spills, they may be the only alternative for clean-ups. Sorbents can be natural organic, synthetic organic, natural inorganic, or a combination of the three (Bayat et al., 2005; Carmody et al., 2007b; Ventikos et al., 2004).

2.3.1. Properties of Sorbent

The ability to absorb and remove oil from the water makes sorbent materials suitable for specific applications, and the disposal methods for the used/oiled sorbent should be considered as well (Rotaru et al., 2014).

Excellent sorbent materials have a range of properties that influence the sorption capacity of sorbents and should be considered when selecting sorbents to clean up oil spills (EPA, 1999);

Buoyancy: Sorbent materials must be buoyant to be effective with floating oils (S. Gupta and Tai, 2016).

Saturation: Oil can swiftly saturate sorbents. Once saturated, it can no longer absorb further oil and should be disposed of as quickly as possible to minimise further leaks (ITOPF)

Rate of adsorption: The adsorption rate is affected by temperature, pressure, area of contact and the interaction between the adsorbent and the adsorbate. When sorbent materials come into contact with liquid and gas molecules, they can attract them to their surface. As a result, the heavier oil binds more effectively to the surface of the adsorbent (Odunlami et al., 2022)

Strength and Durability: When sorbent material is used, it must be strong and long-lasting. The strength of sorbent materials comes from their durability. It will be easy to lose it if it is already damaged, and cleaning up the contaminated surroundings may lead to further contamination (ITOPF)

Oil retention: The weight of the recovered oil can cause the structure of the sorbent material to sag and become distorted, allowing the recovered oil to escape (ITOPF)

Ease of application: Sorbents can be applied mechanically or passively to spills using nozzles or devices (ITOPF)

2.3.2. Oil Recovery and Disposal of Sorbents

Oil recovery and sorbent material reuse are made feasible in oil spill remediation, which is both economical and ecologically friendly (Al-Majed et al., 2012). Compression, thermal regeneration, centrifugation, or solvent extraction can all be used in the recovery of sorbed oil (Edwin, 2007). The section briefly explains some oil recovery methods and different sorbents and their recovery cycle, as shown in Table 2.1. Extraction (Meng et al., 2015), distillation (Cheng et al., 2017), and mechanical squeezing are only a few of the several recovery techniques that have been documented (Jin et al., 2015). There have also been instances of combustion being used to recover sorbent but not oil (Bi et al., 2013). Squeezing is the most ecologically friendly oil recovery technique after extraction and distillation. When organic solvents are used to form a combination of oil and the solvent, which is subsequently removed, extraction may be the least environmentally friendly of the three processes. The combination is often distilled to separate the oil from the solvent and allow for solvent recycling.

Table 2.1: Conventional sorbent used for the removal and recovery of oils

Raw material	Synthesis	Recovery cycles
Kapok fibres	Polybutylmethacrylate Silica nanoparticles	6 (diesel, soybean oil, crude oil, 150NS, 20cst)
Lignin	Organogel Ambient drying	5 (gasoline)
Liquidambar formosana	Pyrolysis	>10 (paraffin and turpentine oil)
Kapok fibres	SiO_2 nanoparticles silanisation	8 (diesel and soybean oil)
Cellulose foam	Drop-casting stearic acid and graphite particles Heat treatment at 100°C	15 (paraffin and Engine oil)
Kapok fibres	Fe_3O_4 nanoparticles and dopamine modification	16 (toluene, gasoline, and diesel)

Raw material	Synthesis	Recovery cycles
Cotton	SiO_2 nanoparticle and octadecyl trichlorosilane modification	10 (n-hexane and chloroform)
Polylactic acid	Vacuum 40°C	5 (hexane, diesel, gasoline, vegetable oil, and petroleum ether) Dioxane and ethanol solvents

Source: (Doshi *et al.,* 2018).

For oily sorbent materials, disposal alternatives include landfill disposal, incineration of polluted sorbent, and biodegradation (Alaa El-Din et al., 2018). In order of sustainability, beginning with the most sustainable disposal techniques are:

1) Reuse

If the material has not been damaged and the sorbed oil has been recovered, this is the most sustainable solution (Edwin, 2007). Several varieties of sorbents can theoretically be reused if the oil can be removed. This can be accomplished by centrifugation, solvent extraction, or compression using a mangle or wringer.

2) Recycle

When oil has been recovered, undamaged sorbent materials can be recycled (Edwin, 2007).

3) Biodegradation

Organic sorbents are biodegradable. Complete decomposition may take some years, although this can be made faster by aeration and fertilisation (Edwin, 2007). Organic sorbent materials often have the advantage of being biodegradable. Land farming organic sorbent disposal may be permitted, provided it conforms to local waste disposal standards and has low oil content. The oiled sorbent is scattered across a large region of land to allow for biodegradation. Although rapid degradation is commonly achieved by aeration, using cultivation equipment and fertiliser application, breakdown might still take many years. Composting is a practical disposal mechanism for some organic sorbents (Tucker, 2012).

4) Incineration

Sorbed oil makes sorbents have large calorific values. They are a useful source of energy when incinerated (Pasila, 2004). If the sorbent material is combustible and does not include water, burning contaminated sorbent may be an option. Although incinerators may exist in the area

where the oil spill occurs, their capacity is often connected to domestic demand. They are likely to be overwhelmed by the rapid entrance of massive volumes of oily waste typical of a large spill. The open-hearth furnace and rotating kiln are the best incinerators for burning large amounts of solid waste. Before burning, large debris objects such as oily sorbent booms must be removed from the waste stream and reduced in size International Tanker Owners Pollution Federation Limited (Musk, 2012).

5) Landfill (Sanitary Dumpsite/Dumpsite)

This is the least desirable way of disposal and is restricted or highly limited in certain countries. Landfills must have an impermeable barrier to prevent leachate from entering the environment (Edwin, 2007). Local or federal regulations are sometimes very strict When it comes to managing the disposal of sorbent material in landfills. In certain countries, oiled sorbent material may need to be disposed of in designated hazardous waste landfills, resulting in higher transportation costs. Modern sites are often protected by a waterproof barrier to prevent drainage. In any case, in areas where these linings are not commonly used, steps should be taken to avoid contamination of local ground and surface waters (Tucker, 2012).

2.4. Types of Sorbents

2.4.1. Natural organic sorbents

This category includes peat moss, straw, hay, sawdust, bark, grown corn cobs, wool, feathers, and other wood-based items (Baltrenas and Vaišis, 2005). Agricultural wastes have been developed as adsorbents for the treatment of oil contamination (Behnood et al., 2013). Raw sugar cane bagasse, raw and fatty acid grafted sawdust for oil, black and white rice husk ash, barley straw, banana trunk fibres, acetylated sugarcane bagasse, carbonised peat bagasse, Dialiumguineense seed husk and hydrophobic aerogels for emulsified oil are some more examples of the natural organic sorbents studied for oil spill clean-up (Hussein et al., 2008b).

They are often readily available and relatively inexpensive. Organic sorbents can absorb three to fifteen times their weight in oil. The drawback is that they are loose particles that make collection complicated when spread on water (Sayed et al., 2003). Combining sorbents with bioremediation is a simple, cost-effective, and environmentally friendly remediation procedure for oil removal from wetlands. Organic materials are readily available and inexpensive. Most organic materials are only useful on dry land and cannot be adapted to clean up oil spills in water.

2.4.2. Natural Inorganic Sorbents

Clay (Sayed et al., 2003) and perlite (Teas et al., 2001) are two examples of natural inorganic sorbents. These sorbents can absorb oil up to twenty times their weight. They are affordable and widely accessible. One advantage is that they have a poor capacity for sorbing non-polar hydrocarbons, which are usually present in oil spill environments (Ribeiro et al., 2003).

Natural inorganic sorbents suffer from certain drawbacks, including being amphipathic (absorbing both water and oil), poor buoyancy, poor recoverability, and poor recyclability (Gote et al., 2003).

2.4.3. Synthetic Organic Sorbents

Most synthetic sorbents can absorb up to 70 times their weight in oil (Adebajo et al., 2003). An example of synthetic organic sorbents is polypropylene (Zhou et al., 2016). It might be difficult to properly dispose of synthetic sorbents that cannot be cleaned after usage since they need to be temporarily kept. They perform best when absorbing oils that can wick into their fibres and have a lower viscosity (Aboul-Gheit et al., 2006). Liners made of organo-clays and coal/mineral mixtures might effectively reduce pollution from petroleum-contaminated waters (Ramos Vianna et al., 2004). Waste plastics, i.e., polythene and propylene powder, were utilised in adsorption tests. It was demonstrated that they could be reused and that heavier crude oil may be more effectively absorbed by these materials than lighter crude oil (Aboul-Gheit et al., 2006). Synthetic substances with strong oleophilic and hydrophobic properties are most often used as sorbents to clean up oil spills. However, these molecules degrade quite slowly in comparison to mineral and vegetable products (Zainudin et al., 2005).

2.4.4. Challenges and Prospects of Natural Organic sorbents

Petroleum and other heavy, volatile oils cannot quickly evaporate from the environment unless they are adequately removed, and often, this oil might result in dangerous conditions (Choi, 1992; D. Wu et al., 2014). As a result, eco-friendly materials and technologies are needed to remove and recover oil from the environment so as to protect it from the negative effects of oil spills; otherwise, aquatic ecosystems are likely to suffer serious damage with long-term effects (Wolok et al., 2020).

Their high adsorption capacity, hydrophobic and oleophilic character, biodegradability, and absence of harmful waste after the procedure make them more valuable (Asadpour et al., 2016). In recent years, the need for organic materials for effective oil removal has evolved; for example, research has focused on understanding some biomaterials, such as lotus leaves and beetles, and the processes underlying their hydrophobic, oleophilic nature and super-wettable surface (Feng et al., 2002).

Because of their properties, biomaterials differ from all other procedures and approaches (Wahi et al., 2013). Natural sorbent biomaterials have a high oil removal rate and do not harm the environment when utilised for oil recovery. Table 2.4 contains a summary of some natural organic sorbents and their sorption capacities. According to studies, certain plants have a significant affinity for oil because of the wax contained in them (Al-Majed et al., 2012; R. K. Gupta et al., 2015). Rice husk, wheat, oats, barley, and oat straw are examples of organic sorbent biomaterials. These sorbents are typically more eco-friendly and less expensive because of their biological origin and derivation from bio-based waste materials (Wolok et al., 2020). Sorbents should be able to recover oil while also being ready for ecological and economical reuse.

Table 2.2: Comparison of sorption capacities of different organic sorbents

Sorbents	**Sorption capacity g/g**	**Reference**
Kapok	(36-45)	Lim et al.
Cotton	(37.9 -40.5)	Hussein et al.
Barley Straw	(7-12)	Hussein et al.
Rice Husk	(6-10)	Galblaub et al.
Bagasse	(3-6)	Bayat et al.
Corncobs	(5-7)	Galblaub et al.
Wheat straw	(2-4)	Sidiras et al.
Onion peels	(0.455)	Sayed and Zayedb
Plantain peels	(5-7)	Ademiluyi et al.
Banana peels	(5-7)	Alaa El-Din et al.
Chicken Feather	(16.0-16.2)	Tesfaye et al.

Although organic sorbents have higher adsorption capabilities, they have major downsides, such as the capacity to absorb water while removing oil, their weight is increased and can result

in sinking (Dave and Ghaly, 2011; Doshi et al., 2018b). To take full advantage of their potential for oil spill cleaning, natural organic sorbent materials must be altered in an environmentally satisfactory and efficient manner, so further modification is required to enhance hydrophobic qualities (Doshi et al., 2018c). An example is coating kapok fibres with nanoparticles such that their reusability is improved also sorption capacity is improved from 40g/g to about 85g/g (Doshi et al., 2018a; Z. Wang et al., 2015).

2.5. Feathers as a Natural Organic Sorbent

Chicken feathers are classified as poultry waste and are usually discarded (Ijeoma and Prisca, 2015). They are not properly disposed of in Nigeria and contribute to the overcrowding of landfills and incinerators. Chicken feathers have been researched to clean polluted surroundings as a sorbent because of their excellent oil sorption capability and recovery; they have proven to be superior sorbents compared to typical synthetic pads (Kelle and Eboatu, 2018; Okoya et al., 2020a). In Table 2.2 above, we also see the sorption capacity of chicken feathers to be higher than barley straw, rice husk, bagasse, corncobs, wheat straw, onion peels, plantain peels, and banana peels.

2.5.1. Function

The barbs, barbules, secondary structures, tertiary structures, and the central shaft of the feather, which spans its length and is linked to the calamus, are all morphological features that demonstrate that chicken feather is composed of three different units (Belarmino et al., 2012; Tesfaye, 2017). Feather barbs have hollow cells with a honeycomb shape when viewed from a cross-sectional angle; this ensures that liquids gather (Tesfaye et al., 2017). Consequently, the existence of voids aids in the absorption of oil by chicken feathers due to physical entanglement within the vacuum. There are around 30 macroscopically diverse varieties of poultry feathers due to keratin organisation differences. Feathers are classified into five types: contour, down, semiplume, filoplume, and bristle (Schmidt and Line, 1996).

Figure 2.2a shows a contour feather. Bristles are the tiniest sort of feather; they are stiff, with few, if any, short barbs towards the tip. Bristles perform a protective purpose on the head of a chicken, as shown in Figure 2.2b. A semiplume is a form of a feather that joins the contour and down, as shown in Figure 2.2c, usually called display feathers. Figure 2.2d shows the down

bird feather. Down feathers are smaller in size than contour feathers and lack barbules and hooklets; their primary purpose is for insulation (Van Tyne and Berger, 1976). Filoplumes are smaller than semiplumes, as can be seen in Figure 2.2e. They most likely provide a sensory role in chickens; they allow birds to detect movement. Figure 2.3 shows the structure of contour feathers.

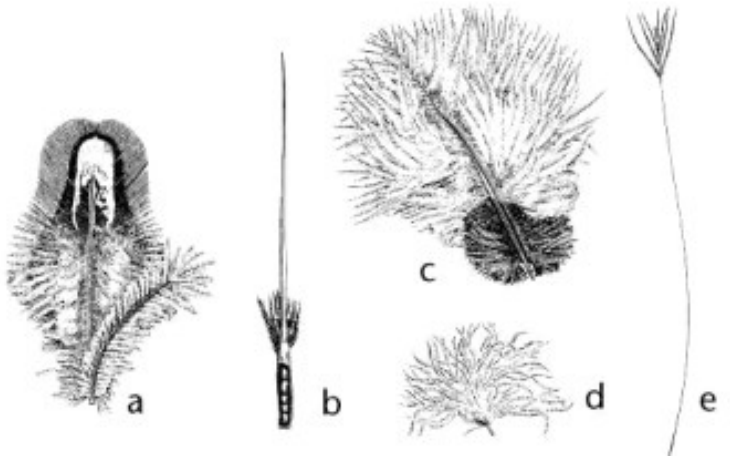


Figure 2.2: Types of chicken feathers: (a) contour, (b) bristle, (c) semiplume, (d) down, (e) filoplume (Bartels, 2003).

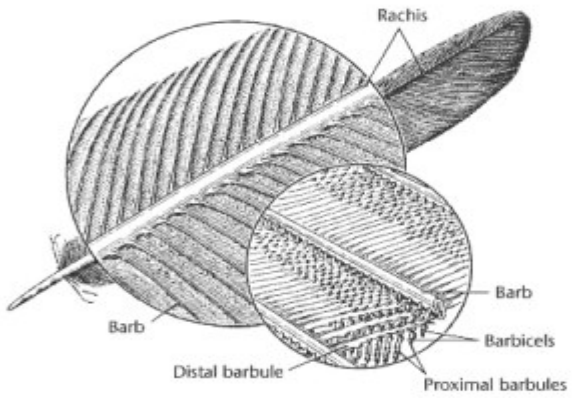


Figure 2.3: Structure of a contour feather (Bartels, 2003)

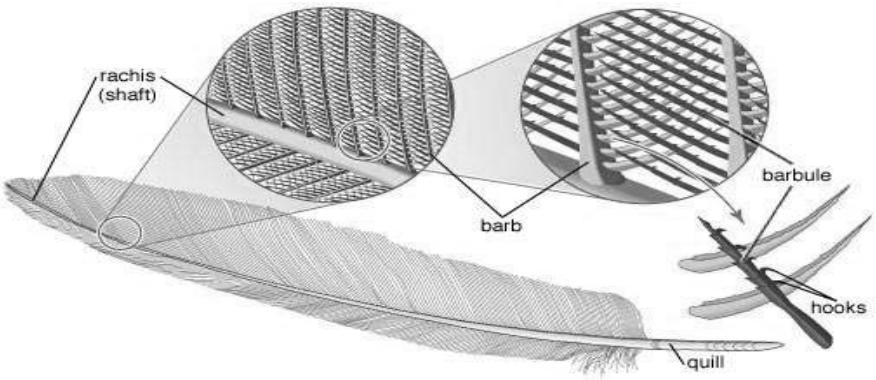


Figure 2.4: Structure of a feather (Source: Encyclopaedia Britannica, 2006).

2.5.2. Physical Properties of Feathers

The feathers act as a protective blanket against harm, rain, and cold (Adetola et al., 2014). The density of the skeletal frame of a chicken feather is reported to be between 0.80 and 0.91g.cm^3 (Hong and Wool, 2005), while the keratin value has a density of 1.30g.cm^3 (Arai et al. 1989). This property plays a major role when processing, transporting, and using feathers. Feathers of the hollow structure and hooks, as well as the rough surface and entangled pores and knots, increase their hydrophobicity and contribute to their high sorption capacity (Tesfaye et al., 2018).

The three different units that make up the morphology of chicken feathers are the central shaft of the feather, which runs the full length and is linked to the calamus, the secondary structures, the barbs, and the tertiary structures, the barbules, as shown in Figure 2.4. Feather barbs have hollow cells with a honeycomb form in the cross-sectional direction, allowing liquid to gather (Belarmino et al., 2012; Tesfaye et al., 2017). The voids and honeycomb-shaped hollow structure allow chicken feathers to absorb oils due to physical entrapment within the void. Chicken feather fractions are mesoporous and microporous (Kelle and Ogoko, 2017).

Porous materials are divided into several categories based on the size of their pores. Mesoporous materials are intermediate between microporous materials with pores smaller than 2µm and macroporous materials with pores greater than 50µm. Microporous materials can sorb and store small molecules due to their small pore volumes and diameters, limiting the accessibility of large molecules. On the other hand, mesoporous materials may accept huge molecules (Y. Lim et al., 2015; Somasundaran, 2006). chicken feathers can sorb more sorbates because microporosity helps create a larger surface, which supports the interaction between sorbate and sorbent.

2.5.3. Chemical Properties of Feathers

Feathers, including chicken feathers, are composed of 91% protein, 1% fats, and 8% water (Tesfaye et al., 2018). The chemical compositions of feathers between different species are relatively constant with carbon (46%-49%), Nitrogen (14.7%-16.2%), Sulphur (2.3%-3.7%), Oxygen, Hydrogen, and other trace elements (Arai et al.,1989; Kornillowicz-Kowalska and Bohacz, 2011; Lange et al., 2016). They are made of fibre and quill which contains keratin, an insoluble and highly durable protein found in hair, horns, animal hooves, and other body parts (Etkin, 2000). The main component of chicken feathers is keratin, a protein that exhibits unique physico-chemical properties for sorption processes (Aguayo-Villarreal et al., 2011). Keratin plays an important role in the enhancement of the advantages of chicken feathers (Moon and Palaniandy, 2019). It has been observed that there are over 18000 different species of birds, and each has unique characteristic feathers. A recent study compared the amino acid content in feather fibres of different species as shown in Table 2.3 and confirmed the presence of at least 16 amino acids in feather material and concluded that the chemical composition remains the same (Bharathi and Raj, 2021). These amino acids cross-link by creating hydrogen bonds or disulphides, as shown in Figure 2.5, resulting in tough, strong, lightweight fibers with high thermal, acoustic, and insulating qualities (Poole *et al.,* 2009). The amino acid sequence of Keratin in birds is similar to that found in reptilian keratins (Fraser and Parry, 1996). Feathers contain specialised groups of mostly Feather Beta-Keratins (FBK) and in some parts also Alpha-Keratins in the nuclei of barbule and barb cells (Z. Wang et al., 2015).

The hydrophobicity of feathers is increased further by their high keratin content, strong disulphide linkages, and surface preening fluids (Liu et al., 2008; Zainudin et al., 2005). The hydrocarbon intermolecular bonds generated between feathers and oil also contribute to their high oil sorption capacity (Kelle and Eboatu, 2018).

Charged amino acids have hydrocarbons in their side chains that are either positive or negative in charge. Several distinct forms of attractive forces operate between the sorbent and the sorbate to induce sorption (Weber Jr. et al., 1991). Organic sorbates, for example, will chemically attach to the sorbent if both the sorbate and the sorbent have chemically reactive moieties. This hydrocarbon side chain explains the mechanism behind the formation of intermolecular bonds between the crude oil and chicken feathers, enabling the crude oil to attach to the chicken feathers.

Table 2.3: Comparison of amino acid content in feather fibres from broiler and white leghorn chicken (Layer Chicken)

S/No	Functional Groups	Amino acids	Broiler Chicken	Layer Chicken
			% Content	% Content
1	Positively Charged	Arginine	4.42	4.54
2	Negatively Charged	Aspartic acid	5.55	5.47
		Glutamine	7.3	7.43
3	Hygroscopic	Serine	12.4	12.27
		Threonine	4.34	4.55
4	Hydrophobic	Tyrosine	1.45	1.35
		Leucine	5.62	5.7
		Isoleucine	3.3	3.23
		Valine	4.21	4.25
		Cystine	7.68	7.57
		Alanine	3.54	3.52
		Phenylalanine	0.85	0.93
		Methionine	0.32	0.27
5	Special	Proline	4.52	4.67
		Asparagine	0.04	0.02
6	Others	Glycine	6.85	6.26
		Lysine	1.21	1.38
		Histidine	0.06	0.13
		Glutamic acid	9.65	9.83

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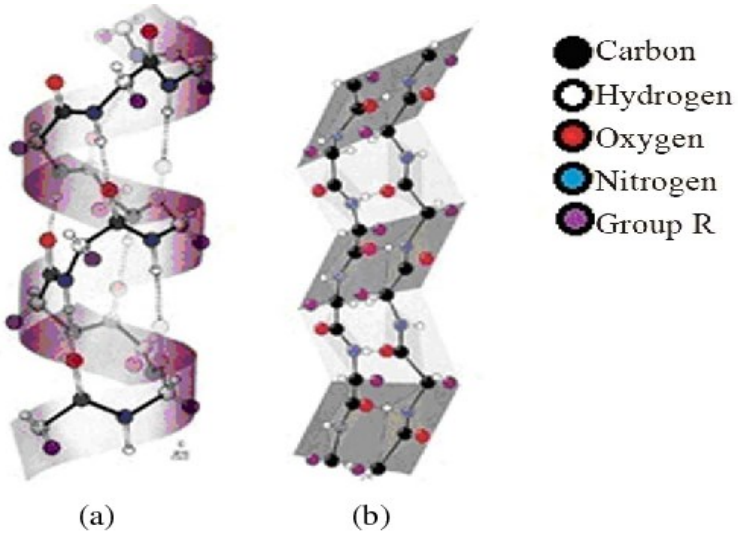


Figure 2.5: 3D polymer structure of Chicken feather (a) α-helix and (b) β-pleated Sheet structure (Hammel et al., 2004)

2.6. Polypropylene as a Synthetic Organic Sorbent

Polypropylene has a wide variety of uses globally, and its use as an oil sorbent is one of them. This is due to its properties of buoyancy, hydrophobicity, and oleophilicity surfaces.

2.6.1. Physical properties of polypropylene sorbent

Some of the physical compositions of polypropylene (PP) are it is semi-rigid, translucent, has good chemical resistance, is tough, has good fatigue resistance, integral hinge property, and good heat resistance (Hindle, n.d.). It was found that mechanical damping and hardness of PP depends on the degree of crystallinity, the impact strength and elongation at break also depends on the molecular weight and molecular weight distribution of PP. A high-impact strength requires a high molecular weight and a narrow molecular weight distribution (Schooten et al., 1961). Polypropylene has high crystallinity and melting temperature. The physical compositions depend on its crystallinity (Rosa and Auriemma, 2006). From an experiment carried out between polypropylene and high-density polyethylene, the PP showed better elastic modulus and strength due to the methyl that is attached to the carbon, which prevents the chain rotation and hence makes the material stronger but inflexible (Hassan Awad et al., 2019). In semi-crystalline polymers, which include polypropylene sheets, the polymer chains are aligned parallel to each other. Light is scattered by crystalline structures, which makes them translucent (S-polytec, 2018). Polypropylene is fatigue-resistant in that it retains its shape after a lot of

torsion, bending, and/or flexing. It is considered tough because of its ability to deform plastically without breaking. It is resistant to chemicals in that it does not readily react with diluted acids and bases (Creative mechanism, 2016).

2.6.2. Chemical Composition of Polypropylene

One of the production processes of polypropylene is the bulk polymerisation process, which is also called the mass polymerisation process. The operating conditions for the bulk polymerisation process are a temperature of 50 to 80°C and a pressure that ranges from 2 to 4 MPa. Since liquefied propylene, which is a monomer, is used as the solvent, the polymerisation reaction is rapid (Sato and Ogawa, 2009). Polypropylene has three basic structures such as atactic, isotactic, and syndiotactic (Ariff et al., 2014). Polypropylene is made from propene or propylene monomers that are durable, rigid, and crystalline. It has a chemical formula of $(C_3H_6)_n$ (Byjus database, 2022). Figure 2.6 shows the three basic structures of polypropylene. If the methyl groups are arranged on the same side of the main chain, then it is isotactic polypropylene, if the methyl groups are arranged disorderly on both sides of the main chain, then it is called syndiotactic polypropylene, if the methyl groups are arranged alternately on both sides of the main chain, then it is called atactic polypropylene (Ariff et al., 2014). Synthetic sorbent mats are predominantly composed of hydrocarbons, and mutually reactive moieties are attracted to one another by dispersion forces such as Van der Waal and London forces. This is why synthetic sorbents absorb so much crude oil. Because the side chains of the mat are mainly hydrocarbon, their amino acid structure is very hydrophobic (Saravanan and Dhurai, 2012).

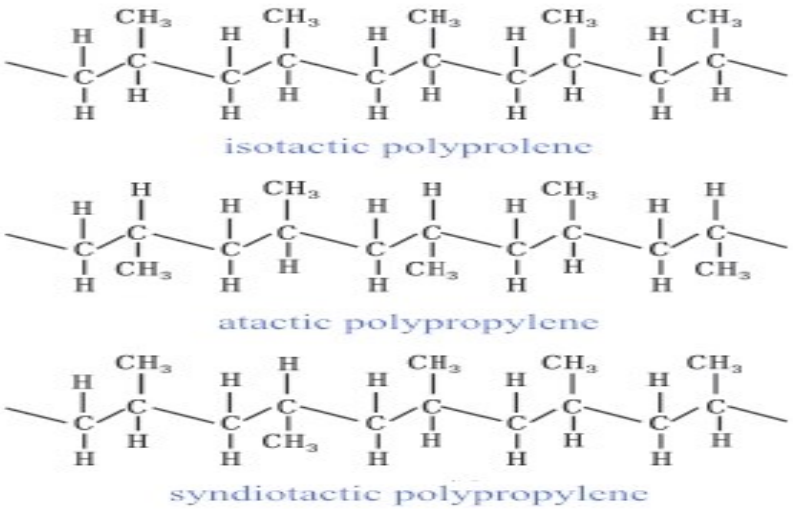


Figure 2.6: Three basic structures of polypropylene (Ariff et al., 2012).

2.7. Global Market for Oil Sorbents

Oil spill prevention mainly entails using technology to control oil leaks, establishing efficient spill-cleaning procedures, and implementing policies to reduce pollution and the catastrophic environmental impacts of spilled oil. One of the most economical and efficient means of cleaning up hydrocarbon spills on the shoreline and on water is the use of sorbents (Carmody et al., 2007b). The use of sorbents to clean up oil spills presents many advantages due to the simplicity of the approach and the inexpensive nature of the materials (Chung et al., 2008). Recently, increasing concerns about the pollution of groundwater by organic chemicals have led to research on the use of various sorbents (Ramos Vianna et al., 2004). Once a sorbent is applied to an impacted wetland, it absorbs the contaminating oil. It retains the oil for a sufficient length of time to allow the biodegradation of hydrocarbon by indigenous bacteria under aerobic conditions (Chung et al., 2008).

Sorbents for oil spills in water include mats, pads, rolls, stockings, and booms. As a consequence of technological improvements, the market for pre-oil spill and post-oil spill management is expected to grow. Oil sorbents that are reusable have a high demand in a variety of processing industries due to an increase in oil spills. More competitors will arise in years to come due to the solution of oil recovery (Transparency Market Research, n.d). According to industry analysts, the need for these goods has surged as a result of enormous unintentional and inadvertent oil spills, which makes single-use products an unnecessary expenditure. Because of the importance of these materials in oil recovery, the market for reusable oil sorbents will grow in the coming years (Transparency Market Research, n.d).

The industrial sorbents market was valued at USD 3.7 billion in 2018 and is expected to grow to USD 5.42 billion by 2026, at a Compound Annual Growth Rate (CAGR) of 5.1% (Intelligence M., 2018). Industrial sorbents are commonly used to remove chemicals or liquids that have been spilled on various surfaces. They are composed of materials designed particularly for absorbing various types of spills, such as chemical spills, which help in the clean-up process and are more efficient than standard sorbents. Since they are chemically inert, industrial sorbents can be used on any surface or chemical. Some of the primary drivers of market development between 2019 and 2026 include rising environmental concerns and legislation addressing chemical and oil spills, a rise in the occurrence of spills both on land and in the water, and swift industrialisation. In order to reduce the total environmental effect, manufacturers of industrial sorbents are encouraging innovation in all-cotton oil sorbents. For example, E Innovate, LLC, a producer of biodegradable oil cleaning solutions, cooperated with

an Indian organisation to make biodegradable towels made of West Texas cotton to clean up oil spills (Transparency Market Research, 2019).

Biodegradable sorbents are becoming increasingly accepted in the industrial sorbents industry due to their ability to get rid of microplastic contamination. The natural materials used in the manufacture of industrial sorbents make compliance with strict environmental regulations less complicated (Transparency Market Research, n.d.)

As a result of the expanding worldwide need for oil-only sorbent material, the oil & gas segment is expected to provide lucrative opportunities for the global industrial sorbents market throughout the forecast period. Oil-only sorbents are hydrophobic by nature and are exclusively used to clean hydrocarbon-containing oils and fuels. A rise in oil spill incidents, as well as a developing oil and gas industry, are driving the demand for oil-only sorbent materials (Transparency Market Research, n.d). The expanding sorbent business necessitates the promotion of agricultural-based sorbents such as chicken feathers.

2.8. Circular Economy

2.8.1. Introduction

It might be difficult to find a single, acceptable definition of the circular economy because of the different dimensions it plays (Kirchherr et al., 2017). The term has been defined in a variety of ways over the years as the concept has evolved. Many of the definitions are based on associated activities and concepts including collaboration in supply chain systems, the use of new business models such as leasing; or the use of waste as a resource (Gladek, 2017).

"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models." (The World Economic Forum, 2024).

According to the Ellen McArthur Foundation, "Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is

based on three principles: design out waste and pollution; keep products and materials in use; regenerate natural systems." (Macarthur, 2022).

According to the UK WRAP (Waste Resources Action Programme), Circular Economy is an alternative to the traditional linear economy (make, use, dispose of) in which we keep resources in use for as long as possible, extract the maximum value from them while in use, and then recover and regenerate products and materials at the end of each service life. (*Our Plan*, n.d.)

2.8.2. Circular Economy and Sustainability

The circularity principle is being pushed even further by the United Nations' sustainable development agenda, which has emerged as a key focus of global attention and implementation (Ezeudu and Ezeudu, 2019). For over three decades, the notion of a circular economy has drawn the interest of the Government, academic, and business sectors. It is considered a platform for enterprises to operationalise the much-discussed sustainable development concept (Ghisellini et al., 2016).

The linear economic model has led to worries about future resource risks and uncertainties as populations rise. There is growing international pressure to use our resources more responsibly and accelerate the transition to a Circular Economy (Bates, 2018; Valavanidis, 2023).

Experts see the circular economy model as a fresh potential for innovation and synergy between natural ecosystems, companies, and our everyday lives. The notion has also gained importance in light of the issues associated with managing the worldwide growth in waste generation and the fact that raw, natural resources cannot be produced indefinitely (Valavanidis, 2023).

The circular economy is also an economic system based on business models that replace the concept of 'expiry date' with the terms reduction, alternative uses, recycling, and material recovery, both in production, distribution processes, as well as consumption processes. The goal is to create sustainable development, which includes environmental quality, economic prosperity, and social fairness for present and future generations. (Kirchherr et al., 2017).

Circularity entails the creation of mechanisms that limit waste generation and provide a platform in which, when a product approaches the end of its useful life, its component elements, as resources may then be productively utilised again, providing additional value (Fogarassy et al., 2017).

England and Wales thrive in this area. They both developed the waste strategy, which emphasises the need to minimise waste production by the use of waste minimisation methodologies. Waste reduction clubs were also established as an important component of the UK initiative to integrate more sustainable practices into business and commerce (Holt et al., 2000).

2.8.3. Core Elements of Circular Economy

The main aspects of the circular economy have traditionally been constructed around the 3Rs: reduce, reuse, and recycle. These three are discussed further below.

The main part of circular economy is operations that directly handle product or material flows. Yet, as the notion has evolved, there has been a shift from a 3R to a 9R framework for completing material loops (Potting et al., 2017; Sihvonen and Ritola, 2015; van Buren et al., 2016). The 3Rs are defined as reducing/eliminating waste, recycling products and materials (at their greatest value), and renewing ecosystems. The other 6Rs are redesign, recover, repair, reject, remanufacture, and repurpose.

2.8.4. Cycles of Circular Economy - Butterfly Diagram

There are several ways to keep products and materials in circulation. According to the Ellen MacArthur Foundation, there are two primary cycles: the Technological Cycle and the Biological Cycle. Products are reused, repaired, refurbished, and recycled in the Technological Cycle, and Biodegradable materials are returned to the ground through processes such as composting and anaerobic digestion in the Biological Cycle. The Circular Economy System Diagram also called "The butterfly diagram" depicts the continuous flow of materials in a circular economy.

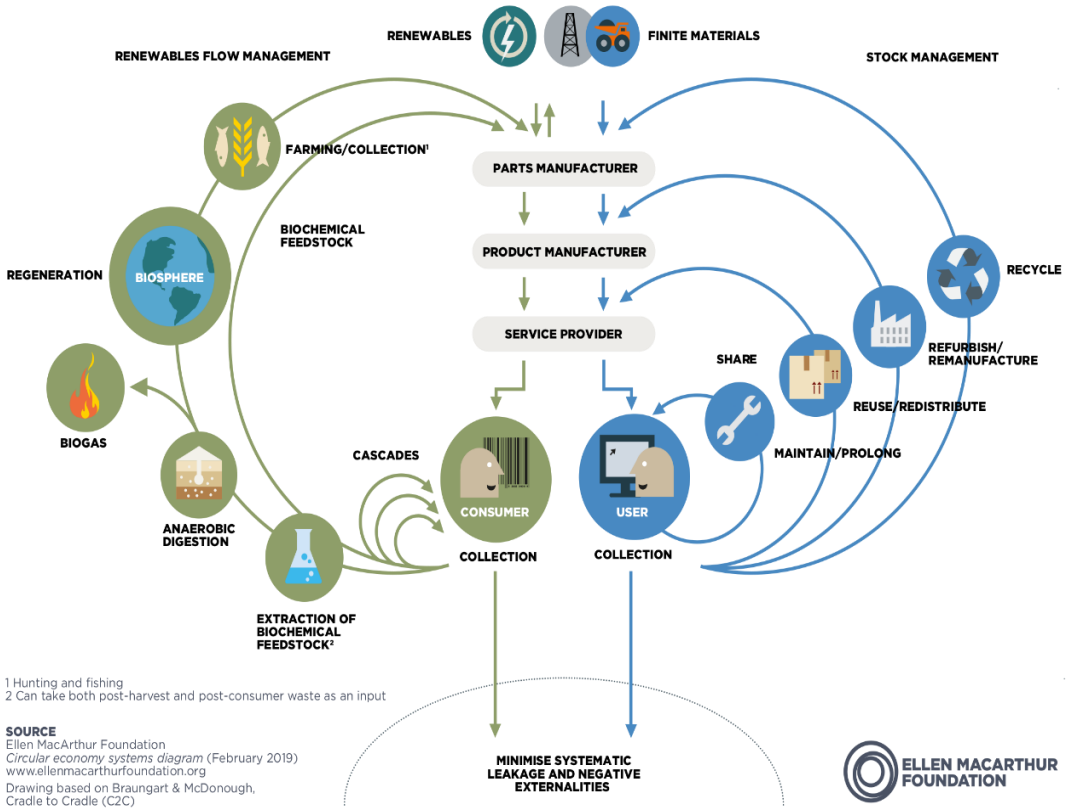


Figure 2.7: Butterfly diagram. (Source: Ellen MacArthur Foundation)

Biological Cycle

The biological cycle, on the left side of the butterfly diagram, is for materials that may biodegrade, such as food. Some biodegradable materials such as cotton or wood may find their way from the technological cycle into the biological cycle after degrading and can no longer be utilised to manufacture new goods (Wouterszoon Jansen et al., 2022). The biological Cycle highlights the processes that restore nutrients to the soil and aid in ecological regeneration.

Technological Cycle

The Technological Cycle is shown on the right side of the butterfly diagram and is divided into loops, and each loop permits resources to continue in use rather than becoming waste.

The inner loops are where the most value may be collected since they preserve more of a product's inherent value by keeping it intact. Inner loops such as sharing, maintaining, and reusing are prioritised above outside loops such as product breakdown and remaking. Loops

also save money for customers and businesses since they reuse items and resources that are currently in use rather than investing in new ones (Kottaridou and Bofylatos, 2019). It is also critical to build many loops, such as constructing a repairable product out of recyclable materials (Fogarassy and Finger, 2020).

2.8.5. Circular Economy Transition

Some wealthy countries are shifting their focus away from traditional waste management techniques and regulations and have fully embraced the circular economy notion as part of their environmental action plans (Matthews et al., 2021). For example, The United Kingdom has a Sustainable Development Plan that compels society to aim for judicious use of natural resources to safeguard the environment while maintaining high and steady levels of economic growth and employment (Phillips et al., 2006).

According to a 2022 European Parliament study, the European Union, which generates more than 2.5 billion tonnes of waste per year, has begun updating its waste management regulations to shift attention to a more sustainable circular economy. Considering the gap between developed and poor countries, one obvious strategy to implement the circular economy is to discover new applications for products that are no longer fashionable in the wealthy world. This would however necessitate new legislation, increased awareness, and enforcement of social regulations when such products, particularly electronic equipment sent to Africa, approach the end of their useful life (Bates et al., 2008).

2.8.6. Circular Economy in Nigeria

Many African countries are hesitant to embrace a circular economy due to a lack of awareness about the implementation procedures and a lack of information. There is however a rising recognition in Nigeria of the need to establish a circular economy (Xue et al., 2010).

As a founding member of the Africa Circular Economy Alliance (together with South Africa and Rwanda), Nigeria is presently actively pursuing circular economy projects. The country has also formed the Nigeria Circular Economy Working Group, which is entrusted with developing a national policy framework to promote circular economy concepts in the country (Oger, 2022). The Nigerian Government, international organisations, and other countries are working together to build a local circular economy. Plastic waste accounts for 2.5 million

tonnes of the 32 million tonnes of solid waste created in Nigeria each year. Furthermore, the country is one of the top 20 contributors to the entire amount of land-based plastic debris that ends up in the seas, accounting for 83% of the overall volume (UNIDO, 2022). This creates circular economic business possibilities across the plastic value chain, which many individuals and firms are capitalising on.

Waste collectors play a significant part in waste recycling in Africa in general, supporting hundreds of crucial people in integrated waste management, who must be recognised, acknowledged, and encouraged (Bates, et Al, 2019). There are several other waste materials to be explored, such as electronics, plastic, glass, metal, and agricultural waste.

Despite the growing engagement of local enterprises with innovative ideas in the circular economy, many of them face financial challenges. With the expanding urban population, increased economic problems, and technological innovation, industry experts are increasingly urging the Government to develop and implement a circular economy action plan. Notwithstanding these commendable steps, Nigeria continues to suffer from bad policy frameworks, insufficient financial mechanisms, a lack of waste data, and bad institutional arrangements (Ezeudu and Ezeudu, 2019).

2.9. Conclusion

This chapter reveals that there is much research on the effective use of agricultural products, specifically chicken feathers as oil sorbents. Their properties, benefits, and potential have been highlighted, but there is little available data on the transformation of chicken feathers into mats, pillows, or booms that can be used commercially.

This study seeks to further confirm the sorption properties of chicken feather materials and develop a low-cost chicken feather sorbent that competes favorably with other conventional products like polypropylene. The study hopes to demonstrate that chicken feathers can be effectively used in developing countries where the cost of sorbents is a challenge, thereby creating a circular economy for chicken feather waste that would have an environmental and economic impact.

Chapter 3 - Characterisation and Oil Sorbency Performance of Chicken Feather Fibre Mat and Conventional Products

3.1. Introduction

Material characterisation is a process to determine the properties of sorbents and how this affects their potential as oil sorbents. The characterisation test was carried out on the standard materials, chicken feather fibre mat, and polypropylene pad, a widely used commercial sorbent for oil spill cleanup. Other commercial sorbents were also selected to compare their performance with the two standard materials used in this research. Two basic characteristics exhibited by sorbents include hydrophobic and oleophilic nature (Radetic et al., 2007). The hydrophobicity refers to the poor wettability of a sorbent by water (Wu et al., 2018). Two important surface properties that influence the hydrophobicity of a surface are surface energy and texture (T. Lim and Huang, 2007). Based on previous work done by some researchers over the years and the availability of equipment, Contact Angle, Inverse Gas Chromatography, Scanning Electron Microscope (SEM), Dynamic Vapour Sorption (DVS), and water sorption tests were selected to evaluate the hydrophobicity of sorbent as shown in Table 3.1. oil sorption, oil recovery, and reusability test was selected to characterise the oleophilic properties of the sorbents highlighted in Table 3.2. Physical and chemical characterisation can be achieved through different means.

Table 3.1: Summary of previous work done by some researchers for hydrophobicity characterisation

Hydrophobicity Experiments	Parameters	Previous Research Work
Contact Angle	Wettability of a Surface	(Kelle and Eboatu, 2018; T. Lim and Huang, 2007; H. Wu et al., 2018).
IGC –SEA	Surface Energy analysis	(Wein, 2015; Huang, 2006; Hefer et al., 2007)
	Surface Homogeneity	(Cares-Pacheco et al., 2014; Legras et al., 2015)
	Adhesion and Cohesion profiles	(Van Oss, 2006; M. Kunaver et al, 2004)
SEM	Surface Morphology	(Burnett et al., 2012; Kondor et al., 2015; Okoya et al., 2020b)
DVS	Uptake and loss of moisture	
Water Sorption Test	Reduction in water uptake	(Tesfaye et al., 2018; Wahi et al., 2013)

Table 3.2: Summary of previous work done by some researchers for oleophilicity characterisation

Oleophilic Experiments	Expected Data	Previous Research Work
Oil Sorption	Gravimetric sorption quantity	Evaluation of Kapok as a natural hollow hydrophobic-oleophilic fibrous sorbent for oil spill cleanup (Inagaki et al., 2002)
Oil Recovery	Recovery ratio/percentage of Sorbed oil recovered from sorbents	Heavy oil sorption and recovery by using carbon fibre felts (Inagaki et al., 2002)
Oil Reusability	Number of Sorption/desorption cycles	Study on the use of banana peels for oil spill removal (Alaa El-Din et al., 2018)

IGC is a technique that can be used for examining the surface properties of fibre materials that influence their sorption performance (Ho and Heng, 2013). Inverse gas chromatography (IGC) appears to be a powerful technique for the characterisation of the surface properties of solids (Ho and Heng, 2013). IGC is based on the physical adsorption of gas molecules on a solid surface. Unlike analytical gas chromatography (GC), where an unknown stationary phase is used to separate and identify a known product, in IGC, the solid being studied is the stationary phase and well-identified molecules known as probes (Cares-Pacheco et al., 2014).

IGC is a vapour adsorption technique in which physicochemical characteristics in the stationary phase are investigated by injecting specific and well-characterized gaseous probes (Hegedus and Kamel, 1993; Voelkel, 1991). It is performed conventionally in columns that contain the packed solid that is being studied, either in the powder form or fibre state (Klein et al., 2015). The interaction between these probes and the solid material that forms the stationary phase is then investigated by determining the retention time for a given probe and used to calculate many physicochemical properties such as enthalpy and entropy (Santos et al., 2005), surface energies of solids (Huang et al., 2006), solubility parameter and crystallinity (Santos and Guthrie, 2005) and surface heterogeneity (Gavril, 2004).

With particular reference to surface energy determination, IGC presents a lot of advantages. These include the ability to quantify strong interactions between the solid and the probe molecules that cannot be characterized by contact angle (CA) measurements (Santos and Guthrie, 2005), and the absence of problems relating to porosity and surface heterogeneity (Tavana et al., 2004) as the interactions of the probe are measured along a broad solid surface and given mean values of interaction through the measure of retention times. IGC came with many benefits. Since its introduction in 1967 and subsequent theoretical development, its application in material science has increased rapidly as it has been used for the characterisation

of polymers, copolymers, biopolymers, blends, fibres, composites, coatings, and their ingredients, chemicals, paper, etc (M. Kunaver et al, 2004).

The IGC test for this study was conducted utilising the iGC-SEA, Surface Measurement System (SMS), UK. The SMS iGC-innovative SEA's injection method significantly increases the injection pulse sizes, enabling the measurement of the injection BET region of the isotherm. As opposed to the IGC's ratio of 1 to 60, the iGC-SEA offers an unmatched ratio of 1 to 4000. If the surface area of the sample is given, the iGC-SEA can be automatically configured to inject the exact amount of probe vapour to accomplish various user-defined surface coverages. A surface heterogeneity profile of the sample will be produced as a result of the measurement of surface attributes at various surface coverages. Understanding energy distribution is particularly helpful in the formulation of interface boundaries and in identifying minute variations in sample surface chemistry.

Dynamic Vapor Sorption (DVS) is a gravimetric sorption technique that measures how quickly and how much of a solvent (e.g. water) is absorbed by a sample. The DVS used in this research is a fully automatic sorption instrument from Surface Measurement System, a pioneer in vapor sorption technology.

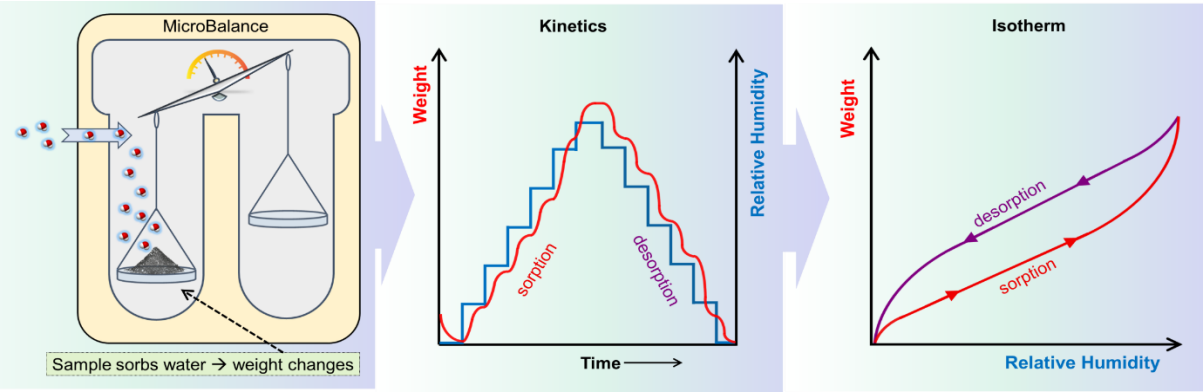


Figure 3.1: Dynamic Vapor Sorption Process (Surface Measurement System, 2020)

This is done by flowing a carrier gas at a specified relative humidity (or partial pressure) over a sample suspended from the weighing mechanism of an ultra-sensitive recording micro-balance. Dynamic vapor sorption looks at the bulk and surface sorption effects of water and organic vapours. Figure 3.1 shows the DVS process.

Other important properties of the DVS equipment used, include:

- Fast equilibrium significantly improves kinetics over static sorption systems.
- Temperature range; 5°C to 8.5°C

- Temperature stability: +-0.1℃
- Optional preheater for sample drying to 200℃
- Wide humidity range typically 0-98% RH
- Humidity Stability +/- 0.3% RH
- Allows use of small samples 1-10mg

Scanning Electron Microscopy (SEM) is a type of electron microscope that scans the surface of a sample with focused beams of electrons, to generate high-resolution images that reveal the morphology, chemical composition, crystalline structure, and orientation of the constituent materials of the sample.

A typical SEM consists of the electron source, electromagnetic lenses that focus the electron beam from the source, a scanning coil to deflect the electron beam over the surface of the sample, a detector, a vacuum system, a data output device, and a power supply (Goldstein et al., 2018).

The preparation of the sample is important. If a sample lacks conductivity, it must be coated with metals such as gold, silver, platinum, or chromium. The sample must be clean and dry for image clarity and so that the electron beam is not obstructed (Stokroos I. et al., 1998)

The Scanning Electron Microscope uses kinetic energy to provide signals regarding the interactions of the electrons. The primary signals are X-ray, backscattered electrons, and secondary electrons. The beam interacts with the material in a number of ways, emitting photons and electrons (Sampathkumar et al., 2013). Backscattered and secondary electrons released from the object above the vacuum are collected by a detector (Hafner, 2007). The major function of the secondary electrons released from the specimen is to identify the morphology and topography of the sample, while the backscattered electrons demonstrate contrast in the elemental composition of the sample (Goldstein et al., 2017; Egerton, 2005). Figure 3.2 shows the schematic of the main components of a scanning electron microscope (SEM) and the representation of the interaction volume.

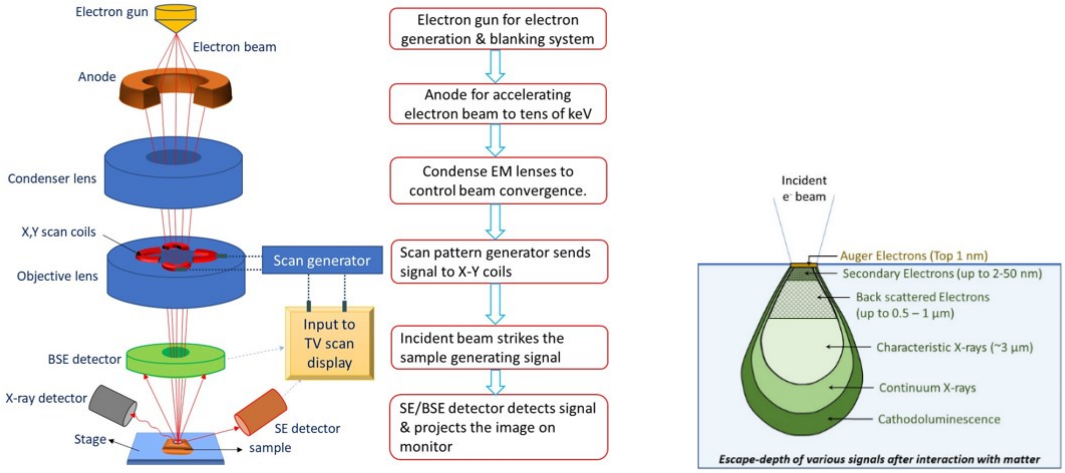


Figure 3.2: Schematic of the main components of a scanning electron microscope (SEM) and the representation of the interaction volume (Virtual Labs, n.d.)

The primary method for characterising the wettability of surfaces is the measurement of the contact angle (CA) (Ramírez-Flores et al., 2010). As shown in Figure 3.3, a water droplet with a high CA assumes a spherical form, whereas a droplet with a low CA tends to spread out. The wetting behaviour of solid surfaces can be classified into four categories according to their static CA. Surfaces are considered hydrophilic when the CA is less than 90°, and ultra-hydrophilic when the CA is less than 10°. Hydrophobic surfaces have a CA that is greater than 90° and less than 150° (Doshi et al., 2018a).

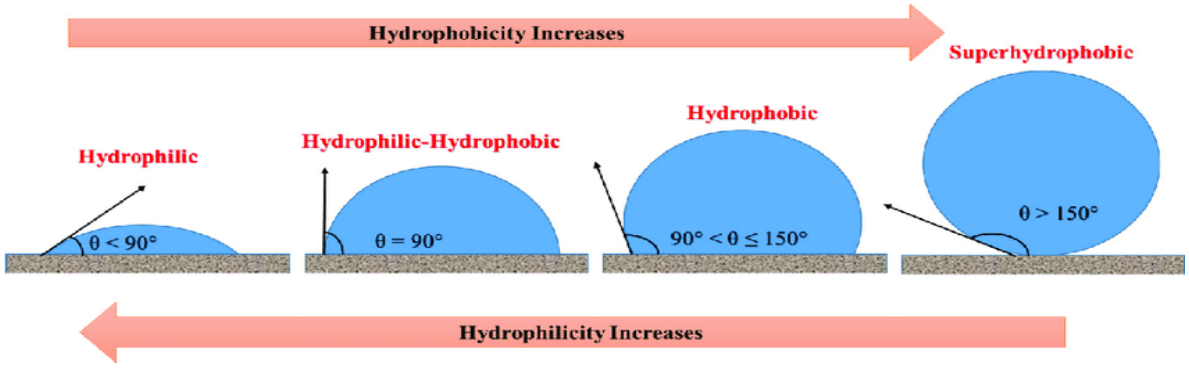


Figure 3.3: Relationship between wettability and water contact angle (Doshi, Sillanpää and Kalliola, 2018: p.264).

3.2. Materials



Figure 3.4a: Chicken Feather Fibre Mat



Figure 3.4b: Duck and Goose Feather Fibre Mat

Chicken feather fibre mat, duck and goose feather mat, and whole chicken feather, collectively referred to as feather materials were obtained from the Civil Engineering Department, Imperial College London. Figure 3.4a-b shows the feather fibre mat. The feather fibre mats could float on water, had a thickness of 2.5-3.0cm, a nominal density in the range of 30- 40kg/m3, off-white and brown colours, and hydrophobic and oleophilic properties.

Conventional Products

Polypropylene pad Drizit 175GSM oil pads (99.5 wt.% polypropylene), Safe Soak TM, Clay Absorbent Granules, Woodloose TM fibres and were obtained from Darcy Co.UK. Figure 3.5a-d shows the conventional products while Table 3.3 contains the properties of these sorbents (Darcy Brochure, ATG,2021)



Figure 3.5: A. Polypropylene Pad B. Clay Absorbent Granules C. SafeSoak™ D. Woodloose™ Fibres (Darcy, N.D.)

Table 3.3: Properties of Darcy Conventional oil sorbents

Darcy Sorbent Products	**Polypropylene Pads**	**Safe Soak**	**Clay Absorbent Granules**	**Woodloose Fibres**
Product Code	PDB17MB050BG	0397/SS	0399	0101
Absorbency (Litres)	38-50	12-19	8-13	125-150
Sorbent Form	Lightweight Pads	Sawdust	Granules	Woodloose
Types of Spills	Oil and water-based spills	Oil and water-based spill	Oil and water-based spill	Marine and oil-based oil spill
Product Based Material	Polypropylene	Treated Sawdust	Recycled Minerals	Biodegradable naturally derived product

Oil

Table 3.4 contains the properties of the different oils used (sourced in the UK) as obtained from the supplier datasheet. The viscosities of engine oil, peanut oil, and vegetable oil at 20℃ were 175mPa·s, 72mPa·s and 66mPa·s respectively. The surface tension for all three oils was in the

range of 31.0-31.1mN/m. The density of engine oil used was 0.88g/cm^3 while that of peanut oil and vegetable oil was 0.918g/cm^3 and 0.912g/cm^3 respectively.

Table 3.4: Properties of the test oils

Oil (Type)	Viscosity (mPa·s)	Surface Tension (mN/m)	Density (g/cm^3)
Engine Oil	175	31.0	0.885
Peanut Oil	72	31.1	0.918
Vegetable Oil	66	31.3	0.912

3.3. iGC-SEA Methodology - Sample Preparation and Analysis

The iGC-SEA would allow the precise amount (n, mole) of probe vapor to pass through the sample column to achieve a specific probe surface coverage, n/nm (where nm is the probe monolayer coverage). A series of probe vapors are injected over a range of surface coverages to obtain a profile of surface energy as a function of coverage (infinite dilution from coverages 0.5% to 20%). The methodology has been described elsewhere (Ho and Heng, 2013).

Samples were packed into individual iGC-SEA pre-silanised glass columns (300 x 4 mm ID). The three samples, chicken feather fibre mat (CFM), polypropylene pad (PP Pad), and engine oil were packed into individual iGC silanised glass columns. About 9-188mg of CFM and polypropylene samples were used. The polypropylene pad was cut and placed in the column in one piece. The CFM was shredded and placed into the column and the engine oil was saturated onto glass beads prior to being placed into the column. Pre-silanised glass beads were used to eliminate any interaction with the glass beads.

The sample columns were then pre-conditioned in-situ for 1hr at 20°C, 293.15 K, and 0% RH with 20ml/min and 10ml/min Helium (purity ≥99.95%), flow rate. The experiment was carried out at 20°C, 293.15 K, 0% RH with 0ml/min, 10ml/min, and 20ml/min total flow rate of helium using methane for dead volume corrections.

The BET-Specific surface area was determined at finite dilution using octane isotherms for each surface energy measurement. Octane, Nonane, heptane, and hexane were used as nonpolar probes for surface energy analyses. Table 3.5 contains the properties of the nonpolar IGC probes. After injecting a gas probe, it interacted with the sample, and the retention time was determined using SMS software. Methane was used as a reference gas probe to determine the

dead volume. The dispersive surface energy (γs^D) calculations were performed using the results from BET measurements applying the Dorris and Gray method (Dorris and Gray, 1980).

Based on the van Oss approach, the specific surface energy (γs^{AB}) of the sample were calculated using a pair of mono-functional acidic and basic probe molecules (dichloromethane -y+: 124.58mJ/m^2 and ethyl acetate -y+: 475.67mJ/m^2) and the Della Volpe scale is employed. HPLC grade, Sigma-Aldrich) on the samples applying the van Oss approach (Ho and Heng, 2013; Volpe and Siboni, 1997). The surface energy profiles and distributions were determined with an R^2 coefficient better than 0.998 and the standard deviation of the data measured in this study is no more than 3% at any probe surface coverage.

Table 3.5: Properties of the non-polar IGC probes used.

Probe	**a (Å^2)[a]**	$\gamma_L^D (mJ/m^2)$[b]	**Supplier**
n-Octane	63	21.1	Sigma-Aldrich
n-Nonane	69	22.4	Sigma-Aldrich
n-Decane	75	23.4	Sigma-Aldrich
n-Undecane	81	24.2	Sigma-Aldrich

a. The surface area that can be occupied by one probe molecule (Liuf and Rials, 1998)
b. The surface tension of the probe liquids at 25°C (Lide, 1995)

The iGC-SEA is compatible with a variety of molecular instruments, including combinations of solvents and gases the SEA analysis software also enables quick data plotting and report generation. Figure 3.6 depicts the schematic for the iGC-SEA.

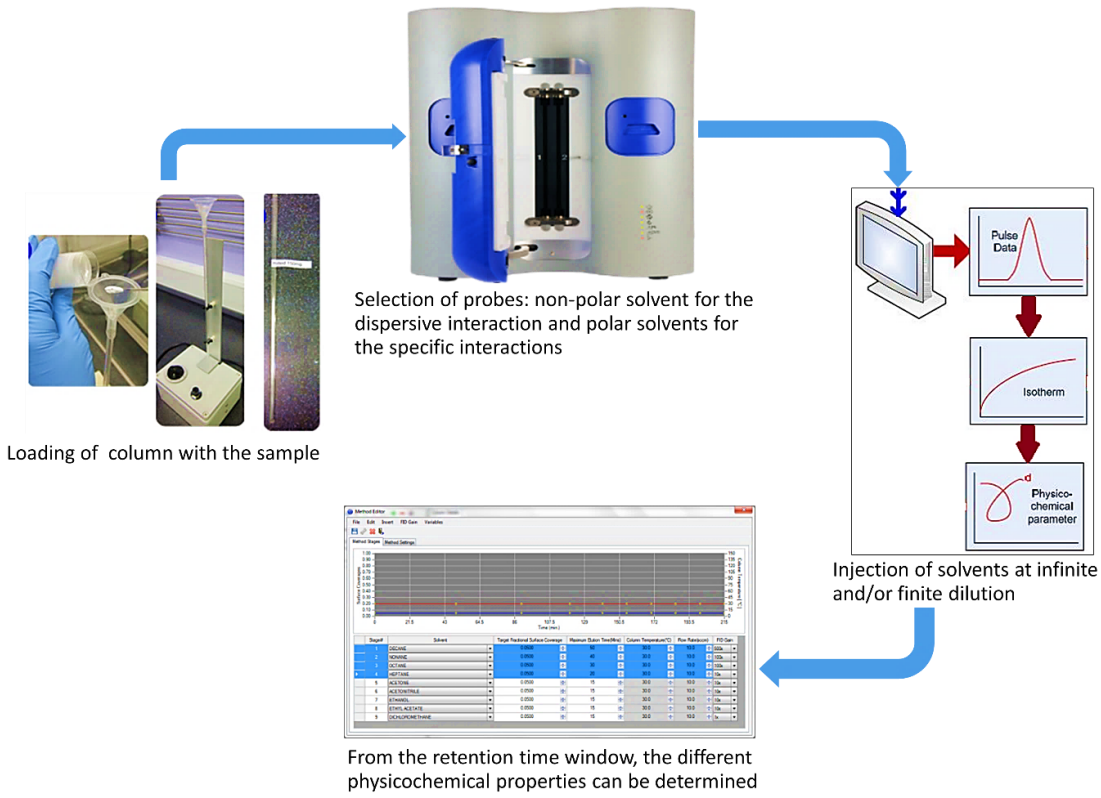


Figure 3.6: Process flow of IGC-SEA (Surface Measurement System, 2020)

3.4. Theory

3.4.1. Determination of BET Surface Energy

The equipment used for the BET is set up for pulse chromatography. The output of the BET value depends on the sample packing, the reproducibility within the column, gas probes, and the variability of single batches. The surface areas of solids were calculated by physical adsorption of octane molecules. The BET equation as shown in equation 1 was used.

$$\frac{1}{n[(P_0/P)-1]} = \frac{c-1}{n_m c}\left(\frac{P}{P_0}\right) + \frac{1}{n_m c}$$

Equation 1: BET Equation

Where, $\boldsymbol{P}$ and $\boldsymbol{P_0}$ are the equilibrium and saturation pressure of adsorbates at the temperature of adsorption, $\boldsymbol{n}$ is the amount of adsorbed gas, $\boldsymbol{n_m}$ is the amount of monolayer adsorbed gas, and **c** is the BET (or sorption) constant. This equation is an adsorption isotherm, and a straight line was obtained by plotting $\frac{P}{P_0}$ versus $\frac{1}{n[\left(\frac{P_0}{P}\right)-1]}$. The $\boldsymbol{c}$ and $\boldsymbol{n_m}$ were calculated from the slope and intercept of the line, respectively. The surface area was determined by equation 2.

$$S_{BET} = n_m N_{Av} a$$

Equation 2: BET Surface Area Equation

Where, N_{Av} is the Avogadro`s number, a is the adsorption cross-section of the adsorbing species.

3.4.2. Dispersive and Specific Acid-base Surface Energies

There are different methods to determine the dispersive surface energy. Dorris-Gray method, Schultz and Hamieh but for this study, the dispersive surface energy was determined by the Doris-Gray method (Doris and Gray, 1980). The specific surface energy was determined by the van Oss approach (Van Oss, 2006). The total surface energy of a material, which is the summation of the dispersive and specific components of the surface energy, was deduced with Equation 3.

$$\gamma s^T = \gamma s^{AB} + \gamma s^D$$

Equation 3: Total Surface Energy

Where γ_S^T is the total surface energy, γ_S^{AB} is the specific component of the surface energy, and γ_S^D is the dispersive component of the surface energy. The Dorris-Gray method was applied during the $_S^D$ analysis, which considers the net retention volume (V_N) as a function of the retention and dead volumes for hexane, heptane, and octane eluants. The dead volume was determined using methane as a surrogate. The dispersive component of the solid sample was then determined from the slope of the plot of $RT\ln(V_N)$ versus the carbon number of the alkane eluants, according to Equation 4.

$$Slope = 2(\gamma_{CH_2}\gamma s^D)^{1/2} \times N_A a_{CH_2}$$

Equation 4: Slope of Correlation Equation

Where;

γ_S^D = dispersive component of the solid surface energy

a_{CH_2} = cross-sectional area of a methylene group

γ_{CH_2} = free energy of the methyl group

N_{Av} = Avogadro`s number.

To determine the specific contribution to the total surface energy, it was necessary to measure the specific free energies of adsorption (ΔG_{SP}) for the various polar probe molecules. To do this, the retention volume of the polar probe molecules (acetone, ethanol, ethyl acetate, and dichloromethane) on the samples was determined. This was done by the polarization approach, which involved the determination of ΔG_{SP} from the plot of $RT\ln(V_N)$ versus the molar deformation polarization of the probe molecules, P_D, according to Equation 5.

$$P_D = [MW \times (r^2 - 1)] / [D \times (r^2 + 2)]$$

Equation 5: Molar Deformation Equation

Where;
MW = molar mass of the probe
r = reflective index of the probe
D = probe liquid density.

Above the straight line in the plot of $RT\ln(V_N)$ versus P_D are points that represent the polar probes while the specific component of the free energy of adsorption, ΔG_{SP}, is indicated by the distance to the straight line. Then, the acid-base numbers, which are related to the specific surface energy, were calculated from the ΔG_{SP} values. The Guttmann approach, also known as the Guttmann method or Guttmann procedure, is a widely utilized technique in determining the contribution of acid-base numbers to specific surface energy (Thielmann, 2004; Voelkel et al., 2015). Developed by Ralph Guttmann, this approach offers a systematic framework for analysing the acid-base properties of solid surfaces, particularly in the context of interfacial interactions.

In the Guttmann approach, the acid-base properties of a solid surface are characterized based on its interaction with various probe liquids of known acid and base strength. These probe liquids typically include polar and non-polar solvents, each representing a specific range of acid and base values on the Guttmann scale. By measuring the contact angles of these probe liquids on the solid surface, one can infer the surface's acid-base characteristics.

According to Gutmann's approach, the electron-accepting and electron-donating characteristics of the surface are represented by the acid and base numbers (K_a and K_b, respectively) (Gutmann, 1967). Although in Gutmann's approach, no specific surface energy can be calculated because these numbers are dimensionless, we deduced the specific surface energies (s^{AB}) of the samples by the van Oss approach. The specific contribution, which is in

two parts including an acidic (γ^+) and a basic (γ^-) parameter of the surface tension, was determined with the Della Volpe scale using a pair of mono-functional acidic and basic probe molecules (dichloromethane - γ^+: 124.58 mJ/m^2 and ethyl acetate - γ^-: 475.67 mJ/m^2) as recommended in several literature (Kondor et al., 2020).

3.4.3. Determination of Specific Free Energies of Adsorption and Acid-Base Numbers

The surface chemistry of the samples was assessed using the Gutmann acid (K_a) and base (K_b) numbers, determined with the Gutmann approach using dichloromethane, ethyl acetate, acetone, and ethanol polar probes. K_a and K_b values of the samples were calculated using the ΔG_{SP} values of polar probes at that surface coverage. The K_a/K_b ratio provides an empirical basis for classifying surfaces with respect to acidity-basicity. It is called surface specific (Sc). If Sc<1, the surface is basic (i.e., electron donor ability prevails over electron acceptor). An Sc>1 shows acidic character whereas Sc≈1 is characteristic of amphoteric surfaces (Santos and Guthrie, 2005).

3.4.4. Determination of Thermodynamic Work of Cohesion and Adhesion

Assuming only physical interactions are present without any irreversible chemical interactions, the geometric mean method was used to calculate the total work of cohesion and adhesion, according to equations 6 and 7, respectively (Surface Measurement System UK, 2020).

$$W_{Cohesion}total = 2[(\gamma s^D \times \gamma s^D)^{1/2} + (\gamma s^+ \times \gamma s^-)^{1/2} + (\gamma s^- \times \gamma S^+)^{1/2}]$$

Equation 6: Work Cohesion

$$W_{Adhesion\ 1-2}total = 2[(\gamma {s_1}^D \times \gamma {s_2}^D)^{1/2} + (\gamma {s_1}^+ \times \gamma {s_2}^-)^{1/2} + (\gamma {s_1}^- \times \gamma {s_2}^+)^{1/2}]$$

Equation 7: Work Adhesion

3.5. Results and Discussion

3.5.1. BET Specific Surface Area of Chicken Feather fibre Mat and Polypropylene Pad

The BET Specific Surface Areas (BET-SSA) of the two samples, CFM and PP Pad were determined with the physical adsorption of octane molecules by iGC-SEA. The BET-SSA of engine oil was also determined. Table 3.6 shows the BET-SSA of the studied samples determined from their octane sorption isotherms. It is observed that the BET-SSA of the CFM was lower than that of the PP pad, and the BET of engine oil was higher than that of both samples. However, the BET-SSA of the CFM in engine oil was higher than that of the PP pad in engine oil.

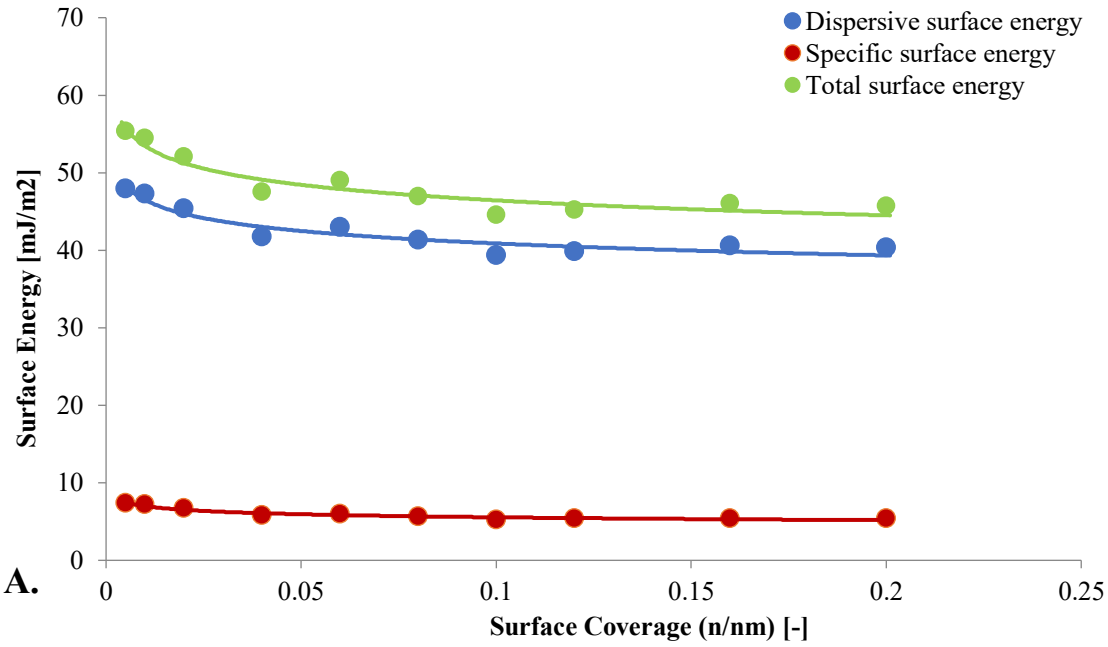
With the interaction of the engine oil and the samples, there was an increase of about ten times the original BET-SSA for CFM and over four times for PP pad. The active sites increased leading to an increase in specific surface area. Both samples are good sorbents of oil. The presence of pores or void spaces within the PP pad sample that sorb the oil may provide additional exposure sites, and reaction with the probe molecules thereby leading to a higher measured BET surface area (Zoccola and Fois, 2004). In the case of CFM, the increase was higher possibly because chicken feather fractions are mesoporous and microporous (Tesfaye et al., 2017) while the PP pad is mesoporous (Kelle and Ogoko, 2017), microporosity helps create larger surface area.

Table 3.6: The BET-specific surface area determined from octane sorption isotherms.

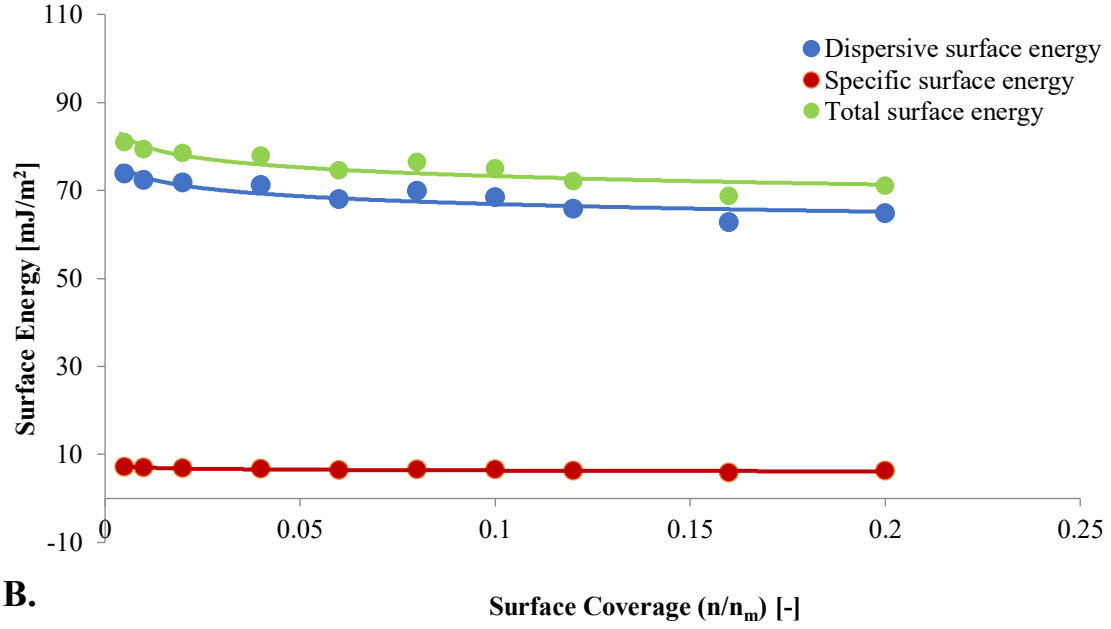
Sample	**Sorption Constant**	**Monolayer Capacity [mMol/g]**	**BET Specific Surface Area [m^2/g]**	r^2
CFM	1.58	0.003	1.15	0.998
Polypropylene Pad	6.90	0.011	2.27	0.998
Engine Oil	7.63	0.087	18.54	0.998
CFM in Engine Oil	5.26	0.064	13.67	0.999
Polypropylene Pad in Engine Oil	4.56	0.038	8.03	0.999

3.5.2. Comparison of Dispersive, Specific (Acid-Base), and Total Surface Energies of CFM, Polypropylene Pad, and Engine Oil

Dispersive (γ_S^D), acid-base (γ_S^{AB}), and total surface energy (γ_S^T) profiles obtained directly from the IGC-SEA for CFM and PP pad - the two samples, and also for engine oil, are shown in Figures 3.7. From the dispersive energy profiles shown in Figure 3.7, the CFM, PP pad, and engine oil were observed to be energetically heterogeneous. The implication is that the surface energy change is a function of the surface coverage. For both samples, the dispersive surface energy constituted a significant portion of the total surface energy. 49mJ/m^2 for CFM, and 72mJ/m^2 for PP Pad. The engine oil was more active and had the maximum dispersive surface energy. This demonstrates how mingling behaviour can affect the surface properties of samples.



A.



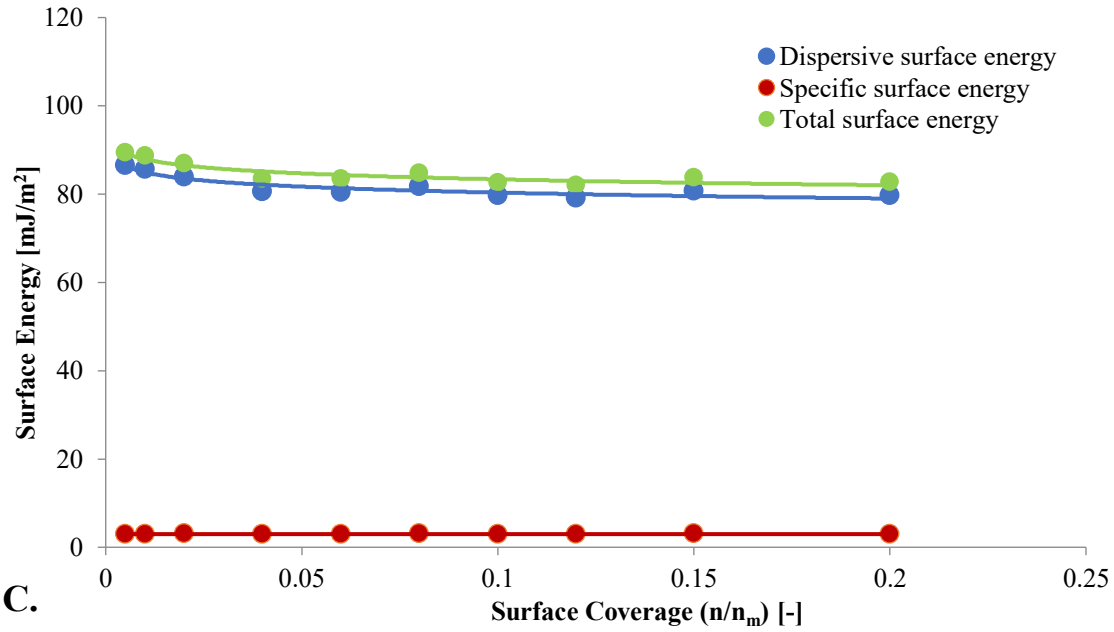
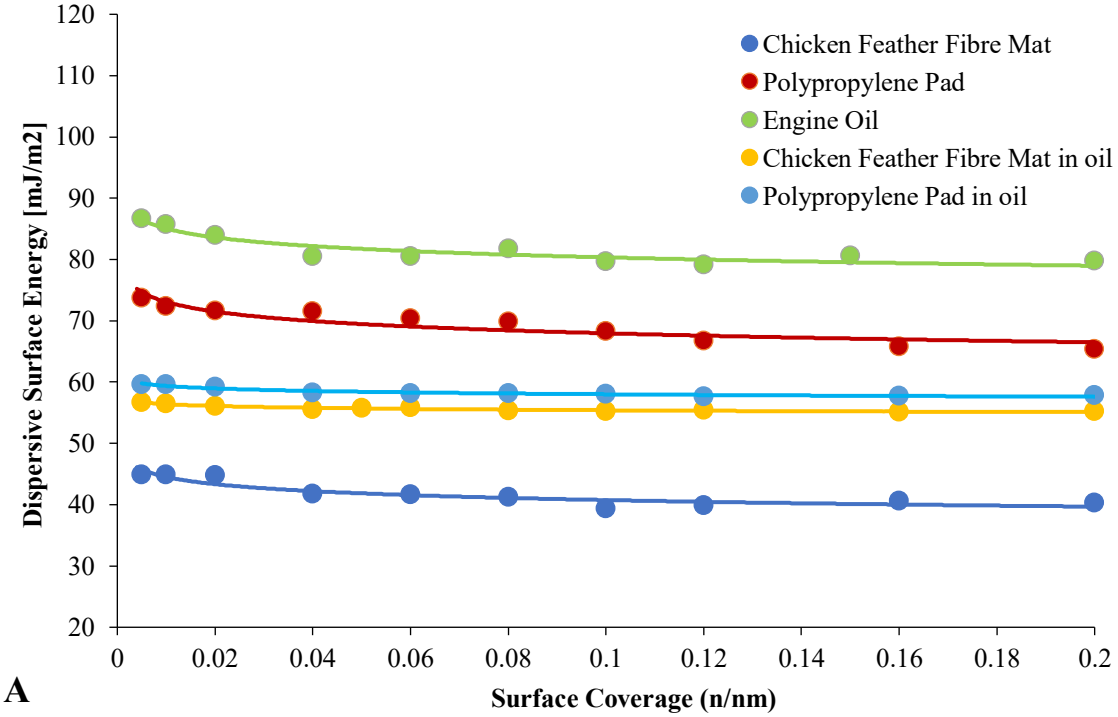


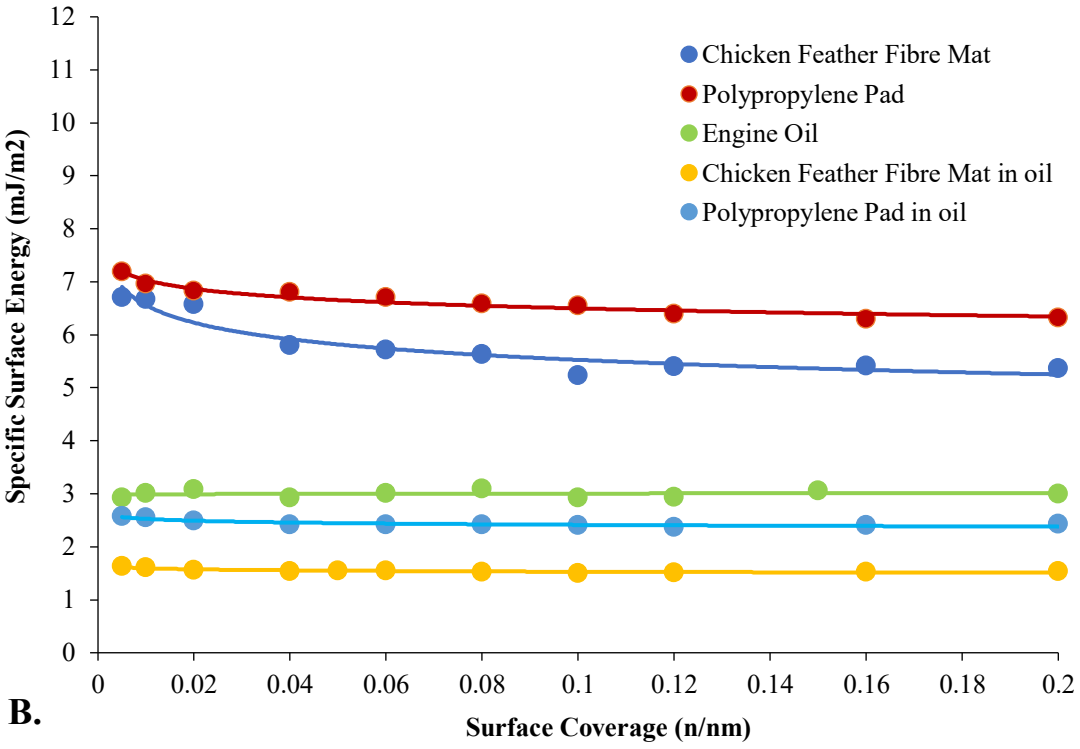
Figure 3.7: Comparison of surface energy profiles (as a function of surface coverage) for A. CFM, B. PP Pad, and C. Engine Oil

The plots of dispersive, specific (acid-base), and total surface energy of the samples are presented in Figure 3.8. The dispersive surface energy (γ_S^D) profiles for CFM, PP Pad, engine oil, CFM in oil, and PP Pad in oil are displayed in Figure 3.8a. For both samples, the γ_S^D changes as a function of surface coverage. The CFM and PP Pad had wider variations of γ_S^D, which means they are more energetically heterogenous. In 3.8a, the CFM and PP pad shows an

energetical heterogenous surface, but with mixing with engine oil, there is a slight increase in the surface energy of CFM while the surface energy of PP Pad is lowered, and both sample surfaces became more energetically homogenous. The γs^D of the samples show the following trend PP Pad > PP Pad in engine oil > CFM in engine oil > CFM. The specific surface profiles of all samples are displayed in Figure 3.8b. The CFM closely follows the PP Pad which has the highest specific surface energy. The both had appreciable concentrations of Lewis acid-base functional groups on their surfaces. Both CFM and PP pad are energetically heterogeneous but with mixing with oil, surface energy is lowered, surface becomes more energetically homogenous. The trend of the specific surface is PP > CFM > PP in engine oil > CFM in engine oil. The Engine oil, CFM in oil and PP Pad in oil had relatively straight γ_S^{AB} values compared to the other two samples, which means the samples when mingled with oil, there is change in behaviour. Comparing with the γ_S^D, γ_S^{AB} contributes a minor part of the total surface energy. The high contribution of dispersive surface energy to the total surface energy of both fibres, CFM and PP Pad, indicates that there are high non-polar surfaces with non-polar interaction potential - this explains their hydrophobicity and good adsorption potential (Carmody et al., 2007a). Figure 3.8c is the total surface energy which follows the dispersive surface energy trend of PP Pad > PP Pad in oil > CFM in oil > CFM. The profiles revealed that the CFM was the most stable since it had the lowest total surface energy (Figures 3.8c).



A



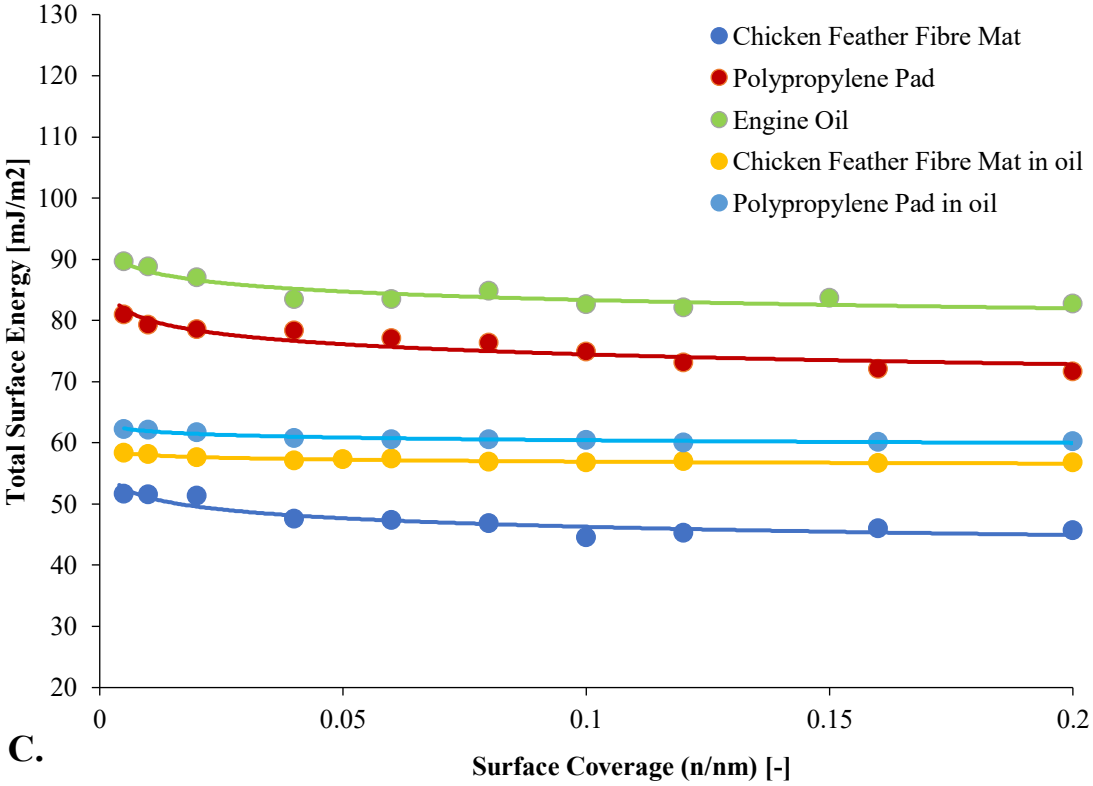
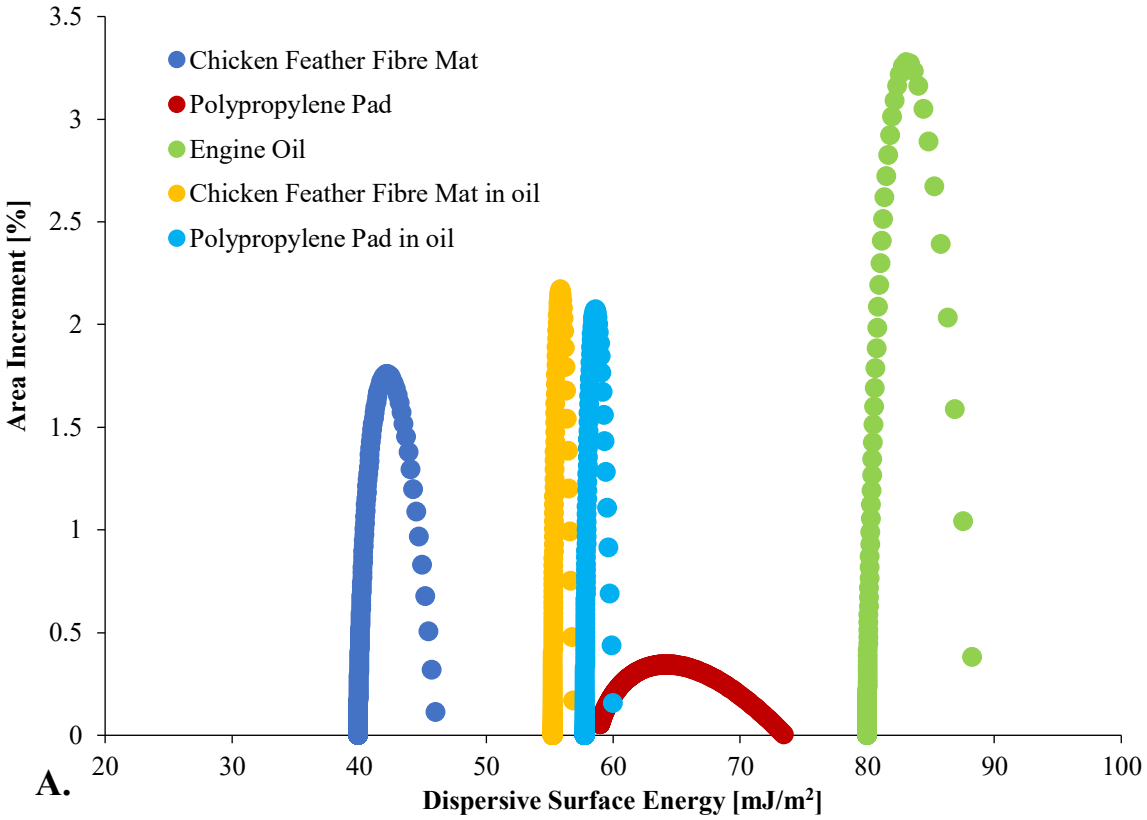
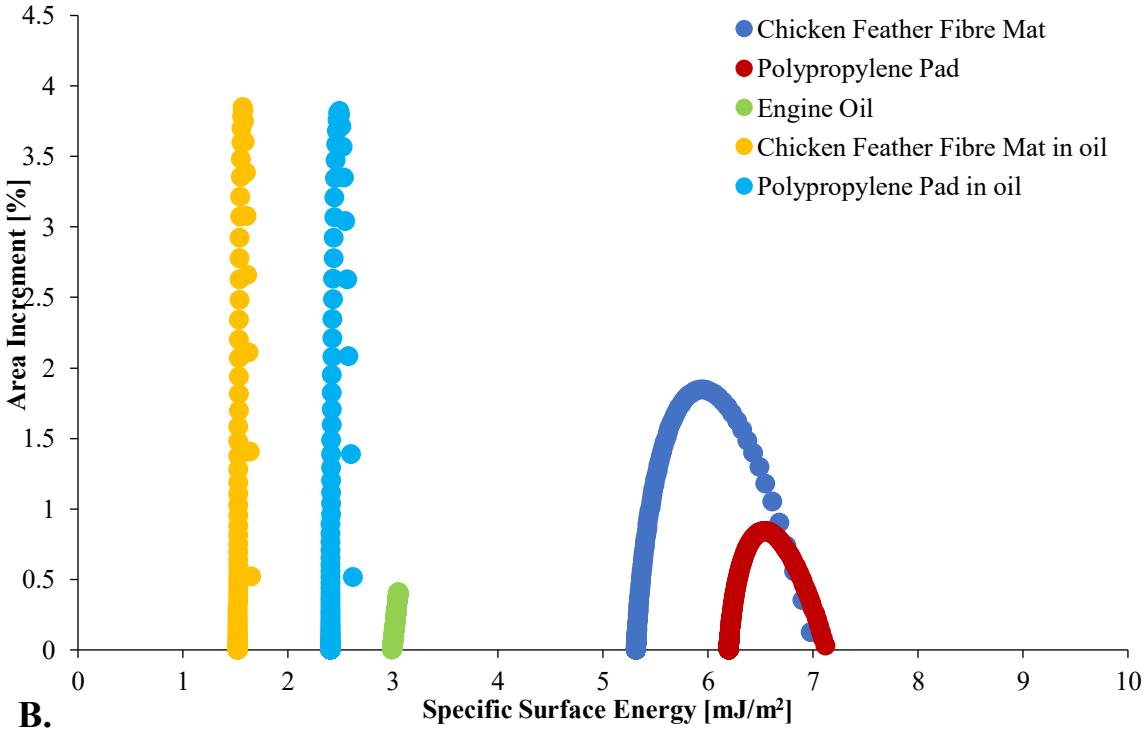


Figure 3.8: Comparison of A. the dispersive surface energy distributions, B. Total surface energy distributions, and C. Specific surface energy distributions, of the samples (as a function of surface coverage).

Figure 3.9 compares the plots of the dispersive surface energy distribution (γ_S^D), specific surface energy distribution ($\gamma_S^{A,B}$), and total surface energy distribution (γ_S^T) versus percentage of surface area increment of the studied samples. At infinite dilution, the probe molecules are predominantly probing the high-energy sites. However, at higher concentrations/surface coverages, lower surface energy sites are taken into consideration and there is an overall decrease in the surface energy (Carmody et al., 2007b). For Figure 3.9a, Table 3.7, the CFM and PP pad were broader and more heterogenous but with the mixing with engine oil, they became very narrow which signifies increase in homogeneity. For the specific surface energy distribution, (Figure 3.9b, Table 3.8), The CFM and the PP pad relatively exhibited a wide distribution of surface energies indicating a heterogenous surface but with the samples mixing with engine oil, the same increase in homogeneity was observed. The same sequence was observed for the Total surface energy (Figure 3.9c, Table 3.9). CFM and PP Pad both had γ_S^{AB} range of value at 5.32 – 6.98 mJ/m^2 and 6.20 – 7.12 mJ/m^2 respectively, PP Pad in engine oil 2.40 – 2.63 mJ/m^2 and CFM in engine oil with 1.53 – 1.65 mJ/m^2, with the CFM and PP Pad exhibiting some variations across the surface coverages measured. The relatively low values of the specific surface component can be interpreted to be as a result of the Hydrogen linkages in the two sample, which are too strong to be broken and replaced by the other probe molecules (Kaewprasit et al., 1998). However, because the γ_S^{AB} contributed less, this implies a lower polarity and more hydrophobicity for CFM, PP Pad, CFM in engine oil and PP pad in engine oil. Overall, the total surface energy distribution (Figure 3.9c, Table 3.9) was more similar to the dispersive surface energy distribution because of the major contribution of the dispersive surface energy.


Chicken Feather Fibre Mat
Polypropylene Pad
Engine Oil
Chicken Feather Fibre Mat in oil
Polypropylene Pad in oil
Area Increment [%]
Dispersive Surface Energy [mJ/m²]
A.


Chicken Feather Fibre Mat
Polypropylene Pad
Engine Oil
Chicken Feather Fibre Mat in oil
Polypropylene Pad in oil
Area Increment [%]
Specific Surface Energy [mJ/m²]
B.

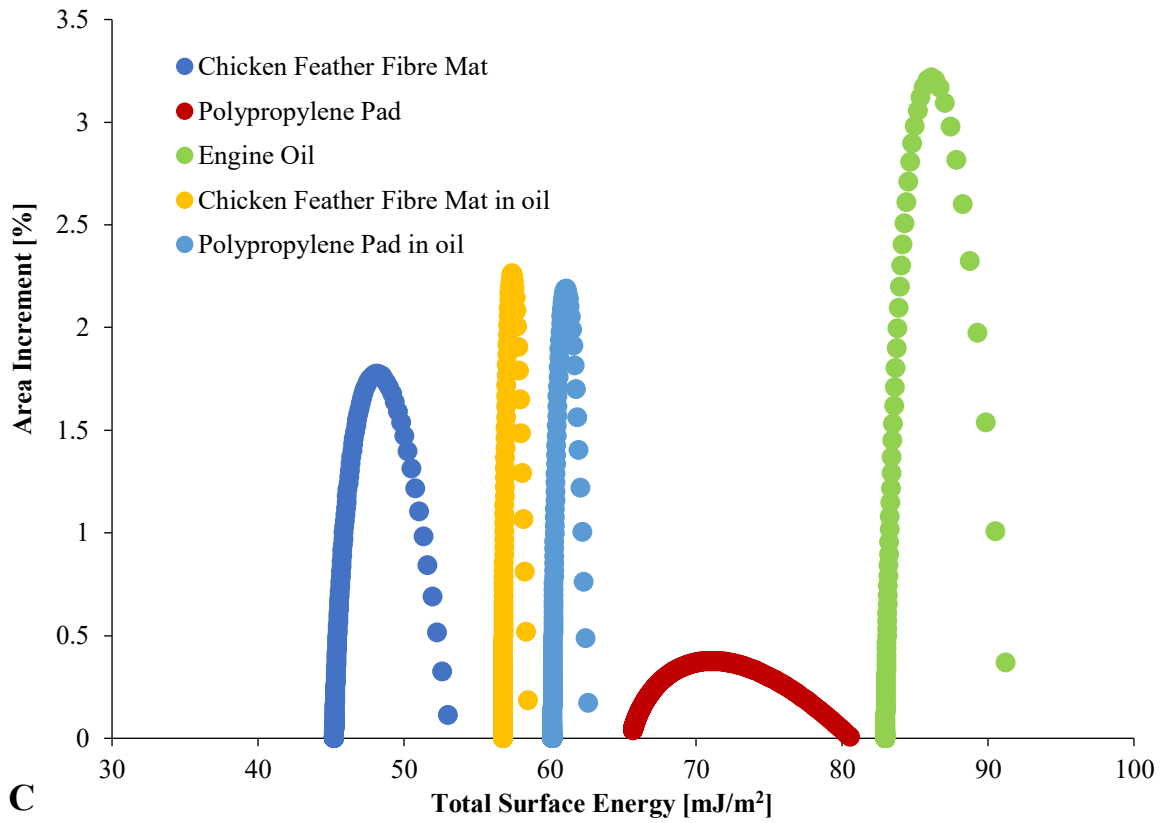


Figure 3.9: Comparison of A. the dispersive surface energy profile of the samples B. Specific surface energy distributions for the samples C. Total surface energy distributions for the samples.

Furthermore, Tables 3.7 to 3.9 show the dispersive surface energy ($\gamma_S^{A,B}$) distributions, specific surface energy (γ_S^D) distributions, and total surface energy distribution (γ_S^T), respectively for studied samples. The tables also show $\gamma_S^{AB.50}$, $\gamma_S^{D.50}$and $\gamma_S^{T.50}$, the medians, which have been defined as surface energy values below which half of the population lie (Beaumont et al., 2021).

The nonpolar nature of Polypropylene reduces its interaction with polar substances, resulting in a lower dispersive surface energy (Weldeyesus, 2016), even though the exhibited value of polypropylene pad is higher than that of chicken feather fibre mat.

Table 3.7: γS^D, Dispersive surface energy distributions for all samples.

Sample	Min [mJ/m^2]	$\gamma_S^{D,50}$ [mJ/m^2]	Max [mJ/m^2]
CFM	39.91	41.05	46.03
Polypropylene Pad	58.98	61.84	73.45
Motor Oil	80.00	81.54	88.29
CFM in Motor Oil	55.26	55.55	56.85
Polypropylene Pad in Motor Oil	57.77	58.19	60.00

The calculated γ_S^D of CFM, PP Pad, CFM in engine oil, and PP Pad in engine oil ranged from 39.91-46.03mJ/m^2, 58.98-73.45mJ/m^2, 55.26-56.85mJ/m^2, and 57.77-60.00mJ/m^2, respectively with $\gamma_S^{D,50}$ of 41.05 mJ/m^2, 61.84 mJ/m^2, 55.55 mJ/m^2, and 58.19 mJ/m^2 respectively, as shown in Table 3.7.

Table 3.8: γ_S^{AB}, Specific surface energy distributions for all samples.

Sample	Min [mJ/m^2]	$\gamma_S^{AB,50}$ [mJ/m^2]	Max [mJ/m^2]
CFM	5.32	5.63	6.98
Polypropylene Pad	6.20	6.37	7.12
Motor Oil	3.00	3.04	3.05
CFM in Motor Oil	1.53	1.55	1.65
Polypropylene Pad in Motor Oil	2.40	2.45	2.63

Table 3.9: γ_S^T, Total surface energy distributions for all samples.

Sample	Min [mJ/m^2]	$\gamma_S^{T,50}$ (mJ/m^2)	Max [mJ/m^2]
CFM	45.23	46.68	53.01
Polypropylene Pad	65.69	68.58	80.55
Motor Oil	82.99	84.52	91.21
CFM in Motor Oil	56.78	57.11	58.50
Polypropylene Pad in Motor Oil	60.10	60.64	62.61

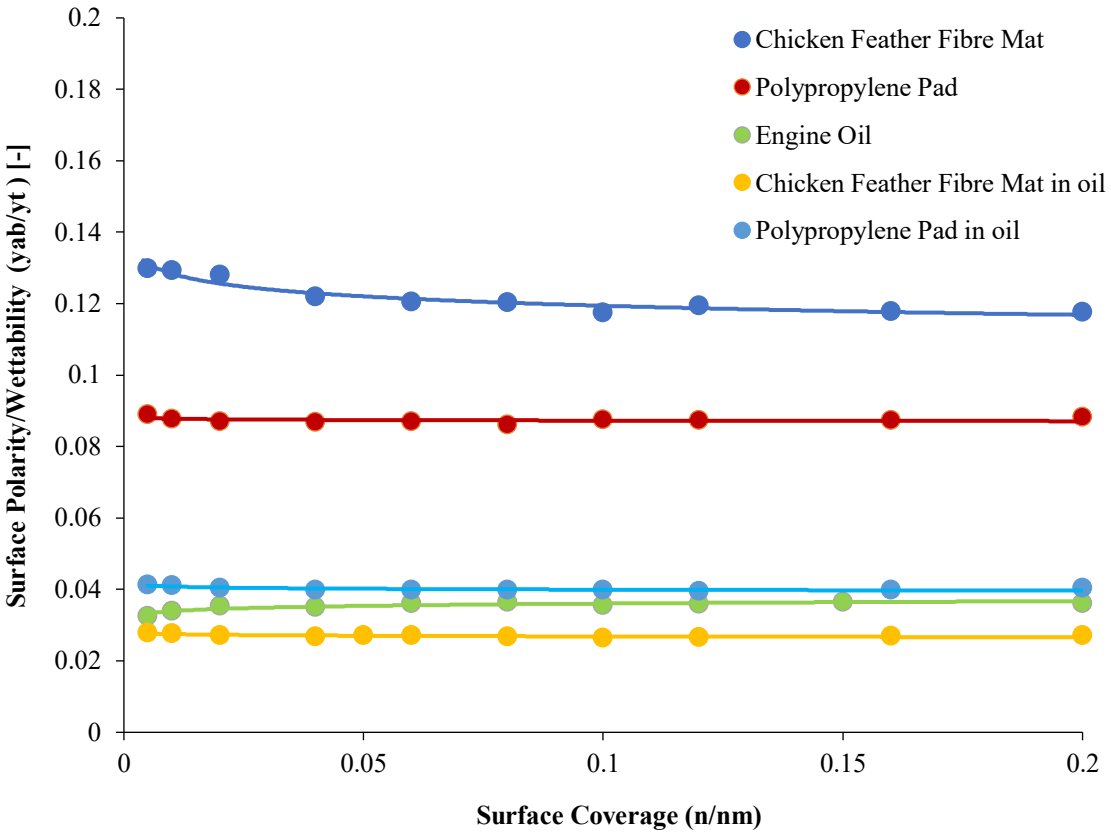


Figure 3.10: Polarity of the samples

Figure 3.10 depicts the polarity of the samples, which was derived from the specific and total surface energies. The CFM had greater surface polarity than the PP pad and engine oil, making it the most hydrophilic. These hydrophobic components on the feather surface interact with nonpolar substances, resulting in a reduction in the dispersive surface energy (Hu, X., et al. 2013). The nonpolar nature of PP pad also reduces its interaction with polar substances, resulting in low dispersive surface energy (Weldeyesus, A. Y., et al. 2016) even though it exhibits a higher value than CFM. The engine oil consists mainly of hydrocarbons. Hydrocarbon side chain accounts for the intermolecular bonds formed between the engine oil and the two fibres, CFM and PP Pad, affecting any other resulting total surface energy.

3.5.3. Changes in Specific Gibbs Free Energies of Adsorption (ΔG_{SP}) and Acid-Base Numbers

Figure 3.11 shows the changes in the specific (acid-base) Gibbs free energy of adsorption (ΔG_{SP}) of different solvents for the studied samples. The ΔG_{SP} profiles showed that the four

samples exhibited strong interactions with all polar probes. Moreover, the ΔG_{SP} profile varied with surface coverage, demonstrating the heterogeneity of the samples. Higher ΔG_{SP} values has been attributed to a higher concentration of polar surface groups or different surface groups with higher specific surface energy (Cordeiro et al., 2011; Montes-Morán et al., 2002). Generally, all the samples showed a strong degree of interaction with all polar probes. The standard free energy of polar solute adsorption on solid surfaces is included to account for the adsorption standard free energy (W. Zhang and Leonov, 2001).

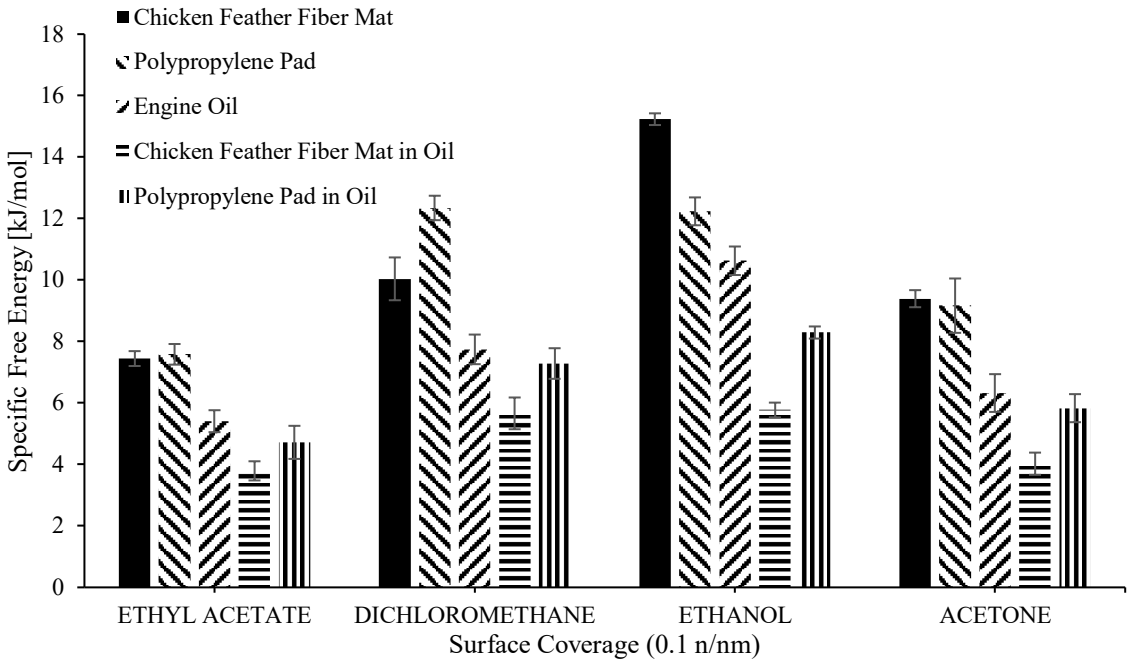


Figure 3.11: Specific (acid-base) free energy profiles of different solvents for samples

The acid and base constants of the samples at infinite dilution and 0.1 surface coverage (n/n_m) are shown in Figure 3.12. It is evident that Kb was higher than Ka for all the samples studied, which is an indication of the basic nature of the surfaces of the samples. This observation is typical of materials possessing higher concentrations of electron-donating surface functional groups (Yu et al., 2017). When Kb/Ka is greater than 1, the surface is thought to be basic, indicating that the solid prefers to donate electrons. On the other hand, when Kb/Ka is less than 1, the surface is thought to be acidic, and the solid prefers to accept electrons (Yu et al., 2017). This means that the CFM and PP pad possessed higher concentrations of electron-donating surface functional groups. For a given adsorbate, it has been reported that the free energy of

adsorption is the sum of the adsorption energies attributable to dispersive and specific interactions (Dìaz et al., 2004).

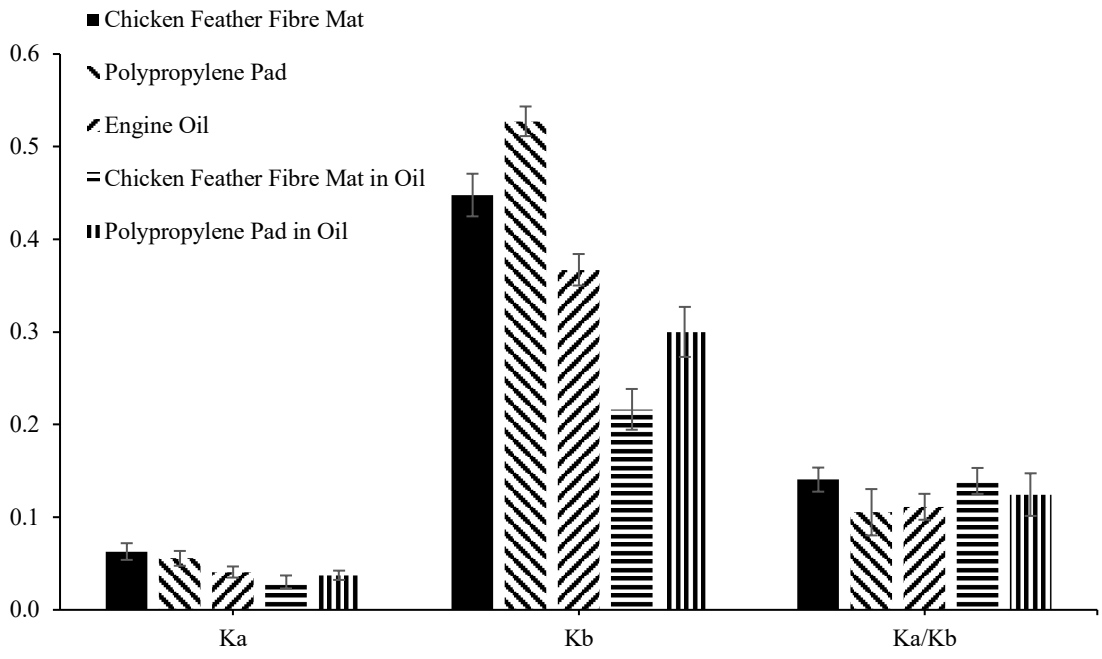


Figure 3.12: Gutmann acid and base numbers of the samples at ID (0.1n/nm)

3.5.4. Thermodynamic Work of Cohesion and Adhesion

The profiles of the work of cohesion and adhesion of the studied samples are shown in Figure 3.13. It is widely known that a high value of work of cohesion shows a high tendency for aggregation in a sample, and vice versa. As can be observed in Figure 3.13a, CFM showed the lowest cohesion energy compared with the other samples, suggesting that it has the lowest tendency to aggregate. The profiles of the work of adhesion of the CFM and polypropylene pad are shown in Figure 3.13b. The work of adhesion was calculated with regards to the engine oil sample, CFM, and polypropylene pad samples. As can be observed in Figure 3.13b, the polypropylene pad had greater adhesion to the engine oil than the CFM.

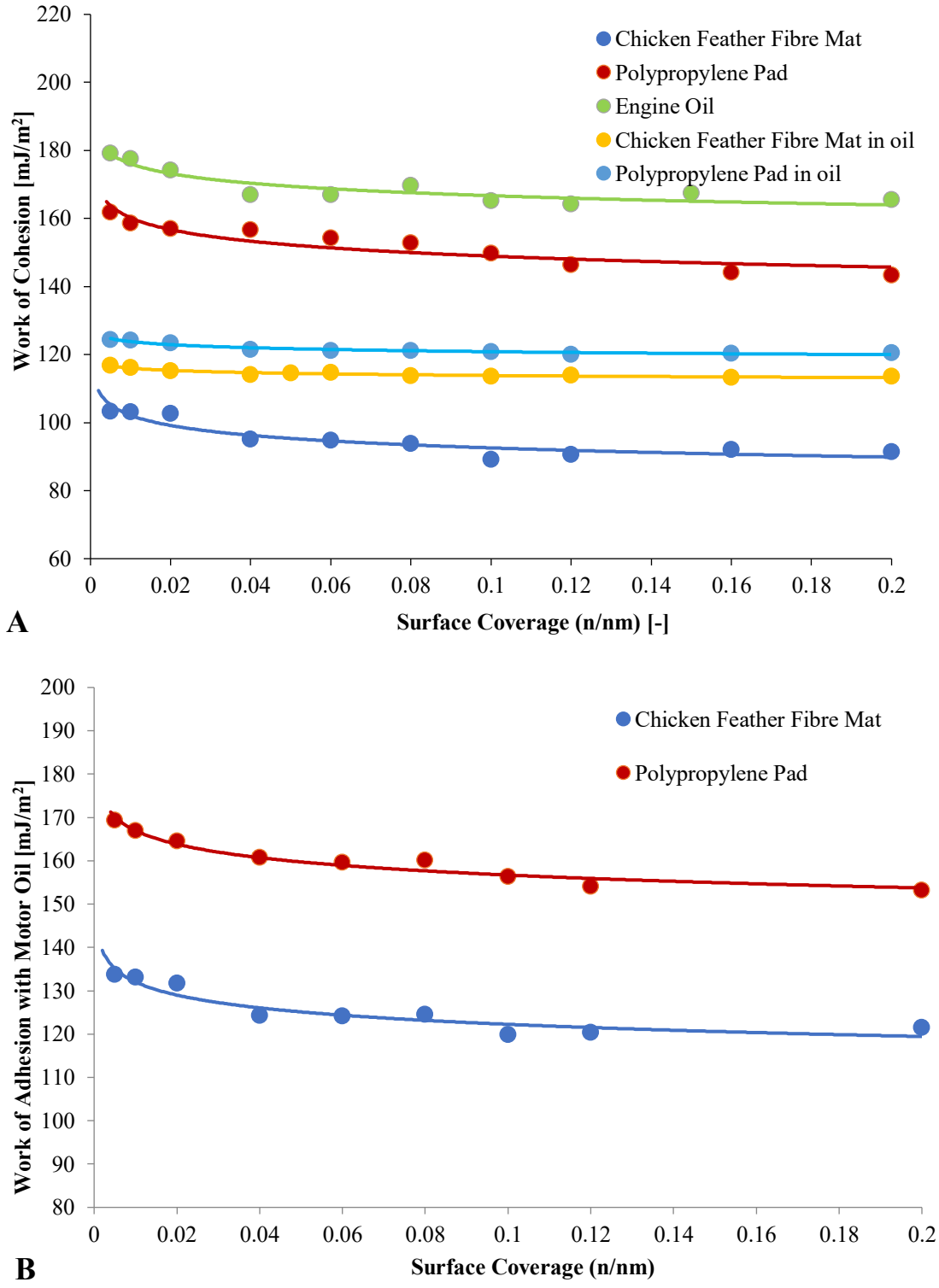


Figure 3.13: A. Work of Cohesion profiles of the samples B. Work of adhesion profiles of samples with regards to Engine Oil sample.

3.6. Characterisation using Dynamic Vapour Sorption

3.6.1. Methodology

Figure 3.14 is the schematic of DVS 100, an automated gravimetric sorption system from Surface Measurements system, UK. The method used is similar to EN ISO 12571. The DVS measures uptake and loss of moisture by varying the vapor concentration surrounding the sample and measuring the change in mass as a function of time. Water sorption isotherms were measured gravimetrically using DVS resolution (Surface measurement systems, U.K) at 25ºC. The experiments were performed at atmospheric pressure using 200ml/min of dry air as the carrier gas. Water vapour concentrations were measured and maintained with 10% steps between the concentrations from 0 to 90% RH followed by 5% step to 95% RH. The RH was then decreased in a similar manner.

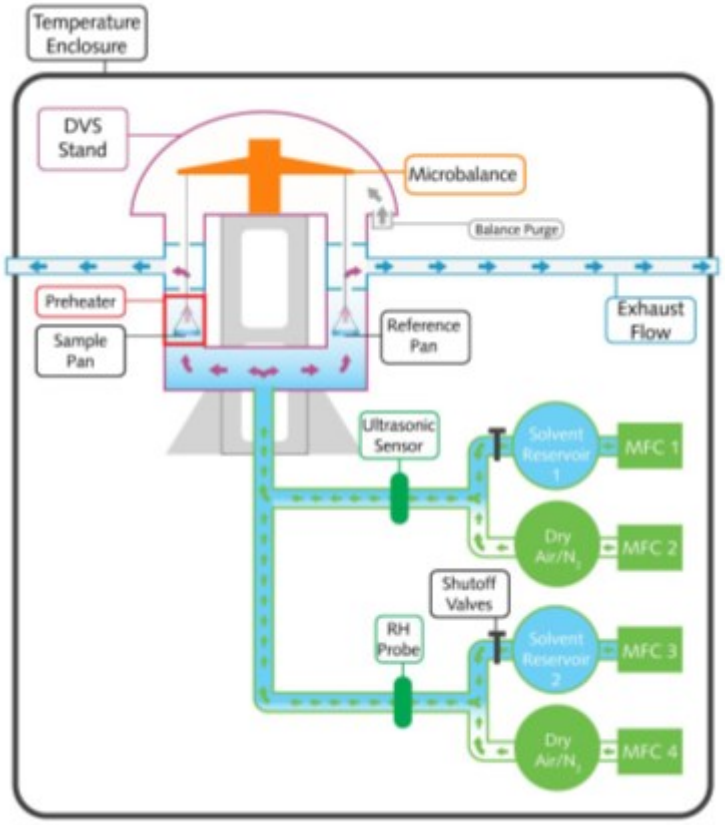


Figure 3.14: Schematic of SMS Dynamic Vapour Sorption (*DVS Adventure - Advanced Water Vapor Sorption Analyzer*, 2024)

Samples of chicken feather fibre mat and polypropylene pad weighing 6g were dried at the experimental temperature for 4 hours in a dry airflow before introducing different concentrations of water vapour. DVS measures the uptake and loss of moisture during the cycle gravimetrically using a high-resolution micro balance ($\pm 0.1 \mu g$). The rate at which the material

equilibrates at each humidity level and the overall shape of the adsorption/desorption curve were also studied. The DVS was also used to analyse samples soaked in engine oil.

3.6.2. Results and Discussion

According to the DVS Analysis, the chicken feather fibre mat has a bulk adsorption dominated mechanism and the polypropylene pad has a surface adsorption dominated mechanism. The chicken feather fibre mat has a mass change in water vapour of around 16% at 95% RH and a wide hysteresis gap, confirming a bulk sorption-dominated mechanism, as shown in Figures 3.15a and 3.15b. The uptake of chicken feather fibre mat is approximately 1.3% mass change in oil vapour at 95% RH, and the wide hysteresis gap confirms a bulk sorption-dominated mechanism, as shown in Figures 3.16a and 3.16b. At 95% RH, polypropylene uptake is only about 0.08% mass change in water vapour and the hysteresis gap confirms the surface sorption-dominated mechanism, as shown in Figures 3.17a and 3.17b. At 95% RH, polypropylene in engine oil absorbs only about 0.14% of the mass and a narrow hysteresis gap confirms a surface sorption-dominated mechanism, as shown in Figures 3.18a and 3.18b. The chicken feather fibre mat absorbs more moisture than the polypropylene pad, this is because natural fibres have both hydrophilic and hydrophobic surfaces. The oil vapor uptake was also higher than that of polypropylene pad.

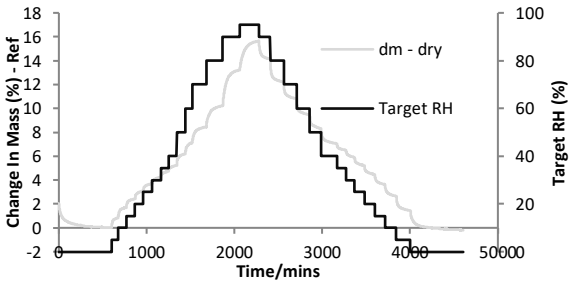


Figure 3.15a: CFM mass change in water vapour

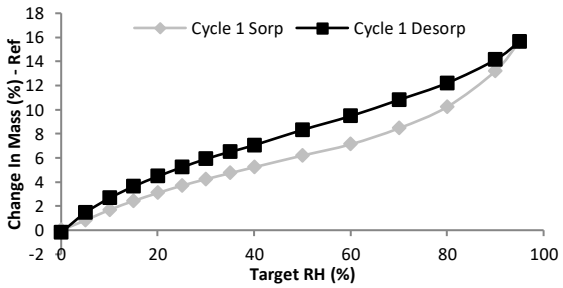


Figure 3.15b: CFM Isotherm in water vapour

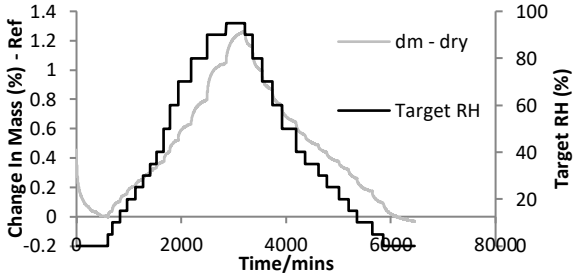


Figure 3.16a: CFM mass change in oil vapour

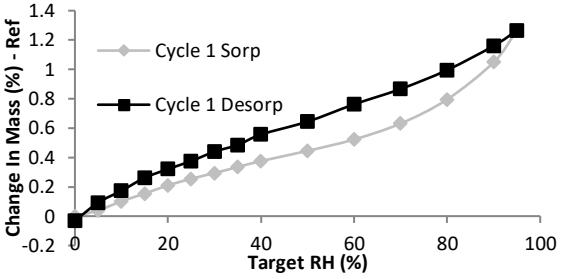


Figure 3.16b: CFM Isotherm in oil vapour

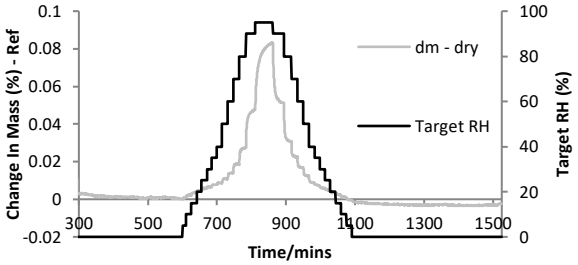


Figure 3.17a: PP mass change in water vapour

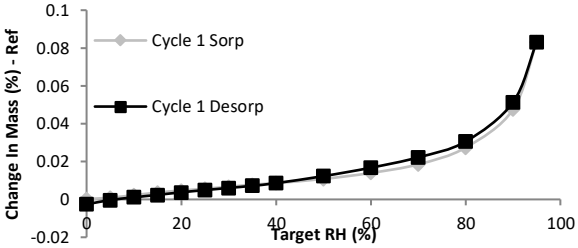


Figure 3.17b: PP Isotherm in water vapour

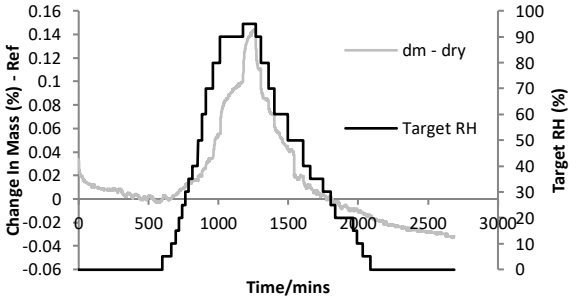


Figure 3.18a: PP mass change in oil vapour

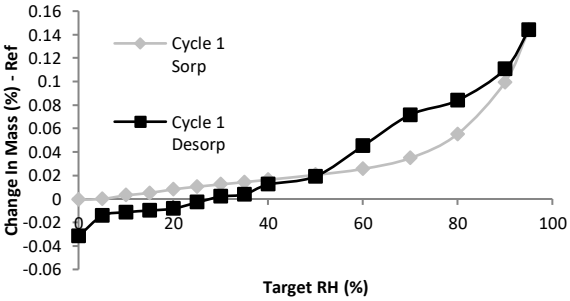


Figure 3.18b: PP Isotherm in oil vapour

3.7. Characterisation using SEM

3.7.1. Methodology SEM Analysis

The samples were dried overnight at 40°C and gold-coated before being examined with a Hitachi TM 4000 Plus tabletop microscope and imaged at 100x and 300x magnification. The SEM analysis was carried out in accordance with the ASTM E986-04 standard.

3.7.2. Results and Discussion

Figures 3.19a-b, 3.20a-b, and 3.21a-b depict the SEM images of the samples captured.

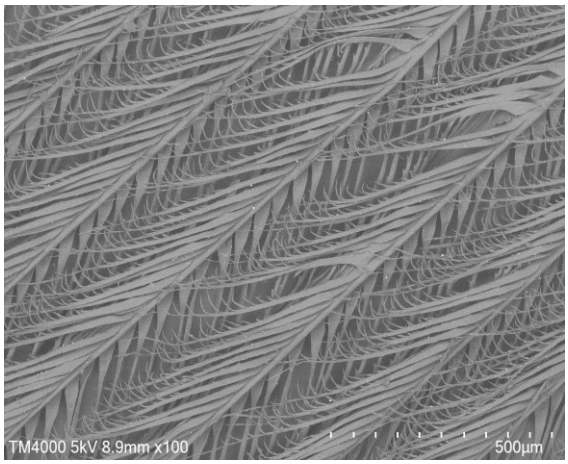


Figure 3.19a: SEM image of Whole Chicken (x100)

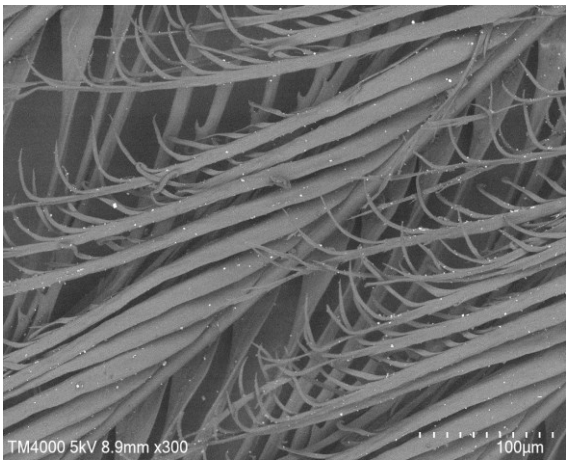


Figure 3.19b: SEM image of Whole Chicken (x300)

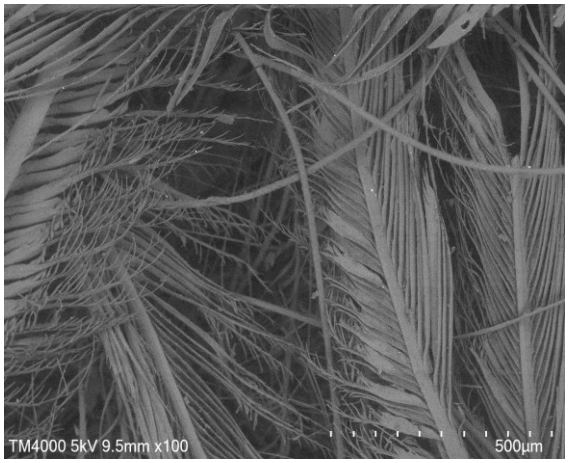


Figure 3.20a: SEM image of CFF Mat (x100)



Figure 3.20b: SEM image of CFF Mat (x300)

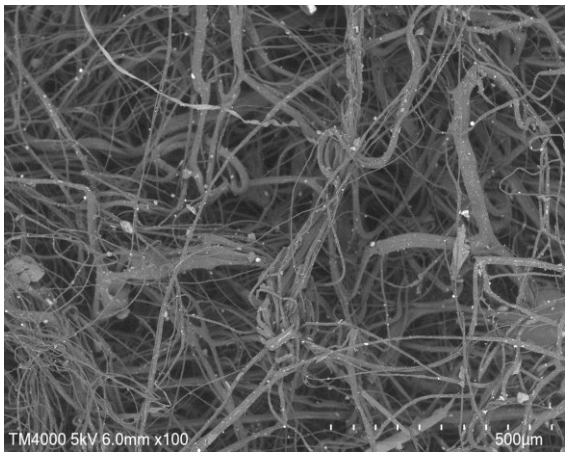


Figure 3.21a: SEM image of PP Pad (x100)

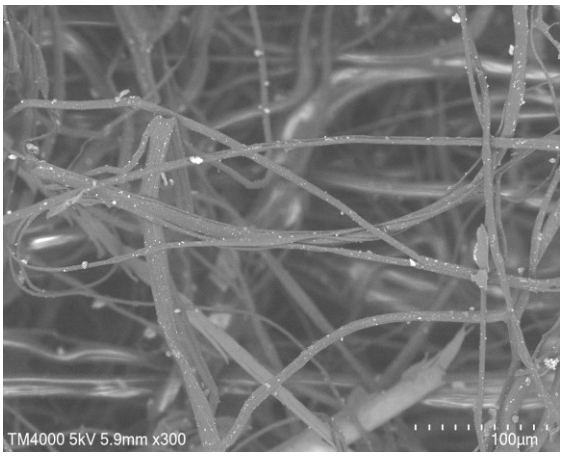


Figure 3.21b: SEM image of PP Pad (x300)

The result of the SEM analysis for the CFM reveals more clearly the rachis, the barbs and the barbules. There is also the presence of honeycomb shaped cells which confirms the existence of air pockets in the feathers. These air pockets will assist the feathers to float in water. Another observation is the entangled pores and rough surfaces which will promote its ability to trap oil. These findings support the claim that feathers have a physical structure that enhances their hydrophobicity (Isık and Demir, 2018; Tesfaye et al., 2018). The PP pad sample also showed interconnected porous structures, rough surfaces. The orientation of the methyl group in the polymer chain of PP pad has a major impact on its morphology (Tzounis et al., 2018). Both samples can be described as hollow fibres.

3.8. Characterisation using Water Contact Angle

3.8.1. Water Contact Angle Analysis

The samples were prepared by drying and pressing to be as flat as possible. At a temperature of approximately 20°C, a Kruss Drop Shape Analyzer (model DSA 100S) was used. During each test, 5µl of deionized water was dropped onto the surface sample, and the CA between the surface of the sample and a drop of water was measured according to the standard technique D5725-97 (ASTM, 1998). The same procedure was repeated for oil. The disappearance of the oil for both samples can be linked to penetration of oil into the surface.

When the samples came into contact with water, spheres formed on their surfaces, however, when the samples came into contact with oil, they absorbed so much oil that the CA could not be determined.

3.8.2. Results and Discussion

The water contact angle of chicken feather fibre mat was 116^{o} and that of polypropylene was 126^{o}. The surface microstructure and chemical composition are two factors that affect the wettability of a solid surface (Barthlott and Neinhuis, 1997; X. Zhang et al., 2013). The hierarchical arrangement of barbs and barbules, along with the presence of hydrophobic proteins and lipids, contribute to the hydrophobicity of chicken feathers. The roughness and nanoscale structures on the feather surface enhance the water repellency, leading to high water contact angles (Bhushan, B., et al. 2007). The polymer structure of the polypropylene pad also impacts its contact angle. The surface energy of the samples therefore relates to its surface

tension and contact angle. This high hydrophobicity of both samples will result in exceptional oil/water selectivity.

3.8.3. Water Sorbency Test

The evaluation of water uptake and buoyancy of Sorbent samples, tests in dynamic conditions were performed based on test methods described in the literature (Cooper and Gasaumel, 1993). In dynamic conditions, the samples were cut into squares for the solid samples, weighed and added to one-litre jars of water and then sealed. The container was fixed to a shaker table for 15 minutes at a frequency of 150 cycles per minute. The contents were allowed to settle, and observations were made and recorded on the adsorbent and the water. This procedure was repeated three times for validation of results. The equation used to compute the water sorption capacity is as.

$$\boldsymbol{S_{wc}}\left(\frac{\boldsymbol{g}}{\boldsymbol{g}}\right) = \frac{\boldsymbol{S_f}\,(\boldsymbol{g}) - S_0\,(g)}{\boldsymbol{S_0}\,(\boldsymbol{g})}$$

Equation 8. Water Sorption Capacity

Where,

$\boldsymbol{S_0}$ = Initial Dry Sorbent weight

$\boldsymbol{S_f}$ = Final weight of the sorbent sample at the end of the test

$\boldsymbol{S_{wc}}$ = Water Sorption Capacity

The experimental results of the water sorbency test are shown in Figure 3.22. The results show that all samples have a low water sorption capacity due to their strong hydrophobicity.

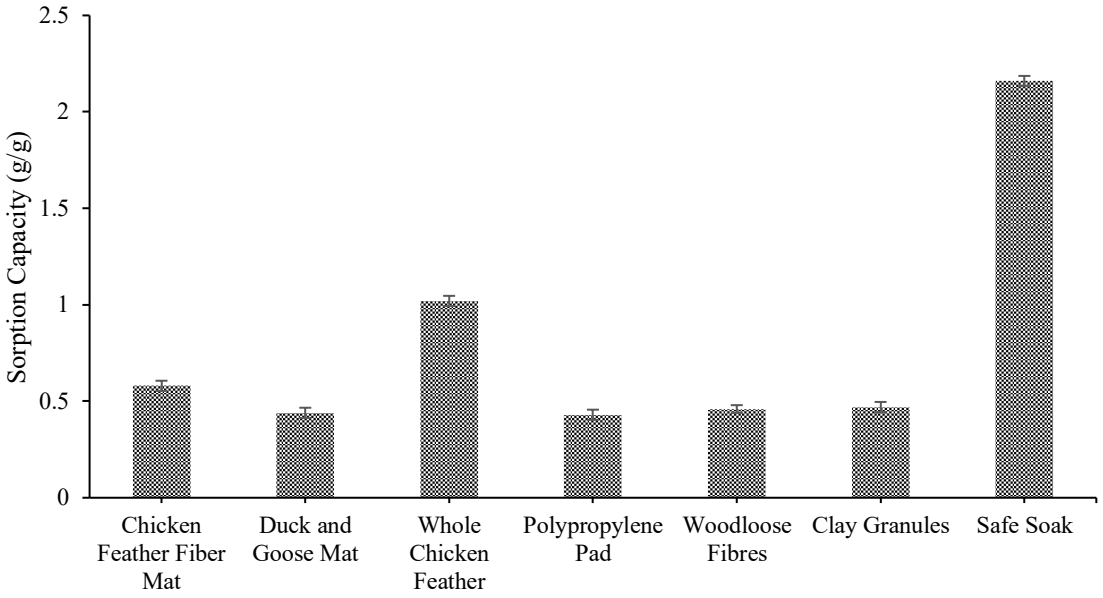


Figure 3.22: Mean Water Sorption Capacities of the sorbents (error bars showing standard deviation)

In this case, chicken feather fibre mat exhibits a higher water sorption value of 0.58g/g compared to the value of polypropylene pad, 0.43g/g. This suggests that chicken feather fibre mat has a greater capacity to sorb water compared to polypropylene pad. All the other sorbents also had below 1.0g/g except whole chicken feather and safe soak which was above 2.0g/g.

The water sorption behavior of materials is influenced by their intrinsic properties. Chicken feather fibre mat, being primarily composed of keratin, possesses hydrophilic characteristics. Keratin has polar groups, such as amine and carboxyl groups, which can form hydrogen bonds with water molecules. This enhances the water sorption capabilities of chicken feather fibre, allowing it to absorb and retain more water even though it is hydrophobic.

On the other hand, polypropylene pad is a hydrophobic polymer that repels water. Its low water sorption value of 0.43g/g reflects its limited ability to repel water. The hydrophobic nature of polypropylene pad inhibits water sorption and promotes water repellency, making it less effective as a sorbent for water compared to chicken feather fibre mat.

3.9. Oil Sorption Performance for Feather Materials and Conventional Products

3.9.1. Oil Sorption Capacity

The procedure for determining the oil sorption capacity generally followed the standard method F726-99 (ASTM, 1998). The short test for 15 minutes and the long test for 24 hours contact

time was carried out. After severally experiments it was observed that there is not much difference between the two methods and so the short test was used.

The sorption experiments were conducted in a static system at room temperature of about 20 ± 2°C. One-litre glass beaker was filled with 700ml tap water and 30ml of engine oil to obtain oil films of about 3ml thickness on the water surface. All samples were weighed, and initial weight noted. The chicken feather fibre mat and polypropylene pad were cut into square shapes and placed on the oil surface and left static for 15 minutes. They were removed with laboratory forceps and placed on tissue paper and allowed to drain for two minutes. Other samples were removed from the oil surface using a sieve.

The samples containing the sorbed oil was then weighed. The mass of the retained oil is the difference between the final and initial weight of the sorbent. The oil sorption capacity was calculated using the equation:

$$\boldsymbol{Oil\ Sorption\ Capacity}\left(\frac{\boldsymbol{g}}{\boldsymbol{g}}\right) = \frac{\boldsymbol{W_f - W_i}}{S_i}$$

Equation 9: Oil Sorption Capacity

$\boldsymbol{Q}$ = Sorption Capacity

$\boldsymbol{W_f}$= Final weight of samples

$\boldsymbol{W_i}$= Initial weight of samples

$\boldsymbol{S_i}$ = Initial mass of the sorbed samples

Experiments were repeated three times, and the standard deviations were calculated. The same procedure was repeated for the other two oils peanut oil and vegetable oil used. Appendix 11.2.1 and 11.2.2 shows oil sorption capacity test for chicken feather fibre mat and polypropylene pad.

The saturation time was also observed for chicken feather fibre mat for engine oil, vegetable. And peanut oil. The weight after each 2-minute interval was noted and it was observed that for all three oils, the chicken feather fibre mat was saturated in the first two minutes of being exposed to oil and the initial two minutes were very rapid and then the rate of sorption reduced. The initial fast adsorption may be attributed to the initial adsorption onto the surface of the material and subsequent penetration into the microscopic voids.

The mean sorption capacities of feather materials and conventional sorbents for vegetable oil, peanut oil and engine oil under static conditions after 15 minutes are presented in Figure 3.23. The chicken feather fibre mat has higher sorption capacity than all other samples for the different oils.

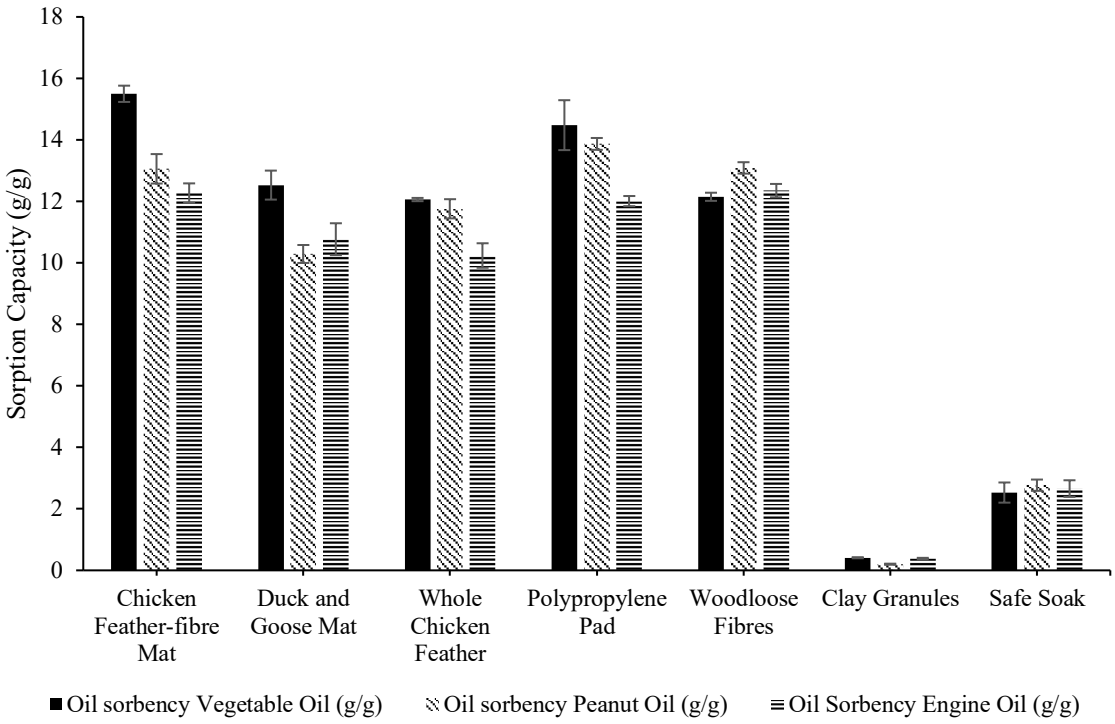


Figure 3.23: Mean oil sorption capacities of feather materials and conventional sorbents using different oils (error bars showing standard deviation)

The highest oil sorption values got from the test conducted, 15.5g/g for chicken feather fibre mat and 14.48g/g for polypropylene pad, represent the amount of vegetable oil that can be absorbed by the materials relative to their weight. 12.27g/g for chicken feather fibre mat and 12.01g/g for polypropylene pad, represent the amount of engine oil that can be sorbed by the materials relative to their weight. 13.06g/g for chicken feather fibre mat and 13.87g/g for polypropylene pad for peanut oil. The feather materials recorded a high sorption capacity for three samples of oil. All other samples also absorbed oil. These values indicate the ability of the sorbents to sorb oil and provide insights into their fundamental properties as sorbents.

The discussion of the result will focus on the standard samples for this research; chicken feather fibre mat and polypropylene pad. The intermolecular bonds formed between chicken feather and the oil leads to the sorption of oils on chicken feather fibre mat. Polypropylene pad is also

a poly-hydrocarbon and should interact more with the oil, leading to a higher sorption result but in the tests result above, chicken feathers fibre mat has higher sorption capacity. The difference could be attributed to the morphological structure of chicken feathers. Additionally, the presence of hydrophobic components, such as lipids and proteins, in the structure of feathers contributes to their affinity for oil-based substances. The structure and surface properties of chicken feathers, including their hierarchical arrangement, interlocking barbs, and barbules influence oil sorption. (Hu, X., et al. 2013).

Polypropylene, as a hydrophobic polymer, is known for its ability to sorb non-polar substances like oils and hydrocarbons. The surface chemistry and surface energy of polypropylene pad play a major role also in its oil sorption characteristics. (Guo, X et al 2014). Its high oil sorption value for all three oil samples indicates its effectiveness as an oil sorbent. The hydrophobic nature of polypropylene promotes the sorption of oil and prevents water uptake, allowing it to selectively sorb oil from oil-water mixtures as in these mixtures described (Huang. Y. et al. 2001).

For the higher density and higher surface tension oil which are vegetable oil and peanut oil, the sorption capacity of the CFM and PP pad were higher. A previous researcher observed this trend. (Abdullah et al., 2010). The similar oil sorption values between chicken feather fibre and polypropylene pad suggest that both materials have comparable oil sorption capabilities. However, it's important to note that the specific sorption behavior can vary depending on the degree of attraction between sorbate and the sorbent, the surface area exposed to the mobile particles, the concentration of the oil, pH and temperature of the liquid phase (Livingston, 2005). During the experiments it was observed that the oil first attached to the surface of both sorbents and spreads through the surface. The next action was capillary action which caused the movement of oil into the pores and then the oil begins to penetrate into the bulk and absorption occurs. (Nwadiogbu et al., 2016; Praba Karan et al., 2011). This confirms the oil sorption process is made up of three stages. The surface attraction is by Van der Waals forces between the fibres and oil (Tijani et al., 2016). During the oil sorption test, the sorbents after saturation point continued to stay afloat on the surface of the liquid and did not sink. From the DVS experiment in section 3.6.2, it was observed that chicken feather fibre mat had bulk dominated sorption mechanism while polypropylene pad had surface dominated sorption mechanism. And so, even though both absorption and adsorption take place in the oil sorption process, in the CFM it was observed that the absorption mechanism dominates.

3.9.2. Oil Recovery

Percentages of oil recovered was determined for all feather materials and polypropylene pad by compressing sorbents in a container that can retain the oil using a 2.3kg cement block, and the container was weighed once again. The mass of oil that could be recovered is the difference between the weight of the saturated sorbent and the weight following compression i.e., oil recovery in grams. Experiments were repeated three times, and the standard deviations were calculated According to this equation, the percentage of oil recovery was determined (Equation 10).

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

Equation 10: Oil Recovery (%)

Figure 3.24 shows oil recovery in percent for feather materials and polypropylene for vegetable oil, peanut oil, and engine oil.

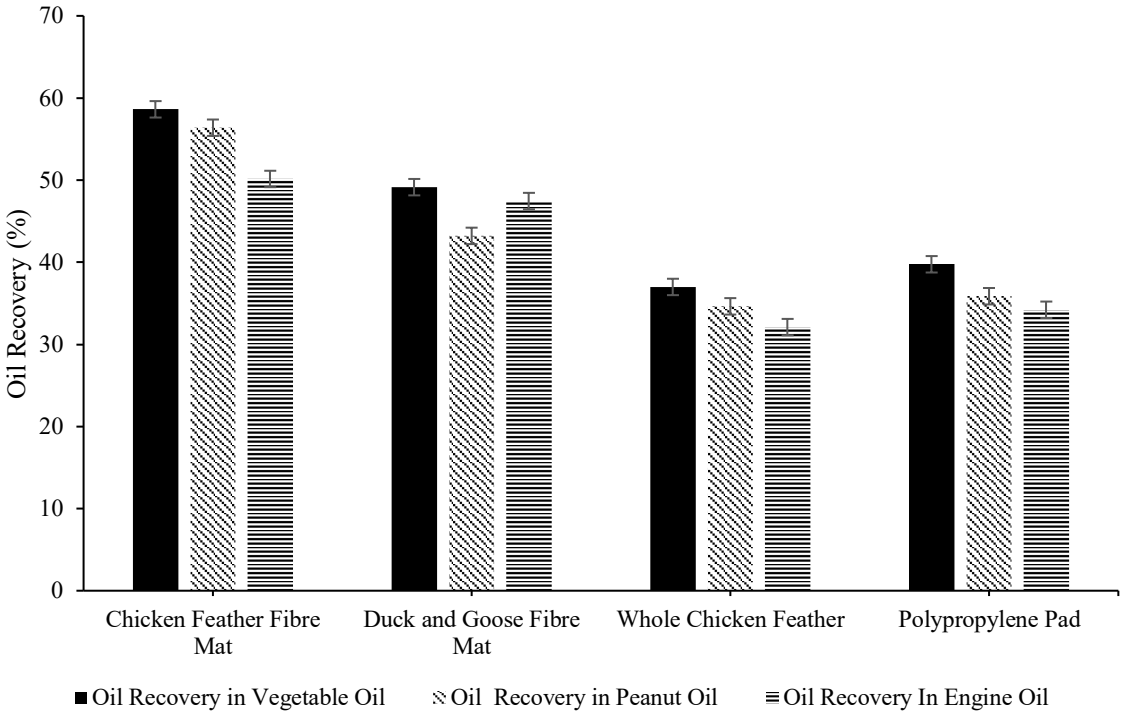


Figure 3.24: Mean Oil recovery in percent for feather materials and polypropylene pad in different oils (error bars showing standard deviation).

The experimental findings of the percentage engine oil recovery values are 50.14% for chicken feather fibre mat, 47.45% for Duck and Goose feather fibre mat, 32.1% for whole chicken feather and 34.21% for polypropylene pad, indicating the efficiency of these materials in recovering engine oil after sorption. The values for vegetable oil were the highest from 58.62%, 49.14%, 39.75% and 36.99% representing chicken feather fibre mat, Duck and goose feather fibre mat, polypropylene pad, and whole chicken feather, respectively. These values represent the proportion of the absorbed oil that can be successfully extracted or recovered from the sorbents and confirms that all sorbents, given their good values can be used for oil spill remediation. The feather materials, have a high porosity and a good structure for trapping oil within the fibres. The retained oil is held securely within the fibres and on application of compression, can result in a higher percentage of recovery than polypropylene pads. The bulk sorption-dominated mechanism observed in the chicken feather fibre mats and the surface-dominated mechanism observed in the polypropylene pads, for the dynamic vapor sorption test, may also have a role to play.

3.9.3. Reusability

The reusability of chicken feather fibre mats was investigated by the sorption-squeezing procedure under identical conditions from the standard method used for oil sorption capacity test. This was repeated as often as the material allowed for without major damage, or until the sorption capacity reached its minimum without further increasing. Experiments were repeated three times and the standard deviations were calculated.

Figure 3.25 shows the recorded sorption capacities for 5 cycles of reuse of chicken feather fibre mats in vegetable, peanut, and engine oil. there is a considerable reduction in sorption capacity after the first cycles but no major damage in the piece of CFM sample and PP pad occurred until after the 5^{th} cycle. During the squeezing process, the CFM recorded a higher oil recovery because it is able to recover much oil from the bulk of its material and so able to absorb oil in subsequent cycles more than the PP pad which has much of the oil sorbed trapped on the surface and will not allow the penetration of more oil into its bulk. A sorbent can be reused when it does not deteriorate or lose its original form immediately after use and can still absorb oil. A similar result was obtained for the polypropylene pad in Figure 3.26, but no damage occurred even after the fifth cycle.

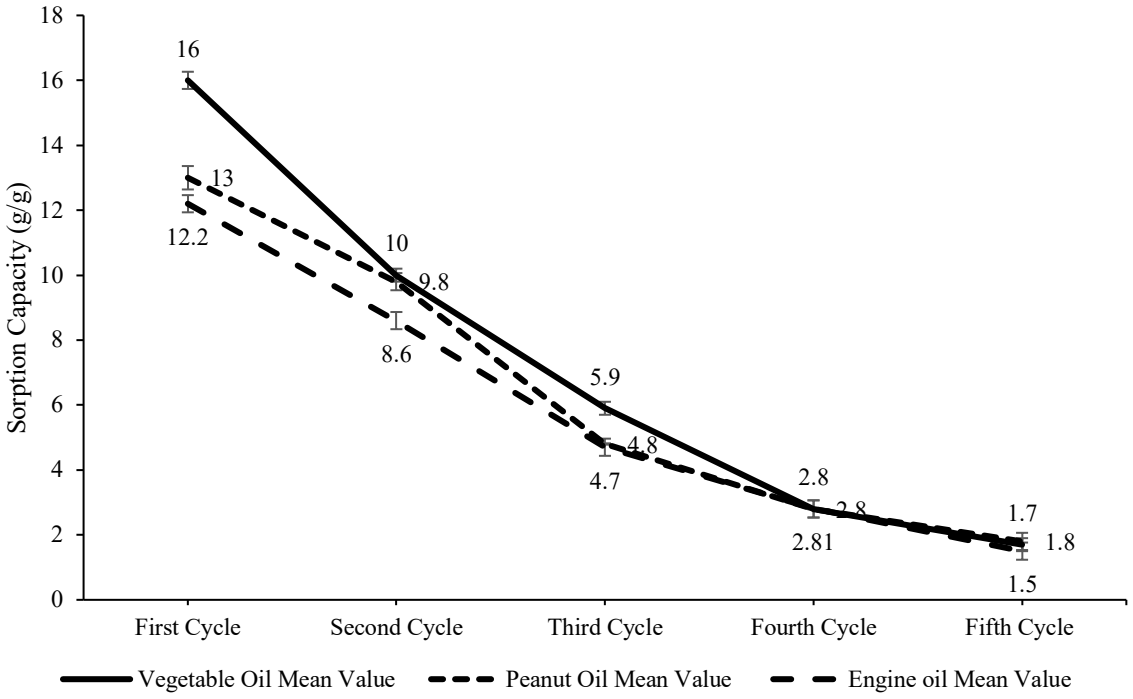


Figure 3.25: Mean sorption capacities of reused chicken feather fibre mats in different oils over 5 cycles (error bars showing standard deviation).

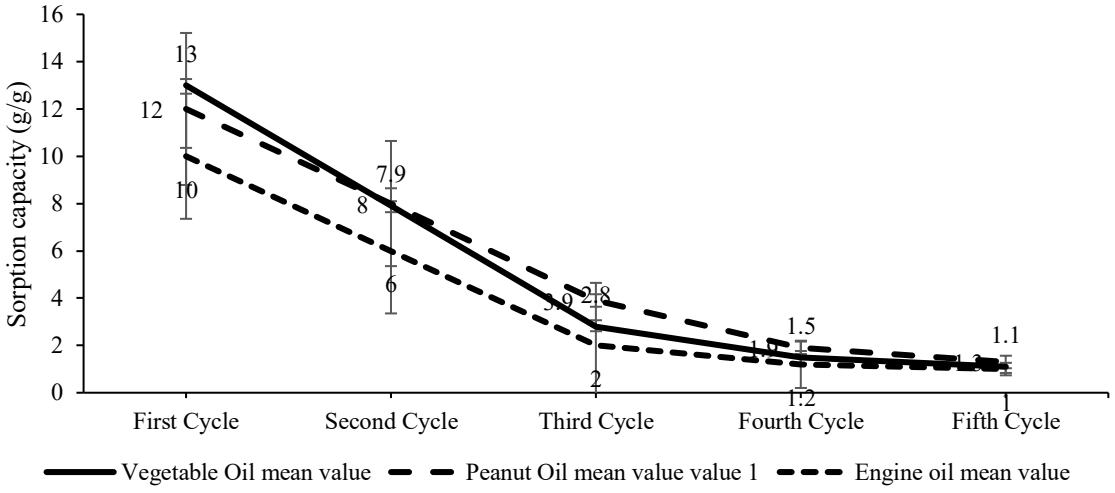


Figure 3.26: Mean sorption capacities of reused PP Pad in different oils over 5 cycles (error bars showing standard deviation).

The durability and resistance to degradation of chicken feathers are important factors affecting their reusability. Feathers with strong and intact structures can withstand repeated use without significant deterioration or loss of oil sorption capacity. Polypropylene is also known for its

robustness and resistance to damage, allowing it to maintain its oil sorption capacity over multiple uses. Additionally, the nonpolar nature of polypropylene facilitates the removal of absorbed oil through simple cleaning methods, enabling its reusability (Guo, X., et al. 2014).

3.10. Conclusion

Table 3.10 is the summary of characterisation results and deduced interpretations which confirm that both chicken feather fibre mat and polypropylene pads are hydrophobic in nature. The iGC-SEA highlighted the surface energetics and surface chemistry of the samples, which are known to have significant implications for sorption-based processes. From the given result above, it was observed that polypropylene pad had exhibited a higher rating as a hydrophobic sorbent than chicken feather fibre mat except in the BET-specific surface area in oil. The higher BET-specific surface area of 13.67m^2/g for chicken feather fibre mat compared to 8.03m^2/g for polypropylene and the bulk sorption mechanism may have an impact on the higher sorption capacity, recovery and reusability displayed by chicken feather fibre mat compared to the polypropylene pad. More research into this behaviour is recommended.

The surface energy of the chicken feather fibre mat and polypropylene pad varied as a function of surface coverage. The dispersive component contributes significantly to the surface energy. It was also observed that the interaction of both samples with engine oil, affect the Total surface energy of the samples, there is a decrease in Total surface energy when polypropylene pad mingles with oil while an increase in Total Surface energy when CFM mingles with engine oil. The effect on the total surface energy can be as a result of the interactions between molecules on the surface of the samples and intermolecular forces. The polarity of the chicken feather fibre mat was higher, making it more hydrophilic than polypropylene. The chicken feather fibre mat had a lower cohesion energy than the polypropylene pad, and the polypropylene pad adhered more strongly to the engine oil.

Table 3.10: Summary of Characterisation Result

Characterisation Techniques	**Unit**	**(CFM)**	**Polypropylene Pad (PP)**
BET S. Surface Area	m^2/g	1.15	2.28
BET Surface Area in oil	m^2/g	13.67	8.03
Dispersive surface energy	mJ/m^2	42.45	53.20
Specific surface energy	mJ/m^2	6.85	6.26
Total surface energy	mJ/m^2	49.30	59.64
Dispersive surface energy in oil	mJ/m^2	55.55	58.21
Specific surface energy in oil	mJ/m^2	1.55	2.45
Total surface energy in oil	mJ/m^2	57.11	60.66
Specific free energies of Adsorption and Acid -Base numbers		Kb/Ka > 1	Kb/Ka > 1
Thermodynamic work of cohesion	mJ/m^2	Low work of cohesion	High work of cohesion
Thermodynamic work of adhesion	mJ/m^2	Low adhesion to engine oil	Greater Adhesion to engine oil
Dynamic vapour sorption	%	Bulk sorption	Surface sorption
Water Contact Angle		116º	126º

The results of the DVS test indicate that polypropylene has a greater surface absorption, whereas chicken feather fibre mat have a greater bulk absorption. CFM absorbs more water vapour than Polypropylene pad and also absorbs more oil vapor than polypropylene pad. The SEM result and water contact angle also align with the IGC result obtained that both sorbents are hydrophobic. As earlier discussed, for a sorbent to be good, it has to have high oil sorption capacity, high oil recovery and should be reusable. Table 3.11 contains the summary of result for oil sorbent performance.

Table 3.11: Summary of Oil Sorbent Performance

Oil Sorbent Performance	Chicken Feather fibre Mat	Polypropylene Pad
Oil Sorption (g/g):		
Engine oil	12.27	12.01
Vegetable oil	15.5	14.48
Peanut oil	13.06	13.87
% Oil Recovery:		
Engine oil	50.14	34.21
Vegetable oil	58.62	39.75
Peanut oil	56.38	35.86
Oil Reusability (g/g) third cycle:		
Engine oil	4.7	2
Vegetable oil	5.9	2.8
Peanut oil	4.8	3.9

The sorption capacities of feather materials were higher for vegetable oil, peanut oil, and engine oil. This was also observed for oil recovery and reusability. For the reusability of CFM and PP pad, at the third circle an oil sorption capacity of above 2.0g/g weight of sample was observed and there was no significant material deformation until after the fifth cycle. This high reduction can also be due to the method of oil recovery applied. To increase the reusability, a better alternative method, such as centrifugation, should be investigated.

The above tests confirm that the amount of sorption that occurs is determined by several factors, including, but not limited to, the surface microstructure of the sorbent and the properties of the sorbate. The study also confirmed that the chicken feather fibre mat removed oil from water through the process of absorption and adsorption. Overall, the CFM had a high sorption capacity, high oil recovery and reusability.

Chapter 4 - Characterisation and Oil Sorbency Performance of Local Chicken Feather Materials

4.1. Introduction

Local waste chicken feathers, white chicken feathers (Broiler CF), and brown chicken feather (Old layer CF) materials were characterised and their oil sorption potential was determined. These species of waste feathers were obtained from chickens that were locally reared in Port Harcourt, Rivers State, Nigeria. They were compared with the two standard sorbents used for comparison in this research work: chicken feather fibre mat, a natural sorbent, and polypropylene pad, a widely used commercial sorbent for oil spill cleanup. As in the previous chapter, the hydrophobicity and oleophilicity properties were assessed. However, due to limitations in the equipment available in the specific laboratory used in Nigeria, IGC-SEA, dynamic vapour sorption, and CA measurements were not carried out. The experimental tests done were XRF, SEM, Proximate Analysis (Moisture Content, Volatile Matter, Ash Content, Fixed Carbon), Bulk Density, Iodine Number, and Methylene Blue. The reason for selecting SEM analysis has been discussed previously in Chapter 3, so only the benefits of XRF, Proximate Analysis, and other experimental tests will be highlighted in this introduction.

X-ray fluorescence (XRF) is a non-destructive technique used to determine the presence of components, qualitatively and statistically, in a sample (Mark and Michael, 1996). It utilises the interaction of materials with high-energy X-rays, which excite the atoms of the sample material, causing them to emit secondary X-rays that are unique to each element. By measuring the energy and intensity of the emitted X-rays, XRF accurately determines the elemental composition of the sample (van Grieken and Markowicz, 2002). XRF was used to determine the elemental composition of chicken feathers in a 2018 study by Hasan et al. According to the study, a variety of components, including calcium, sulphur, phosphorus, manganese, and potassium, are present in chicken feathers and are essential for their growth and durability. In a separate study, XRF analysis was used to examine the elemental composition of chicken feathers to determine if they were suitable for use as biosorbents in wastewater treatment (Khosa et al., 2013; Reddy and Yang, 2007). A significant advantage of XRF is that the sample material is neither altered nor destroyed; it is non-destructive, and it is also relatively quick, accurate, and precise. Since XRF analysers do not give radioactive emissions, they can be utilised in a variety of environments (Herrero-Alonso et al., 2016). It is useful for quality control and process monitoring because it can provide a quantitative analysis of elemental concentrations. As a technique for surface analysis, XRF also has significant disadvantages

and limitations. Depending on the X-ray energy and sample matrix, the depth of analysis is limited to a few microns to millimetres, meaning that complex or layered materials may not be good candidates for XRF analysis (Marguí et al., 2022).

In line with the objective of the chapter, the following parameters were selected as previous researchers have employed to characterise samples as contained in Table 4.2.

Table 4.1: Previous Sample characterisation research using Proximate analysis, bulk density, iodine number, and methylene blue adsorptive capacity.

Experiment	**Research Done**
Moisture Content	(Onoh et al., 2019): Kinetic, Isotherm and Thermodynamics Studies of the Adsorption of Crude Oil from Surface Water Using Esterified Rice Husk and Saw Dust.
Bulk Density	(Olabimtan et al., 2020): Determination of Selected Gravimetric, Frictional and Functional Parameters of Natural Corn as Crude Oil Sorbent on Surface Aquatic Environment.
Ash Content	(Wajima, 2020). Carbonaceous Adsorbent Derived from Sulfur-Impregnated Heavy Oil Ash and its Lead Removal Ability from Aqueous Solution.
Fixed Carbon	(Kusdarini and Budianto, 2022). Characteristics and Adsorption Test of Activated Carbon from Indonesian Bituminous Coal.
Iodine Number	(Asadullah et al., n.d.): Preparation and Adsorption Studies of High Specific Surface Area Activated Carbons obtained from the Chemical Activation of Jute Stick.
Methylene Blue	(Akuso et al., 2019): Production and Characterisation of Activated Carbon (AC) from Corncob for Methylene Blue and Chromium (VI) Adsorption.
Volatile Matter	(Dizbay-Onat, 2023). Evaluation of Physical Adsorption of the Activated Carbon Layers Used in the Commercial Face Mask Inserts.

Moisture content is the amount of water present in a material, expressed as a percentage of the material's total mass. It was deployed because it is a crucial factor in determining the stability and durability of materials, as excessive moisture content can lead to degradation, spoilage, and diminished performance (Nielsen, 2010).

Bulk density refers to the mass per unit volume of a substance, which is typically expressed in grammes per cubic centimetre (g/cm^3). It is a determining factor in the packing efficiency and flowability of powders, granules, and other particulate materials (Mansaray and Ghaly, 1999). Volatile matter is the portion of a substance that evaporates when heated to a particular temperature, typically expressed as a percentage of the material's initial mass. Fixed carbon is the portion of a material that remains after volatile matter has been removed by heating at a particular temperature, expressed as a percentage of the material's initial mass. Ash content is the inorganic residue that remains in a material after it has been completely burned, expressed as a percentage of its initial mass. It is frequently employed as an indicator of the mineral content and the potential for fouling and corrosion of fuels and other materials (Mansaray and Ghaly, 1999). The iodine number quantifies the iodine adsorption capacity of a material in terms of grammes of iodine adsorbed per kilogramme of material. It is frequently employed as a measure of the surface area and porosity of adsorbent materials, such as activated carbon and biomass. Methylene blue adsorption capacity refers to the amount of methylene blue dye that a material is capable of adsorbing, expressed in milligrammes of dye per gramme of material. It is frequently used to determine the surface area and pore structure of adsorbent materials, such as biomass and clay minerals (Nielsen, 2010).

The physical and chemical properties of a material, which can significantly impact its ability to absorb oil spills, can be determined using a variety of analytical techniques. The data obtained from these analyses can be used to evaluate a material's oil-sorbing capacity (Jadhav et al., 2019). A material with a high carbon and hydrogen content, a rough surface morphology, and hydrophobic properties may have a greater oil sorption capacity (Li et al., 2016).

4.2. Materials

4.2.1. Chicken feather materials

The sorbents used were local chicken feathers, as seen in Figures 4.1a and 4.1b, and chicken feather fibre mat (CFM), the standard sorbent used in this research.



Figure 4.1a: Old Layer Feather (OLF) - Brown



Figure 4.1b: Broiler Feather (BF) - White

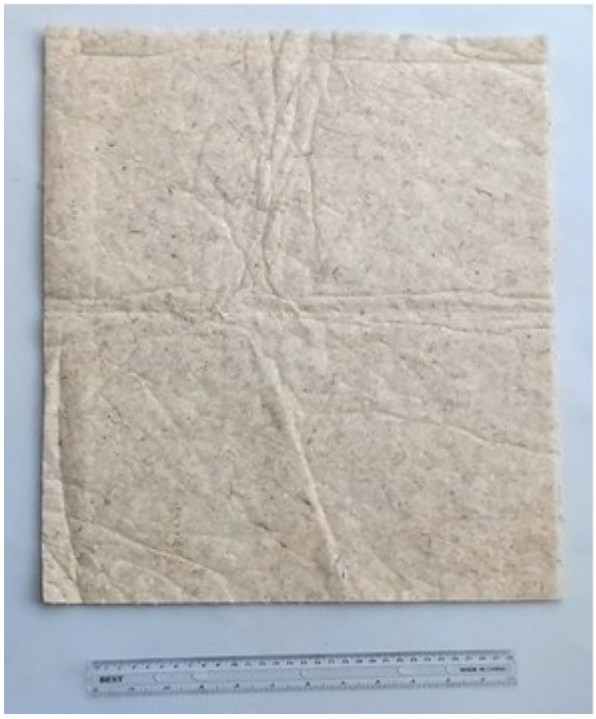


Figure 4.1c: 3M^{tm} Polypropylene Pad (PP Pad)

4.2.2. Polypropylene Pad

3M^{tm} petroleum sorbent static resistant pads (made from polypropylene and polyester), as seen in Figure 4.1c, were purchased from a local sorbent supplier in Nigeria and used in the analysis. The details of the 3M polypropylene pad are contained in Table 4.2.

Table 4.2: Properties of 3M^{tm} Polypropylene sorbents

Properties	**Polypropylene**
Manufacturer/ Code	3M
Thickness (cm)	0.5
Length (cm)	48
Width (cm)	40
Nominal Density (g/cm^3)	0.031
Buoyancy	Floats in water
Colour	Off White
Sorption	Hydrophobic/Oleophilic

4.2.3. Testing Oil

The vegetable and engine oil used for the experiments for oil sorbency performance was characterised for kinematic viscosity and density using Stanhope:5E1A Vin Kinematic viscometer and Anton Paar DMA 35 Densimeter in accordance with ASTM D445-04. Peanut oil was not used; only engine oil and vegetable oil were used to represent oil of hydrocarbon origin and non-hydrocarbon origin. Also, to represent high and low viscosities. The result is given in Table 4.3 below.

Table 4.3: Viscosity and density values for engine oil and vegetable oil at 25°C

Oil	**Kinematic Viscosity (cm^2/s)**	**Density (g/cm^3)**
Engine Oil	3.05	0.8988
Vegetable Oil	0.55	0.9287

4.2.4. Preparation of local Chicken Feathers

The local chicken feathers were obtained from a Creek Road chicken slaughterhouse in Port Harcourt, Nigeria. White chicken feathers are from broiler chickens, whereas the brown feathers are from old-layer chickens. Old layers are usually small, egg-laying poultry, but broilers are fast-growing and are used to obtain meat. (Organic Alberta, n.d.). They were washed with running water, sundried for two weeks, and then grounded with a mechanical household blender.

4.3. Proximate Analysis of Local Chicken Feather Materials and Polypropylene Pad

The proximate analysis (Moisture Content, Volatile Matter, Ash Content, and Fixed Carbon) of the samples was determined using the American Society for Testing Materials (ASTM D2866-2869). At least three replications were made for each sample.

4.3.1. Moisture Content

In line with this method, 5.0g of the sample was used in this experiment. The sample was placed in a petri dish and placed inside the oven. Each container was weighed before and after placing the sample. The sample was placed in a temperature-controlled oven with temperature fixed for 105℃ for 30 minutes. Afterward, the samples were reweighed and replaced in the oven. The process was repeated at 30, 20, 15, and 5 minutes until the uniform weight was recorded. The equation below was employed to achieve the moisture content of the sample.

$$\boldsymbol{Moisture\ Content} = \frac{\boldsymbol{MC_i - MC_f}}{\boldsymbol{M_i}} \times \mathbf{100}$$

Equation 11: Moisture Content (Dry Base)

$$\frac{\boldsymbol{MC_i - MC_f}}{\boldsymbol{MC_f}}$$

Equation 12: Moisture Content (Wet Base)

Where;

$\boldsymbol{MC_i}$ – Initial mass of sample before drying.

$\boldsymbol{MC_f}$ – Final mass of sample after drying.

4.3.2. Volatile Matter

Volatile matter was determined in accordance with ASTM D3175-02 (ASTM, 2002). Thus, 2.0g of each sample was heated until the sample was dry and then subjected to extreme heat of about 450°C, then weighed again. The volatile matter was calculated using the Equation 13.

$$\boldsymbol{Volatile\ Matter} = \frac{\boldsymbol{W_0 - W_1}}{\boldsymbol{W_2}}$$

Equation 13: Volatile Matter

Where,

W_0 = Weight of preheated sample

W_1 = Weight of sample after heating

W_2 = Weight of precombustion sample

4.3.3. Ash Content

This method involves preconditioning porcelain crucibles in a muffle furnace under a vent hood at an ashing temperature of 450℃ for at least 30 minutes. The crucible was then removed, placed in a desiccator, and allowed to cool. Then 1.0g of the sample was added into the crucible and tried in an oven temperature of 105^{o}C for 1 hour. The weight was recorded as Di; thereafter, the dried sample was sent back into the furnace, and the temperature was raised to 450^{o}C; after 1 hour, it was removed and placed in a desiccator and allowed to cool. Then, the final weight was taken to be D_f – ash weight.

The percentage ash content was determined thus:

$$AC\% = \frac{D_f}{D_i} \times 100$$

Equation 14: % Ash Content

Where D_i – Initial weight of the sample

D_f – final weight of sample.

4.3.4. Fixed Carbon

The percentage of fixed carbon was determined by using the values obtained from ash content, moisture content, and the yield of charcoal.

It is expressed mathematically as:

$$\%\, FixedCarbon = 100 - (\%\, MoistureContent + \%\, Yield\ of Charcoal + \%\, Ash)$$

Equation 15: % Fixed Carbon

4.4. Further Characterisation tests

4.4.1. Bulk Density

Bulk density was determined according to ASTM C29/C29M-07 (ASTM, 2007). Experiments were done in triplicates to validate the results. Thus, the sample was passed into an empty cylinder, which was weighed. The initial weight was W_1. The cylinder was then filled with the sample to the brim and overflowed. The excess of the sample was carefully scraped from the top of the cylinder by gently moving the edges of the spatula perpendicular to and in contact with the top surface of the cylinder, ensuring that the spatula is prevented from scoping or removing the sample from the top of the cylinder. The sample was then tapped for ten minutes. The volume of the packed sample was recorded as V_s. If W_2 is the weight of the sample and the cylinder, the weight of the sample was obtained by;

$$\boldsymbol{W_s = W_1 - W_2.}$$

The bulk density was determined by the equation below.

$$\boldsymbol{B_D(g/ml) = \frac{W_s}{V_s}}$$

Equation 16: Bulk Density

4.4.2. Iodine Number

The iodine number was determined using ASTM D1510-16 (ASTM, 2016). In line with this method, 2.0g of the samples were introduced into a clean and well-dried iodine flask. Then, 20 ml of 0.1M iodine solution was applied, and the flask was placed in a shaker/stirrer, which was then allowed to stay 24 hours before the mixture was filtered. Experiments were done in triplicates to validate the results.

The filtrate was collected in another flask, and 10g of the filtrate was titrated against sodium thiosulphate solution using starch as an indicator.

The value of the iodine number was determined using the equation below.

$$\frac{B_r - s}{Br} \times \frac{V}{W_S} \times M \times 126.91$$

Equation 17: Iodine Number

Where;

$\boldsymbol{M}$ – Molarity (mol/dm^3)

$\boldsymbol{B_r}$ – blank reading (ml)

$\boldsymbol{S}$ – Volume of thiosulphate used (ml)

$\boldsymbol{V}$ – Volume of iodine used (ml)

$\boldsymbol{W_S}$ – Weight of sample used (g/kg)

4.4.3. Methylene Blue (MB)

The batch adsorption experiment was carried out in accordance with ASTM C1777-20 (ASTM, 2020). Experiments were done in triplicates to validate results. The experiment was conducted in a set of 250ml flasks containing the sorbent and 10.0mg of MB solution with various initial concentrations (10, 25, 50, 100, 250, 500 and 1000mg). The flask was agitated in an isothermal water-bath shaker at 120rpm and 30± 1°C until equilibrium was reached. After decantation and filtration, the equilibrium concentration of dye in the solution was measured at 650µm using a UV – Spectrophotometer. The amount of dye adsorbed, and the percentage removal of MB was calculated using the equation below.

$$\boldsymbol{q_e} = (Co - Ce)\frac{V}{M}$$

Equation 18: Amount of Dye Absorbed

$$\%Removal = \frac{\boldsymbol{C_{i-}\, c_e}}{\boldsymbol{C_i}}$$

Equation 19: % Removal of Methylene Blue

Where:

$\boldsymbol{q_e}$ - Amount of dye in mg per gram of adsorbent

$\boldsymbol{C_0}$ and $\boldsymbol{C_e}$ – are, respectively, the initial concentration and equilibrium time of MB (Mg/g)

$\boldsymbol{V}$ – Volume of Solution

$\boldsymbol{M}$ – Mass of adsorbent

4.4.4. Results and Discussion

Figure 4.2a-d shows the moisture content, volatile matter, ash content and fixed carbon content results for broiler chicken feathers (Broiler CF), old layer chicken feathers (Old layer CF), chicken feather mat and polypropylene pad. The moisture content of polypropylene is the

highest at 2.2%, followed by old layer chicken feather at 1.83%, chicken feather mat at 1.78% and broiler feather at 1.42%. When the sorbents have high moisture content, the available surface area is occupied by the water molecules, which can reduce their sorption capacity (Munoz et al., 2017). For the volatile content, the old layer has the greatest amount of 62.07%, the polypropylene is 61.30%, the chicken feather mat is 27.72%, and the broiler is 15.22%. The higher the volatile content, the more interference in sorption capacity. The broiler feather had the least percentage of volatile matter.

The ash content is Broiler chicken feathers contain 7.83% ash, Polypropylene pad and old layer chicken feather both contain a percentage of 5.48%, while the chicken feather fibre mat contains 2.84% ash. For the oil sorption capacity to be high, the ash content will need to be low. The ash content in sorbents affects their porosity. A high ash content leads to a decrease in porosity, which can limit the available sorption sites and overall sorption capacity (Ahmad et al. 2005). Sorbents with a higher fixed carbon content tend to have higher sorption capacities (Diaz-Diestra et al., 2019). The percentage of fixed carbon in the samples was 68.02% in broiler chicken feathers, 31.86% for chicken feather fibre mat, and 31.06% for polypropylene pads, while the lowest concentration was 30.84% in old layer chicken feathers.

The proximate analysis results confirm that chicken feather materials have good sorption properties. Broiler feathers had the least moisture content; broiler chicken feathers had the least volatile content, closely followed by chicken feather fibre mat. Chicken feather fibre mat contains the least ash content, followed by old layer chicken, and finally, the fixed carbon was highest in broiler chicken feathers.

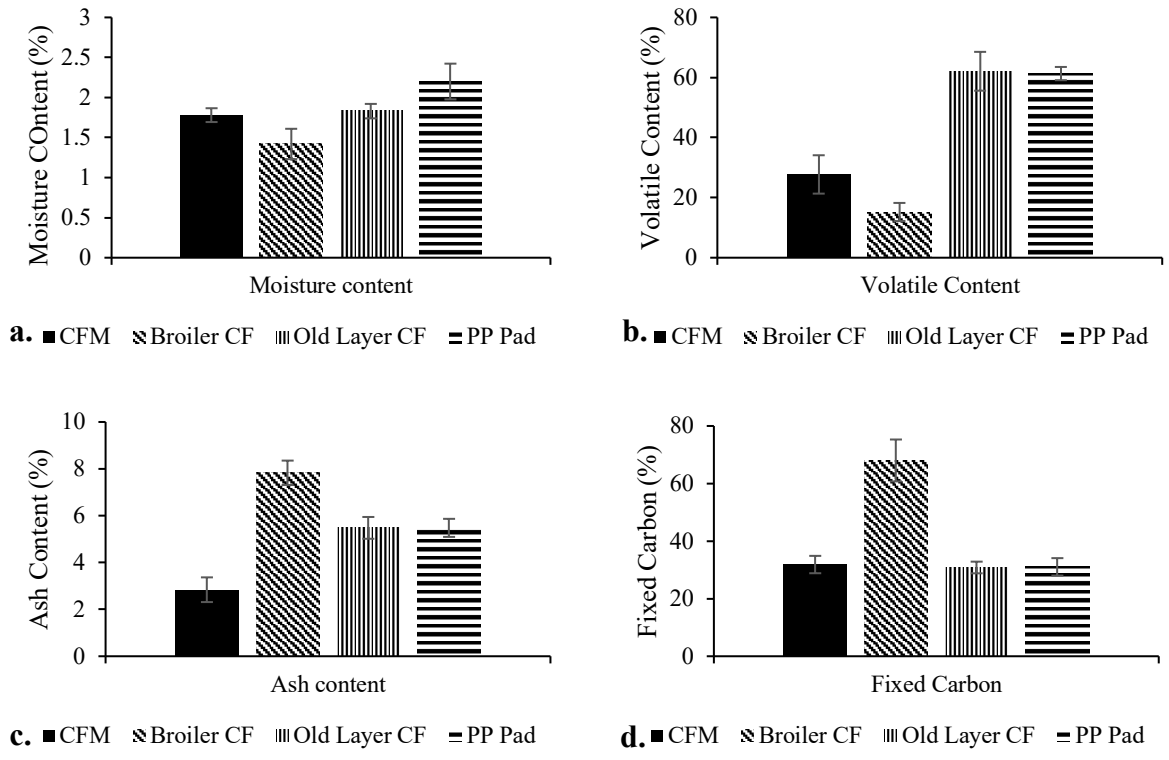


Figure 4.2a-d: Mean Proximate Analysis results for Broiler CF, Old Layer CF, CFM and PP Pad (error bars showing standard deviation)

A lower bulk density will result in better sorption capacity. Yargicoglu et al. characterised six different wood samples and granular activated carbon and observed that all carbonaceous materials presented a low bulk density reflecting high porosities. (Yargicoglu et al., 2015). The chicken feather mat has the lowest bulk density of 0.18g/cm^3. Chicken feather broiler and chicken feather old layer have the same result of 0.19g/cm^3, and polypropylene has 0.38g/cm^3. Bulk density is inversely related to the porosity of a sorbent material. Higher bulk densities indicate lower porosity, which means there are fewer void paces available for sorption (Lu et al., 2016). The iodine number is often used as an indicator of the adsorption capacity of a sorbent material such that, in most cases, a higher iodine number indicates a large surface area and higher sorption capacities (Tan et al., 2020). The chicken feather fibre mat has the highest iodine content (737.60g of iodine per kilogramme of carbon) and is closely followed by broiler chicken feathers with 579.59g of iodine per kilogramme of carbon. The old layer chicken feathers and polypropylene pad had values of 361.34g and 128.42g, respectively.

The methylene blue adsorptive capacity is related to the surface area and porosity of sorbent material, such that higher methylene blue adsorption indicates a large surface area and sorption

capacity for organic compounds. (Foo and Hameed, 2011). The chicken feather fibre mat had the maximum adsorptive capacity. The information gives an overall understanding of the qualities of these materials, which is helpful in deciding their usefulness as oil sorbents.

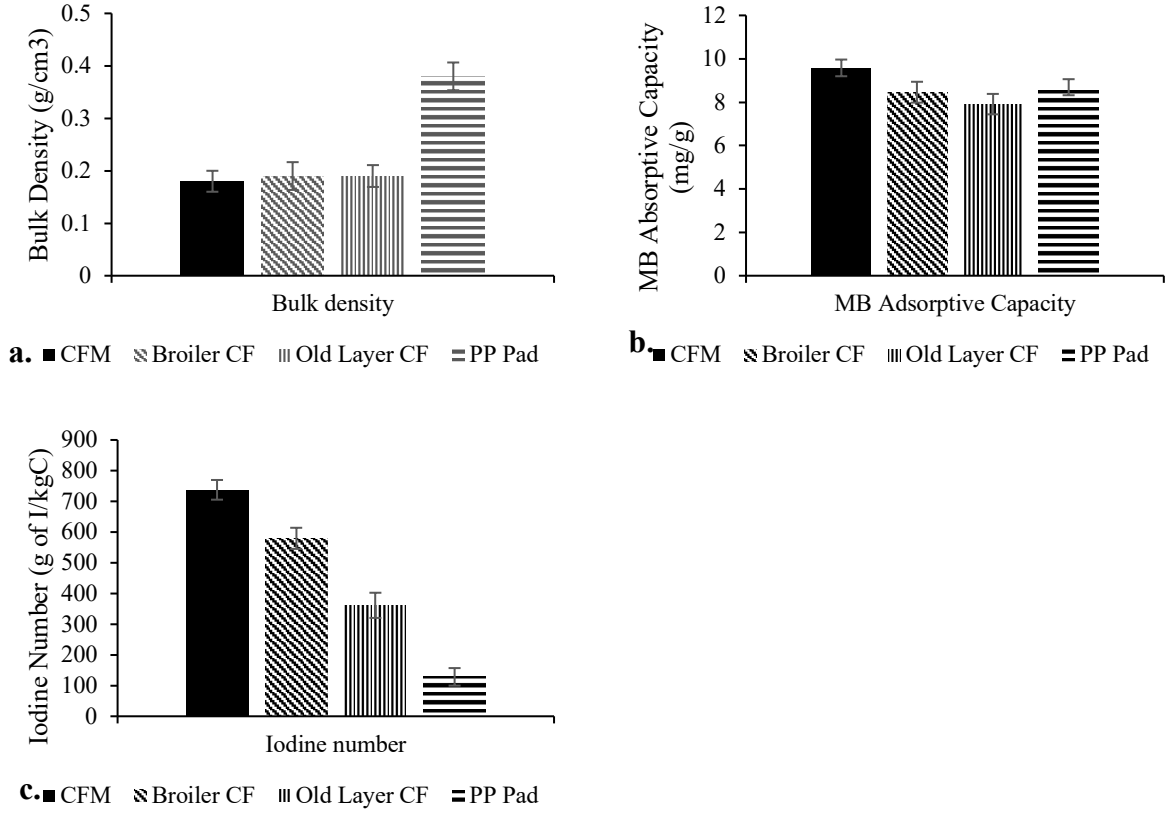


Figure 4.3a-c: a. Mean Bulk Density, b. Mean Methylene Blue Adsorptive Capacity, and c. Mean Iodine Number results for samples (error bars showing standard deviation)

4.5. Characterisation of Local Chicken Feathers using XRF Analysis

4.5.1. Methodology

X-ray Fluorescence spectrometry (XRF) was used to determine the major elements in the sample as a percentage of their composition. The samples were analysed with a xenematics Genius IF model, which produces high X-rays and permits quantitative analysis of the elements. The support of Taiwo Ademiluyi and the laboratory staff team is duly acknowledged in carrying out this experiment.

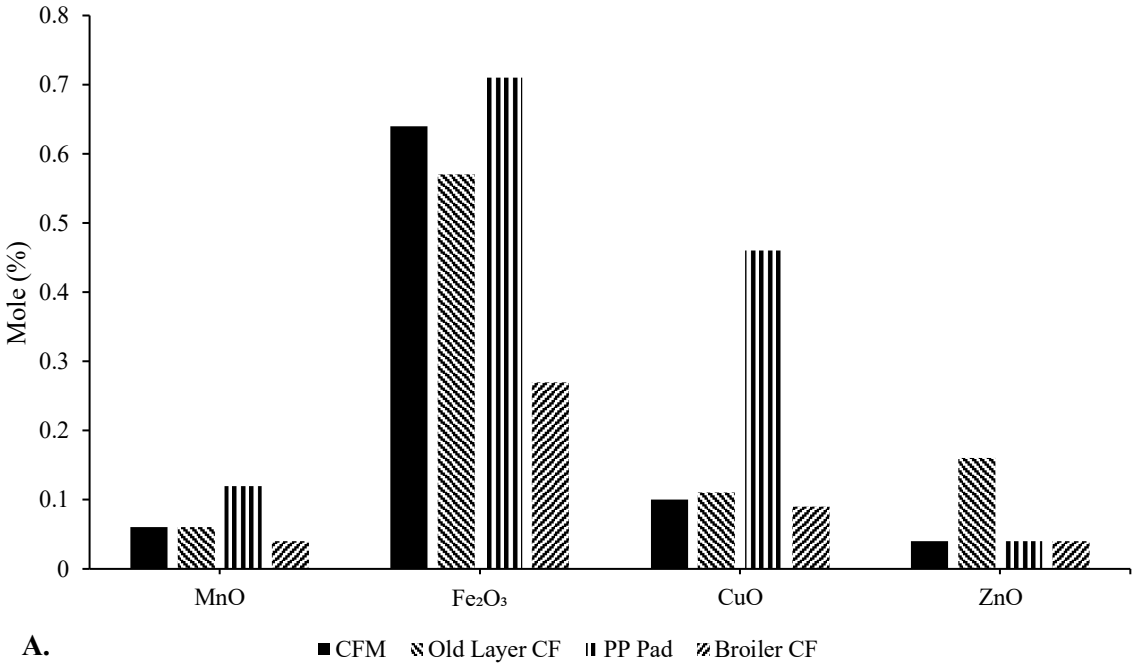
4.5.2. Results and Discussion

The findings of the XRF analysis are displayed in Figure 4.4a-b. The table displays the mole percentages of each elemental component in each of the four sorbents.

A variety of metal oxides and other substances, such as SiO_2, MnO, Fe_2O_3, CuO, SO_3, CaO, MgO, K_2O, Al_2O_3, and ZnO, are among the components as seen in Figure 4.4a-b. SiO_2, which is a prominent component of many mineral-based materials (Sangeetha et al., 2012), is present in substantial levels in all four sorbents.

The results show that all feather materials have much higher concentrations of SO_3 than polypropylene pads. The higher percentage composition of SO_3 could suggest a possible influence on the adsorption capacity of chicken feather materials through biosorption, ion exchange, chelation, coordination, and complexation (Solís-Moreno et al., 2021). The high percentage of quartz (silica oxide) in CFM (25.01%) and polypropylene pad (28.15%) could be responsible for a good chemically active surface area, as shown in Table 3.2. It confirms the research by (Behnood et al., 2013; Bulut and Aydin, 2006) that quartz has a property that enables it to retain micropores within the surface of the adsorbents.

The concentrations of SO_3, CaO, MgO, and K_2O in both the CFM and the local chicken feathers are substantially higher compared to those in the polypropylene pads. This may be because chicken feathers are organic and have higher concentrations of these components than synthetic polypropylene (Solís-Moreno et al., 2021).



A.

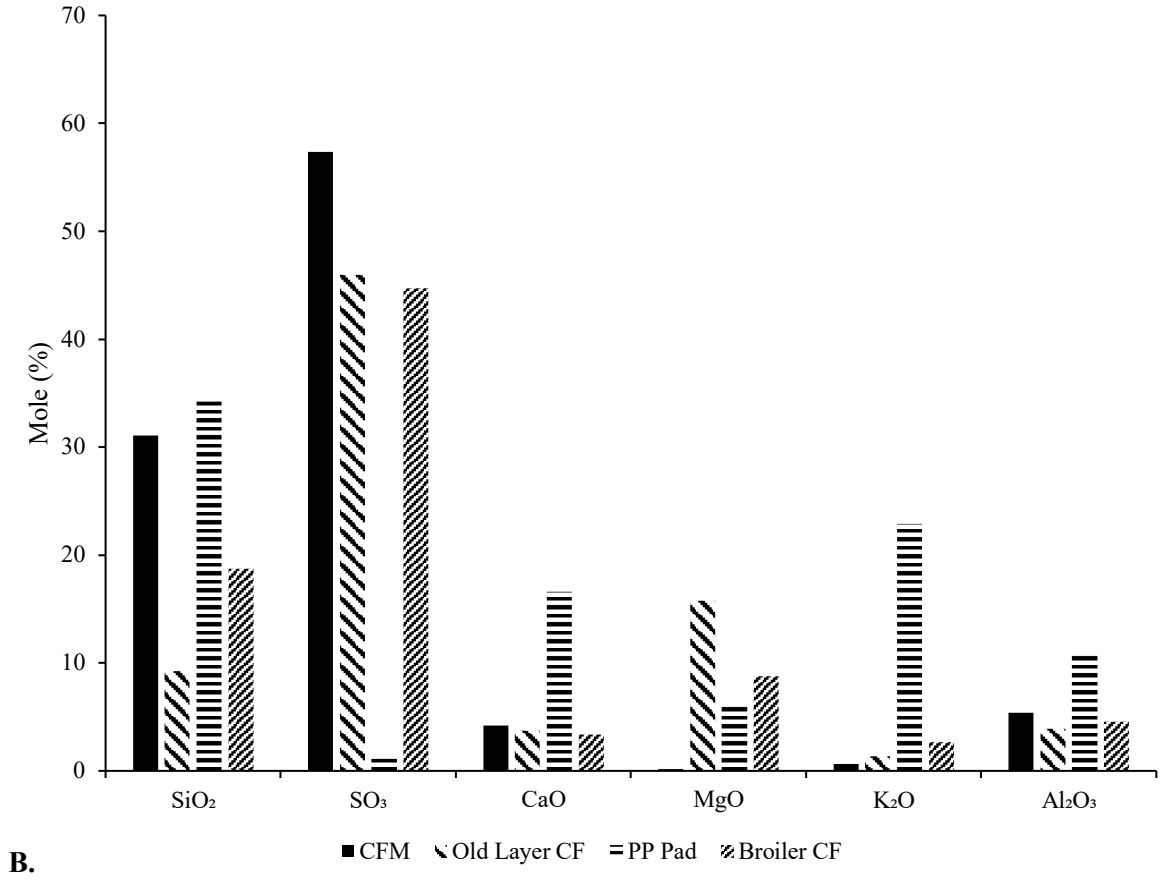


Figure 4.4a-b: XRF analysis results for samples.

4.6. Characterisation of Local Chicken Feather using SEM

4.6.1. Methodology

SEM analysis was performed utilising the model Phloem Pro X following the same procedure in Chapter 3 and in accordance with ASTM standard D6700 (ASTM EI 508-20) at a voltage of 15KV and a magnification of x1000.

4.6.2. Results and Discussion

The SEM analysis provided visual insights into the microstructure of the chicken feather materials and 3M-Hp polypropylene pad. The images obtained from SEM analysis allowed for the observation of the surface morphology of the materials.

The SEM images of the chicken feather fibre mat, broiler chicken feather, old layer chicken feather, and polypropylene pad can be seen in Figures 4.5a-b and 4.6a-b. The old layer and

broiler chicken feathers have very rough and highly irregular surfaces. Another visible feature is the pores on their surfaces. Entangled pore structure and rough morphology of sorbents promote oil retention (Wahi et al., 2013). Chicken feather fibre mats had a similar surface structure. The polypropylene also had pores and hollow structures but looked less rough than the other chicken feather materials.

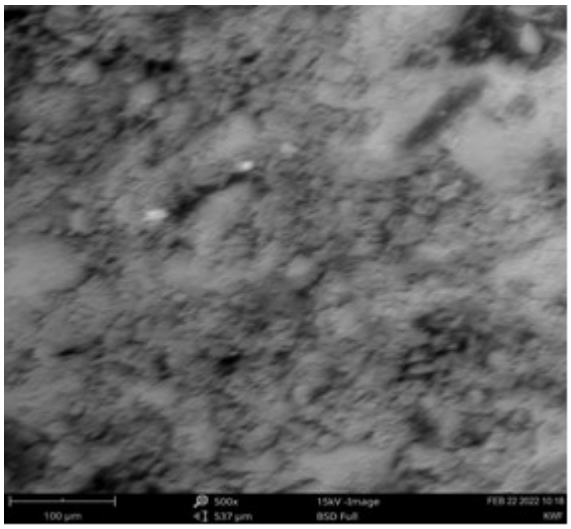


Figure 4.5a: SEM image of Broiler CF



Figure 4.5b: SEM image of Old Layer CF

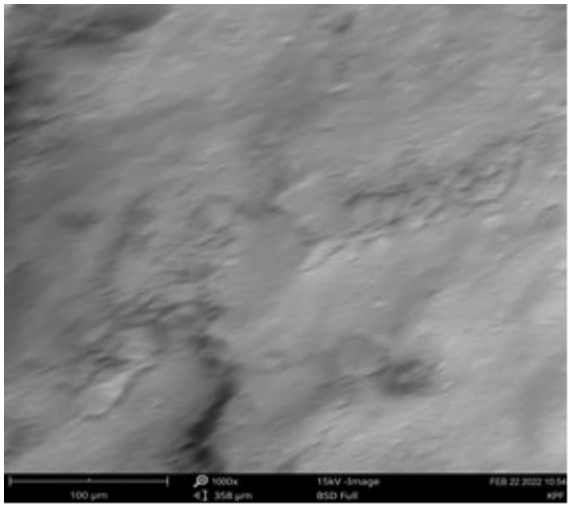


Figure 4.6a: SEM image of CFM

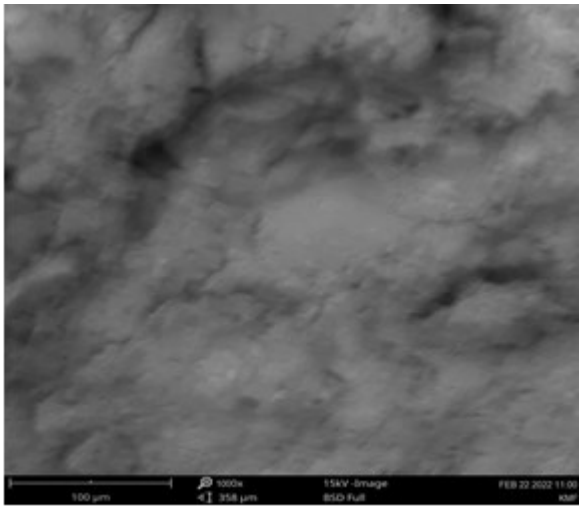


Figure 4.6b: SEM image of PP Pad

4.7. Sorbency Performance of Local Chicken Feathers

4.7.1. Methodology

The oil sorbency capacity for loose sorbents was determined based on ASTM F726-17. About 4g of each sorbent was placed into the flask containing the oil/water mixture, and the same procedure for the oil sorption capacity procedure used in Chapter 3 was repeated. The only difference was in the saturation of the sorbents with oil; a stainless-steel mesh was used to retrieve the sorbent, which had stuck together in a small roundish ball. The oil recovery and reusability were determined by the same standard procedure.

The oil sorption capacity, oil recovery and oil reusability of the two standard sorbents, chicken feather fibre mat and polypropylene pad, followed the same procedure in Chapter 3, Section 3.9.

4.7.2. Results and Discussion

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 4.7. The sorption capacity in engine oil was 15.7g/g and 10.4g/g. Given the same conditions, the chicken feather fibre mat had a sorption capacity of 18.4g/g for vegetable oil and 19.0g/g for engine oil. The polypropylene had a sorption capacity of 17.60g/g for engine Oil and 21.0g/g.

The oil sorption capacity with respect to engine oil was higher than the vegetable oil for all chicken feather materials. This means the oil with the higher viscosity and less density was easier to adhere to the surfaces and move into the bulk of chicken feather materials than the polypropylene pad. For vegetable oil with a lower viscosity and higher density, polypropylene pad had the highest sorption capacity compared to all other chicken feather materials. This result was different from the data obtained in Chapter 3, where CFM had the higher sorption capacity for both vegetable oil and engine oil. This could be a result of a different model of polypropylene pad used for the experiments. When compared to the chicken feather fibre mat and polypropylene pad, the local species have very good sorption potential.

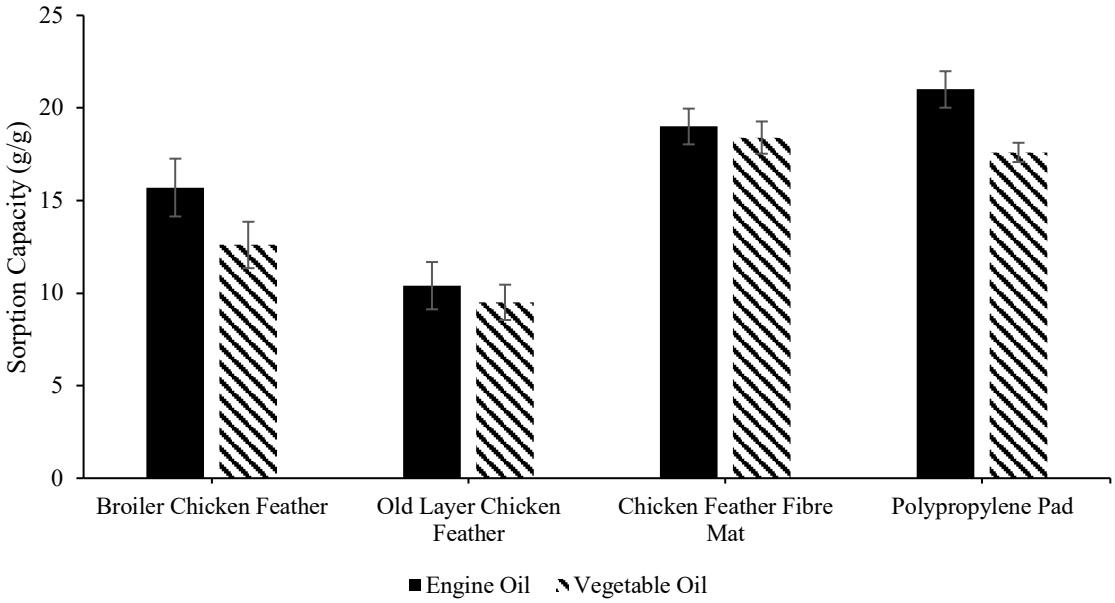


Figure 4.7: Mean sorption capacities for chicken feather materials and polypropylene pad (error bars showing standard deviation)

The oil sorption capacity with respect to vegetable oil for the samples followed the trend PP pad > CFM > Broiler > Old Layer. The trend for Engine oil was CFM > Broiler chicken feather > PP pad > Old layer chicken feather.

4.8. Oil Recovery

4.8.1. Results and Discussion

The percentage oil recovery of broiler chicken feathers and old layer chicken feathers in vegetable oil was 56.7% and 54.5%, respectively; in engine oil, it was 59.9% and 56.5%, as seen in Figure 4.8. The oil recovery for chicken feather fibre mat and polypropylene pad in vegetable oil was 69.9% and 74.3%, while for engine oil, this was 74.4% and 70.6%.

The oil recovery result trend was consistent with the oil sorption capacity for both engine oil and vegetable oil. For the engine oil, use CFM > PP Pad > Broiler chicken feather > Old layer chicken feather, and vegetable oil is PP Pad > CFM > Broiler chicken feather > Old layer chicken feather. The lighter oil could be squeezed out more easily from the bulk sorbent compared to the heavy viscous oil, which will stick to the bulk in the sorbent.

The lower oil recovery result in broiler chicken feathers and old layer chicken feathers is based on the amount of oil sorbed. Overall, the local chicken feather has good oil recovery.

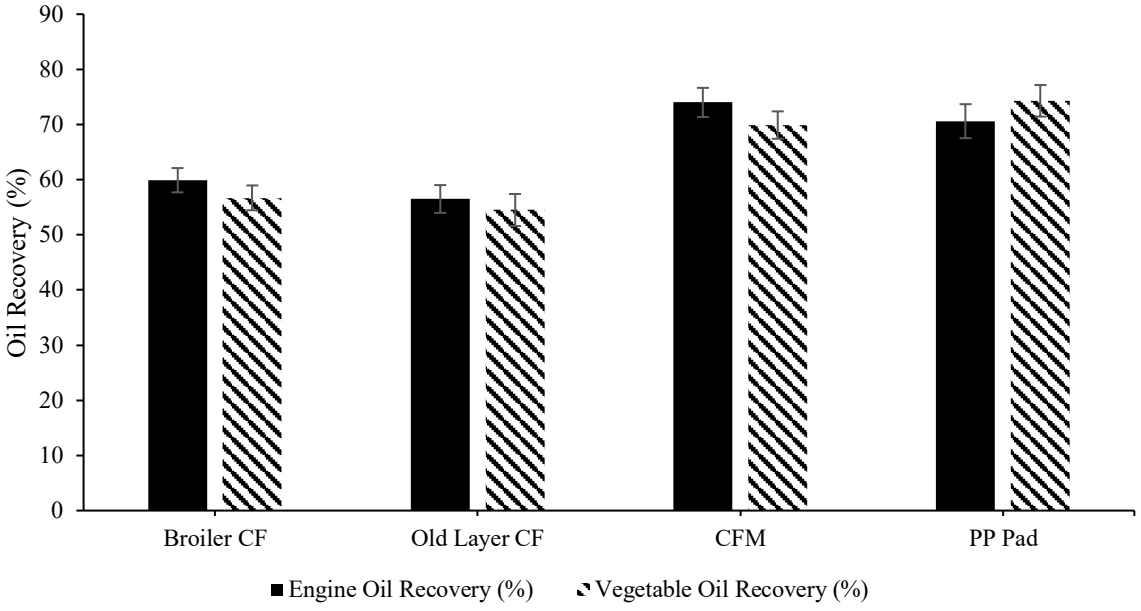


Figure 4.8: Mean oil recovery for chicken feather materials and polypropylene pad (error bars showing standard deviation).

4.9. Oil Reusability

4.9.1. Results and Discussion

The four sorbents were able to absorb oil for more than two cycles, so they can be designed for multiple uses. Not all sorbents have the capacity for multiple applications, but these sorbents can be graded as excellent because they can absorb oil for several cycles before deteriorating. Broiler chicken feather sorbent and old layer chicken feather sorbent retained their oil-sorption capacity following multiple uses (J. C. Wang et al., 2019). The reusability of oil sorbent materials depends on several factors, including the structure and composition of the material as well as the type of oil being absorbed. For instance, materials with a large surface area and hydrophobic characteristics, such as activated carbon, can retain their sorption capacity even after repeated use (Olu-Owolabi et al., 2018).

As seen in Figures 4.9 and 4.10, the oil sorption capacity is reduced after the first cycle, which suggests that oil is retained in the sorbent after pressure is applied to remove the oil. This remaining oil occupies part of the initial void spaces that should have been available to the new oil adsorbed in the following cycle. This results in a decrease in oil sorption capacity in the

subsequent cycles. Since the local chicken feathers were in shredded form, a lot of the particles were lost, and this may have affected the reusability, but they were still together in the rounded form and able to absorb oil.

As observed with chicken feather fibre mat and polypropylene pad in the previous chapter, there was a significant drop in the sorption capacity after the first cycle, but all samples remained intact even after the third cycle. It was discovered that the sorption capacity, oil recovery and oil reusability of different species of chicken feathers could differ even though, as earlier seen in Chapter 2, there is no chemical structure difference between broiler and old layer; the composition of different species are constant, but they may be slight variation may be as a result of the ratio of amino acid content which depended on the age, breed, environment and food as noticed by (Fisher et al., 1980; Martinez-Hernandez et al., 2005).

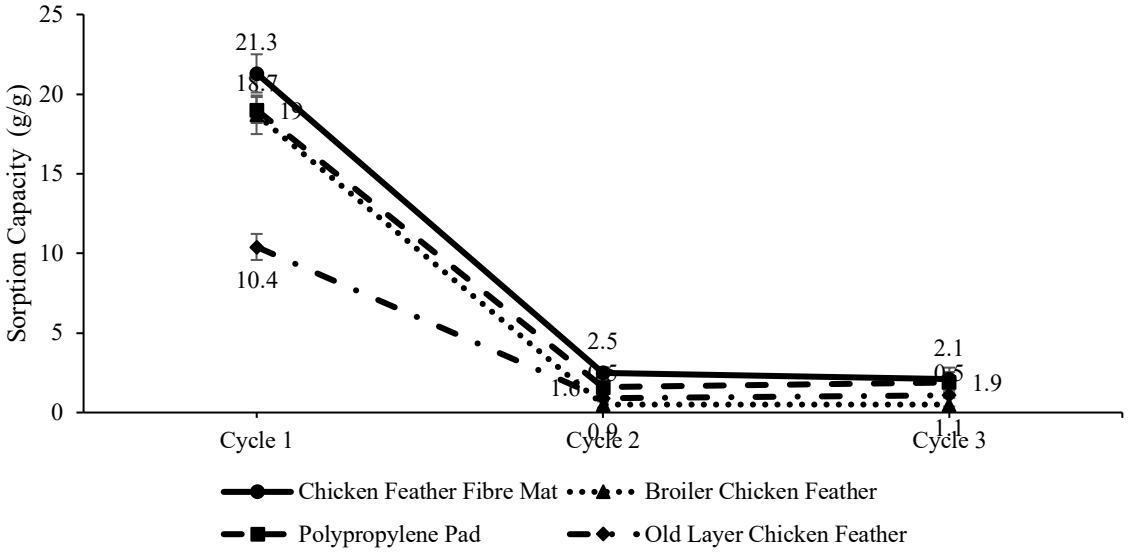


Figure 4.9: Mean sorption capacities of reused samples in engine oil over 3 cycles (error bars showing standard deviation)

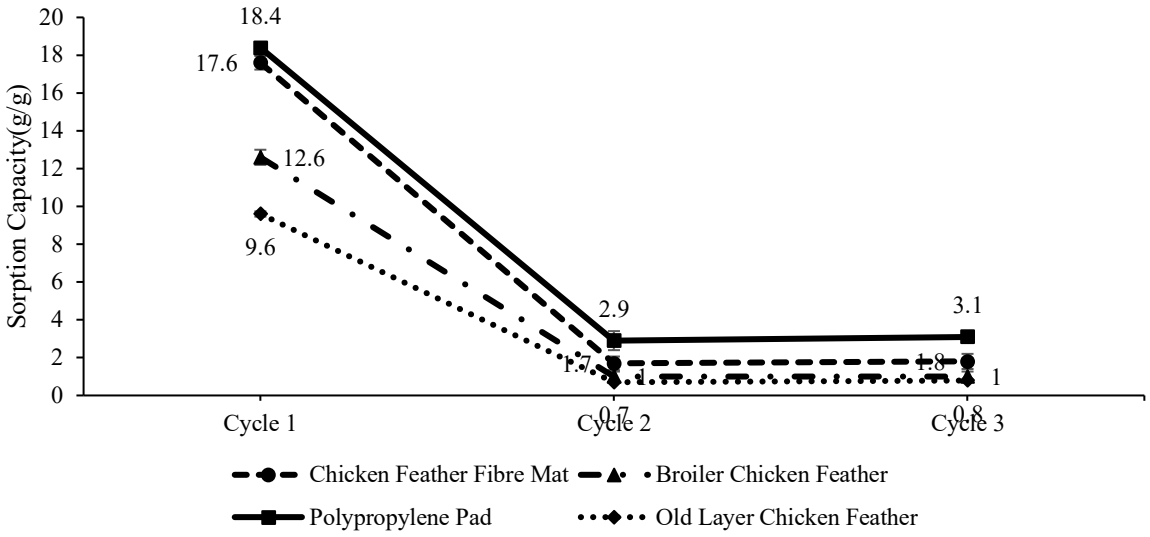


Figure 4.10: Mean sorption capacities of reused samples in vegetable oil over 3 cycles (error bars showing standard deviation)

4.10. Conclusion

The comparison of characterisation of local chicken feather materials with the standard sorbents confirms that they have good characteristics as sorbents. Even though chicken feather fibre mat and polypropylene pads demonstrate a higher sorption capacity compared to the local chicken feather materials in Table 4.4 below, the broiler chicken feather and old layer chicken feather had excellent sorption performance compared with other natural sorbents like barley straw, rice husk, and corn cob with sorption capacities of 7-12g/g, 6-10g/g and 5-7g/g, respectively, in Table 2.2 in Chapter 2.

Table 4.4: Summary of Oil Performance

Oil Sorption Performance	**White Chicken Feather Pad**	**Brown Chicken Feather**	**Chicken Feather Mat**	**Polypropylene Pad**
Oil Sorption (g/g):				
Engine oil	15.7	10.4	19.0	17.6
Vegetable oil	12.6	9.5	18.4	21.0
% Oil Recovery:				
Engine oil	59.9	56.5	74.0	70.6
Vegetable oil	56.7	54.5	69.9	74.3
Oil Reusability (g/g) - third cycle:				
Engine oil	0.5	1.1	2.1	1.9
Vegetable oil	1	0.8	1.8	3.1

The broiler chicken feather outperformed the brown chicken feather for both engine and vegetable oils for all the oil sorption performance tests carried out, but in the preceding chapter, the old layer chicken feather was used in the production of the chicken feather pillow because the location of the broiler chicken feather was far from the production site and transportation cost was very high.

However, the findings demonstrated local chicken feather materials are effective sorbents, confirming their suitability for use in sorbent production.

Chapter 5 - Chicken Feather Pillow Production

5.1. Introduction

The interest in the use of chicken feathers as a natural sorbent material has increased due to their low cost and abundance as a by-product of the poultry industry. The average weight of a reared chicken ranges from 1.7kg to 2.2kg and feathers constitute between 5 and 9% of the live weight (Urdaneta-Rincon and Leeson, 2004). However, these natural sorbents must be fabricated into pads, mats, or pillows, or placed within a mesh or bag if they are to compete with conventional products. According to a market research report published by Mordor Intelligence, the global sorbent market was worth USD 3.4 billion in 2020 and is projected to reach USD 4.8 billion by 2026, expanding at a CAGR of 6.1% during the forecast period of 2021 to 2026 (Nigeria E-commerce Market Insights, n.d.). As part of this research, Chicken Feather Pillows (CFP) were designed and manufactured for use as sorbents in oil spill remediation. Poultry feathers are waste materials in poultry industries and are usually given out to end-users at no cost by the poultry farmers. This chapter provides a comprehensive overview of the production process of Chicken feather pillows including collection, washing, drying, shredding, and packaging. The associated cost involved in producing chicken feather pillow was also determined.

In order to achieve the production of CFP, the work of other researchers involved in the use of feathers for industrial purposes and experimental procedures in the laboratory were examined for more complete understanding of the processes and procedures.

For the laboratory, small-scale use of feathers follows different approaches for washing and drying. Aderonke et al. (2020) studied the use of chicken feather waste as an adsorbent for the removal of Crude oil Polluted Water (CPW) in comparison with commercial Activated Carbon. They washed chicken feather waste in detergent containing tap water to remove stains, oil, and grease and then rinsed with distilled water to remove any detergent left and sun-dried to a constant weight.

Tesfaye et al (2018) approached the preparation of feathers differently as freshly plucked wet untreated chicken feathers were purified by washing with 0.5g/L aqueous solutions of SDS to remove the grease, and other wastes and kill potential harmful pathogens. The treated feathers were further purified by rinsing in distilled water for 10 minutes and then laid on aluminum foil and dried to a constant mass at 100°C in an air-forced dryer. Dried treated and untreated feathers were pulverized to 350μm size using a heavy-duty milling machine before use to

increase the surface areas of the feathers. Ifelegbu also has a different method, the CFs were soaked for 24 hours and washed with bleach to remove odour (Ifelegbu et al., 2016). The hard rachis was removed from the shaft using scissors while the soft barbs were washed and oven dried. The CFs were further soaked with sodium bicarbonate and dried in an oven set at 140°C for 24 hours. The dried samples were pulverised to increase surface area. From the above methods, the feathers were washed using a three-stage washing procedure, which was adopted. The drying procedures used, and the separation of fibers were also improved and employed to produce chicken fibres for oil sorbent.

A novel absorbent textile from chicken feathers was developed for use in oil spill remediation (Ye et al., 1999). In this process, the feather fibres were mixed with low-melt staple fibres and resin to produce different feather textiles. Another study investigated the production of value-added products from feather fibres and protein (Fan, 2008). In all the processes investigated, the focus was on how to adapt locally available equipment to produce fibres from chicken feathers that can be used to produce oil sorbent. When the process is cost-effective, the sorbent will be highly affordable, which is a key factor for the successful use of the local sorbent by indigenous companies. Therefore, instead of seeking to produce a mat or pad, a simpler approach of a sorbent pillow was the goal of this research.

The chicken feather pillow preparation process flow chart developed by this research work to manufacture this absorbent material for oil spill clean-up is presented in Figure 5.1 below.



Figure 5.1: Chicken feather pillow preparation process

5.2. Washing of Feathers

5.2.1. Sample Testing of Waste Feathers

Waste chicken feathers were collected from Rumuokoro chicken slaughterhouse located in Obio-Akpo LGA, Rivers State, Nigeria. By carefully sorting the feathers, those heavily soiled with blood and dirt were not collected. The production process was handled in batches of 4kg of waste chicken feathers.

The feathers were subjected to microbiological analysis for the detection, and identification, of microorganisms in order to determine the level of contamination. The support of Metaspec laboratory team is acknowledged for the quality test prior to washing of feathers and also after washing the feathers. The contaminants must be removed from chicken feathers in order to assure performance and environmental safety. In addition, feathers may contain pathogenic microorganisms such as bacteria and fungi, which pose a risk to the health of humans and animals (Matsakas et al., 2018).

In a previous study, it was noted that the presence of impurities in poultry feathers can reduce their ability to absorb oil (Sun et al., 2021). Researchers discovered that feathers treated with a surfactant to remove impurities had a substantially greater adsorption capacity than feathers that were not treated. Moreover, impurities can interfere with the chemical and physical properties of the sorbent material, impacting its overall performance and possibly resulting in product failure (Matsakas et al., 2018). Before using chicken feathers as a sorbent material, they must be thoroughly cleaned and freed of contaminants.

The potential for bacterial contamination of feather materials was assessed using a standard agar plate. In this investigation, colonies formed by feather extracts were counted and a colony-forming unit (CFU) was calculated. As a result of the presence of debris in the unclean samples, the concentration of debris in the unwashed feathers was high. The average CFU of unwashed feathers was approximately $5.8x10^5$cfu/g, which was acceptable in comparison to the standard of $1x10^6$cfu/g outlined in "Feather and down-Test Methods-Determination of microbiological state (The European Standard EN, 1884)".



Figure 5.2: Old layer Chicken Feather

5.2.2. 3-Stage washing procedure

A three-stage washing process consisting of pre-wash, main wash, and final wash was used by the researcher in order to provide clean feathers. Even though the structures and levels of pollution in different feathers can vary depending on species, the washing process must provide clean feathers to protect the public. Cleaning is done during the washing process, typically

using water, soap, detergent, or other chemicals. Feathers must first be washed and rinsed to maintain proper cleanliness and health. The process can be made more sustainable by using detergents with low impact on the environment. To clean, sanitise, and whiten the feather fibres, detergent was mixed with a lot of water. The filth and blood stains were removed from the material by properly washing it with a mild solution such as dishwashing soap. This also reduces the quantity of germs present in the feather samples. Using a patting motion, dirt was gently rubbed away by working fingers along the feather's length. Later, clean water was used to rinse the feather. Hydrogen peroxide (H_2O_2)-diluted water was also used as a mild antibacterial to wash the feather. In addition to being a powerful disinfectant, hydrogen peroxide can also be used as a bleaching agent. The active oxidizing agent is the perhydroxyl ion species (Howitt, 1995). It does not react with the feather fibre and so the mechanical properties of the feather fibre are retained. It is also environmentally friendly to use hydrogen peroxide because it breaks down to water and oxygen after treatment and it is safe for disposal (Takeuchi, et al, 2009).

A total of 2kg of feathers was watched in each batch. About seventy to eighty litres of freshwater was used to wash about two kilogramme of feathers. The wastewater was collected in a tank and dumped in an off-site wastewater treatment facility. Table 5.1 displays the various steps in the feather cleaning process at various water usage and chemical addition levels.

Table 5.1: Feather Washing Procedure

Stage	**Cleaning Description**	**Quantity of Chemical (H_2O_2) (Litres)**	**Physical Changes Observed**	**Target Substance Removed**
Stage 1	Wash with Water	0.0	Shrinking of barbs	Dirt and light stains
Stage 2	Wash with Soap and rinse	0.0	Shrinking of barbs	Blood and faecal stains
Stage 3	Wash with Chemical and rinse	1.0	Feathers were whiter	Heavy stains

5.2.3. Post-Washing Quality Test

Further tests to evaluate the bacterial loading were conducted. The unwashed samples contained debris, which was not observed in washed samples (red arrowheads). As a natural consequence, washed feathers exhibited a lower CFU than unwashed samples as observed in Table 5.2. The results did not reveal the presence of salmonella, bacteria, and faecal matter in

the feathers. This shows that the cleaning stage was successful and can produce legally compliant materials.

Table 5.2: Microbial Testing of Feathers

Feather Sample	Faecal coliform (cfu/g)	Salmonella (cfu/g)	Bacteria (cfu/g)	Odour
Before Washing	3.2×10^4	1.6×10^2	5.8×10^5	Heavy
After Washing	0.8×10^2	0.2×10^1	0.1×10^5	Light

5.3. Drying

5.3.1. Methodology

The drying process is a mass transfer method that involves removing water or another solvent from the washed feathers, using the four principles of excess water removal, evaporation, dehumidification, and temperature regulation. The drying procedure is crucial in making chicken feather oil sorbents. When feathers are dried properly, moisture is removed, which inhibits the growth of germs and lowers the likelihood of odour and mold formation (Bansal et al., 2017). Depending on the method used and the quantity of feathers being dried, the drying time for chicken feathers can range from a few hours to several days. It is essential to make sure the feathers are thoroughly dried to prevent decreased oil sorption performance.

The temperature at which chicken feathers are dried is among the most crucial factors to consider. Low temperatures may impede the drying process and lead to insufficient drying, while high heat may cause the feathers to become brittle and damaged. The ideal temperature for drying chicken feathers is between 60 and 80°C (140-176°F) (Bansal et al., 2017).

The feather materials were typically dried directly in the air, with high sunlight and relatively low humidity. The feather materials for one batch were laid out on an open surface for many days and were turned over numerous times in the sun. The materials used to make feathers undergo this natural process, which significantly lowers their water content. The type, exposure length, sunshine intensity, and research request all affect how much moisture is maintained following this process. Due to the availability of sunlight in the tropics, sun drying is a straightforward and affordable natural method.

In contrast, thermal heat generated by a handheld dryer enables more exact control of the drying process. By this automated procedure, hot air is used to eliminate moisture from the feather components very evenly. The resultant values obtained showed that the handheld dryer performed better with a higher percentage of water removed from the wet-washed feathers over a shorter time frame.

After being out in the sun for roughly two days, the feathers were dried for an additional 18 hours using a mechanical hand hair dryer (handheld dryer) for hot air drying. The two drying techniques employed were solar drying and industrial air-drying utilising a NOVA handheld hair dryer. (2000) 2000 Watts. 46℃ to 60℃. Each batch of feather dried was about 1.8-2kg in weight. Table 5.3 contains the drying method performance result. When using the handheld dryer for about 18 hours in total, higher drying performance was observed.

5.3.2. Results and Discussion

Table 5.3: Drying Method Performance Result

Trial	**Sunlight- Two days**			**Handheld dryer- 18hours**		
	Weight (g)		**% weight loss**	**Weight (g)**		**% weight loss**
	Before	After		Before	After	
1.	1800	1200	33.3	1800	1000	44.4
2.	1800	1300	27.8	1800	1000	44.4
3.	1800	1200	33.3	1800	1100	38.9

5.4. Chicken Feather Shredding

Four different machines were tested for their potential to create lightweight, air-trapping homogenous feather fibre bulk material. Some indicators were visual fibre appearance, creation of fines, and uniformity of shredded sizes.

5.4.1. Binatone BLG-452 Kitchen Blender

Binatone BLG-452 kitchen blender with a 1.5 litres capacity was used. A blender is an electrical kitchen appliance used for mixing liquids and soft foods together or turning fruit or vegetables into liquid. It can grind dried and wet food into a fine texture. It comprises a jar,

housing, blades, and lid. It is a countertop blender featuring a motor base beneath a jar with blades inside. The assembled jar snaps onto a coupler, which protrudes from the housing and attaches to the blade. The base of the blender is the housing, which contains a high-speed, fan-cooled electric motor as well as the speed controls. The blades are constructed of stainless steel for durability and maximum sharpness. The blades of the kitchen blender were not sharp enough, and the centrifugal force was not strong enough to shred the feathers. The jar is shaped as a tapered jar to effectively funnel food down into the blades. However, this meant that the feathers came out curled and bent over rather than shredded.



Figure 5.3: Industrial Blender

5.4.2. Sanyo SBS 260C Office Paper Shredder

The Sanyo SBS 260C office paper shredder is a mechanical instrument used to cut or shred sheets of paper into strips, fine particles, or smaller spiral fragments at a very slow rate. Belts and pulleys connect the paper cutter and the electric motor, which are the two primary components of the shredder machine. The motor powers belts and gears to transmit energy to the paper cutter, which shreds paper with sharp metal corners as it rotates. Typically, the paper shredder consists of a receptacle or container into which the shredded material falls. The top of the receptacle features a lid with a slot through which the paper is fed. The equipment evaluations were slow and required multiple shredding cycles to reduce the feathers. The

resulting fibres exhibited fragmentation and a degree of fibrillation, but the process was extremely sluggish because the feathers escaped the blocks and rollers.



Figure 5.4: Paper Cutter

5.4.3. Rotary Grinding Machine

The grinding mill consists of four major units: the hopper unit, the pulverising unit, the power unit, and the collection unit. The hopper unit holds the material to be crushed and transports it to the crusher unit in a hygienic manner. The crushing device is comprised of housing for the helical-profiled shaft. The welded helical profile moves and compresses the material as this shaft rotates. The crushing staff feeds the crushed material into the two-disc grinding equipment. One of the grinding machines' discs is stationary, while the other rotates with the shaft in the crushing section. This mechanism is responsible for grinding the material into fine particles. A ball bearing and a screw-stop structure are incorporated to govern the grinding efficiency of the disc. The feathers were fed into a machine curled and mashed but were not shredded to the required sizes for this investigation.



Figure 5.5: Rotary Grinding Machine

5.5. Preparation of Chicken fibres using Electric Motor-Powered Milling Machine

A locally fabricated electric motor-powered milling machine, as seen in Figure 5.6, was able to successfully shred the feathers. The specifications of the miller are as follows.

- Single phase
- 4HP electric motor
- 1400 RPM
- 115kg Weight
- 50Hz
- Triple blade (7” diameter) with an adjustable blade sitter

The shredding process of the fabricated milling machine produces fluffy barbs and barbules making it a preferred machine for this purpose.



Figure 5.6: Electric Powered Milling Machine

5.5.1. Structure and Operational Mechanism of The Miller

The structural diagram in Figures 5.7a-e below presents a different view of the fabricated miller to reveal its detailed components. The Isometric view (Figure 5.7a) shows a generalized view of the miller, revealing its external features particularly the rectangular outlet to receive the shredded feather. The left view (Figure 5.7b) shows the external view of the steel blending chamber/miller body. From the Top plan in Figure 5.7c, the blade compartment is revealed and comprises an 8mm fixed plate welded to the bottom of the miller plate having three equally angled iron blades and the rotary blades welded to an adjustable shaft plug. The rotary blades spin against the fixed blades to shred the feathers when powered by the electric motor. The front and back views as shown in Figure 5.7d and Figure 5.7e reveal the electric motor compartment from different angles.

5.5.2. Operational Mechanism and Production of Shredded Feather

The miller is plugged into a power source and the blade shaft plug is adjusted in order to shred feathers of average barb size of 2cm x 9cm to >0.3cm. Dry feathers were loaded into the steel chamber with a dimension of 420cm x 400cm which serves as a hopper unit. The feathers were

shredded or cut into the desired sizes by adjusting the lower blade shaft higher to narrow the space between the rotary blade and the fixed blade and the product was collected via the outlet box. The shredding process of the fabricated milling machine produces fluffy barbs and barbules alongside the hard/rough rachis and vanes. The rachis and vanes were manually separated and discarded since they can damage the delicate pillow materials. The fluffy shredded feathers are then collected for packaging into pillows.

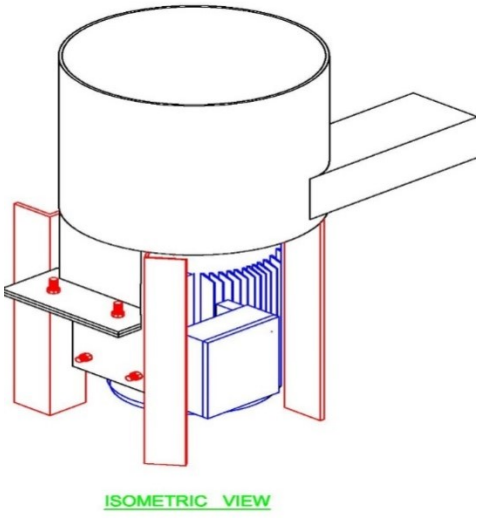


Figure 5.7a: Isometric View of Locally Fabricated Miller

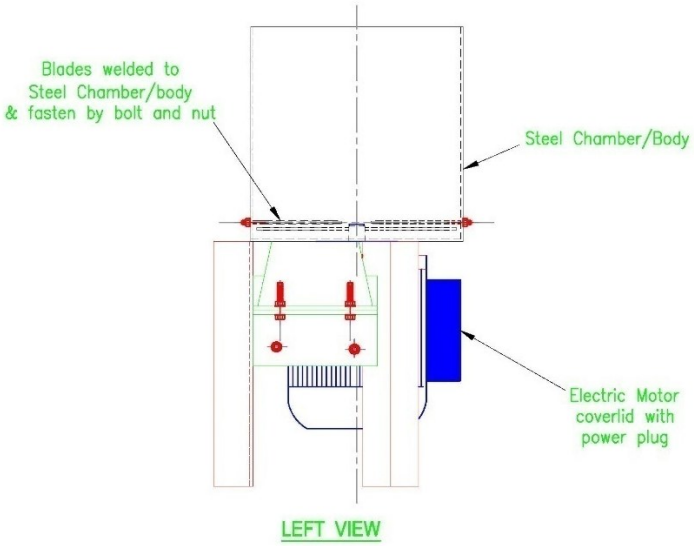


Figure 5.7b: Left View

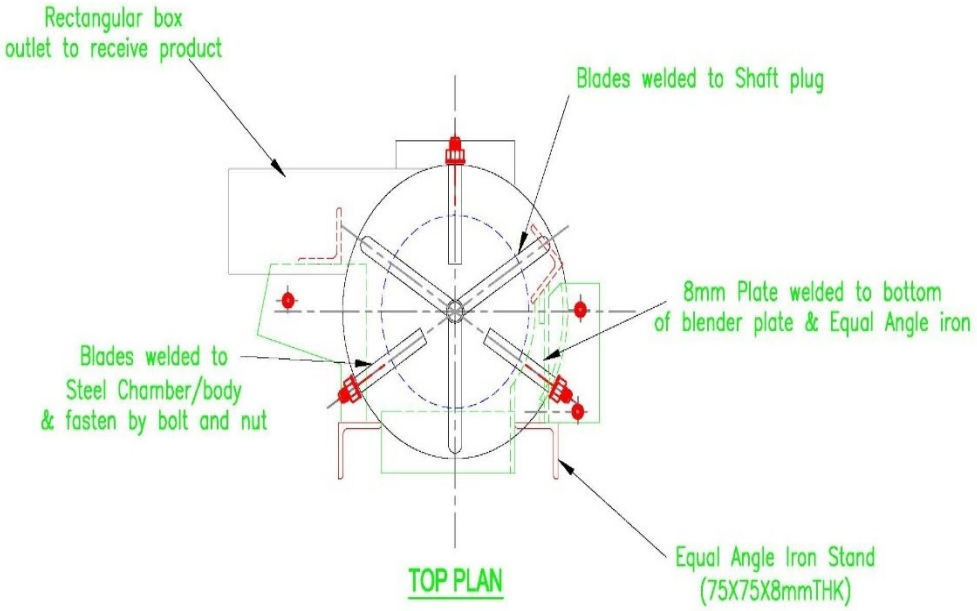


Figure 5.7c: Top Plan of Locally Fabricated Miller

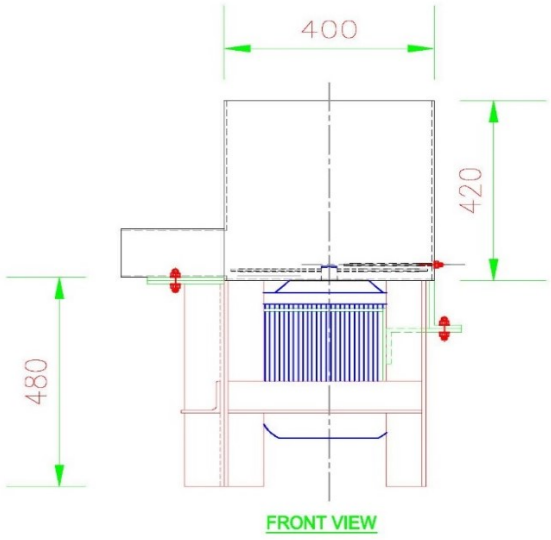


Figure 5.7d: Front View

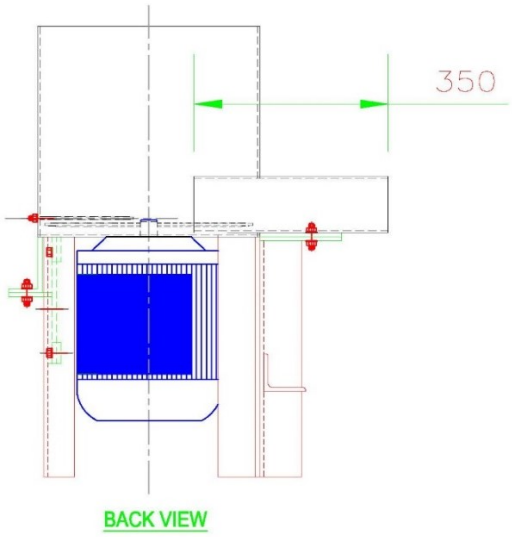


Figure 5.7e: Back View

5.6. Selection of Feather Pillow Casing

5.6.1. Introduction

The pillow casing containing the shredded feathers was permanently closed by stitching, instead of having an aperture at one end. There were two sizes of pillows produced; the larger ones weighed 205g and measured 14x9 inches, while the smaller ones weighed 115g and measured 10x7 inches per pad. The types of materials tested for pillowcase absorbency and permeability were cotton, microfiber (a material that is breathable, lightweight, and durable), polyester (a synthetic), linen, silk, and satin.

5.6.2. Methodology- Selection of Chicken Feather Pillow Casing

Figure 5.8a-e shows the five pillow casing materials procured and their material porosity was evaluated. The materials were composed of various pore sizes of silk and cotton. The subsequent tests confirmed that they would not interfere with the sorption procedure. A hazardous test review was conducted to affirm that the final material selection would not harm the aquatic environment.

Table 5.4: Properties and description of material

Description of Material	Material texture	Colour	Texture
Netlike polyester	Silk	Light blue	Loose
Organza	Silk	Brownish-gold	Very tough, brittle and sleek
Cotton	Microfiber	White	Tough
Nonwoven fusible gumstay	Cotton	White	Tough
Nonwoven Hair stay	Silk	White	Tough



Figure 5.8a-e: a. Netlike Polyester b. Organza c. Cotton d. Non-Woven Fusible Gumstay e. Non-Woven Hair Stay

The pore sizes of the materials were examined, and all five materials fulfilled the requirements. The porosity of the material was determined by flowing engine oil through it at a predetermined flow rate of 500ml/min, and the amount of oil that passed through was measured and recorded in Table 5.5.

Table 5.5: Pillow Material Porosity Test Result

Parameter	A	B	C	D	E
Initial weight of material (g)	280	280	280	280	280
Weight after 1st test	367	377	366	379	375
Weight after 2nd test (g)	369	374	364	376	377
Weight after 3rd test (g)	374	374	365	275	375
Average weight from the three tests (g)	370	375	365	375	375
Final weight of oil drained (Average weight - Initial weight) (g)	90	95	85	95	95

5.6.3. Discussion

In terms of material porosity, materials B, D, and E performed very well at 95%, while material C performed poorly with an 85% porosity rate. Material A had a porosity rate of 90%. The best-performing materials (B, D, and E) were then evaluated for their texture and feather-repelling capability. Material B was found to be brittle and too smooth for a pillow, whereas material E was too loosely woven and could be shredded by any rachis or barbs remaining after sorting. Material D was chosen because it was deemed optimal.

5.7. Packaging

5.7.1. Introduction

The packaging design plays a crucial role in product differentiation and identification. It provides a distinctive shape that distinguishes the product from its competitors. It is the primary packaging system, in direct contact with the product.

In addition to its aesthetic appeal, the packaging protects the feathers inside, assuring the integrity of its contents, as seen in Figures 5.9 and 5.10 and care was taken not to compress the pillows. It is designed to keep the product intact and the user safe while in use, as well as prevent harm while the product is on the shelf. Figures 5.11 show the packaged sorbents ready to be deployed, while Appendix 11.3 shows produced chicken feather pillow and locally fabricated miller at the production location.

The selected feather material has dimensions of 205 grams x 14 inches x 9 inches and 115 grams x 10 inches x 7.0 inches for weight, length, and width of the big and small pillows respectively. The density was 0.759g/cm^3 and 0.865g/cm^3 for the small and large pads

respectively. The pillows were shaken to distribute the feathers over the entire pillow protector before final sewing and careful storage at room temperature.

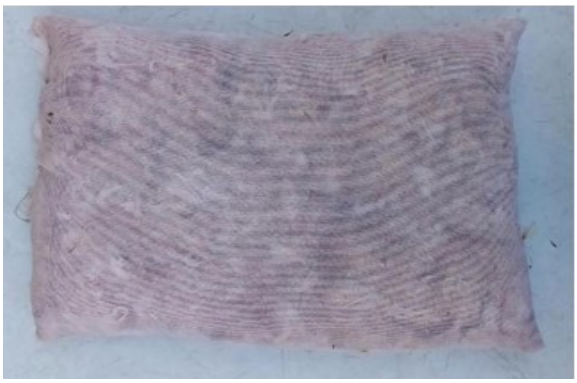


Figure 5.9: CF Pillow Large (Large CF Pillow)



Figure 5.10: CF Pillow Small (Small CF Pillow)



Figure 5.11: Displayed Small and large CF pillows

5.8. Cost of Production

The cost of the production of the chicken feather pillow was derived from the cost of the unit processes which is also the cost of all other activities involved in each process. The chicken feather pillow preparation cost includes the collection, washing, shredding, packaging**,** and disposal of waste materials which was very insignificant. Table 5.6 gives the overall breakdown of the cost incurred by the researcher, in processing a batch of chicken feathers of 4,000g to produce 30 small-sized chicken feather pillows.

Table 5.6: Cost of Production for Thirty Small-Size Chicken Feather Pillow

Description of Activities	**Amount ($)**	**Summary Cost ($)**
COST OF FEATHERS (4kg)		5.00
Cost of feathers	0.00	
Transportation of Feathers	5.00	
COST OF WASHING FEATHERS		55.00
Equipment cost	10.00	
Water cost	25.00	
Cleaning chemicals	5.00	
Laboratory Testing cost	10.00	
Wastewater disposal cost	3.00	
Labor cost	2.00	
COST OF DRYING		20.00
Equipment	18.00	
Labor	2.00	
COST OF SHREDDING FEATHERS		25.00
Equipment	23.00	
Labor	2.00	
COST OF PACKAGING FEATHERS		18.00
Cover Materials	8.00	
Sewing Cost	5.00	
Labor cost	2.00	
Disposal cost	3.00	
TOTAL COST FOR 30 SMALL CFP		123.00
AVERAGE COST FOR I CFP		4.10

This chapter described a successful method for transforming waste chicken feathers into oil sorbent. The production process is undoubtedly a cost-effective method of producing a sorbent material, with an average cost price of $4.00 - $4.60, that can be sold for $5.00 - $6.00 which is relatively cheaper than the cost of FB 52022 Absorbent (W) pillow, at $8.00, which is used in the Niger Delta region presently. Although the cost of washing and shredding the feathers was the highest in the entire process, the overall production cost of CFP will make it

competitive. The use of CFP will enhance a circular economy for the utilisation of this waste material.

Another advantage of this process is that it prevents adverse environmental impacts such as water, land, and air pollution, which aligns with the primary objective of the biological cycle in models of circular economy. It also keeps the biological materials within a closed-loop system of collection of the waste chicken feathers, to be used as a raw material for the production of chicken feather pillows.

5.9. Conclusion

The author has immensely contributed to developing an environmentally friendly sorbent as a way of mitigating the problem of feather wastes especially in the Niger Delta region of Nigeria. The innovation will enhance the circular economy for waste chicken feathers and ensure economic advantages through the simple and cost-effective production process of chicken feather pillow.

Chapter 6 - Oil Sorbency Performance of Chicken Feather Pillow

6.1. Introduction

Sorbent materials have been classified by ASTM by describing the common shapes/types of spill sorbents (Federici and Mintz, 2014);

Type I: Roll, film, sheet blanket or pad.

Type II: loose adsorbents (powder form).

Type III: Enclosed Sorbent (pillows, adsorbent booms)

Type IV: Agglomeration unit (pompoms)

Chicken feather pillow, a Type III sorbent according to ASTM, would be a highly effective sorbent compared with polypropylene pads for oil spill remediation. So, three different oil sorbency tests were conducted on chicken feather pillows to determine the possible applications of chicken feather pillows. Sorbents can be used with booms to improve oil spill cleanup (Dave and Ghaly, 2011). When there are floating oil layers, elevating skimmers can be used with sorbents to have a quicker and more effective oil spill clean-up.. The objective of this chapter is to identify different practical applications for chicken feather pillows.

6.1.1. Outdoor Oil Sorption Test in Water Tanks

The first test involved a batch process conducted in open plastic tanks with a capacity of approximately 1500 litres at the River State University of Science and Technology, Rivers State Nigeria. The experiment was performed in a tank because variables that affect oil sorbency can be controlled, allowing for precise and repeatable measurements of sorbency. Given that the spill is contained, and the sorbent material can be quickly recovered, it is economical, simple to measure, and safe. Tank experiments allow for the comparison of sorbent materials under the same circumstances, allowing for an evaluation of their performance and the choice of the best material for a particular application. Two different oils were used to represent hydrocarbon and non-hydrocarbon spills. Also, the impact of low- and high-viscosity oil on oil sorption performance will be examined.

6.1.2. Field Test in Oil Spill Locations

The second test was pilot test trials conducted in surface water bodies polluted with various types of oil, including fresh crude oil, weathered crude oil, light hydrocarbon oil, and cooking

oil. The selection of these locations was based on an immediate oil spill that just occurred, except in the case of the weathered oil location, which has been there for some years. To evaluate the performance of chicken feather pillows in real-world scenarios, it is necessary to conduct field experiments in various locations with various types of oil spills. For instance, testing the sorbents in a freshwater environment may yield different results compared to a saltwater environment due to differences in salinity and pH levels. Table 6.1 gives a brief description of the water bodies. In the appendix, Appendix 11.5.1 shows the Bodo River with the weathered oil spill, Appendix 11.5.2 is Marine Base River where there was the diesel oil spill, Appendix 11.5.3 is the oil mill canal with the palm oil spill, and Appendix 11.5.4 shows the Ebube stream where the crude oil spill occurred.

Table 6.1: Description of Water Resources

Location	**Type of Water Resource**	**Properties**
Marine Base	Abuloma River	Slow-flowing fresh water
Ebube	Ebube Ejama stream	Fast-flowing Freshwater stream
Bodo	Bodo River	Slow-moving shallow freshwater links to the Atlantic Ocean
Eleme	Eleme Water Drainage Canal	Slow-moving artificial freshwater canal for municipal drainage and flooding control

The coordinates of the sampling areas were collected using Garmin Oregon 550t GPS device. The device was turned on in an open space away from tall trees and buildings and held up for a few minutes to acquire satellite signals. The Easting and Northing coordinates of the point are recorded in degrees, minutes, and seconds from the display screen. The device changes coordinates as we move from one point to the other. The coordinates of the different locations are tabulated in Table 6.2 below, and Figure 6.1 below shows the exact description and geographical locations of the second field test locations.

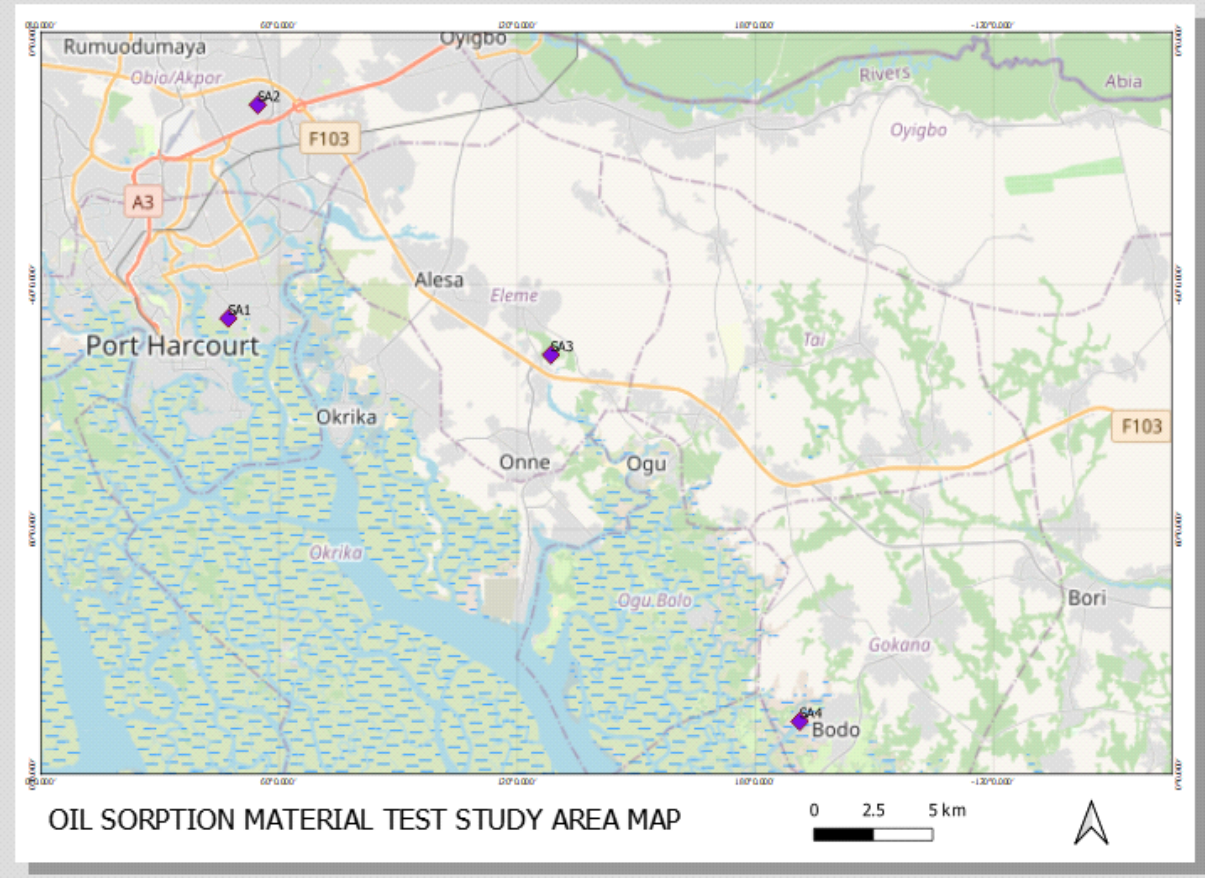


Figure 6.1: Study Area Map

Table 6.2: Study location coordinates for Four Locations

Station	Description	Easting	Northing
SA1	Marine Base (Port Harcourt)	007°01.859E	04°46.076N
SA2	Oil Mill Canal (Obio/Akpo)	007°03.400E	04°51.112N
SA3	Bodo (Eleme)	007°15.678E	04°35.266N
SA4	Ebubu (Eleme)	007°09.341E	04°46.316N

6.1.3. Industry Application Test

Savannah Energy PLC is an AIM-quoted British independent energy company. The assets of Savannah in Nigeria include two world-scale oil and gas fields, Uquo and Stubb Creek, and the Accugas midstream business, all of which are located in Southeast Nigeria. Savannah holds an 80% economic interest in the exploration, development, and production of gas in the Uquo field. The Uquo field is a non-associated gas field, with gross 2P reserves of 458.0 Bscf as of the end of 2020 (Our Assets - Savannah Energy, 2024). It produces gas that is processed and

transported through the infrastructure of Accugas' to end customers. This is a gas and associated crude oil processing plant where natural gas is separated from associated crude before being purified by the removal of non-methane hydrocarbon, fluids, and other impurities, to produce a pipeline quality or dry natural gas. Common processes in the treatment and purification are condensation and water removal, acid gas removal, dehydration, mercury removal, nitrogen rejection, NGL Recovery, Separation, Fractionation, and Treatment of Natural Gas Liquids. (Natural Gas, 2024). The flow chart of the gas processing plant is given below in Figure 6.2.

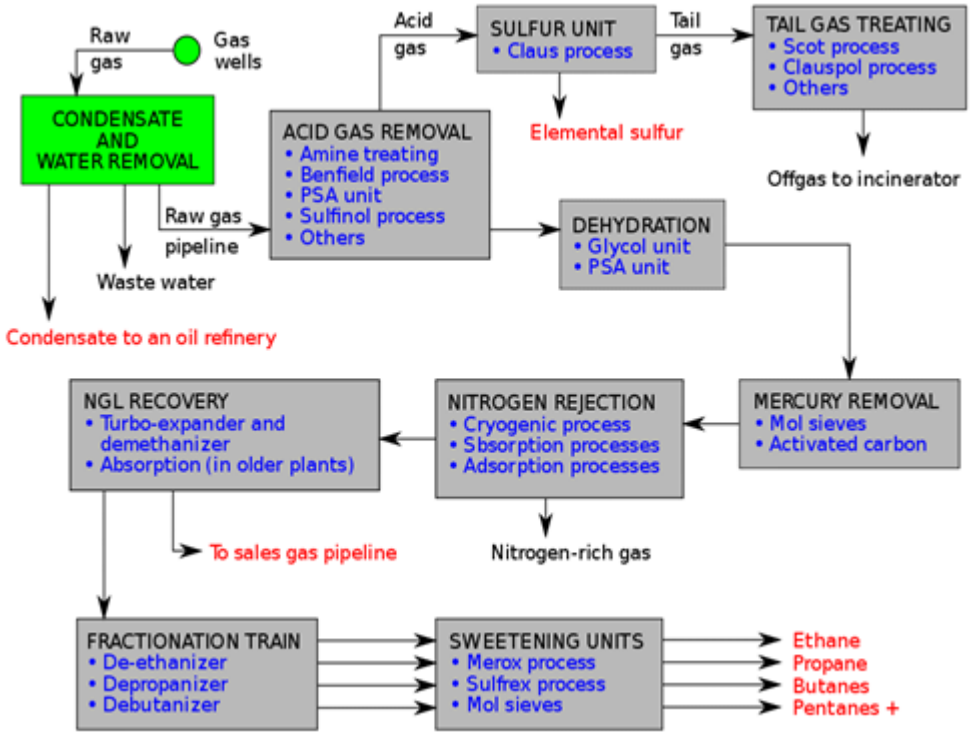


Figure 6.2: Flowchart of natural gas processing plant (Source: Wikipedia, Natural Gas)

Waste/aqueous effluents associated with the process are rich in hydrocarbon oil as well as heavy metals. It is collected in the inlet of a double chamber effluent pit. The floating oil is then separated from water by gravitation and collected in the chamber, which is the Endress + Hauser oil and gas separator. The diagram below, Figure 6.3, is an Endress + Hauser oil and gas separation-group separator that uses the principle of evaporation and floatation to separate crude oil from its accompanying constituents. The separator is a closed chamber maintained at 150°C and 100 bar, with four different valve-controlled piping channels: the left side pipe that feeds the crude mixture into the separation compartment, the gas outlet pipe on the top of the

chamber, the water outlet pipe and oil outlet pipe both at the bottom of the chamber. Also, numerous sensors of different alphabetic labels are used to monitor and maintain important process parameters like temperature, pressure, and flow rates. A mixture containing crude oil, water, gas, and sometimes sediments at different percentage compositions is fed into the separator. Under this condition, the gas component, which is far less dense, is collected from the gas outlet pipe. The oil which is lighter floats on the water until it rises above the steel rod and is then collected in the oil compartment from where it is piped out, while the water is released underneath the mixture collection compartment and discharged as wastewater (Wastewater Characteristics and Effluent Quality Parameters, n.d.).

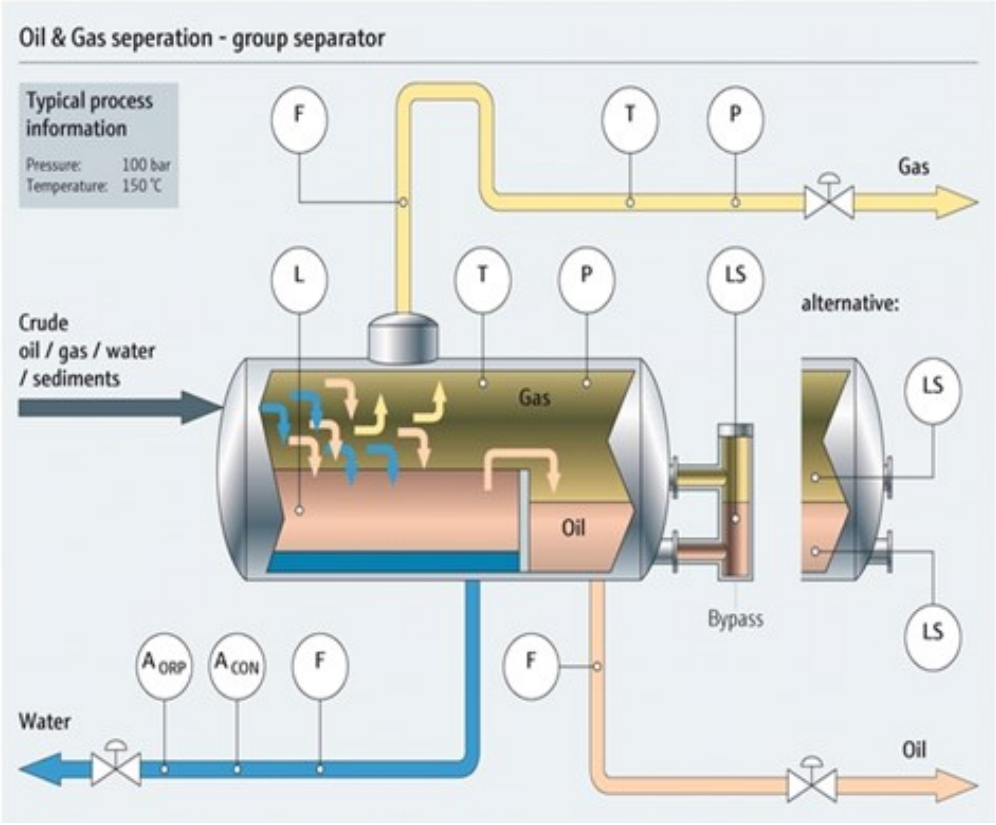


Figure 6.3: Schematics of oil and gas separation at Uqua central processing facility (Thomas, 2022)

6.2. Outdoor oil sorption Test in Tanks

6.2.1. Materials

The Sorbent materials used were Chicken Feather Pillow (CFP), Chicken Feather Fibre Mat (CFM), and 3M Polypropylene Pad (PP Pad).

Table 6.3: Viscosity and Density Values for Engine Oil and Vegetable Oil

Oil	Kinematic Viscosity @ 28°C (cm^2/s)	Density (g/cm^3)
Engine Oil	2.07	0.8988
Vegetable Oil	0.49	0.9287

6.2.2. Methodology

The methodology for water sorbency, oil sorbency, oil recovery, and reusability followed the same oil sorption test standard ASTM 726-16 as described in chapters 3 and 4. Tests were done in triplicates to validate the results.

6.2.3. Water Sorbency

The results of the water sorbency and buoyancy tests in Table 6.4 below revealed that the sorbents remained afloat on the water surface after 15 minutes of immersion with no change in the overall appearance of the sorbents. The amount of water sorbed for the chicken feather pillow, chicken feather fibre mat, and polypropylene pad were 0.98g/g, 0.97g/g, and 0.96g/g respectively. The investigation of the amount of water pickup confirms that all samples possess hydrophobic properties, making them ideal for oil spill clean-up. The low water sorption capacity of these sorbents allows them to absorb oil selectively without absorbing surrounding water, thereby reducing the weight of the sorbent, and making its handling and disposal easier. The chicken feather pillow stayed afloat on the surface of the tank and had a low water pick-up of only 0.98g/g.

Table 6.4: Result of Water Sorbency and Buoyancy Test for the Sorbent Materials

Parameter \ Sorbent	CFP	PP Pad	CFM
Water Sorbency (g/g)	0.98	0.96	0.97

6.2.4. Oil Sorbency

As shown in Figure 6.4 below, it was observed that the polypropylene pad exhibited a higher sorbency for both vegetable oil and engine oil. The oil sorbency for the chicken feather pillow was 8.8g/g for engine oil and 8.0g/g for vegetable oil. The oil sorbency for the chicken feather

fibre mat was 12.7g/g for engine oil and 11.2g/g for vegetable oil. Polypropylene, which was the highest, was 13.1g/g for engine oil and 12.5g/g for vegetable oil.

This result was different from the laboratory result for vegetable oil in Chapter 4, which had the chicken feather fibre mat having the highest sorption capacity for vegetable oil. The sequence was Chicken feather fibre mat > Polypropylene pad > Chicken feather pillow (Old layer feather). The vegetable oil sorption capacity for the chicken feather fibre mat was 15.50g/g, while polypropylene pad was about 15.01g/g, so the sorption capacity difference was less than 0.02g/g. The sequence in the laboratory for engine oil was consistent with the Tank test result; Polypropylene pad > Chicken feather fibre mat > Chicken feather pillow.

The environmental conditions for the outdoor tank experiment which were different from those of the laboratory may have caused the slight variation in result. For example, the temperature for the tank experiment was about 28 ± 2°C, much higher than the laboratory of 23 ± 2°C. With an increase in temperature, some researchers have reported a drop in sorption capacity. There was a slight drop in the laboratory result for the oil sorption capacity of the old layer feather (Chicken feather pillow), chicken feather fibre mat, and polypropylene pad. Overall, the trend for oil sorption capacity for both engine oil and vegetable oil results obtained for three samples in the laboratory is the same as that obtained for the outdoor tank test.

Chicken feather pillow exhibited good oil sorption properties in the tank test and had comparable results to polypropylene pad. Appendix 11.4.1 shows tank trial images with polypropylene pad, chicken feather fibre mat, and chicken feather pillow.

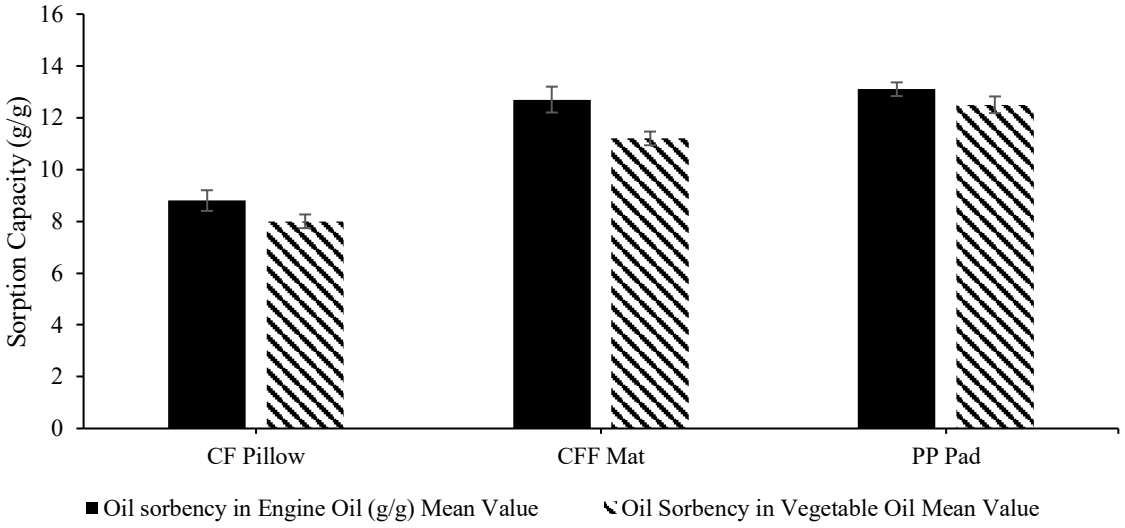


Figure 6.4: Mean sorption capacities of samples in engine oil and vegetable oil (error bars showing standard deviation).

6.2.4. Oil Recovery

As shown in Figure 6.5, the PP pad had a higher oil recovery for both engine oil and vegetable oil, followed by the CFM and CFP. The oil recovery for the CFP was 70%, and 66.6% for engine oil and vegetable oil. The observed oil recovery for CFM was 72% for engine oil and 72.1% for vegetable oil. PP pad was 81% for engine oil and 93.9% for vegetable oil. Again, the oil recovery rate for the CFP was excellent compared with the two standard samples.

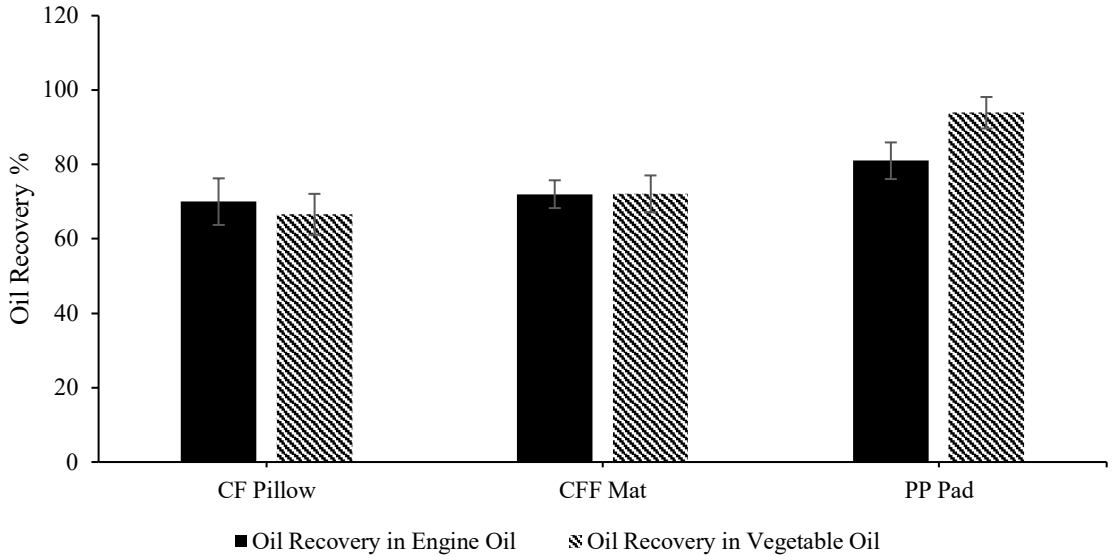


Figure 6.5: Mean oil recovery of samples in vegetable oil and engine oil. (error bars showing standard deviation)

6.2.5. Oil Reusability

Experiments involving the cyclic reuse of chicken feather pillow, chicken feather fibre mat, and polypropylene pad revealed that after the first cycle, the sorption capacity of all three sorbents dropped significantly, as seen in Figure 6.6 for vegetable oil and Figure 6.7 for engine oil. In vegetable oil, the sorption capacities recorded during the first cycle, for CFP, CFM, and PP Pad were 8.0g/g, 11.2g/g, and 12.5g/g, respectively. The second cycle were 2.0g/g, 2.0g/g, and 2.9g/g, respectively. Sorption was still observed after the fifth cycle with the sorption capacities for CFP, CFM, and PP pad at 0.7g/g, 2.2g/g, and 2.8g/g, respectively. In engine oil, the sorption capacities recorded during the first cycle, for CFP, CFM, and PP Pad were 8.8g/g, 12.7g/g, and 13.2g/g, respectively. The second cycle were 1.7g/g, 3.3g/g, and 3.3g/g, respectively. Sorption was still observed after the fifth cycle with the sorption capacities for CFP, CFM, and PP pad at 0.9g/g, 2.8g/g, and 3.4g/g, respectively. The values recorded indicate that these sorbents can be reused. It is noteworthy that after the first cycle, the chicken feather fibre mat sustained structural damage, resulting in fragments. In contrast, neither the chicken feather pillow nor the polypropylene pillow sustained any structural damage.

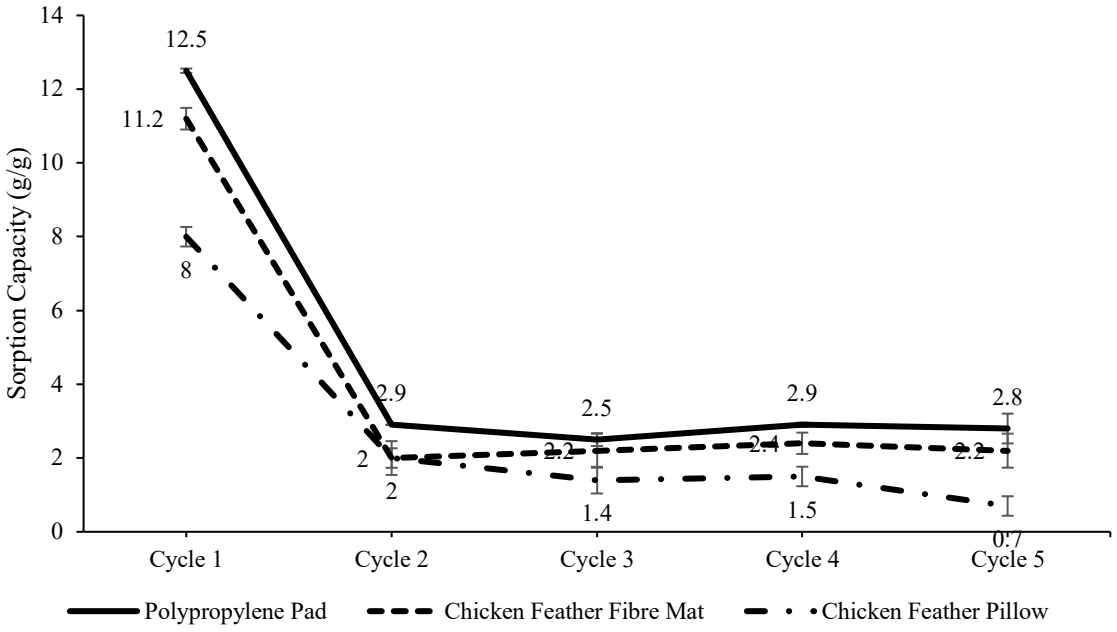


Figure 6.6: Mean sorption capacities of reused samples in vegetable oil (error bars showing standard deviation)

The huge drop in oil sorption capacities for all three sorbents can be due to the oil recovery method, and the inability of the bulk of the fibres of all three sorbents to accommodate more oil. The drop in sorption capacity of CFM was also due to the loss of fibres during its fragmentation because the fibres are loose and not in a casing. It resembles a typical mat with an exposed surface, requiring more effort to maneuver and position correctly during use. The chicken feather pillow is encased in a durable cover, and its design allows for easy handling and placement in areas where oil spill cleanup is required. There was no structural damage to the CFP and PP pad even after the five cycles. Appendix 11.4.2 shows oil saturated polypropylene pad, chicken feather pillow, and chicken feather fibre mat after 3 cycles.

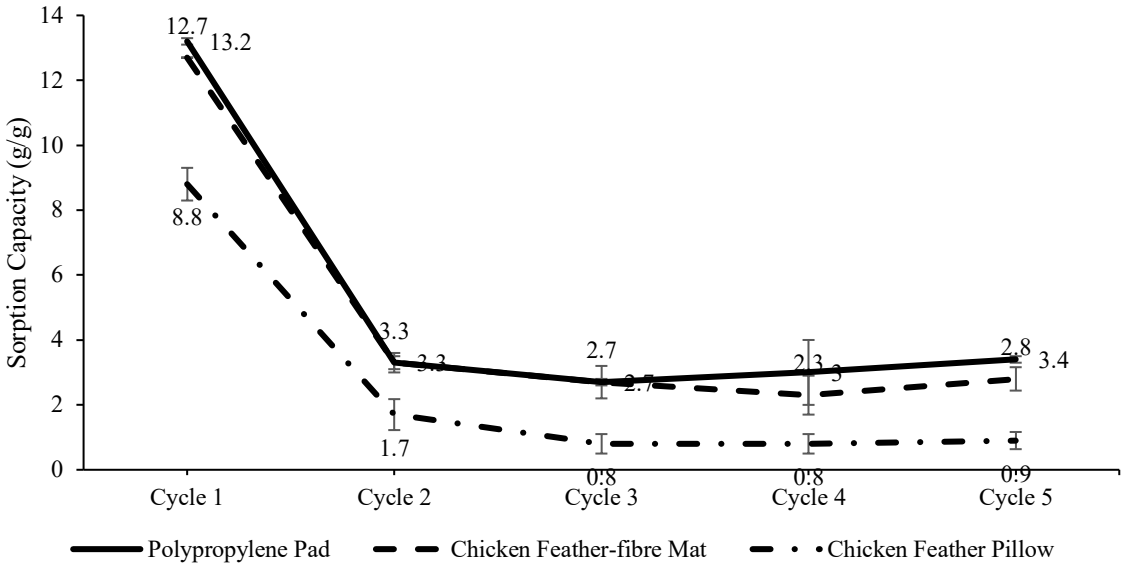


Figure 6.7: Mean sorption capacities of reused samples in engine oil (error bars showing standard deviation)

6.4. Trial Field Test in 4 locations

6.4.2. Materials

Four different sorbents were used. Chicken feather pillow, chicken feather net- (This is slightly different from chicken feather pillow, whole chicken was just put into the net material and tied, the feathers were not shredded), chicken feather fibre mat, and polypropylene pad.

Other materials and equipment used included a portable handheld digital electronic scale (WH-A08), weighted metal rings, masking tape, nitrile gloves, and nose masks.

The oil in different locations was characterized for viscosity and density using Stanhope, 5E1A Vin Kinematic viscometer, and Anton Paar DMA 35 Desimeter. The result is given in Table 6.5.

Table 6.5: Viscosity and Density Values for Oils in 4 different locations

Oil	**Kinematic Viscosity @ 30°C (cm^2/s)**	**Density (g/cm^3)**
Diesel Oil	1.65	0.8988
Weathered Oil	2.19	0.9287
Palm Oil	4.88	0.9679
Crude Oil	0.30	0.7911

6.4.3. Methodology

The methodology for this experiment is in line with the procedures developed for the testing of sorbents, by Environment Canada's Emergencies Engineering Division, River Road Environmental Technology Centre (Cooper and Gausemel, 2005). Sorbent materials were tested for water sorbency, sorption capacity, oil recovery, and reusability for the Tank trials, while only oil sorption capacity was done for the test in the four different spill locations due to difficulties experienced with permission for extended hours, from stakeholders, at oil spill sites, to carry out the other tests that were not done.

A space of 2-4 m^2 was mapped out in the selected water. Sorbents were placed on a 3-5mm layer of oil floating on the water in the tank and in the four different locations. The sorbent was left undisturbed for 15 minutes. The sorbent was then carefully removed by handling the tip and allowed to drip for 2 minutes before being suspended vertically for weighing. Sorption capacity was calculated with the same equation in Chapter 3, Equation 9. The tests were repeated three times to validate the results, and a standard deviation was obtained.

6.4.4. Results and Discussion

Temperature can have a significant effect on oil sorbency in the field. Depending on the time of day and environmental factors such as wind, rain, and sunlight, the temperature in the field may fluctuate significantly. Field trials are conducted in real-world environments where conditions such as temperature, humidity, wind speed, and wave action can significantly differ from controlled laboratory (tank) settings. These variations can affect the behavior of oil, the performance of sorbents, and the dynamics of oil-sorbent interactions. (Ossai et al., 2020).

Higher temperatures can increase oil evaporation, thereby decreasing the quantity of oil available for sorption. In addition, higher temperatures can modify the physical and chemical properties of the sorbent material, including a reduction in porosity, surface area, and surface chemistry. In this study, the temperature in the field was higher, about 31 ± 2°C compared to the tank, which was about 25 ± 2°C, and the laboratory, about 23 ± 2°C. Some researchers have observed that with temperature increase, the Brownian motion of the oil particle increases and so the energy needed to cause the oil particles to adhere to the sorbent surface will increase (Augustine. O et al., 2015; Junchen Zou et al., 2014; Simonovic. B et al., 2009)

Sometimes the viscosity and oil-water interfacial tension would decrease with an increase in temperature (Gao et al., 2018; Yu et al., 2019). So, the effect of temperature is also dependent on the viscosity and surface tension of the oil.

The pH and salinity of the water can affect the sorption capacity of the sorbent material, as they can alter the surface charge of the sorbent material and the solubility of the oil in water. All the locations were freshwater resources, so they had the same degree of Salinity. In addition to temperature, several other variables can influence the outcomes of field tests for oil sorbency. Wind is a significant component that can scatter oil and make it challenging to assess and contain. The behaviour and efficiency of oil sorbent materials in an open field can be affected by all these variables at the time of testing in the four different locations, there was no interference due to wind action. Grass, bushes, and other vegetation can absorb or interfere with the oil sorbent components, thus affecting oil sorbency. All the different locations had minimal interference from grasses and bushes.

The results in Table 6.6 demonstrated that there was a huge drop in the oil sorbency of the sorbent materials from the result obtained from the laboratory in Chapters 4 and the tank trial.

Table 6.6: Oil Sorbency Test in Four Locations

Sorbent	**Diesel (g/g)**	**Palm Oil (g/g)**	**Weathered Oil**	**Crude Oil**
Chicken Feather Pillow	1.9	2.8	1.7	1.3
Chicken Feather Net	1	1.5	1.3	1
3M HP Polypropylene Pad	1.9	3.3	2.2	2.3
Chicken Feather fibre Mat	2.5	3	1.8	1.4

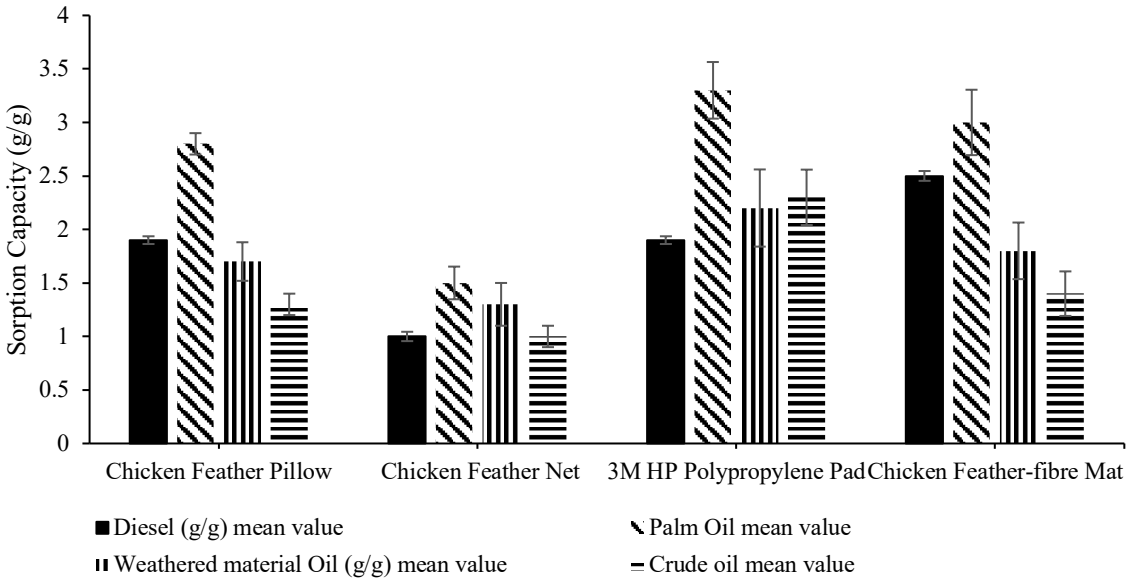


Figure 6.8: Mean sorption capacities of samples in diesel oil, palm oil, weathered material oil, and crude oil at different spill locations (error bars showing standard deviation)

The chicken feather pillow has a larger surface area than the chicken feather net. The difference in physical structures can explain why the oil sorbing capacity of a chicken feather pillow is greater than that of a chicken feather net. The degree of shredding and arrangement of feathers can affect their ability to adsorb (Pospisilova et al., 2016). In this instance, the lack of shredding in the chicken feather net limited its ability to absorb oil effectively, resulting in reduced sorption capacity compared to the chicken feather pillow.

The oil with the highest viscosity and density was palm oil. The chicken feather pillow had the highest sorbency in the location with palm oil spill at 2.8g/g, followed by diesel oil spill location at 1.9g/g, weathered oil at 1.7g/g, and crude oil at 1.3g/g. The other sorbents also had similar results. The oil sorbency in the palm oil location for the chicken feather net, polypropylene, and chicken feather fibre mat was 1.5g/g, 3.3g/g, and 3.0g/g respectively. The chicken feather pillow performed best in the location with palm oil, the most viscous oil of all the other oils. Oil with high viscosity attaches quickly to the surface of fibres due to the higher specific gravity, which also desorbs easily. (Choi and Cloud, 1992; Rengasamy et al., 2011a) However, this is not consistent with all fibres; it depends on the natural properties of the fibre (Deschamps et al., 2003).

Besides temperature, a major condition that may have caused the decrease in the oil sorption capacity, as observed in the laboratory and the tank experiment, is contact time. The contact time should have been increased to 30 minutes and 24 hours. For some oil sorbents, an increase in contact will result in an increase in sorption capacity (Khaled et al., 2010). The thickness of the oil spill layer may have also caused the drop because it was observed in all four locations, the oil spill thickness on the surface of the water was less than 5mm.

Besides the drop, it was observed that in all oil types, chicken feather pillow had a good oil sorption capacity of above 1.3g/g which is in the range of wheat straw, 2-4 g/g (Sidiras et al., 2014) and this can be improved on.

6.5.2. Methodology For Oil and grease removal from wastewater

The effluent from the facility is discharged through a 0.5-metre diameter x 150-metre length pipe into a 200-meter open rectangular concrete drainage from where it empties into the environment. Arrangements have been made to mitigate any escape of oil from the saver pit through the discharge channels by placing absorbent pads across the concrete drainage just before the point of release into the environment. In the first experiment conducted, sorbent pillows, as seen in Figure 6.10, were deployed before the Accugas booms, as seen in Figure 6.12. In the second experiment conducted, the facility's synthetic absorbent booms were removed, and the chicken feather pillow, as observed, was deployed within the effluent discharge pipe, as seen in Figure 6.11, and along the effluent drainage, as seen in Figure 6.13, for five days to test the efficiency of absorption. Four large-sized chicken feather pillows (205 grams x 14 inches x 9 inches) were carefully positioned to ensure that no effluent passed without flowing through the pillows before being released into the environment. Samples of the effluent were collected every day at points approximately 3 metres in front of the feather pillows and behind. Figure 6.14 shows the oil-soaked chicken feather pillow after application along the effluent drainage. Absorption performance data for the facility synthetic booms were also collected from the HSE unit of Accugas for comparative analysis. Data was analysed using Microsoft Excel and presented graphically.

6.5.3. Results and Discussion

The results of the sorbent application test in Table 6.7 below indicate that the daily average quantity of oil and grease absorbed by the chicken feather pillow was 5.8ppm, with a total of 29ppm absorbed for the five days, with the highest daily value of 7ppm recorded in the first day of application. For the sorbent material of Accugas, an average of 4.4 ppm with a total of 22 ppm was recorded for the five-day period, while the highest amount of absorbed oil and grease of 5 ppm was recorded for the first and fifth days.

From the above result, the daily amount of oil and grease still left in the wastewater for discharge into the environment was reduced below the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) EGASPIN 2018 value of 10ppm for effluent limitation values for discharge from production facilities (EGASPIN, 2018).

Table 6.7: Sorbent Pillow Application Testing for Accugas

Parameter	**Oil & Grease (Ppm)**			
	Amt. Before	**Amt. After**	**Amt. Sorb.**	**% Amt. Absorbed**
	Accugas Absorbent Boom			
Day 1	9	4	5	55.6
Day 2	6	2	4	66.7
Day 3	8	4	4	50.0
Day 4	10	6	4	40.0
Day 5	10	5	5	50.0
Total	43	21	22	51.2
	Deployed Chicken Feather Pillow			
Day 1	11	4	7	63.6
Day 2	7	2	5	71.4
Day 3	10	4	6	60.0
Day 4	8	2	6	75.0
Day 5	6	1	5	83.3
Total	42	13	29	69.0

Figure 6.9 shows the oil sorbency performance of chicken feather pillow in effluent discharge. In five days, chicken feather pillow adsorbed 69.0% of the oil whereas Accugas material adsorbed 51.2%. It is therefore concluded that the chicken feather pillow was also able to significantly reduce the amount of oil and grease from wastewater. Combining the chicken feather pillow with the Accugas booms, a reduced quantity of oil and grease was observed. This can help Accugas comply with even more stringent regulations and further safeguard our environment.

$$\%\, Sorbency = \frac{Total\ Sorb}{Total\ Amt.Before}$$

Equation 20: % Sorbency

Accugas Absorbent Boom: 22/43 = 51.2%

Deployed Feather Pillow: 29/42= 69.0%.

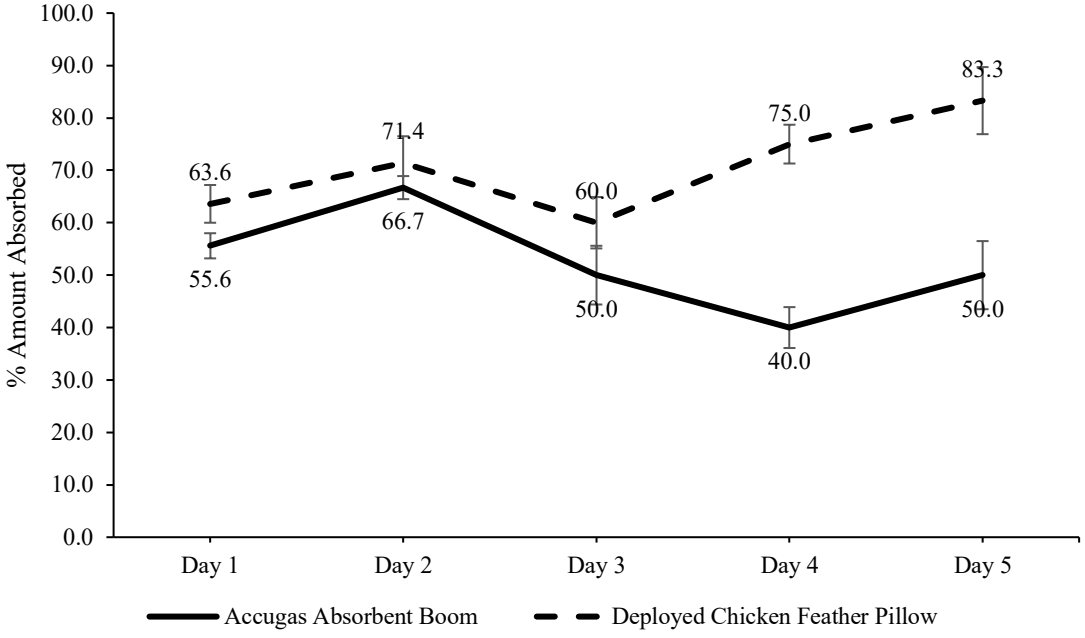


Figure 6.9: Chicken feather oil sorbency performance in effluent discharge



Figure 6.10: Sorbent pillows deployed before the booms



Figure 6.11: Sorbent pillows deployed within the effluent discharge pipe



Figure 6.12: Effluent discharge booms



Figure 6.13: Sorbent pillows deployed along the effluent drainage.



Figure 6.14: Sorbent pillows after application, along the effluent drainage.

6.6. Conclusion

The chicken feather pillow yielded a good oil sorption capacity, oil recovery, and reusability result for vegetable oil and engine oil for the tank test, just as the polypropylene pad and chicken feather fibre mat. The excellent design of the chicken feather pillow had a good advantage over the chicken feather fibre mat for reusability because, after 5 cycles, there was no observed damage to the structure, and appreciable sorption was still observed, just as in the case of 3M polypropylene, the synthetic sorbent. For the oil spill in four different locations, the Chicken feather pillow was as good as the natural sorbent and the synthetic sorbent. The successful removal of oil in the wastewater discharge using the chicken feather pillow indicates the good sorbent properties of the Chicken feather pillow. 3M polypropylene is processed for oil sorption, so the physical and chemical properties of polypropylene should have been modified. A good result in all the testing for the chicken feather pillow confirms that it is a successful minimum viable product (MVP). It is an appealing alternative to synthetic sorbents such as polypropylene pads.

Chapter 7: End-of-Life Options for Chicken Feather Pillows

7.1. Introduction

The disposal of used oil pillows and sorbents should be carried out in accordance with regulatory procedures, and it requires special precaution in its collection, storage, transportation, treatment, and disposal to prevent damage to persons, properties, and aquatic organisms (Henry and Heinke, 1996). Proper disposal ensures the protection of the environment (Jones, 2001). The objective of this chapter is to carry out qualitative research on the developed chicken feather pillow to confirm the findings of the pre-study carried out with Tolulope Olusina as part of her M.Sc. research project titled "Developing New End-of-Life Options for Oil-Contaminated Chicken Feather Mats". From the study, the most viable and safest end-of-life options for used chicken feather materials in the Niger Delta region identified were incineration, transesterification (biodiesel production), and biodegradation. Some key policies and regulations guiding the disposal of these sorbents which will play in major role in the disposal of chicken feather pillows in Nigeria are listed in Table 7.1.

A regulatory framework for incineration, biodiesel, and composting operations exists with the sole aim of regulating the oil and gas activities in the Niger Delta. The principal aim of the 1993 Environmental Impact Assessment (EIA) Act is to delineate the protocols and techniques that facilitate the early evaluation of environmental impact assessments on operations associated with oil and gas projects in the Niger Delta region (EIA Decree, 1992). Incineration and composting are disposal methods stipulated in the Act, hence, companies operating in the region are mandated to carry out their activities accordingly to minimize the harmful effects it may have on the environment, as captured in previous EIA reports in the region (Shell EIA Report, 2020). The 1988 Harmful Waste Act forbade the transportation, storage, and disposal of hazardous wastes on any land, in territorial seas, or on any associated property (Nwufo, 2010). According to the statute, participating enterprises in the area under consideration must dispose of effluents appropriately through incineration (Environmental Law & Policies in Nigeria AA – ELRI, n.d.).

To protect and develop the environment, conserve biodiversity, and promote sustainable development of the natural resources of Nigeria, the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act of 2007 established the following goals: coordinating and liaising with relevant stakeholders, both inside and outside of Nigeria

regarding the enforcement of environmental standards, regulations, rules, laws, policies, and guidelines; disposing of waste through incineration and biodiesel; this requires the oil and gas companies operating in the region to make sure that their operations comply with the Act's provisions (Sodipo and Owolabi, 2019). The Nigerian Biodiesel Policy and Incentives (2007) was established with the goal of progressively decreasing the country's reliance on imported fuel, lowering environmental pollution, and simultaneously developing a commercially viable industry that can create long-term jobs domestically (Ohimain, 2007).

Nigerian industry discharge is regulated by the National Environmental Protection Regulations of 1991(Management of Solid and Hazardous Wastes). Beyond the boundaries set by the Federal Environmental Protection Agency, no industry or facility is permitted to release poisonous or hazardous materials into Nigeria's air, water, or land (FAOLEX, 1991). Biodegradation as a disposal method for the Act under consideration is the term used to describe how materials and polymers are broken down and assimilated by living microbes to create non-toxic breakdown products (Raman et al. 2012). The above policies and regulations briefly discussed play a major role in the end-of-life disposal of used chicken feather pillow.

The study was done through qualitative research which involved semi-structured interviews (Doody and Noonan, 2013) with focused participants who are prospective end users of the chicken feather pillow who are currently using other sorbents for oil spill cleanup and are involved in the disposal of used sorbents. This method combines questionnaires with guided conversations (Yin, 2011; Ryan et al., 2009). The interviews were carried out in this format to get maximum attention and participation from these prospective users.

Table 7.1: Regulatory Framework for Incineration, Biodiesel and Composting Operations

Regulatory Framework	**Disposal Category**	**Impact**
Environmental Impact Assessment (EIA) Act of 1992	Incineration and Composting	It requires an EIA on incineration and composting according to its regulations. -The assessment levels decided by the Federal Ministry of Environment (Nwufo, 2010)
Harmful Waste (Special Criminal Provision) Act 1988	Incineration	Regulates the emission of toxic substances into the air (Environmental Law Research Institute, 2011)
National Environmental	Incineration and Biodiesel	-Enforces compliance with environmental laws, guidelines, policies, and standards.

Regulatory Framework	Disposal Category	Impact
Standards and Regulations Enforcement Agency (NESREA) Act of 2007		-Provides Air quality permits (Sodipo et al.,2017) -Regulates standard for effluent discharge.
Nigerian Biodiesel Policy and Incentives (2007)	Biodiesel	-Supports the emergence of industry-producing biofuel/biodiesel (Federal Republic of Nigeria, 2007)
National Environmental Protection (Management of Solid and Hazardous wastes) Regulations 1991	Biodegradation	-Monitors discharge and handling of toxic and hazardous waste. -Regulates studies on potential recovery from hazardous waste. (FA0, 2013)

7.1.1. Incineration/Small Scale

Incineration is the process of burning hazardous materials at temperatures high enough to destroy contaminants (USEPA, 2012). Although this method reduces the volume of waste and can generate energy, it is important to consider the impacts it can have on the environment. Oil pillows at end-of-life, especially those containing synthetic materials, may release harmful pollutants when burned. Thus, incineration should be conducted using modern pollution control technology to minimize the harmful effects it may have on the environment. The incomplete combustion of waste releases carbon monoxide into the atmosphere, which is absorbed by the blood and lungs (Chen et al., 2017; Sadiq, 2022). Waste incineration can be a useful source of energy (Pasila, 2004). In accordance with the guidelines of the International Tanker Owners Pollution Federation Limited (ITOPFL), large debris such as oily sorbent booms should be removed from the waste stream and reduced in size before burning (Musk, 2012). In Africa, oil mats and pillows are sometimes incinerated in regions where adequate facilities are available.

The initial preparation involves oil recovery through the compression of feather pillows. The material would then be shredded (Safaric et al., 2020) and put into the primary chamber to remove moisture content and prepare it for combustion prior to transmission to the secondary chamber. In the secondary chamber, combustion of materials occurs in a controlled environment, which leads to the production of heat, gaseous emissions, and solid residue. There

are usually emissions of harmful chemicals and gases and this is often a concern for the public (Iyanda and Olaniyi, 2014).

Incineration plants exist in the Niger Delta region of Nigeria. These facilities include Shell Petroleum Development Company (SPDC) Medical Incineration Plant, Port Harcourt, Boskel Medical, Municipal and Industrial Incinerator, Port Harcourt, The Initiates Plc. Multi-Purpose Incinerator, Port Harcourt, and the Nigerian Navy Medical Incinerators located at Nigerian Navy Hospitals in Borokiri, Port Harcourt, and Warri, Delta State. These incinerators were built by the operators to provide a reliable source of waste disposal and ensure effective waste management in the region.

7.1.2. Biodiesel Derivation

Biodiesel is a liquid biofuel that is obtained by chemical processes from vegetable oils or animal fats and alcohol that can be used in diesel engines alone or blended with diesel oil (Gerpen et al., 2004; Romano et al., 2006). The process will begin with oil recovery from contaminated materials and then a pretreatment process that requires the use of an acid such as hydrochloric acid or sulphuric acid to reduce the free fatty acids in the materials to methyl esters through the process of esterification (Romano et al., 2009; Knothe et al., 1997). The next stage is the extraction of lipids from the chicken feather material by dissolving it in sodium hydroxide and heating it at a temperature of about 90^0C for 45 minutes (Ahmed Al-Souti et al., 2018). Excess water is evaporated in this process, and the chicken feather material is ready for transesterification (Fukuda et al., 2001). The transesterification process is a reaction that occurs between the fats, alcohol, and catalyst to yield a mixture of ester suspended on top and glycerol below (Romano and Sorichetti, 2011). The mixture is then allowed to cool and decanted to separate the ester, which is then washed with water and dried to produce a translucent ester known as biodiesel. Glycerol is the byproduct of this process.

7.1.3. Biodegradation

Biodegradation presents an alternative way to dispose of oil pillows sustainably. Biodegradation is a biochemical process that refers to the degradation and assimilation of polymers/materials by living microorganisms to produce non-harmful degradation products (Raman et al., 2012). Some oil pillows are designed to be biodegradable and leave no harmful

residues in the environment. These pillows are usually made from natural materials, such as cotton or jute, which are more easily decomposed by bacteria and fungi. (Edwin, 2007). One of the unique benefits of organic sorbent materials is its biodegradable nature. The process of biodegradation will start with the pretreatment of the oil-contaminated chicken feather mats or pillows, and then the oil is squeezed out. The material will then be ground to aid the degradation process. This involves cleaning and preparing the feathers for subsequent biodegradation (Cervantes-González et al., 2010). Microorganisms are introduced with the specific purpose of breaking down the keratin structure inherent in feathers. This transformative process not only facilitates the decomposition of feathers but also enhances their sorption properties, rendering them adequate for applications such as oil spill cleanup or water purification (Liu et al., 2023). SPDC operates an engineered dumpsite and composting facility at Jeddo, Delta State. The manure produced by the facility is applied to degraded land/soil to restore fertility.

7.2. Methodology

In a study with Tolulope, an Analytical Hierarchical Process (AHP) was employed to prioritize the alternatives and then determine the feasible treatment option for oil-contaminated feather mats based on key factors identified, which were technology, cost implications, environmental impacts, and regulatory framework (Olusina, 2020). In this study, an assessment framework was developed by the researcher for the different key factors, for the three alternative disposal options based on research done. The factors were modified to include public perception. To get an understanding of the most feasible option or the least realistic option to select, a ranking scheme was introduced. In this method, a rank is given to each of the five key factors and compared with each disposal option. Each key factor is assigned a score on a scale of 0 to 2. The five key factors have two major subcategories that are very important, so the assessment has an overall score that can range from 0 to 10. At rank 0, the assessment corresponds to negative, difficult, or not possible. At rank 1, the key factor has some good results but not as good as they should be. At rank 2, the key factor has a lot of positive feedback and can enable the selection of waste disposal options (Chen and Smith, 2019).

7.2.1. Technological Considerations

Technological consideration as a key factor focuses on the requirements and challenges of the proposed technology. It takes into consideration the ease of application of the technology as a

factor to be considered for feasibility in developing countries. The factors that could potentially affect cost requirements and quality outcomes form the scope of technological considerations. These include optimum operating conditions, process efficiency, resource recovery, infrastructure requirements, etc.

The assessment for ranking of technology for disposal of chicken feather pillow is presented in Table 7.2, ranging from rank 0 – 2. Rank 0 implies that there is no resource recovery and limited process efficiency at present, rank 1 implies medium resource recovery and considerable efficiency presently, while rank 3 implies high resource recovery and high process efficiency; hence, technology with resource recovery and process efficiency of rank 2 has the potential to reduces the volume of waste entering the landfill by higher percentage and recovers valuable energy that benefits all parts of society vice versa.

Table 7.2: Assessment for Ranking of Technology for Disposal of Chicken Feather Pillow

Technology	**Rank 0**	**Rank 1**	**Rank 2**
Resource Recovery	No resource recovery	Medium resource recovery	High resource recovery
Process Efficiency	Not much process efficiency presently	Considerable efficiency presently	High efficiency presently

7.2.2. Environmental Impact

The assessment for ranking of environmental for disposal of chicken feather pillow is presented in Table 7.3, ranging from rank 0 – 2. Rank 0 signifies high pollution of greenhouse gas emissions in the environment, whereas rank signifies a minimum to zero air pollution and greenhouse gas emissions in the environment. In the same way, an environmental health impact is highly negative if it is ranked 0 and very minimum health impact if it is ranked 2. Rank 1 is considered moderate for both air pollution and health impacts.

Table 7.3: Assessment for Ranking of Environmental Factors for Chicken Feather Disposal

Environmental	Rank 0	Rank 1	Rank 2
Air Pollution/GHG Emissions	High Pollution	Moderate Air Pollution	Minimum to Zero Air Pollution and Greenhouse Gases
Health Impact	High Negative Health Impact	Moderate Health Impact	Very minimum Negative Health Impact

7.2.3. Cost Considerations

This key factor evaluates the feasibility of the technology and factors that may influence it. Thus, capital and operating costs, subsidies and incentives, and additional costs arising from the peculiarity of the technology in a new environment are factors for consideration under this key factor.

The assessment for ranking of cost factors for disposal of chicken feather pillow disposal is presented in Table 7.4, ranging from rank 0 – 2. Rank 0 implies that capital cost is expensive, while cost-effectiveness is described as not cost-effective. Similarly, rank 0 signifies that the process is relatively less costly for capital costs and very cost-effective in terms of cost-effectiveness. As such, rank 0 should be adopted in the process, while rank 0 should be discarded.

Table 7.4: Assessment for Ranking of Cost Factors for Chicken Feather Pillow Disposal

Cost Factor	Rank 0	Rank 1	Rank 2
Capital Cost/ Process Cost	The process is costly	The process is not so costly	The process is relatively less costly
Cost Effectiveness	Not cost-effective	Moderately cost-effective	Very cost-effective

7.2.4. Policy and Regulatory Framework

This key factor dwells on the political factors and regulations that may affect the ability to build and sustain the technology in the Niger Delta region. Treatment methods are chosen after

examining the policies from the waste management sector, renewable energy, oil spill remediation, and environmental sectors.

Table 7.5 shows the assessment for ranking of policy and regulatory factors for the disposal of chicken feather pillows. Rank 0 signifies the absence of renewable policies now and the absence of oil spill remediation regulation presently, whereas rank 2 shows the existence and implementation of renewable energy policies as well as oil spill remediation regulations.

Table 7.5: Assessment for Ranking of Policy and Regulatory Factors for Disposal of Chicken Feather Pillow

Policy and Regulatory Framework	**Rank 0**	**Rank 1**	**Rank 2**
Renewable Energy Policies	No renewable energy policies presently	Some renewable energy policies are present but inadequate	Renewable energy policies are present and adequate
Oil Spill Remediation Regulations/ Waste Management	No oil spill remediation regulation presently	Some oil spill remediation regulations are present but inadequate	Oil spill remediation regulations are present and adequate

7.2.5. Public Perception

The role of an individual is important to implement any policy or change. Previous research suggests that people who are more aware of environmental issues are more interested in participating in waste sorting and recycling (Adekola et al., 2021). For the used chicken feather pillows to be successfully managed, a proper end-of-life option needs to be implemented; the users need to be environmentally aware and buy into the proper waste disposal option. The sustainability of the environment can be determined by the interaction between the environment and mankind. (Ruggerio, 2021). The Nigerian Government indicated a commitment, through public enlightenment, to biofuel production from local feedstock, with emphasis on biochemical and biodiesel, with a projected annual marketability of 5.04 billion and 900 million litres, respectively (Galadima et al., 2011).

Table 7.6 shows the Assessment for Ranking of Public Perception for the disposal of chicken feather pillows. Rank 0 implies that there is no awareness of disposal options, while rank 2 reveals full awareness of disposal options. For Buy-in, rank implies no interest in chicken feather pillow disposal, while rank 2 implies its presence, and as such, rank 2 is considered suitable for public perception.

Table 7.6: Assessment for Ranking of Public Perception for Disposal of Chicken Feather Pillow

Public Perception	**Rank 0**	**Rank 1**	**Rank 2**
Awareness of Disposal Option	No awareness of disposal options	Have some knowledge about disposal options	Fully aware of disposal options
Buy-in	No interest in chicken feather pillow disposal	Some support for chicken feather pillow disposal	Full buy-in to chicken feather pillow disposal

7.3. Results And Discussion

7.3.1. Technology Considerations

Results from Table 7.7 showed that biodegradation was ranked 2 for both resource recovery and process efficiency, while incineration was ranked 1 for both cases as well. Figure 7.1 shows a chart of the ranking. This signifies that biodegradation technology has a higher score for resource recovery and process efficiency in the region. The Niger Delta region has been able to adopt and develop modern incineration technology as a waste management method. The establishment of such facilities in the region, as stated in Section 7.1.1, attests to this technological advancement. Biodiesel also had a good rating of 2 for resource recovery and 1 for process efficiency. Biodiesel technology is still in the infancy stage in Nigeria.

Table 7.7: Assessment for Ranking for Technological Considerations for Chicken Feather Pillow Disposal Options

Technology	**Incineration**	**Biodiesel**	**Biodegradation**
Resource Recovery	1	2	2
Process Efficiency	1	1	2
Total	2	3	4

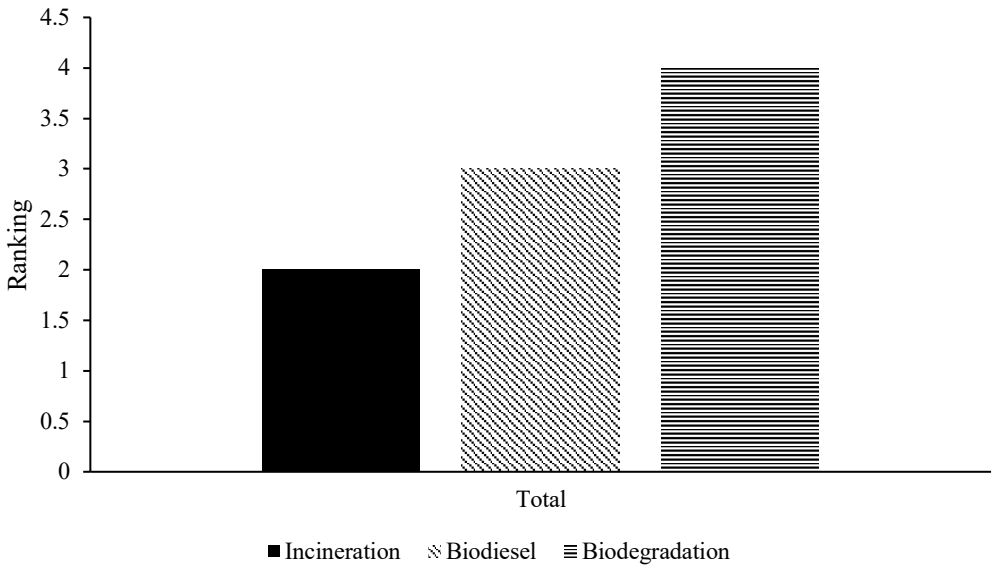


Figure 7.1: Ranking Chart of Technological Considerations for Chicken Feather Pillow Disposal Options

7.3.2. Environmental Impact

Results from Table 7.8 revealed that biodegradation was ranked 2 while incineration was ranked 0 and Biodiesel 1 and Figure 7.2 shows a chart of the ranking. There is a more negative impact on the environment from incineration than biodiesel and biodegradation. All three biodegradation and incineration had the same score in health impact, implying a moderate impact on human health.

Table 7.8: Assessment for Ranking of Environmental Factors for Chicken Feather Pillow Disposal Options

Environmental Impact	Incineration	Biodiesel	Biodegradation
Air Pollution/ GHG Emissions	0	1	2
Health Impact	1	1	1
Total	1	2	3

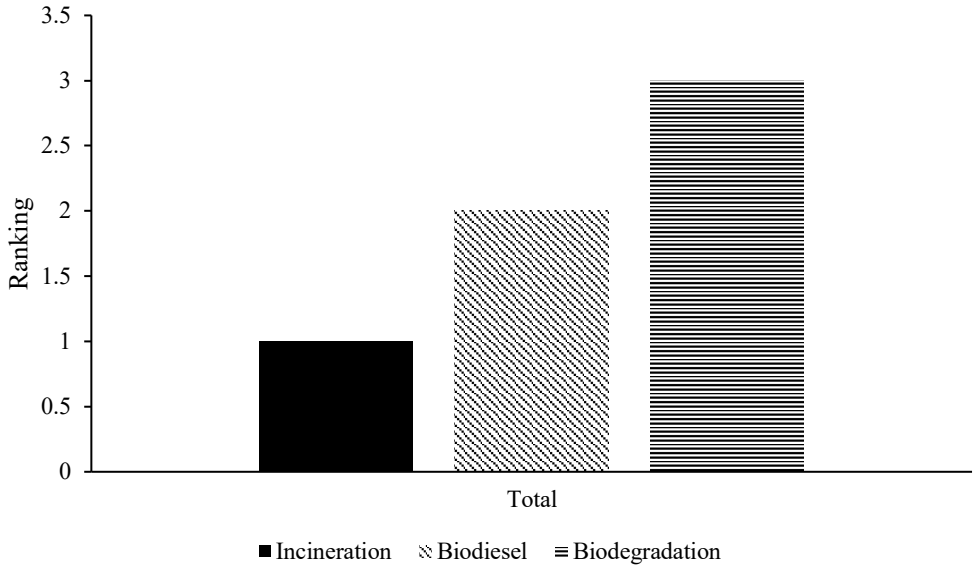


Figure 7.2: Ranking Chart of Environmental Impact for Chicken Feather Pillow Disposal Options

7.3.3. Cost Factor

From Table 7.9, biodegradation was ranked 2 for both capital or process cost and cost-effectiveness, respectively, while incineration and biodiesel were ranked 1, respectively. Figure 7.3 shows a chart of the ranking. This implies that biodegradation has a greater tendency to optimize cost as opposed to biodiesel and incineration options.

Table 7.9: Assessment for Ranking of Cost Factors for Chicken Feather Pillow Disposal Options

Cost Factor	Incineration	Biodiesel	Biodegradation
Capital / Process Cost	1	1	2
Cost Effectiveness	1	1	2
Total	2	2	4

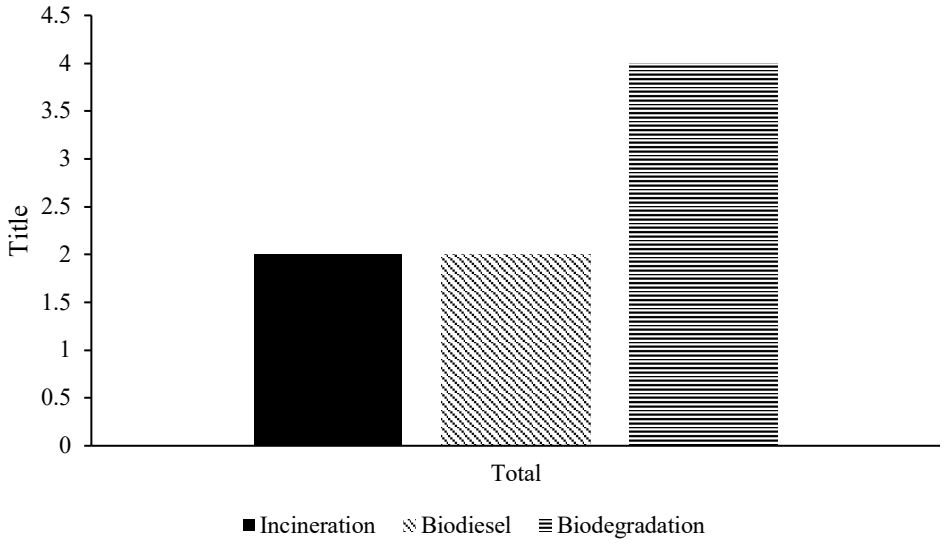


Figure 7. 3: Ranking Chart of Cost Factor for Chicken Feather Pillow Disposal Options

7.3.4. Policy and Regulatory Framework

Results from Table 7.10 showed that biodegradation and incineration were ranked 0 for renewable energy policies, signifying the absence of impact on renewable energy policies and moderate impact (ranked 1 for both cases) on oil spill remediation regulations in the Niger Delta region of Nigeria. Figure 7.4 shows a chart of the ranking. Implicit to these findings is that there is still a lack of enabling legislation in the energy sector (Oniemola and Sanusi, 2009). This key factor considers the prevailing policies, supporting standards, regulations, and enforcement.

Table 7.10: Assessment for Ranking of Policy and Regulatory Factors for Chicken Feather Pillow Disposal Options

Policy and Regulatory Framework	Incineration	Biodiesel	Biodegradation
Renewable Energy Policies	0	0	0
Oil Spill Remediation Regulations	1	1	1
Total	1	1	1

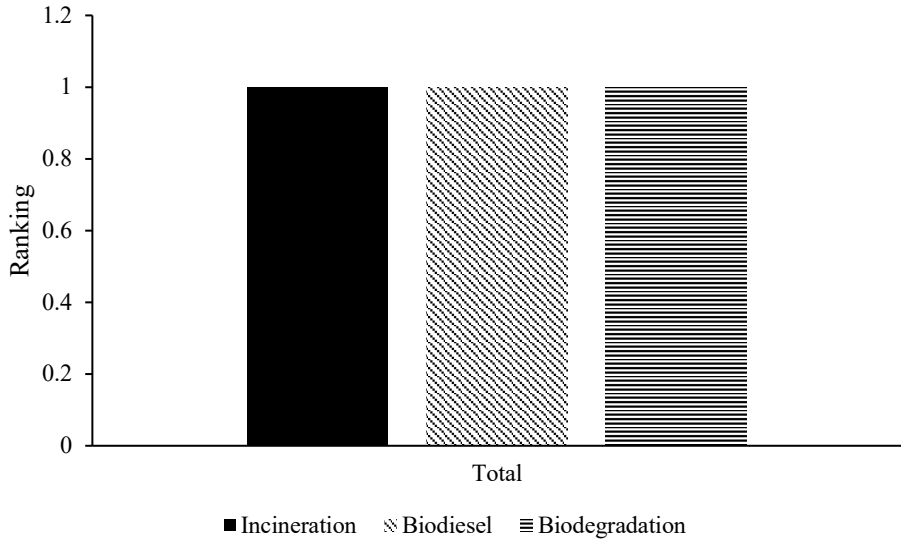


Figure 7.4: Ranking Chart of Policy and Regulatory Factors for Chicken Feather Pillow Disposal Options

7.3.5. Public Perception

From Table 7.11, biodegradation and incineration were ranked 2 and 0, respectively, implying that biodegradation has a greater impact on awareness of disposal options while incineration does not have an impact on awareness of disposal options. Figure 7.5 shows a chart of the ranking. For buy-in, biodegradation was ranked 2, while incineration was ranked 1, respectively. This implies that biodegradation has a greater impact on buy-in regarding public perception, while incineration possesses a moderate impact. For instance, the NDDC, Ministry of Niger Delta Affairs, and other regulatory bodies have, over time, enlightened the public on the need to properly dispose of waste, thereby giving the proposed chicken feather disposal options a soft landing (Abonyi and Eleje, n.d).

Table 7.11: Assessment for Ranking of Public Perception for Chicken Feather Pillow Disposal Options

Public Perception	Incineration	Biodiesel	Biodegradation
Awareness of Disposal Option	0	1	2
Buy-in	1	1	2
Total	1	2	4

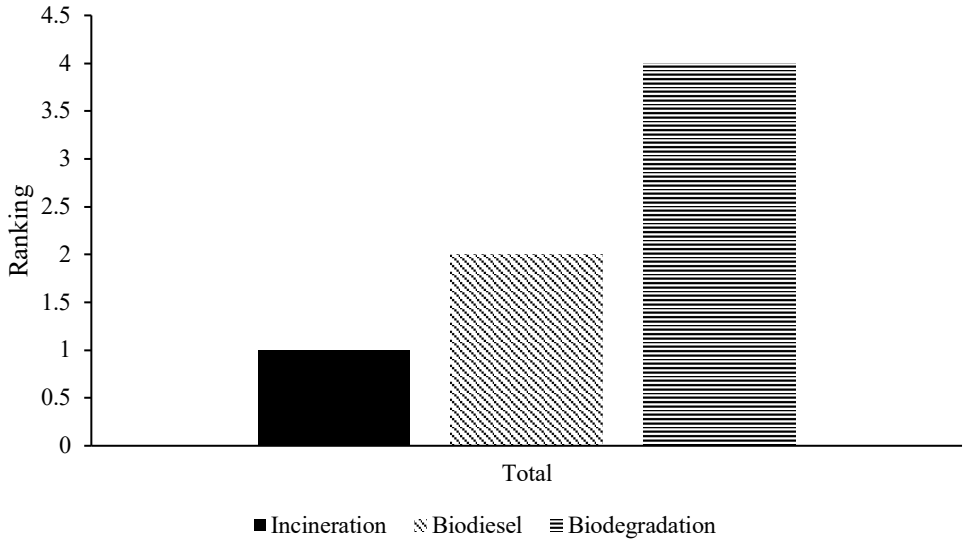


Figure 7.5: Ranking Chart of Public Perception for Chicken Feather Pillow Disposal Options

Table 7.12 shows the summary of the assessment for ranking of key factors for chicken feather pillow disposal options. Figure 7.6 shows a chart of the ranking. Biodegradation has a total score of 16 (48.48%) for the various key factors. Biodiesel has a score of 10 (30.30%), while incineration has 7 (21.21%), respectively and Figure 7.7 shows a chart of the percentage ranking. This implies that biodegradation, just as in the findings of research done with Tolulope, has the highest rank for all the key factors, and this disposal option is the most suitable for application in the Niger Delta region.

Table 7.12: Assessment for Ranking of Key Factors for Chicken Feather Pillow Disposal Options

Key Factors \ Disposal Options	**Incineration**	**Biodiesel**	**Biodegradation**
Technological Considerations	2	3	4
Environmental Impact	1	2	3
Cost Factor	2	2	4
Policy and Regulatory Framework	1	1	1
Public Perception	1	2	4
Total	7	10	16
Percentage	21.21%	30.30%	48.48%

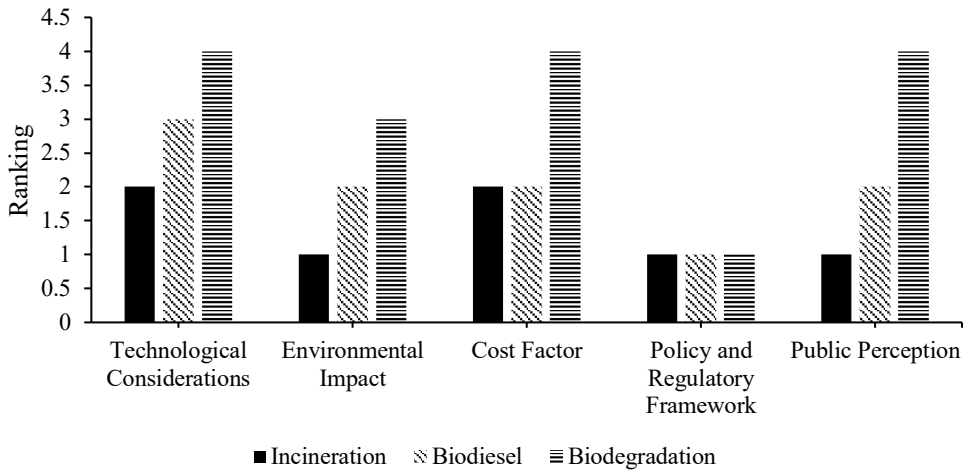


Figure 7.6: Ranking Chart of Key Factors for Chicken Feather Pillow Disposal Options

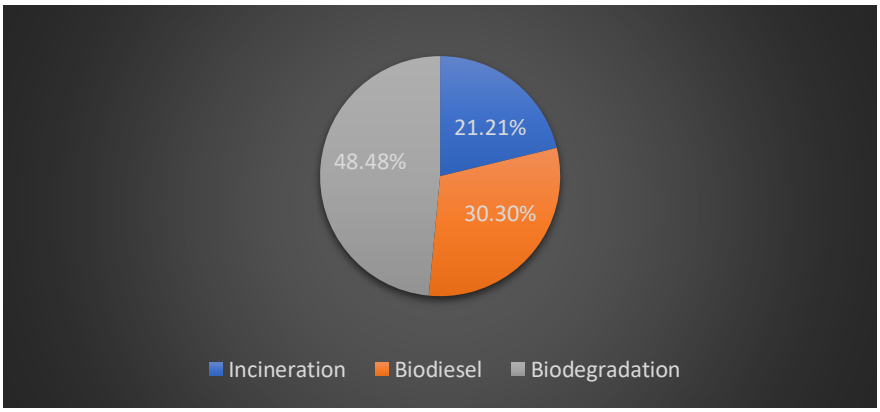


Figure 7.7: Chart showing percentage ranking of Chicken Feather Pillow Disposal Options

Biodegradation of the chicken feather pillow is the most viable or suitable end-of-life option because it has more enabling factors than limiting constraints. More feasible technology, lower cost implications, and less environmental impact. Even though it does not have much policy and regulatory framework at the moment, we concluded from the study that:

1. In the target region, biodegradation is the preferred option for the treatment of contaminated chicken feather mats.
2. Relatively low-cost implications, eco-friendliness, and ease of application of required technology make biodegradation a suitable option.
3. Adoption of biodegradation as a treatment method for contaminated chicken feather mats will ensure environmental sustainability and mitigate social challenges within the target communities.

This is in line with results from various studies on the treatment of oil contamination and CF wastes in Nigeria and Europe (Wrześniewska-Tosik et al., 2012; Cervantes-González, et al., 2010; Ngene and Tota-Maharaj, 2017). A similar study was done in Canada, a comparative study of alternative sustainable waste treatment streams for poultry feathers and their potential applicability in Ontario (Amirmohsen, 2013). The study explored alternative waste treatment methods to determine whether they could complement the sustainable waste management landscape in Ontario. Alternative sustainable waste treatment streams include biofuels, bioplastics, water purification, and hydrogen storage. The results of this study showed that in Ontario, about 70 million pounds of poultry feathers are produced annually, and this can potentially be turned into 2,677,500 gallons of biodiesel. The author concludes that due to the abundance of poultry feathers in Ontario province, developing alternative ways to use them will add value and provide viable options that will ensure a safer and cleaner environment.

The results of this research showed that biodegradation is a good option for the disposal of chicken feather pillows at the end of their useful life. Also, commercial quantity can be achieved for the products if reverse logistics, which allows customers to return the sorbent pillows, is introduced.

7.4. Conclusion

The disposal of chicken feather oil pillows at end-of-life is a critical aspect to consider when selecting the product for oil spill remediation. These pillows are designed and developed to effectively absorb and contain oil spills, making them essential in environments where oil leakage is a concern. After converting the feather wastes to oil spill sorbents, it is important to consider environmentally friendly disposal methods to minimize and mitigate their impact on the environment and prevent another phase of waste management problem. Results from the study showed that biodegradation has a total of 16 ranks (48.48%) for the various key factors. Biodiesel has 10 ranks (30.30%), while incineration has 7 ranks (21.21%), respectively. This implies that biodegradation has the highest impact on all the key factors. Following the discussion of the key factors above. The proposed chicken feather pillow disposal options are suitable for application in the Niger Delta region, given that there are already existing general applications of the key factors or disposal options in the region under consideration.

Chapter 8 - Feasibility Study for Commercialisation of Chicken Feather Pillow

8.1. Introduction

Waste chicken feathers are a significant by-product of the poultry industry. Their disposal poses a formidable challenge due to the high solid waste volume and resulting negative environmental impact, especially in developing countries. Recent research has, however, demonstrated that chicken feathers have multiple potential applications. The commercialisation of waste chicken feather pillows has the potential to reduce the environmental impact of poultry farming and generate new revenue streams for farmers and manufacturers. Research revealed that price, sorption capacity, and competition were the most frequently mentioned qualities consumers look for when purchasing sorbents (Ludvigsson and Strömberg, 2008).

This feasibility study seeks to investigate the commercial viability of waste chicken feather pillows. The economic feasibility of producing and marketing the product will be evaluated. The results of this study will inform the decision-making process of parties interested in investing in the production and marketing of waste chicken feather pillows.

This feasibility study seeks to provide insightful information regarding the commercialization of waste chicken feather pillows, including potential benefits and obstacles.

8.2. Methodology

The research for this study was conducted over four months. Market data, organizational data, and financial data were collected for setting up a chicken feather pillow production company.

Primary market research was done through surveys and interviews. Individuals from five (5) companies (Potential customers) and three (3) established manufacturing companies were interviewed. Visits were also carried out to about ten other startups in different sectors in the region to gather needed information. Secondary research was also conducted using the internet, research reports, and books.

8.3. Competitors

There are several sorbent suppliers in Nigeria. Table 8.1 gives a list of some of the most widely used products, the manufacturers, shapes, and costs. From the table, the cheapest sorbent pillow goes for about $8.00, and the cheapest sorbent pad costs $1.00. This means that for the chicken feather pillow to be cheaper than what is already available, the cost must be less than $8.00.

Table 8.1: Cost of sorbents used in Nigeria.

Product	Manufacturer	Price ($)	Shape
Absorbent Pad	Brad SPC	1.3	Pad
HP-156 Sorbent Pad	3M	1.00	Pad
Absorbent Boom	Brady SPC	144.00	Boom
Absorbent Pillow	Drizit	11.00	Pillow (Cushion)
FB 52022 Absorbent (W) Pillow	Foss Environmental Worldwide	8.00	Pillow

8.4. Market Size

The market size of the oil spill clean-up in Nigeria can be categorized as the total available market, the serviceable available market, and the serviceable obtainable market.

The total available oil spill market can be estimated to be the total amount of money required to clean up the entire oil spill occurrence in Nigeria in a year. This is estimated to be 77 million dollars (an average of 25,308 barrels of crude oil is spilled annually, and it costs about $3047 to clean 1 barrel) (Therkelsen, 2020).

The serviceable available market can be described as the actual amount of oil spill that is within reach – by virtue of key resources and channels – to clean up. This can be estimated to be a third of the total available market, given that most of the crude oil spills in Nigeria occur in 3 states - Rivers, Delta, and Bayelsa - and only one state can be realistically and feasibly served at present. Hence, the serviceable available market is 25.7 million dollars (*Redirect Notice*, n.d.). The serviceable obtainable market is the oil spill clean-up revenue, which can be realistically captured. Here, we consider the specific market segments within the sector that

can be garnered using current operational and marketing resources. We estimate that the company can capture 10% of the serviceable available market, which is 2.57 million dollars.

From the interviews carried out, customers are frustrated by the cost of the absorbents in the market. While the products may be affordable for oil companies, entire segments of the oil spill market are left out. These include car repair workshops, manufacturing companies, and filling stations. Potential customers expressed interest and willingness to access affordable chicken feather pillows as soon as possible. Six customer segments were identified: manufacturing companies, oil companies, petrol stations, car repair companies, and petroleum product depots. They are discussed below.

8.4.1. Manufacturing Companies

Manufacturing companies often contribute to oil spills in marine environments through various means. Accidental spills can occur during the transportation of oil through ships or vessels due to factors such as collisions, grounding, or equipment failure. Human error is also a significant factor, as mishandling machinery or negligence in following proper protocols can lead to leaks or spills during manufacturing processes aboard ships or offshore platforms. Equipment failure, whether due to wear and tear or inadequate maintenance, poses a continual risk for oil spills in marine environments. Additionally, natural disasters such as storms, hurricanes, or tsunamis can damage offshore oil infrastructure, leading to significant spills into the marine ecosystem (Violante et al., 2018). Furthermore, deliberate acts of sabotage or vandalism targeting offshore oil facilities can result in intentional oil spills, exacerbating environmental damage. These issues are particularly prevalent in regions with high offshore oil activity, and it is very common in the Niger Delta Region of Nigeria (Mba et al., 2019).

8.4.2. Shipping Operators

Shipping companies are prone to causing oil spills in marine environments through various means, including accidents, human error, equipment failure, and natural disasters. Accidents can arise during the loading, transportation, or unloading of oil cargo, such as when tankers run aground, collide with other vessels, or suffer hull breaches (Walker et al., 2019). Human error, due to factors like inadequate vessel maintenance, communication breakdowns among crew members, or insufficient training, can also precipitate oil spills. Equipment failures, such as

malfunctioning valves or ruptured pipelines, are additional sources of potential spills in marine settings. Furthermore, natural disasters like hurricanes, typhoons, and tsunamis can inflict damage on ships and offshore drilling platforms, thereby causing significant oil spills into marine ecosystems.

8.4.3. Oil Companies

Oil companies can spill oil in several ways, including exploration and drilling, transport, storage, processing, and offshore drilling (Michel and Merv, 2016). Oil can be spilled during the exploration and drilling phase. For example, equipment failure or human error on an oil rig may result in an oil spill. Pipelines, tankers, and trucks used to transport oil are also subject to accidents that lead to oil spills. For example, a tanker truck may overturn, or a pipeline may rupture. Oil companies store and process oil in large tanks and facilities, which can experience equipment failure, leaks, or overflows. Accidents can also occur in offshore drilling rigs.

8.4.4. Filling Stations

Marine (or floating) filling stations are susceptible to oil spills through various means, including tank overfilling, leaks, equipment failure, accidents, human error, and natural disasters. These stations typically house large tanks capable of holding significant quantities of fuel. Overfilling these tanks can lead to oil spills through vents or pipelines connected to the tanks. Additionally, tank leaks, often caused by corrosion or other factors, can result in the seepage of oil into the marine environment, contaminating surrounding waters. Malfunctions in pumps, hoses, and other dispensing equipment can also contribute to oil spills, causing oil to discharge directly into the water. Accidents, such as collisions between vessels or machinery at marine filling stations, have the potential to damage tanks or dispensing equipment, leading to oil spills. Furthermore, errors made by station personnel or tanker operators, such as failing to properly close valves, can exacerbate the risk of spills. Finally, natural disasters such as floods, earthquakes, and storms can inflict damage on marine filling stations, resulting in oil spills and environmental harm.

8.4.5. Car Repair Companies

Car repair companies can spill oil in several ways, including oil changes, fluid changes, accidents, and improper storage. During oil changes, mechanics drain old oil from the engine and replace it with new oil then dispose of it into the surrounding marine environment. If the oil drain plugs or filter is not tightened properly, or if the oil filter seal is damaged, oil can leak out of the engine and onto the ground. Car repair companies may also change other fluids, such as transmission fluid or coolant. If these fluids are not drained or refilled properly, they can leak or spill out of the vehicle. Accidents can happen in repair shops just like in any other workplace. If a mechanic accidentally knocks over a container of oil or a piece of equipment, it can spill oil onto the ground. Car repair companies must store used oil and other fluids safely and securely to prevent spills. Used oil stored in leaking containers or areas where it can be knocked over can spill.

8.4.6. Petroleum Products Depot

Petroleum product depots with marine jetties are susceptible to oil spills through various means, including tank leaks, overfilling, accidents, human error, and natural disasters. These depots utilize large storage tanks for housing significant quantities of oil and other petroleum products, which can develop leaks due to corrosion or other factors. Moreover, oil spills can occur if tanks are overfilled, leading to overflow through vents or pipes connected to the jetties (Oko et al., n.d.). Accidents such as collisions between vessels or equipment at the jetties can result in ruptured tanks or pipelines, causing oil spills into the marine environment. Human error is also a contributing factor, as employees may fail to properly close valves or adhere to established safety protocols during loading or unloading operations at the jetties. Additionally, natural disasters like floods can inflict damage on tanks, pipelines, and other infrastructure at the marine depots, potentially leading to oil spills. Given these risks, strict adherence to safety measures and regular maintenance of equipment is crucial for preventing and mitigating the impact of oil spills from marine jetties associated with petroleum product depots.

8.5. Operations Plan

8.5.1. Status and Business Considerations

The business readiness plan precedes a startup company. To evaluate the success of a technology venture, the approach used will be the Cloverleaf model developed by Heslop, McGregor, and Griffith (Oosthuizen and Buys, 2003).

The three dimensions that will be used to evaluate startups are: technology readiness, market readiness, and commercial readiness.

A. Technology Readiness

This is the stage in the research and development of the product. There are nine levels of technology readiness, as shown in Table 8.2. The chicken feather pillow is at level 9. During this research, TRL 1 to 9 have been covered, and a minimum viable product has been produced.

Table 8.2: Technology Readiness

Technology Readiness Level	Description of Stage
TRL 1	Concept identified, not validated by peers
TRL 2	Theoretically viable, validated by peers
TRL 3	Proof-of-Concept demonstrated analytically/ experimentally
TRL 4	Prototyping, basic demonstration of functionality under lab conditions
TRL 5	Prototyping, basic demonstration of functionality under field conditions
TRL 6	Piloting, testing full systems in a simulated environment
TRL 7	Piloting, testing full systems in a real environment
TRL 8	Actual production in a simulated environment
TRL 9	Actual production in an actual environment

B. Commercial Readiness

Commercial Readiness Levels (CRL) is a system used to measure the maturity and commercial viability of a technology or product. It is similar to Technology Readiness Levels (TRLs) but focuses on the commercial aspect rather than the technical aspect (*CRL*, n.d.). Chicken feather pillow is at commercial readiness level 5. Table 8.3 shows the description of stages in CRL.

Table 8.3: Commercial Readiness Levels

Commercial Readiness Level	**Description of Stage**
CRL 1	Basic research: Research conducted to establish the feasibility of a concept or technology.
CRL 2	Applied research: Research conducted to demonstrate the practical application of a concept or technology.
CRL 3	Proof of concept: A prototype or model is developed to demonstrate the technical feasibility of a product or technology.
CRL 4	Alpha testing: The product or technology is tested in a laboratory environment to verify functionality and identify any technical problems.
CRL 5	Beta testing: The product or technology is tested in a real-world environment to validate its performance and identify any usability or reliability issues.
CRL 6	Limited commercial deployment: The product or technology is deployed in a limited capacity to test market acceptance and identify any issues that may arise during commercial use.
CRL 7	Full commercial deployment: The product or technology is fully deployed and available for purchase by customers.
CRL 8	Continuous improvement: Ongoing efforts are made to improve the product or technology based on customer feedback and market trends (*CRL*, n.d.).

C. Market Readiness:

Market Readiness Levels (MRLs) are used to measure the commercial readiness of a new product or technology. MRLs are like Commercial Readiness Levels (CRLs) but with a focus on market demand and acceptance rather than technical feasibility (Oosthuizen and Buys, 2003). Chicken feather pillow is at market readiness level 4. Table 8.4 shows the description of stages in MRL. There is no universally accepted standard for MRLs, but generally, the following levels are used:

Table 8.4: Market Readiness Levels

Market Readiness Level	**Description of Stage**
MRL 1	Market opportunity identification: Initial research to identify market opportunities and potential customer needs.
MRL 2	Market analysis: Further research to analyze the size and growth potential of the market, the competitive landscape, and regulatory requirements.
MRL 3	Market validation: Validation of the market opportunity through customer surveys, focus groups, and other market research methods.
MRL 4	Minimum viable product (MVP): Development of a minimum viable product or service that meets the needs of early adopters.
MRL 5	Launch and early sales: Launch of the product or service, with initial sales to early adopters.
MRL 6	Growth: Continued sales growth and expansion into new markets and customer segments.
MRL 7	Scaling: Scaling up production and distribution to meet increasing demand.
MRL 8	Market dominance: The product or service becomes the market leader in its category (*Market Readiness Levels*, n.d.).

The startup can also have a development plan for the first 12 months to guide its activities. See Figure 8.1 below.

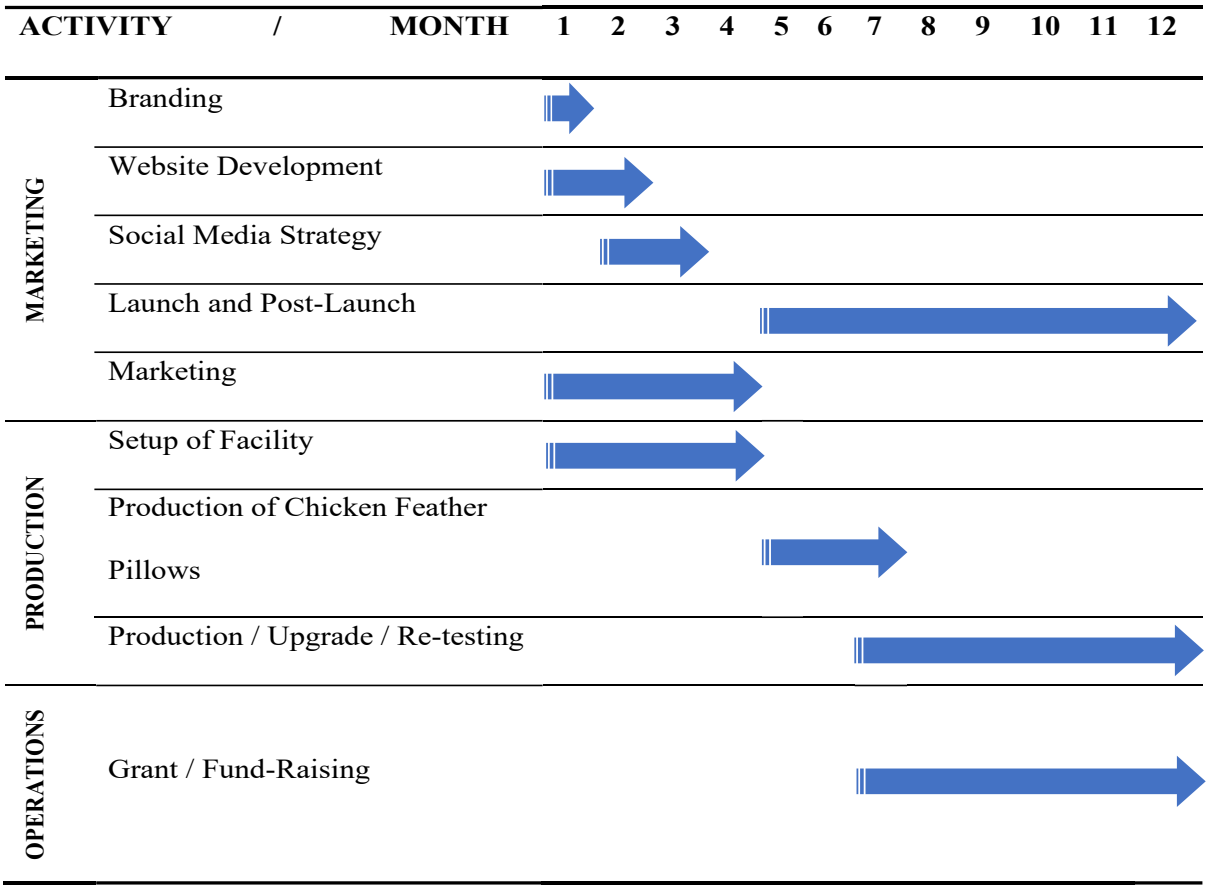


Figure 8.1: Development Strategy

8.5.2. Business Model Canvas

The Business Model Canvas is a strategic management tool used to design, evaluate, and communicate a business model (Barquet et al., 2011). It is a visual chart with pieces reflecting the value proposition, infrastructure, consumers, and finances of a company or product. It helps organizations align their efforts by highlighting potential trade-offs.

In this case, the canvas will be used to outline a business model for the use of chicken feather fibre pillows as oil sorbents in oil spill remediation. The business model canvas can help outline a clear and concise plan for the use of chicken feather fibre pillows as oil sorbents in oil spill remediation. By focusing on customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure, the startup company can develop a sustainable and effective business model that meets the needs of its customers and the environment.

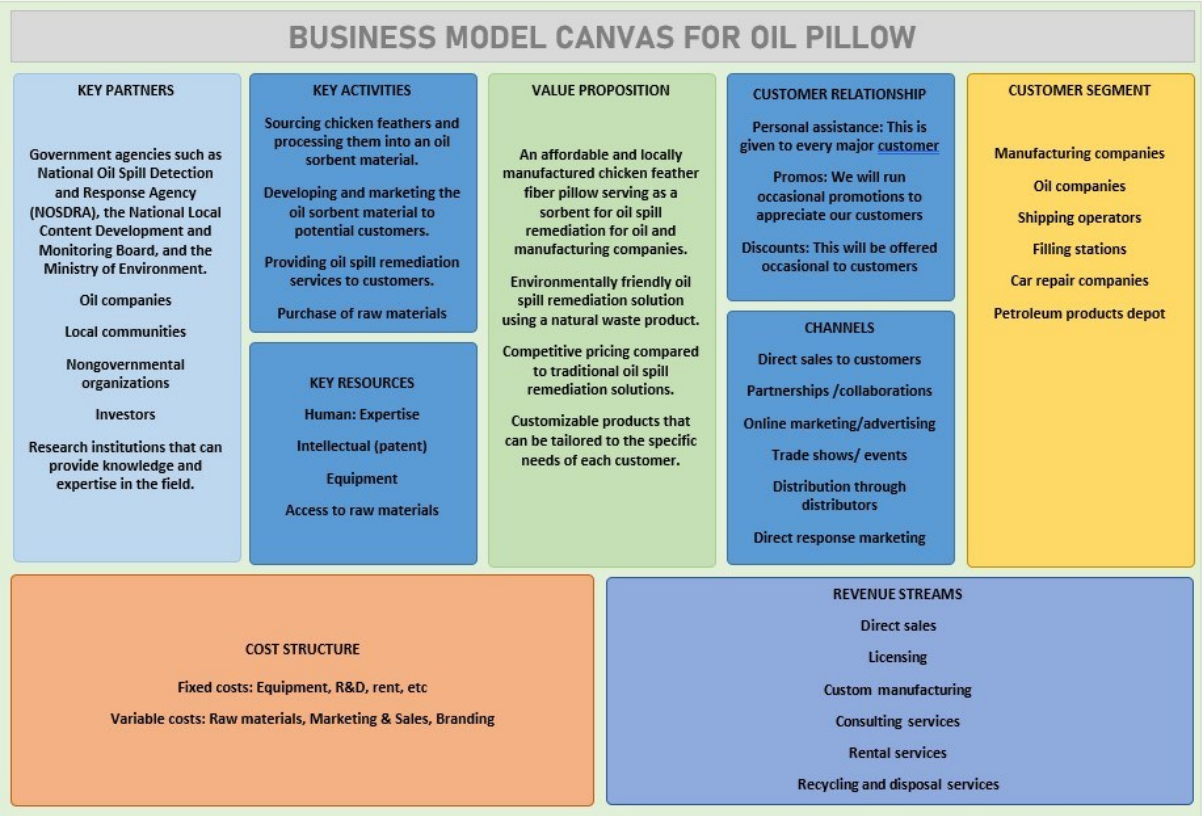


Figure 8.2: Business model Canvas for the use of chicken feather pillows as oil sorbents in oil spill remediation

8.5.3. Value Channels

Since it is a startup company, a mix of the following methods for distribution and sales is proposed, considering the nature of the product and target market;

1. **Direct sales to customers:** The company should sell the products directly to customers. The company may also reach out to potential customers, such as oil companies, shipping companies, or government agencies, to pitch its products and capabilities.
2. **Partnerships and collaborations:** The company will form partnerships and collaborations with other businesses, such as suppliers, contractors, or distributors, to expand its reach and increase its customer base.
3. **Online marketing and advertising:** The company should use online marketing and advertising channels, such as social media, search engine optimization (SEO), and pay-per-click (PPC) advertising, to reach potential customers and increase their share of mind.

4. **Trade shows and events:** The company should participate in trade shows and events related to the oil and gas industry or environmental protection to showcase its products and services and network with potential customers.
5. **Distribution through distributors:** The company should distribute products and services through distributors or resellers who have established relationships with customers in the target market.
6. **Direct response marketing:** The company should use direct response marketing techniques, such as sending direct mail or email campaigns to potential customers, to generate leads and increase sales.

8.5.4. Key Resources

The key resources that the startup will have to launch into the market are:

Human: It is important to have two or three engineers with academic and industry expertise. Business experts with experience in launching and growing businesses locally will also be sourced. Additionally, the company needs a formidable advisory team with decades of expertise and experience in the oil and gas sector. The key positions and roles in the company include the Chief Executive Officer, Operations Manager, Engineering Manager, Quality, Health Safety and Environment Manager (QHSE), Supply Chain Manager, Sales and Marketing Manager, Finance Manager, and Human Resources Manager. The CEO is the person who sets the vision, strategy, and direction of the company. The Operations Manager will be responsible for overseeing the day-to-day operation of the manufacturing process, including production planning, inventory management, quality control, and logistics. The Engineering Manager will oversee the design and development of the product, ensuring that it meets the required specifications and quality standards. The QHSE manager will be responsible for the Quality, Health, Safety, and Environment of all processes involved in production and ensure that the products meet the required quality standards. The Supply Chain Manager will be responsible for managing the supply chain, including sourcing materials, negotiating with suppliers, and managing business relationships. The Sales and Marketing Manager will be responsible for developing and executing the company's sales and marketing strategy, including identifying and targeting potential customers, creating promotional materials, and managing sales channels. The Finance Manager will manage the company's finances, including budgeting, forecasting, accounting, and financial reporting. Finally, the Human Resources Manager will be responsible for managing the company's human resources, including

recruiting and hiring employees, managing benefits and compensation, and overseeing employee training and development.

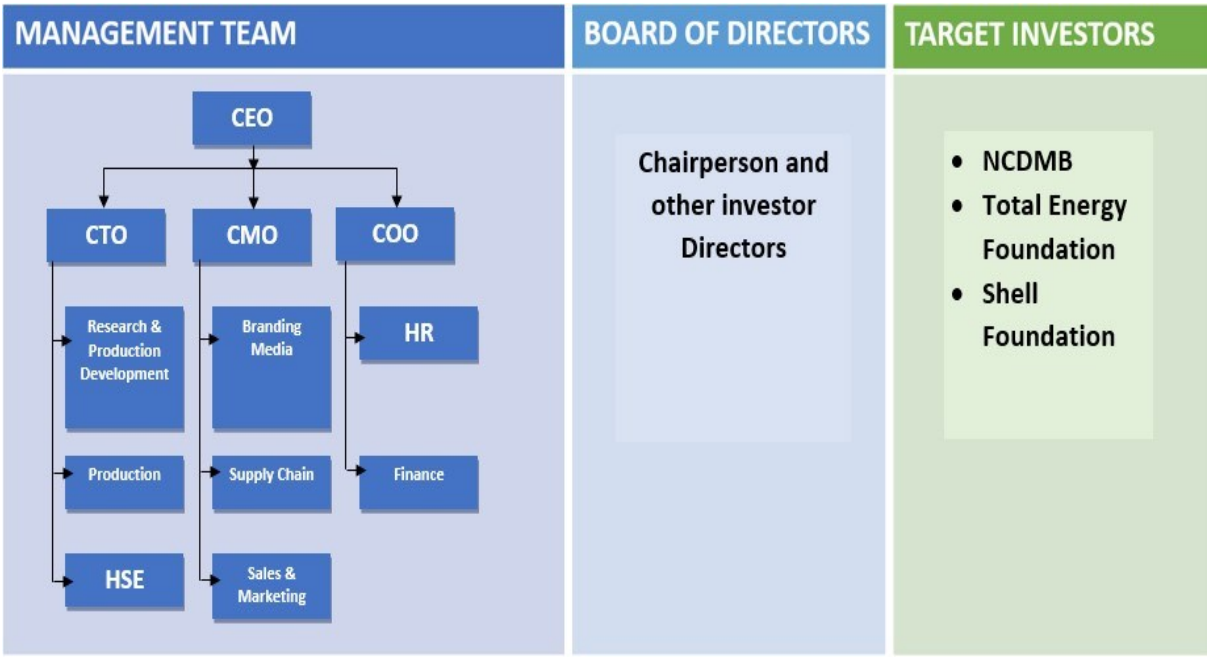


Figure 8.3: Management Team

1. Intellectual Property:

   This product has been patented in Nigeria with the patent number: NG/PT/NC/2023/6929.

2. Technology

   The production technology is simple and locally available. All equipment needed for feather processing and packaging, such as milling equipment, feather drying and sewing machines, can be sourced locally.

3. Access to raw materials

   One of the company's major operational assets is access to abundant raw materials and sustainable inbound logistics. The use of chicken feathers as the major raw material for making sorbents will not only contribute to environmental sustainability, but it will also promote economic growth locally. Nigeria has one of the largest chicken livestock in Africa, with roughly 166 million heads. This implies there would be an abundance of chicken feathers for oil spill remediation at affordable cost, especially as the material is locally available and can be easily processed, stored, and transported. Given that currently, chicken

feathers constitute an issue for slaughterers and the environment, their use as a sorbent would make a viable and compelling case for developing a circular economy.

8.5.5. Key Partners

To quickly penetrate the market and compete favourably, the startup company will need to establish some key partnerships;

1. **Government agencies:** The company should partner with government agencies in the agriculture sector and those responsible for overseeing and regulating oil spills, such as the National Oil Spill Detection and Response Agency (NOSDRA), the National Local Content Development and Monitoring Board, and the Ministry of Environment. These agencies may provide funding or other resources to support clean-up efforts in identified communities.
2. **Oil and gas companies:** The company should partner with some oil and gas companies operating in the region to coordinate clean-up efforts and share information about the type and amount of oil spilled.
3. **Local communities:** Company should partner with local communities affected by oil spills to ensure that clean-up efforts are sensitive to their needs and concerns. This may involve working with community leaders, providing information about the clean-up process, and involving community members in clean-up and restoration efforts.
4. **Non-governmental organizations (NGOs):** Company should partner with NGOs working on environmental issues to help protect wildlife and ecosystems affected by oil spills. These organizations may provide expertise and resources to help with clean-up and restoration efforts.
5. **Investors:** The company should also partner with investors who are interested in supporting the growth and development of an innovative and socially responsible startup. These investors may provide funding and resources to help the company scale up its operations and reach more communities affected by oil spills.

8.5.6. S.W.O.T Analysis for Chicken Feather Pillow

A key strength of the startup company is that it will have a product that is more affordable than the current competition. During the research, no company was identified that manufactures

natural sorbents locally. Another strength is that all equipment used was fabricated and purchased locally. The firm will probably be located within the Niger Delta region. This will give it a cost and location advantage over other sorbent manufacturers, who must import their products into the country. Easy access to abundant raw materials will also contribute to the success of the business.

The fact that raw materials would also be sourced locally means that it could influence legislation to make it difficult for imported sorbents to enter the Nigerian market. The product can also be promoted as a homegrown solution to spillage. It is a likely source of income for locals, and this means it can get massive support from poultry farmers and unemployed persons seeking to earn some income.

A weakness is that the company's revenue stream in the first year may largely depend on the sales of its oil spill cleaning pillows, which could leave it vulnerable to changes in demand or competition. The company may not have a diversified product portfolio to mitigate risks associated with fluctuations in demand or competition. The company may have limited distribution channels, which could make it difficult to reach new customers or expand into new markets. Finally, while the company's product can help clean up oil spills, major awareness is essential so that customers know that there is no environmental impact in using the pillows themselves. Figure 8.4 shows a summary of SWOT analysis for the chicken feather pillow.

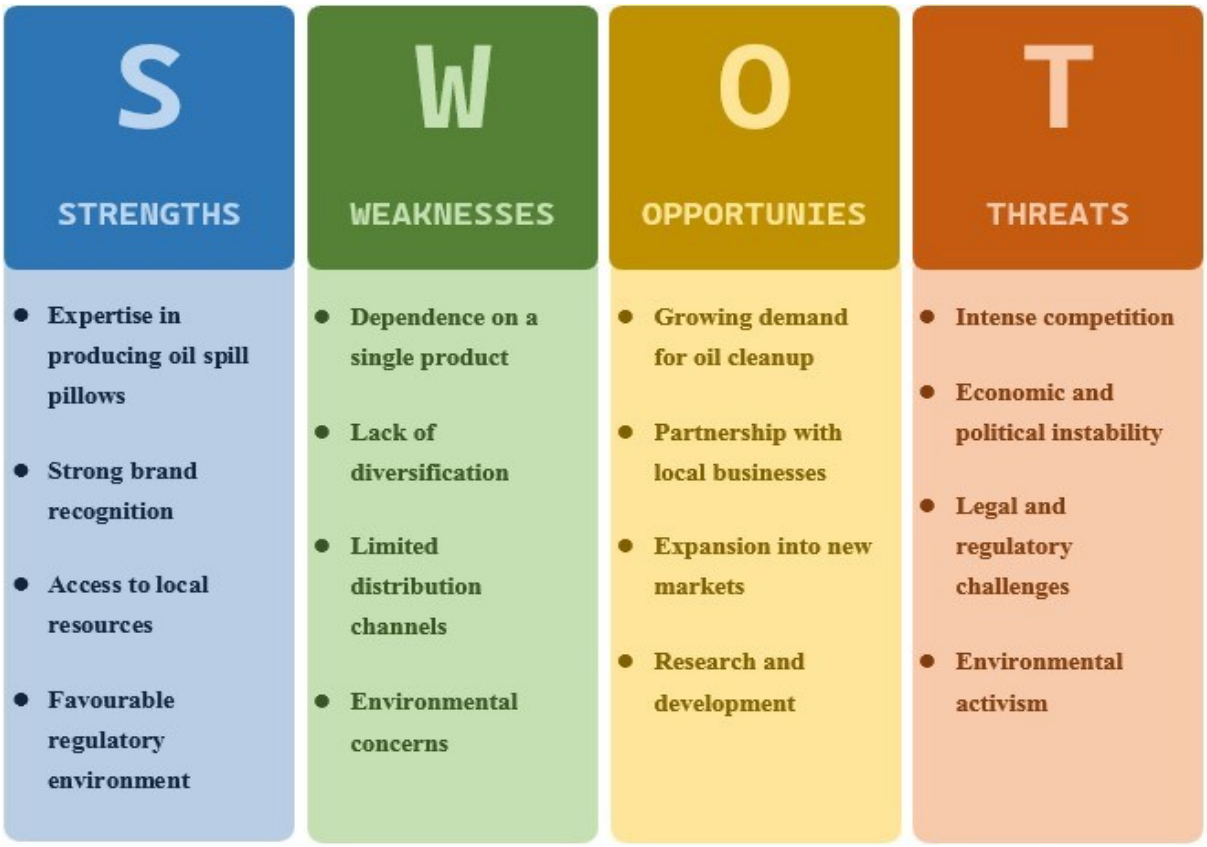


Figure 8.4: SWOT Analysis for Chicken Feather Pillow

A major opportunity is that the Niger Delta is a region with a history of oil spills, and the demand for effective and efficient clean-up solutions is likely to continue to grow. This will enable the company to partner with local businesses in the oil and gas sector to distribute its products and services. The Nigerian government has implemented policies to promote clean-up efforts, which will provide opportunities for the company to partner with government agencies and secure contracts (Amnesty International, 2021).

Through the Nigerian Content Development Monitoring Board (NCDMB), the local content policy in Nigeria seeks to use local expertise and resources to develop the oil and gas industry. Oil companies seeking to cut costs could find the solution interesting. Many African countries have discovered oil in recent years. This solution can be promoted in emerging oil-producing countries as an affordable, local oil sorbent.

A major threat is that the company will face intense competition from established players in the market. Secondly, the Niger Delta region has a history of economic and political instability, which could impact the company's operations and financial performance.

8.6. Financial Analysis/Financial Model

8.6.1. Financial Plan

The financial plan is an important aspect of the feasibility study for the commercialization of waste chicken feather pillows for oil spill remediation. It helps to determine the financial viability of the project and ensure that there is a strategy in place to finance the business. The financial analysis is related to the investment to be made, the projected returns, and the funds source deployed for the business (Rachmansyah, 2018).

8.6.2. Pricing and Revenue Model Pricing and Revenue Model

It is proposed that the company should have six possible revenue streams:

1. **Direct sale:** One unit of the pillow is $5.7. The pricing method used here is the mixed method, which is a combination of value-based pricing and cost-based pricing. For value-based pricing, the utility value of the product and the cost that clients incur today in alternative solutions were considered. The cost-based pricing considered the cost of a unit product, $4.59 (a cumulation of the fixed cost per unit as shown in Table 8.6, and the variable cost per unit as shown in Table 8.7) with a margin of profit.

Direct Sales is the major revenue stream. Others include:

2. **Licensing:** The company can license its technology and products to other companies for a fee. This would allow the licensee to manufacture and sell the oil spill cleaning pillows under the chicken feather pillows company's brand or using a new brand.
3. **Custom manufacturing:** The company can provide custom manufacturing services to customers who require specialized products or solutions for their specific needs.
4. **Consulting services:** The company can offer consulting services to customers on the proper use and application of the oil spill cleaning pillows.
5. **Recycling and disposal services:** The company can offer disposal services for used oil spill cleaning pillows, providing an additional revenue stream while also promoting the circular economy.

8.6.3. Assumptions

To aid the financial analysis of the projected income and expenditure account statement, the researcher made the following financial assumptions based on the production of the chicken feather pillow for the trial test and the current economic reality, as shown in Table 8.5. Through

these assumptions, the fixed and annual costs, breakeven analysis, the projected income and expenditure accounts, and sensitivity analysis were computed.

Table 8.5: Financial Analysis Assumptions

Item	Assumed Value
Marketing and Sales (% of revenue)	10%
Selling price per pillow	$5.71
Conversion rate (Dollar to Naira)	700
Quantity of feather (in grams) per pillow	105
Cost of 1 gram of washed and dried feather	$0.00
Cost of cover material per pillow	$0.57
Cost of sewing per pillow	$0.29
Cost of transportation for 1g of feather	$0.00
Number of pillows per client per quarter average	25
Periodicity of purchase by an Average customer annually	1
Periodicity of purchases by our best customer annually	4
Number of clients per week in Q1	10
Client growth rate /quarter in Year 1	130%
% Revenue on R&D expenditure	20%
Marketing and Sales (% of revenue)	10%
Selling price per pillow	$5.71
Conversion rate (Dollar to Naira)	700
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Cost of transportation for 1g of feather	$0.00
Number of pillows per client per quarter averagely	25
Periodicity of purchase by an Average customer annually	1
Periodicity of purchases by our best customer annually	4
Number of clients per week in Q1	10

Item	Assumed Value
Marketing and Sales (% of revenue)	10%
Client growth rate /quarter in Year 1	130%
% Revenue on R&D expenditure	20%

8.6.4. Unit Level Cost Analysis

The unit cost of chicken feather pillows is a determining factor of the health of the business. Table 8.6 contains the Projected annual fixed cost which is $42,962.57. In the first year, the quantity sold is projected as 18,561 as shown in Table 8.8.

$$Unit\ Cost\ = \frac{\text{Fixed cost}\ +\ \text{Variable cost}}{\text{Total quantity produced}}$$

Equation 21: Unit Cost

For the first year,

⇒ Fixed cost = $42,962.57; Variable cost = $42,260.24; Quantity = 18,561

⇒ Unit cost = $4.59

This cost correlates with the cost of production for a single small-sized chicken feather pillow, as stated in Chapter 5.

8.6.5. Fixed and Annual Variable Costs

The fixed annual cost is shown in Table 8.6. The fixed costs are assumed constant for the period under review while the annual variable costs are varied. The reason is that the fixed costs are high at low levels of production. The variable cost per unit, as shown in Table 8.7, is $2.28. The total variable cost is $42,260.24 at a quantity of 18,561, as seen in Table 8.8. Overall, the variable costs are high at high levels of production.

Table 8.6: Annual Fixed Costs

Item	**Fixed Costs**
Professional fees/Licenses	$1,000.00
General & Admin expenses (including staff training)	$1,500.00
Office expenses	$1,000.00
Rent	$1,500.00
Utilities	$1,000.00
R&D/ Product development	$21,212.57
Equipment	$15,750.00
TOTAL	$42,962.57
Fixed cost/unit	$2.31

Table 8.7: Annual Variable Cost

Annual Expenses	**Variable Cost**		
	Year 1	Year 2	Year 3
Cost of feather	$8,352.45	$15,141.47	$19,652.32
Cover material	$10,606.29	$19,227.27	$24,955.32
Cost of sewing	$5,303.14	$9,613.63	$12,477.66
Transportation	$1,392.08	$2,523.58	$3,275.39
Waste disposal	$6,000.00	$8,000.00	$10,000.00
Sales & Marketing	$10,606.29	$24,034.00	$31,194.15
Total	$42,260.24	$78,539.95	$101,554.84
Variable cost/unit	$2.28		

Table 8.8: Revenues for Year 1

Year 1	**Q1**	**Q2**	**Q3**	**Q4**	**Total**
Clients	120	156	203	264	264
Quantity	3000	3900	5070	6591	18,561
Revenue	$17,142.86	$22,285.71	$28,971.43	$37,662.86	$106,062.86

8.6.6. Income Statement

The income statement, as seen in Figure 8.9, summarizes the revenue, cost of goods or services, and expenses in projected sales in the first, second, and third years of operation: $106,063, $240,341, and $311,942, respectively. The cost of goods sold in the first, second, and third years of operation are $31,654, $54,506, and $70,361, respectively. The profit margins in the first, second, and third years of operation are 70%, 77%, and 77%, respectively. The operating profit margins in the first, second, and third years of operation are 2%, 31%, and 31%. Net profit: $1,628, $74,281, and $98,002, respectively. In the first year of operation, the margins are high enough to cover operations, so the business will operate at a net profit of $1,628.

Table 8.9: Income Statement

Income Statement	**Year 1**	**Year 2**	**Year 3**
Sales Revenue	$ 106,063	$ 240,341	$ 311,942
less: Cost of goods sold	$ 31,654	$ 54,506	$ 70,361
GROSS PROFIT	$ 74,409	$ 185,835	$ 241,581
Gross Margin	70%	77%	77%
less: Sales & Marketing	$ 10,606	$ 24,034	$ 31,194
Wages, Payroll taxes & Benefits	$ 34,830	$ 62,565	$ 83,850
G&A	$ 1,500	$ 3,000	$ 3,000
Office expenses	$ 1,000	$ 2,000	$ 2,000
Rent	$ 1,500	$ 1,500	$ 1,500
Utilities	$ 1,000	$ 1,500	$ 1,500
R&D	$ 21,213	$ 12,017	$ 15,597
Professional fees/Licenses	$ 1,000	$ 1,000	$ 1,000
Depreciation	$ -	$ 3,938	$ 3,938
Other expenses			
Total Operating Expenses	$ 72,649	$ 111,554	$ 143,579
Net profit before taxes	$ 1,760	$ 74,281	$ 98,002
Operating Margin	2%	31%	31%
Income taxes (exempted)	$ -	$ -	$ -
Interests	$ -	$ -	$ -
Net Operating income	$ 1,760	$ 74,281	$ 98,002

Income Statement	Year 1	Year 2	Year 3
Depreciation	$ -	$ 3,938	$ 3,938
Income taxes	$ -	$ -	$ -
Interests	$ -	$ -	$ -
EBITDA	$ 1,760	$ 78,219	$ 101,940

8.6.7. Breakeven Analysis

The breakeven analysis determines the point at which the company should be profitable. In other words, how many units of the product must be sold to cover the fixed and variable costs of production? In Table 8.5, the assumed sales price per unit is $5.71 while Table 8.7 captures the variable costs per unit at $2.28.

Breakeven Analysis

The breakeven points in units will be calculated with the formula below.

Breakeven Point in Units

$$\text{Breakeven Point in Unit} = \frac{\text{Fixed Costs}}{\text{Sales price per unit} - \text{Variable costs per unit}}$$

Equation 22: Breakeven Points in Units

$$\text{Breakeven Point in Unit} \Rightarrow \$42{,}962.57 \div (\$5.71 - \$2.28) = 12{,}498$$

To calculate the breakeven points in sales revenue, the contribution margin has to be calculated.

$$\text{Contribution margin} = \frac{\text{Sale price per unit} - \text{Variable costs per unit}}{Sale\ price\ per\ unit}$$

Equation 23: Contribution margin

⇒Contribution Margin = ($5.71 - $2.28) ÷ $5.71 = 0.6

$$Breakeven\ point\ in\ Sales\ Revenue \Rightarrow Fixed\ Costs \div Contribution\ Margin$$

Equation 24: Breakeven point in Sales Revenue

Breakeven point in Sales Revenue for year 1 = $42,962.57÷0.6 = $71,419.22

8.6.8. Sensitivity Analysis

In order to assess the feasibility and financial viability of commercializing chicken feather pillows as oil spill sorbents, a sensitivity analysis was conducted. This analysis aimed to evaluate the impact of various factors on the project's Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA) over the first three years of operation (Mukhambetov et al., 2020). Analysis was done based on the assumptions in Table 8.5 above.

Cost of Feathers Sensitivity:

Fluctuations in the cost of feathers were considered to affect production costs. The sensitivity analysis assessed the impact of changes in the cost of feathers on EBITDA, determining the threshold at which increased feather costs negatively impact profitability. Table 8.10 shows the values of the analysis while Figure 8.5 shows how an increase in the cost of feathers results in a decrease in EBITDA. The cost of feathers, $8,352.45, $15,141.47, and $19,652.32 for Years 1, 2, and 3, respectively, can be seen in Table 8.7, and the corresponding EBITDA, Table 8.9. The value for the cost of feathers was varied, and Table 8.10 shows the effect on the EBITDA for Years 1, 2, and 3. The analysis showed that with a significant increase in the cost of feathers, which could occur when farmhouses and poultry houses start selling waste chicken feathers, there would be a loss, as the negative values on the EBITDA for Year 1 show but the EBITDA for Years 2 and 3 would be enough to cover for the loss.

Table 8.10: One-way Sensitivity Analysis on the effect of cost of feathers on EBITDA for the first three years

YEAR 1							
Cost of Feathers	$2,000.00	$4,000.00	$6,000.00	$8,352.45	$10,000.00	$12,000.00	$14,000.00
EBITDA	$8,112.50	$6,112.50	$4,112.50	$1,760.05	$112.50	-$1,887.50	-$3,887.50
YEAR 2							
Cost of Feathers	$6,000.00	$9,000.00	$12,000.00	$15,141.47	$18,000.00	$21,000.00	$24,000.00
EBITDA	$87,360.22	$84,360.22	$81,360.22	$78,218.75	$75,360.22	$72,360.22	$69,360.22
YEAR 3							
Cost of Feathers	$5,000.00	$10,000.00	$15,000.00	$19,652.32	$25,000.00	$30,000.00	$35,000.00
EBITDA	$116,591.92	$111,591.92	$106,591.92	$101,939.61	$96,591.92	$91,591.92	$86,591.92

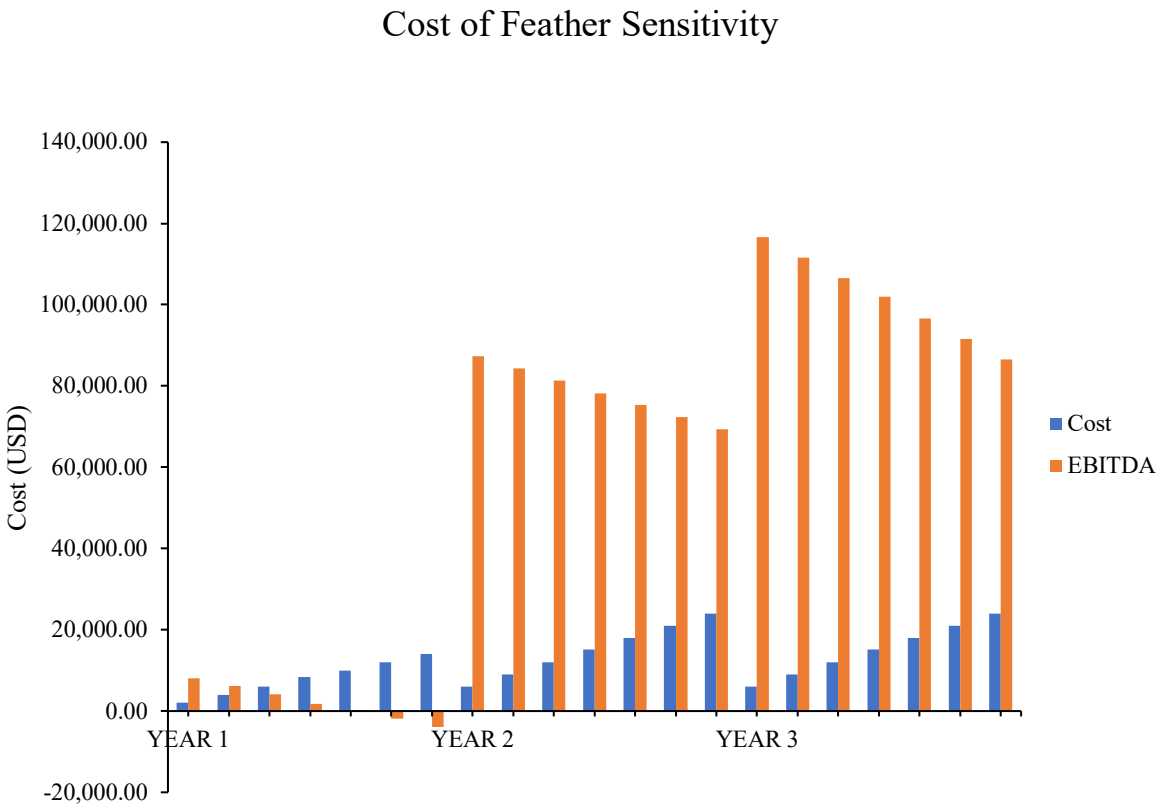


Figure 8.5: Sensitivity Analysis for the effect of Cost of Feathers on EBITDA

Operational Expenses Sensitivity:

Operating expenses such as wages, marketing, and administrative costs were considered to affect overall profitability. The sensitivity analysis assessed the impact of changes in operational expenses on EBITDA, identifying cost-saving opportunities to improve profitability. Table 8.11 shows the values of the analysis, while Figure 8.6 shows how an increase in the operational expenses results in a decrease in EBITDA. The operational expenses, $72,648.86, $111,553.62, and $143,578.73 for Years 1, 2, and 3, respectively, and the corresponding EBITDA, can be seen in Table 8.9. The values for the operational expenses were varied, and Table 8.11 shows the effect on the EBITDA for Years 1, 2, and 3. The analysis showed that with a significant increase in the operational expenses, which could occur with an increased rate of equipment leasing, rent, dollar exchange, etc., there would be a loss, as the negative values on the EBITDA for Year 1 show, but the EBITDA for Years 2 and 3 would be enough to cover for the loss.

Table 8.11: One-way Sensitivity Analysis on the effect of operating expense on EBITDA for the first three years

				YEAR 1			
Operating Expense	$55,000.00	$60,000.00	$65,000.00	$72,648.86	$80,000.00	$85,000.00	$90,000.00
EBITDA	$19,408.90	$14,408.90	$9,408.90	$1,760.05	-$5,591.10	-$10,591.10	-$15,591.10
				YEAR 2			
Operating Expense	$40,000.00	$65,000.00	$90,000.00	$111,553.62	$140,000.00	$165,000.00	$190,000.00
EBITDA	$145,834.87	$120,834.87	$95,834.87	$78,218.75	$45,834.87	$20,834.87	-$4,165.13
				YEAR 3			
Operating Expense	$55,000.00	$85,000.00	$115,000.00	$143,578.73	$175,000.00	$205,000.00	$240,000.00
EBITDA	$186,580.83	$156,580.83	$126,580.83	$101,939.61	$66,580.83	$36,580.83	$1,580.83

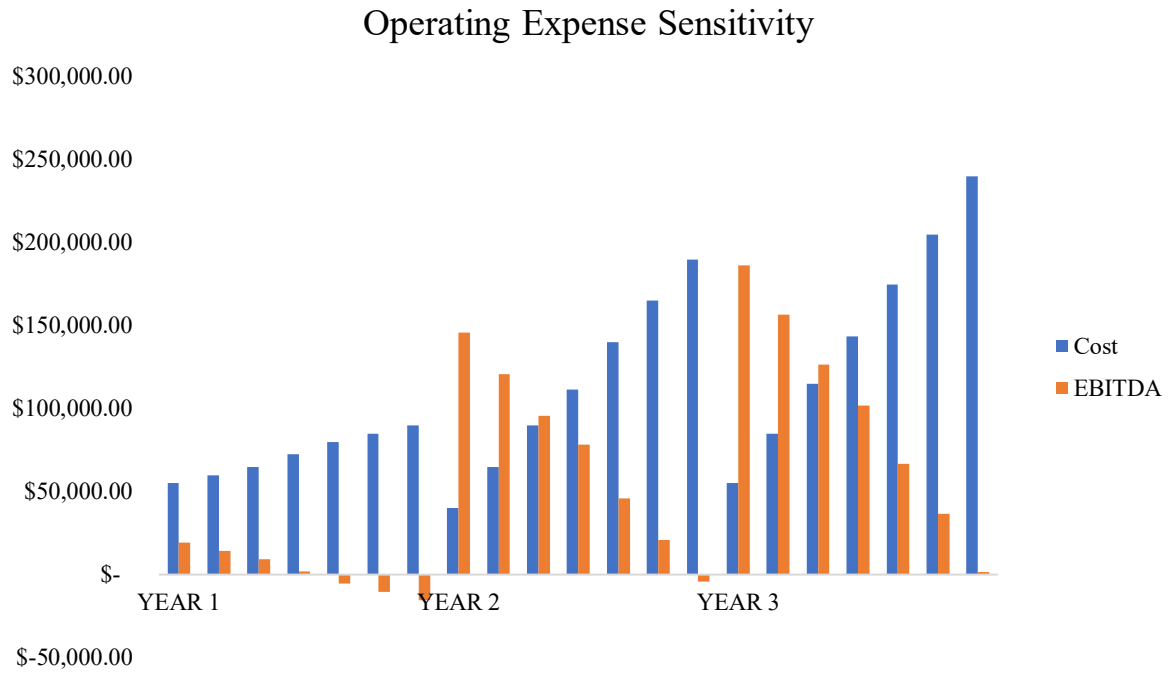


Figure 8.6: Sensitivity Analysis for the Effect of Operational Expense on EBITDA

Cost of Feather and Operational Expenses Sensitivity:

Fluctuations in the cost of feathers and operational expenses such as wages, marketing, administrative costs, and research and development (R&D) expenditures were considered to impact production costs and overall profitability. The sensitivity analysis assessed the combined impact of changes in the cost of feathers and operational expenses on EBITDA,

identifying the thresholds at which increased costs negatively affect profitability. By analysing the interplay between these two key factors, the sensitivity analysis provided insights into the project's financial resilience and helped identify strategies to optimize cost efficiency while maximizing EBITDA. In Table 8.12 below, the cost of feathers for each year and the variations are captured in the first data row, while the operational expenses for each year and variations are captured in the first data column. The remaining values are the resulting changes in the EBITDA.

Table 8.12: Two-way Sensitivity Analysis on the effect of change in cost of feathers and operational expenses on EBITDA

Year 1		**Cost of Feather**				
	$1,760.05	$6,500.00	$7,500.00	$8,352.45	$9,500.00	$10,500.00
Operational Expense	$55,000.00	$21,261.35	$20,261.35	$19,408.90	$18,261.35	$17,261.35
	$65,000.00	$11,261.35	$10,261.35	$9,408.90	$8,261.35	$7,261.35
	$72,648.86	$3,612.49	$2,612.49	$1,760.04	$612.49	-$387.51
	$85,000.00	-$8,738.65	-$9,738.65	-$10,591.10	-$11,738.65	-$12,738.65
	$95,000.00	-$18,738.65	-$19,738.65	-$20,591.10	-$21,738.65	-$22,738.65

Year 2		**Cost of Feather**				
EBITDA	**$74,281.25**	$5,000.00	$10,000.00	$15,141.47	$20,000.00	$25,000.00
Operational Expense	$70,000.00	$125,976.34	$120,976.34	$115,834.87	$110,976.34	$105,976.34
	$90,000.00	$105,976.34	$100,976.34	$95,834.87	$90,976.34	$85,976.34
	$111,553.62	$84,422.72	$79,422.72	$74,281.25	$69,422.72	$64,422.72
	$130,000.00	$65,976.34	$60,976.34	$55,834.87	$50,976.34	$45,976.34
	$150,000.00	$45,976.34	$40,976.34	$35,834.87	$30,976.34	$25,976.34

		Cost of Feather				
EBITDA	**$98,002.11**	$10,000.00	$15,000.00	$19,652.32	$25,000.00	$30,000.00
Operational Expense	$95,000.00	$156,233.15	$151,233.15	$146,580.83	$141,233.15	$136,233.15
	$120,000.00	$131,233.15	$126,233.15	$121,580.83	$116,233.15	$111,233.15
	$143,578.73	$107,654.42	$102,654.42	$98,002.10	$92,654.42	$87,654.42
	$170,000.00	$81,233.15	$76,233.15	$71,580.83	$66,233.15	$61,233.15
	$195,000.00	$56,233.15	$51,233.15	$46,580.83	$ 41,233.15	$36,233.15

By conducting this comprehensive sensitivity analysis, stakeholders can make informed decisions regarding the commercialization of chicken feather pillows as oil spill sorbents, effectively managing risks and maximizing profitability.

8.6.9. Sources and Uses of Startup Capital

The startup capital, which will cover expenditures for the first 12 months, will be used to secure the following expenses, which are divided into monthly and one-time costs. Funds can be raised from research grants, such as the National Research Fund (NRF), the Tertiary Education Trust Fund (TETFund), the Tony Elumelu Foundation, etc., and pre-seed investment from business incubation funds. These costs are divided into monthly and one-time costs in Table 8.13 and Table 8.14.

Table 8.13: Startup Company Monthly Costs

Wages/ payroll taxes	12	$ 2,903	$ 34,830
Marketing & Sales	24	$ 442	$ 10,606
Utilities	24	$ 42	$ 1,000
Rent	12	$ 125	$ 1,500
Cost of materials (Q1)	3	$ 1,382	$ 4,146
R&D cost	12	$ 1,768	$ 21,213
General & Admin	24	$ 63	$ 1,500
Total			$ 74,795

Table 8.14: Startup Company One-time costs

License/Professional fees	$ 3,000
Office Supplies	$ 2,000
Machinery	$ 15,750
Total	$ 20,750
Total Startup Cost	$ 95,545

8.7. Conclusion

From the study conducted, there is a high potential for a commercialization process for chicken feather pillows. There is a huge market that can be tapped into for economic gain. The SWOT analysis indicates that investment in the commercialisation of chicken feathers has very bright prospects of success, and the challenges to a successful venture can be overcome. The breakeven in units is 12,498, while the breakeven point in Sales revenue is $71,419.22. In addition, within the first year of operation, the margins are high enough to allow the business to operate at a net profit of $1,628. These all make a compelling case for the establishment of a business to commercialize chicken feathers processing sorbent for oil spills and promote a circular economy in Nigeria and other developing countries.

Chapter 9 – Barriers to Circularity for Chicken Feather Waste in Niger Delta Region of Nigeria

9.1. Introduction

The Nigerian agricultural sector generates a substantial quantity of waste, which is difficult to manage due to the linear economy's old take-make-dispose model.

Due to increased awareness of the circular economy, which emphasises the concept that waste should be minimised to the greatest extent possible and viewed as a resource, more efforts are being made to utilise agricultural waste for other purposes. Particularly, cassava peel ash, empty palm oil fruit brunch ash, rice husk ash, and other agricultural residues are being investigated for use in the production of structural concrete (Fapohunda et al., 2021). Extensive research has also been conducted on biogas production from poultry feathers and cow manure (Owamah et al., 2020). In Nigeria's poultry industry, a substantial quantity of chicken feather waste is generated from the more than 450,000 tonnes of chicken produced annually for a market that consumes more than 1.5 million tonnes of chicken annually (H. I. Kelle and Eboatu, 2018).

As stated by the Ellen MacArthur Foundation, the attainment of circularity in a waste management system necessitates adherence to a set of diverse conditions. Among these conditions, it is of paramount importance to promote business models that are purposefully designed to maintain waste and materials in a state of productive use, thereby retaining their inherent value. In their comprehensive report, "Circular Advantage," Accenture has identified and highlighted five distinct business models that serve to foster circularity, namely: circular supplies, resource recovery, product life extension, sharing platforms, and product-as-a-service (Circular Advantage. Innovative Business Models and Technologies to Create Value in a World Without Limits to Growth | Sharing Cities Alliance, n.d.).

An exemplary demonstration of circularity can be observed in the utilization of used chicken feathers as an oil sorbent for the purpose of oil spill remediation, which effectively combines the principles of circular inputs and resource recovery. The associated benefits stemming from this practice are manifold and encompass various dimensions. Firstly, it engenders considerable cost savings in waste management endeavors. Secondly, it augments the value of waste chicken feathers by conferring upon them a renewed purpose. Thirdly, it ensures the security of supplies for chicken feather pillows. Additionally, the utilization of used chicken feathers contributes to environmental improvement and entails noteworthy economic advantages.

The significance of reusing materials and goods at the end of their useful lives becomes evident in the context of a circular economy. To surmount the obstacles hindering the transition towards circularity, it is imperative to identify and address the barriers that could impede such progress, as emphasized by Dieckmann et al. (2020).

Acquiring a comprehensive understanding of the challenges inherent in establishing a circular economy for discarded chicken feathers would prove exceedingly valuable. This is particularly pertinent due to the abundant availability of these materials, coupled with the non-ecofriendly nature of prevailing linear economy disposal methods employed in the Niger Delta region, which have the potential to introduce greenhouse gases into the environment, as highlighted by Xia et al. (2016).

The Niger Delta region in Nigeria is renowned for its substantial hydrocarbon resources, making it one of Africa's most significant reservoirs of oil and gas. With reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas, this area ranks 12th globally in terms of hydrocarbon accumulation (Tuttle et al., 1999). Geographically, the region comprises nine states that have been designated as such primarily due to the presence of oil and gas deposits, as seen in Figure 9.1. These states are Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers State (National Population Commission, NPC, 2006).

Abia State shares borders with Enugu and Ebonyi to the north and northeast, Imo State to the west, Cross River State to the east, Akwa Ibom State to the southeast, and Rivers State to the south. Its largest city and economic hub is Aba. The economy of Abia State relies on the production of natural gas, crude oil, and agricultural commodities, notably yams, maize, taro, oil palm, and cassava. Manufacturing also plays a significant role in and around Aba (Aba, Nigeria, 2023).

Akwa Ibom State is bordered by Rivers State to the east, Cross River State to the west, Abia State to the north, and the Gulf of Guinea to the south. It contributes significantly to the nation's crude oil production (About Akwa Ibom - Akwa Ibom State Government, 2023). The economy of Akwa Ibom State is primarily centered around the production of crude oil and natural gas, as it leads the country in oil output. Notably, Ibeno, Mbo, and Eastern Obolo are oil-producing local government areas within the state. The agricultural industry is also experiencing substantial growth, with cocoyam, yam, and plantain being prominent crops.

Bayelsa State is bordered by Rivers State to the east and Delta State to the west, while its southern boundaries are defined by the stunning waters of the Atlantic Ocean. It possesses

significant reserves of crude oil and natural gas and is characterized by numerous creeks, lagoons, rivers, and marshes where commercial fishing thrives. Fishing serves as the primary occupation of the Bayelsa people (Yenagoa | Nigeria, Map, and Population, 1998).

Cross River State is situated in the southeastern part of Nigeria, sharing borders with the Republic of Cameroon to the east, Benue State to the north, Ebonyi State to the northwest, and Akwa Ibom State to the south. Major cash crops in Cross River State include oil palm, rubber, and cocoa. Additionally, the region is known for its deposits of limestone, gypsum, titanium, tin ore, ceramic raw materials, and hardstone ((Cross River State, Nigeria - Maryland Sister States, 2017).

Delta State is a prominent oil-producing state, bordered by Edo State to the north, Anambra to the east, Bayelsa to the south, and Edo State again to the west. As a leading jurisdiction in terms of oil production, the economy of Delta State is predominantly focused on the extraction of crude oil and natural gas (Akanbi et al., 2021).

Edo State capital, Benin City, ranks as the fourth-largest city in Nigeria and serves as the center of the rubber industry in the country. Edo State shares borders with Kogi State to the northeast, Anambra State to the east, Delta State to the southeast, and Ondo State to the west. The state's substantial oil and gas reserves contribute significantly to the nation's overall output. Edo State is renowned for its deposits of marble, clay, granite, limestone, and gold (Stets and Simwa, 2023).

Imo State is situated in Nigeria, bordered to the north by Anambra State, to the west and south by Rivers State, and the east by Abia State. The state's capital is Owerri. The economy of Imo State heavily relies on the production of palm oil, which is widely utilized by the majority of its population for cooking purposes (Chukwu et al., 2011). The region is also endowed with natural resources such as lead, zinc, crude oil, and natural gas.

Ondo State shares boundaries with Kwara and Kogi to the north, Edo to the east, Delta to the southeast, Osun and Ogun to the west, and the Bight of Benin of the Atlantic Ocean to the south. Agriculture serves as the backbone of the state's economy, with cotton and tobacco cultivated in the northern region, cocoa in the central area, and rubber and timber (including teak and hardwoods) in the southern and eastern parts. Ondo State holds the distinction of being the leading cocoa-producing state in Nigeria. Additionally, the state produces rice, yams, corn (maize), coffee, taro, cassava, vegetables, and fruits. Notable industrial establishments in the

state include a textile plant in Ado-Ekiti and a palm oil refinery in Okitipupa (Ondo | Nigeria, Map, and Facts, 2023).

Rivers State, located in southern Nigeria, shares borders with Anambra and Imo to the north, Abia and Akwa Ibom to the east, and Bayelsa and Delta to the west. Agriculture and fishing are the primary industries in the region. The state is abundantly endowed with valuable mineral resources, particularly large quantities of crude oil and natural gas within the Niger River basin (Rivers | Nigeria, Map, History, and Population, 2023).



Figure 9.1: Niger Delta states in Nigeria (*Map of the Niger Delta Region.*, n.d.)

9.2. Methodology

The method used for the assessment is the Circular Economy (CE) barriers method developed by Dieckmann et al. (2020). It provides a novel approach to identifying barriers to circular economy and can be applied to a wide range of end-of-life materials and products. The method identifies nine top-tier barriers that cover the key aspects relevant to defining the CE potential of materials and end-of-life products. The barrier categories are:

1. Material Characteristics
2. Processing Technologies
3. Environmental Impact
4. Organisation Context

5. Industry/Supply Chain
6. External Drivers
7. Public Perception
8. Regulatory Framework And
9. Economic Viability.

Each potential barrier is assessed against Levels 0 - 3 which allows potential barriers to circular economy to be identified and the total barrier to be quantified on a scale of 0 to 27. Figure 9.2 shows the top-tier barrier assessment framework.

Top-tier Barriers	**Assessment Levels**			
	Level 0	Level 1	Level 2	Level 3
Material Characteristics	No Potential	Some Possibility	Good Potential	High Potential
Processing Technologies				
Environmental Impact				
Organisational Context				
Industry and Supply Chain				
External Drivers and Incentives				
Public Perception				
Regulatory Framework				
Economic Viability				

Figure 9.2: Top-tier Circular Economy barrier assessment framework (Circular Economy Barriers-Dieckmann, 2020)

A comprehensive field volunteer team was assembled and contacted across the nine states of the Niger Delta region to engage in a three-month data collection initiative. The primary responsibilities of the team included distributing questionnaires, conducting targeted interview sessions, and gathering essential data. The team members underwent regular sessions for orientation, fieldwork briefing, and reporting. Special attention was given to familiarizing them

with the principles of the circular economy, the chicken feather pillow project, interviewee selection criteria, and the application of assessment techniques.

The selection process for interviewees was meticulously crafted to ensure a diverse pool of candidates with relevant backgrounds and extensive experience in key fields such as agriculture, waste management, and oil pollution management. Careful consideration was given to sourcing interviewees from various sectors, including government organisations, the poultry processing industry, potential end-users of chicken feather pillows, and companies specializing in the utilization of waste chicken feathers. This approach aimed to capture a comprehensive range of perspectives and expertise relevant to the study's objectives.

Prior to conducting interviews, a comprehensive training program was provided to all field volunteer team members. This training covered essential concepts such as circular economy principles, the sorbent properties of chicken feather pillows, and the methodology for assessing barriers to circularity. By ensuring field volunteer team members were well-informed and equipped with the necessary knowledge, the interviews were conducted on a level playing field, fostering meaningful discussions and insightful responses.

The interview process itself was conducted with meticulous attention to detail, with an average duration of approximately one hour per interview. A minimum of five individuals were interviewed in each state, ensuring geographic diversity and capturing regional nuances in perspectives and experiences. Ethical consideration was a key factor in the survey process. The first ethical consideration was to ensure the full introduction of the profile of the researcher. Care was also taken not to coerce any individual into the survey (Graham, 2005). All participants were briefed and assured of the confidentiality and anonymity of the responses they were providing. Respondents were also assured that participation was voluntary, and they can pull out at any time, which was stated in the questionnaires. The research was done in collaboration with Rivers State University, Department of Chemical Engineering, and so an ethical consent procedure was carried out and an ethical approval letter was issued on completion, which can be seen in Appendix 11.7.2.

In addition to interviews, an online questionnaire was distributed as part of the data collection process. A total of 180 individuals completed the questionnaire, in different categories, providing supplementary insights and perspectives on the utilization of chicken feathers and barriers to circularity.

For further details of questionnaire categories, Appendix 11.6.1 to 11.6.4 highlights questionnaires for different categories including business organisations, poultry/ slaughterhouse owners, individuals/heads of communities, and Government officials/ policymakers. "Questionnaires for Expert Interviews on the Barriers to Circularity" in the Appendix (11.6.5.) provides a comprehensive overview of the interview questionnaire, while details of responses to questionnaires are highlighted as follows, "Summary of Responses from 60 Respondents on Questions for the Use of Chicken Feather" in the Appendix (11.6.6.) which highlights specific responses obtained from 60 individuals representing various categories of interviewees and “Summary of response from 5 expert interviewees” which presents responses from subject experts, highlighted in Appendix (11.6.7).

9.3. Results and Discussion

9.3.1. Material Characteristics

In accordance with Dieckmann's barrier assessment framework for transitioning to a circular economy (CE), a particular category focused on evaluating how the characteristics of the material influence the transition process. This assessment was conducted for all eight barriers identified in the framework. In Table 9.1, the feedback received from the field regarding the subcategories related to material characteristics is presented. The table highlights the responses from the state that received the highest score and the state that received the lowest score.

In the context of material characteristics, the respondents in Cross Rivers State demonstrated a higher level of awareness compared to those in Imo State. The respondents in Cross River acknowledged that waste chicken feathers were not complex, possessed aesthetic value, exhibited slow degradation, were not hazardous, and had economic value. Similar findings were observed in Imo State, except that the respondents did not perceive aesthetic potential in waste chicken feathers (CFW), and the economic value was deemed low.

It is worth noting that Cross River State has a notable tradition of utilizing feathers extensively during the annual Calabar festival and other local festivities (Carlson, 2019). This cultural context may have influenced the greater familiarity and appreciation of waste chicken feathers in Cross Rivers State compared to Imo State.

Table 9.1: Assessment of Material Characteristics (MC) negatively affecting or enabling circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

MC Sub-category	State	No Potential (Level 0)	Some Potential (Level 1)	Good Potential (Level 2)
MC1 Composition: Is the material complex or heterogeneous?	Cross River			The CFW is not complex
	Imo			Same
MC2 Economic Value: Can the value of material hinder the transition to a circular economy?	Cross River			There is good economic value
	Imo		There is no reasonable economic value	
MC3 Components/Parts: Are those different components that are difficult to separate?	Cross River			Clean material can be recovered for use
	Imo		It can be recovered with much more effort	
MC4 Aesthetic Value: Are there any aesthetic values that can benefit the transition to circularity?	Cross River			CFW has aesthetic value
	Imo		Little Appreciation for aesthetic value	
MC5 Stability: Does the material degrade?	Cross River			CFW does not rapidly degrade
	Imo			Same as above
MC6 Hazardous Level: Is the material hazardous?	Cross River			CFW is stable and does not cause adverse health
	Imo			Same as above
MC7 Degree of Contamination: Is the material contaminated?	Cross River			Material is not Contaminated
	Imo		CFW a bit mixed up with other agricultural waste	

Figure 9.3 depicts the range of assessment scores for material characteristics across the nine states, ranging from 1.4 to 2.0. On average, this top-tier barrier received an assessment score of 1.78, indicating a reasonable potential for transitioning toward a circular economy. Most respondents expressed the belief that, when handled appropriately, waste chicken feathers do not pose any recognized health or environmental hazards. These feathers can undergo processing to a certain extent and exhibit stability, displaying a low likelihood of rapid deterioration.

Notably, respondents from four states - Akwa Ibom, Cross River, Delta, and Edo - assigned a score of 2, suggesting that they perceive chicken feathers as capable of effectively mitigating the frequent oil spills experienced in their regions (Amnesty International, 2013). The absence of a score of zero across all nine states implies a consensus among respondents regarding the positive attributes of chicken feathers as a material for oil spill remediation. According to the assessment, respondents expressed concerns about waste chicken feathers containing problematic or hazardous substances that could adversely impact human health and the environment. Given the high level of literacy in the Niger Delta states (Literacy Rate in Nigeria 1991-2018, 2024), this perspective carries significant validity.

It is worth noting that the collection of waste chicken feathers from poultry farms in Rivers State may face greater contamination and pollution challenges due to the high concentration of black soot in the air. The atmospheric pollution results from various combustion processes occurring in both industrial and small-scale refineries (Maduawuchi, 2021). Consequently, these pollutants can accumulate on chicken feathers, elevating contamination levels. Conversely, regions with lower industrial emissions are likely to experience less atmospheric pollution and, consequently, lower contamination levels of chicken feathers. Overall, the findings indicate that the material properties of waste chicken feathers do not pose significant obstacles to the transition toward circularity.

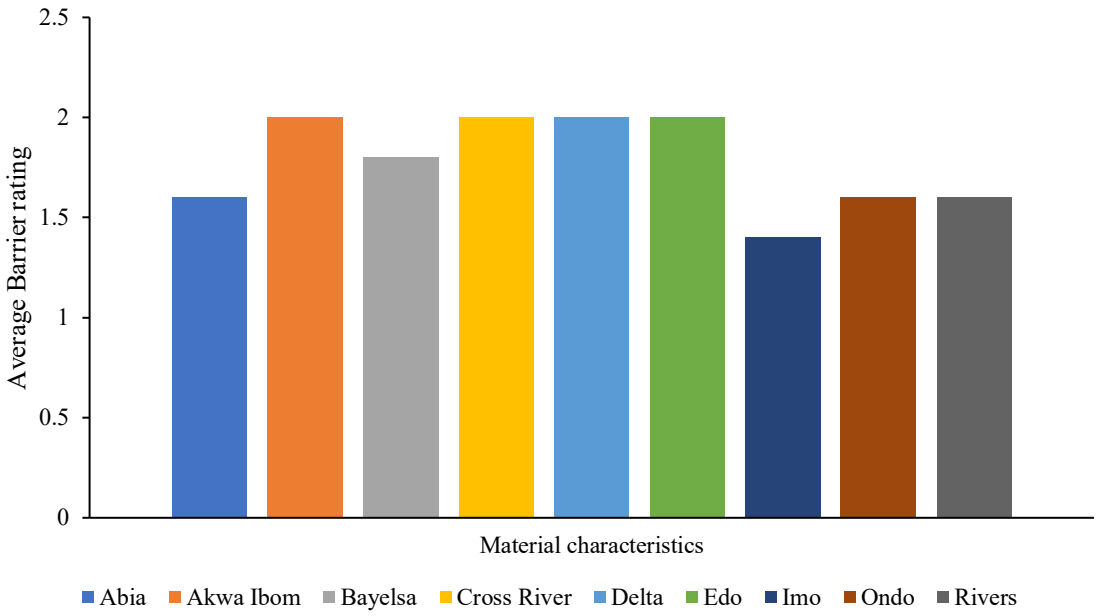


Figure 9.3: Average material characteristics impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.3.2. Processing Technologies

Table 9.2 provides a comprehensive discussion of the subcategories of processing technology, focusing on Cross Rivers State and Bayelsa State. Notably, Bayelsa State exhibits the lowest readiness rating for processing technology, which aligns with its overall level of development. As the least developed and industrialized state in the Niger Delta region, Bayelsa State's economy predominantly relies on agrarian activities, with a significant emphasis on fishing (Yenagoa | Nigeria, Map, and Population, 1998).

In contrast, Cross River State presents a distinct scenario. The poultry farms in this state demonstrate a higher degree of preparedness in terms of processing facilities dedicated to the effective removal and separation of chicken feather waste. Furthermore, Cross River State benefits from the availability of competent human resources and well-established logistics systems, facilitating the seamless transfer of waste chicken feathers to relevant companies or processing centers.

Table 9.2: Assessment of Processing Technologies (PT) negatively affecting or enabling circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

PT Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
PT1 Technology Readiness: Is the processing technology readily available?	Cross River			
	Imo			
PT2 Processing Waste Adoption: Are there resulting wastes that would hinder the transition to circularity?	Cross River			CF Pillow waste can be managed
	Imo			Same
PT3 Processing Complexity: Is the process complex or simple?	Cross River			The CFW can be processed easily
	Imo			same
PT4 Resources Needed: Are the resources for technology are efficient?	Cross River			
	Imo		The Human resources component needs to be overcome	
PT5 Ease of Implementation: Is it easy to implement the processing?	Cross River			The Process can be integrated easily
	Imo		Human Resources is a bit slow to adapt	

In Figure 9.4, the assessment results obtained from respondents demonstrate a range of scores from 0.8 to 1.4. These scores indicate that the necessary technologies may be limited, but they are potentially readily accessible due to their low cost and local availability for the production of chicken feather pillows.

The assessment results highlight that Abia, Akwa Ibom, and Bayelsa States encounter more significant challenges in transitioning to circularity with regard to processing technologies. Conversely, Cross River, Delta, Edo, Imo, Ondo, and Rivers States face relatively fewer obstacles in this regard.

An important aspect to address involves fostering collaboration between manufacturers and technology suppliers to expedite the adoption process and facilitate a seamless transition. Notably, Abia State's thriving industrial sector holds considerable potential in promoting the development and implementation of these technologies for processing chicken feathers pillows, necessitating the creation of substantial awareness and concerted efforts.

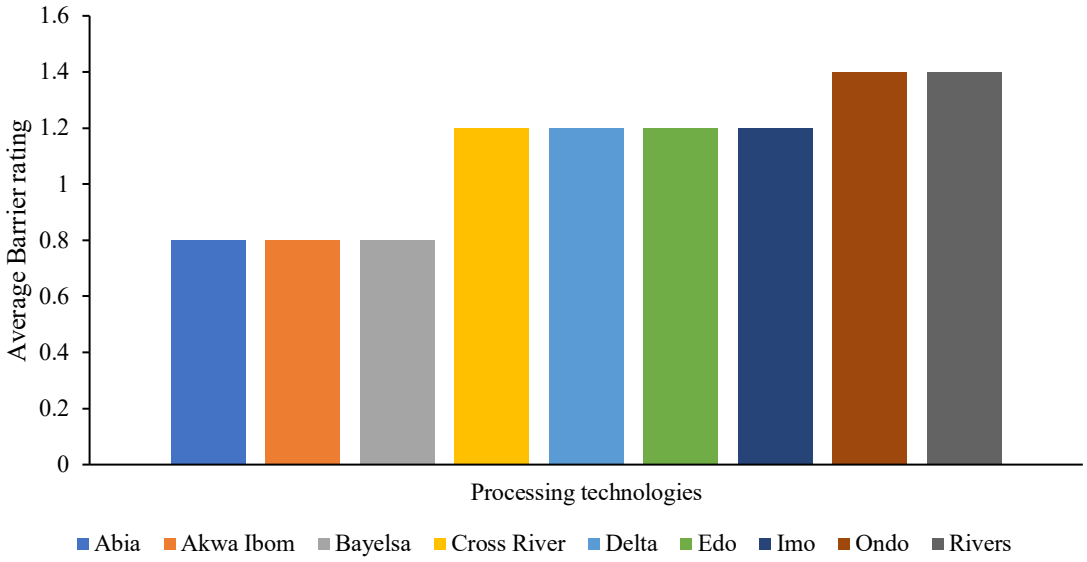


Figure 9.4: Average processing technologies impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.3.3. Environmental Impact

This category encompasses the assessment of the environmental consequences associated with the current linear management of end-of-life products. The presence of a high environmental impact is more likely to serve as a driving force towards the transition to a circular economy, thus making it a crucial factor for evaluation.

Table 9.3 presents the average results for the subcategories, focusing on Cross Rivers State, which exhibits the highest potential for circular economy (CE) transition, and Imo State, which demonstrates the lowest potential. Additionally, Figure 9.6 illustrates the results of the environmental impact assessment conducted across all nine states.

Table 9.3: Assessment of Environmental Impacts (EI) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

PT Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
EI1 Embodied Carbon: What is embodied carbon in material?	Cross River			CFW has high levels of energy
	Imo			Same as above
EI2 Sustainability of Current Disposal: Is the current disposal having an adverse effect on the environment?	Cross River			The Disposal method needs urgent attention to avoid Environmental impact
	Imo			Same as above
EI3 Sustainability of the New Proposed Option: Is the new a better option to reduce the environmental impact of the material?	Cross River			The integration of the circular management of CFW would reduce the Environmental Impact
	Imo		Other methods to manage CFW are adopted and no urgency for new option	

The assessment scores obtained for all the Niger Delta States range between 1.6 and 2.4, indicating the presence of linear disposal practices that could potentially have mild to severe negative environmental effects. These scores primarily reflect the disposal challenges associated with chicken feathers, which impose a burden on large poultry producers. It is important to note that the material itself is not inherently harmful unless it is burned, leading to the emission of undesirable gases.

In Nigeria, there is also a prevalence of small-scale chicken farming, mainly for personal consumption (FAO, 2019). When these individual producers dispose of chicken feathers, it often results in pollution in the surrounding communities. The assessment results indicate that respondents believe linear disposal of waste chicken feathers should be discouraged, thus

facilitating the transition towards a circular economy. Figure 9.5 shows environmental pollution caused by chicken feathers.



Figure 9.5: Environmental Pollution caused by chicken feathers in Kobis Farms, Cross Rivers State

Considering the smaller scale of the chicken industries in Abia, Ondo, and Rivers compared to other regions of the country, where the assessment scores suggest a potentially low potential for transitioning to circularity, the existing linear disposal practices are likely to have fewer negative environmental effects in these areas.

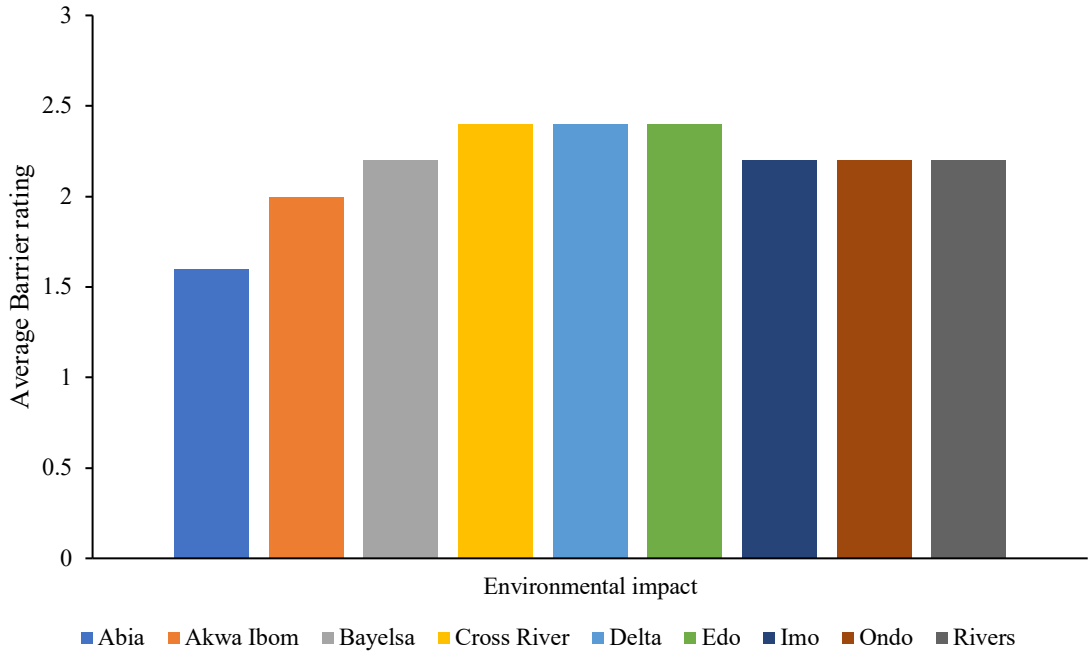


Figure 9.6: Average environmental impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.3.4. Organisational Context

The primary objective of this category is to determine the willingness of poultry/slaughterhouses (PSH) to change their current practices of disposing of chicken feathers and make them available to those who can utilize them. Table 9.4 presents the average subcategory result for Cross Rivers State, which exhibits the highest potential for circular economy (CE), while Imo State shows the lowest potential. Figure 9.7 illustrates the assessment results for the organisational impact in all nine states.

According to the study, it is observed that many PSHs are already actively involved in distributing waste chicken feathers to small businesses engaged in the production of pillows and home decor. This is true throughout all the Niger Delta States. The majority of PSHs are open to modifying present procedures and management techniques in order to ensure the transition to circularity.

Table 9.4: Assessment of Organisational Context (OC) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

PT Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
OC1 Organisational Culture: Does the organisation owning the material encourage development and change?	Cross River			The Poultry Farms/SH are already engaged in some activities promoting the reuse of CFW
	Imo		They are focused on their poultry business	
OC2 Top management Buy-in: Is there a complete buy-in from top management for change to circularity?	Cross River			Owners of farms are Very open to new ideas
	Imo	Do not really think it is worth considering		
OC3 Priority of sustainability and Corporate Social Responsibility (CSR)	Cross River			Sustainability and CSR is important and promoted
	Imo		Sustainability is part of the vision but not in terms of circular economy adoption	
OC4 Availability of Resources: Are there resources to encourage the transition?	Cross River			There are available resources
	Imo	Limited resources		
OC5 How does the organisation view the risk?	Cross River			The Poultry Farms are willing to take risk
	Imo	Avoid risk		
OC6 How important is innovation to the organisation?	Cross River			They encourage innovation
	Imo			They encourage innovation

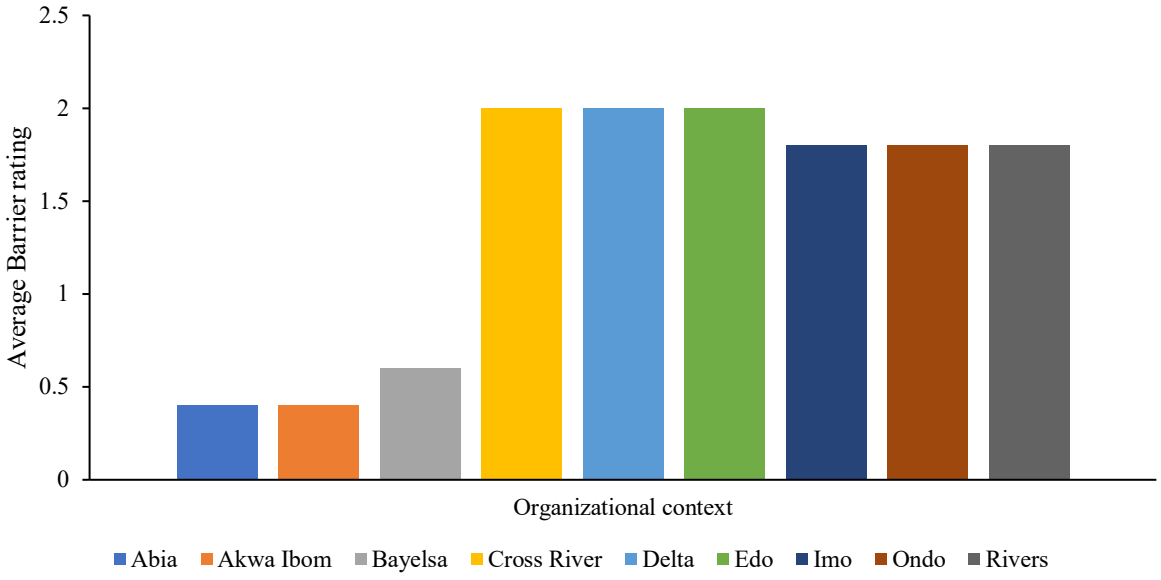


Figure 9.7: Average organisational context per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

The PSHs are dynamic, regularly explore novel concepts and procedures, and strive for constant adaptation and change, according to assessment scores of 2 and 3. They are also able to learn the value of sustainability and implement steps to that end, such as funding research and recognizing innovators.

Cross Rivers, Delta, Edo, Imo, Ondo, and Rivers States all find themselves in this predicament. In these States, resources that promote the shift to a circular economy are readily accessible and require little effort to use.

The assessment results of 0 and 1 obtained in the states of Abia, Akwa Ibom, and Bayelsa strongly indicate stringent organisational policies and limited support for the development of innovative ideas. These results also highlight challenges in fostering creativity, particularly in the context of sustainability, as well as a lack of resources necessary for the transition to a circular economy.

Upon evaluating the organisational charts of Abia, Akwa Ibom, and Bayelsa, it becomes evident that there is a lack of clearly defined roles, responsibilities, and support systems within the poultry/slaughterhouse (PSH) sector. This lack of clarity can have detrimental effects on resource allocation, overall direction, and the ability to effectively drive circular economy initiatives. It is imperative for PSH entities in these states to establish clear roles and

responsibilities, provide necessary support and resources, and enhance the capabilities of staff members involved in waste management and circular economy endeavors. By strengthening their organisational structures and support mechanisms, which can be facilitated through local Poultry Associations, these states can overcome existing obstacles and promote more effective application of circular economy principles.

On a positive note, it was discovered that several poultry farms and PSH establishments in Cross Rivers State have already implemented effective organisational structures and are actively involved in the sale of used chicken feathers to small businesses that rely on them as raw materials for manufacturing, as seen in Figure 9.8.



Figure 9.8: Chicken feathers packaged in Kobis Farm for sale to local Sleeping Pillow company.

9.3.5. Industry and Supply Chain Issues

The assessment results obtained in the states of Abia, Akwa Ibom, and Bayelsa, scoring 0 and 1, strongly indicate the presence of inflexible organisational policies and limited support for the development of innovative ideas. These findings shed light on the challenges faced in fostering creativity, particularly in the realm of sustainability, and the insufficient availability of resources required for a successful transition to a circular economy. Table 9.5 presents the average subcategory result for Cross Rivers State, which exhibits the highest potential for

circular economy (CE), while Imo State shows the lowest potential. Figure 9.9 illustrates the assessment results for the industry and supply chain issues in all nine states.

Upon analysing the organisational charts of Abia, Akwa Ibom, and Bayelsa, it becomes evident that there is a lack of clearly defined roles, responsibilities, and support systems within the poultry/slaughterhouse (PSH) sector. This lack of clarity can have adverse effects on resource allocation, overall direction, and the ability to effectively drive circular economy initiatives. It is imperative for PSH entities in these states to establish well-defined roles and responsibilities, offer the necessary support and resources, and enhance the capabilities of their staff members involved in waste management and circular economy endeavors. Strengthening the organisational structures and support mechanisms, with the assistance of local poultry associations, can help overcome existing obstacles and facilitate a more effective application of circular economy principles.

Table 9.5: Assessment of Industry and Supply Chain (ISC) issues negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

ISC Sub-category	**State**	**No Potential (Level 0)**	**Some Possibility (Level 1)**	**Good Potential (Level 2)**
ISC1 Acceptance of Current Practice: Industry and Supply Chain issues that influence the transition from linear to circular	Cross River			Most Participants are willing to Transition CFW to CE
	Abia		Some Participants in the value Chain show interest	
ISC2 Overall Affinity to Circular Economy: Willingness to change old patterns to transition material to a circular economy?	Cross River			They are eager to Transition to CE model
	Abia		They are considering CE model	
ISC3 Producer Liabilities: Do the people who control the material consider the current	Cross River			The Poultry Farms are the owners
	Abia			Same

ISC Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
linear disposal model to be acceptable?				
ISC4 Infrastructure Readiness: Can enough materials be collected?	Cross River			There is enough CFW and infrastructure
	Abia	Not sufficient CFW		
ISC 5 Storage and Handling: Can the material be easily stored and handled?	Cross River			Storage of the CFW is available
	Abia	Storage for CFW not available		
ISC5 Distribution Issues: Is the material highly distributed and difficult to locate/access	Cross River			Linkage for collection of CFW is well-organised
	Abia	Collection of CFW difficult		
ISC6 Stakeholder Responsibility: Is it clear who can be held responsible for the material and disposal impacts?	Cross River			The Poultry Farms take responsibility for the end-of-life (EOL) of CFW
	Abia			Same
ISC7 Communication: Is the Supply Chain well Connected to accommodate increased communication effort to transition to circularity?	Cross River			The Poultry Farmers Association is Active and linkage between the Farmers, middlemen and Companies that use CFW.
	Abia	The Supply Chain is not well Connected		

On a positive note, it was discovered that several poultry farms and PSH establishments in Cross Rivers State have already implemented effective organisational structures and are actively engaged in the sale of used chicken feathers to small businesses that rely on them as raw materials for manufacturing.

The assessment results, ranging from 0.6 to 2.2, indicate diverse viewpoints among respondents. Individuals in Abia, Akwa Ibom, and Bayelsa states express concerns regarding potential supply chain challenges that could hinder the transition to a circular economy. Conversely, respondents from other states present different opinions, highlighting the regional variations in conditions and experiences. Respondents from Cross River, Delta, Edo, Imo, Ondo, and Rivers states share a common desire among value chain participants to shift towards a circular economy. These stakeholders express their willingness to collaborate and develop innovative approaches to achieve this objective. There is a consensus that the current linear model is flawed and calls for reform are emphasized.

Overall, respondents agree that the transition to a circular economy for materials is desirable, and stakeholders are motivated to contribute to its realization, despite potential challenges in specific states. The examination also reveals that the supply chain in these states, along with all its participants, is well-connected and can effectively communicate, especially through digital channels, to access storage facilities and obtain information on procedures and products. However, the evaluation results in Abia, Akwa Ibom, and Bayelsa states indicate a strong acceptance of the existing linear disposal practices within the industry, leading to a lack of interest in embracing the circular economy.

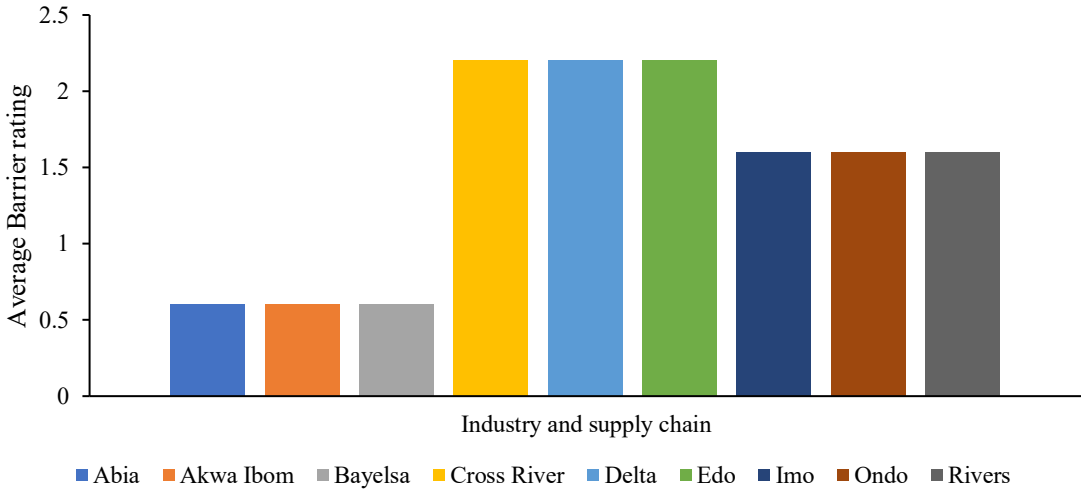


Figure 9.9: Average industry and supply chain impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.3.6. External Drivers

This category focuses on assessing the influence of external forces and financial incentives in facilitating the transition from a linear to a circular economy. The evaluation takes into account factors such as consumer and end-user perspectives, industry trends, access to subsidies, and drivers for research and development (R&D). Table 9.6 provides the average subcategory results for Cross Rivers State and Abia State. However, the overall results for all states were poor, with an average score at level 1.

Table 9.6: Assessment of External Drivers (ED) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

ED Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)
ED1 Subsidies: Are there incentives to encourage change from linear model?	Cross River		The government insists on compliance with Environmental standards
	Abia		Same
ED2 End user/Consumer Perspective: Is the producer aware of the importance of moving towards a Circular economy?	Cross River		Individuals are aware that there can be a better option for EOL which can have a positive impact on the Environment and Economy
	Abia		Same
ED3 Industry Trends: Are there overall industry trends and drivers which impact the transition to circularity?	Cross River		Some companies use CFW as resource
	Abia	Not many companies involved in the use of CFW	
ED4 Research and Development: Is the material currently part of research and development program?	Cross River		There is some ongoing Research and Development for the use of CFW as industrial wastewater purification
	Abia		Same

To address this situation, it is crucial to enhance awareness among organisations regarding the existence and potential support from institutions like the Africa Circular Economy Facility (ACEF), which commenced operations in 2022. Collaborating with ACEF can provide valuable assistance and funding. The evaluation results highlight a significant issue with the lack of sufficient drivers, such as government grants, subsidies, and tax incentives, to facilitate the transition towards circularity.

Efforts should be made to increase awareness and utilization of available support systems and financial incentives to encourage stakeholders in the Niger Delta region to embrace circular economy principles. Collaborating with organisations like ACEF can provide access to necessary resources and assistance in overcoming financial barriers, enabling a smoother transition to a circular economy.

9.3.7. Public Perception

The objective of this evaluation is to assess the influence of consumer sentiment on the transition from a linear to a circular economy. Consumer attitudes and perceptions play a crucial role in driving industry adaptation and signaling the necessity for change to policymakers. Within this category, several aspects are considered, including public perception of the current linear disposal system, public awareness of the existing linear system, and public interest in transitioning to a circular economy.

Table 9.7 provides the average subcategory results for Cross Rivers State, which exhibits the highest potential for achieving a circular economy, and Bayelsa State, which has the lowest potential. Figure 9.10 illustrates the results of the public perception impact assessment for all nine states.

Based on assessment ratings of 2 and 3, it is evident that a significant portion of the population in Cross River, Delta, and Edo States holds a neutral or positive opinion regarding the reuse of leftover chicken feathers in innovative applications. This positive sentiment can be attributed to media coverage, which likely sparked public interest and stimulated extensive discussions regarding available end-of-life options. Consequently, the public in these states has gained awareness of the associated challenges and can independently determine whether to support initiatives aimed at fostering circularity. These assessment results also suggest that similar circumstances, albeit on a smaller scale, may be observed in other states within the region.

Table 9.7: Assessment of Public Perception (PP) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

PP Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
PP1 Linear disposal: What is the public perception of the current linear disposal of this material?	Cross River			Majority of the Public are Knowledgeable about Sustainability and seeing waste as a resource
	Bayelsa	The Public, media and Government not paying attention		
PP2 Discussion: What is the level of public discussion and concern associated with the material?	Cross River			There is much awareness on the management CFW
	Bayelsa	Not much discussion on the management of CFW		
PP3 Origin and Visibility: Are the public aware of this material and where it comes?	Cross River			The Public is aware of the EOL options of CFW
	Bayelsa	Not much awareness on the EOL		

Furthermore, the scores indicate that debates concerning the current management of waste feathers may be minimized in Cross River, Delta, Edo, Imo, Ondo, and Rivers States if industry and end-user efforts to promote circularity prove to be ineffective. This is particularly true if the existing end-of-life approach is widely accepted by the public and endorsed by the media in these states.

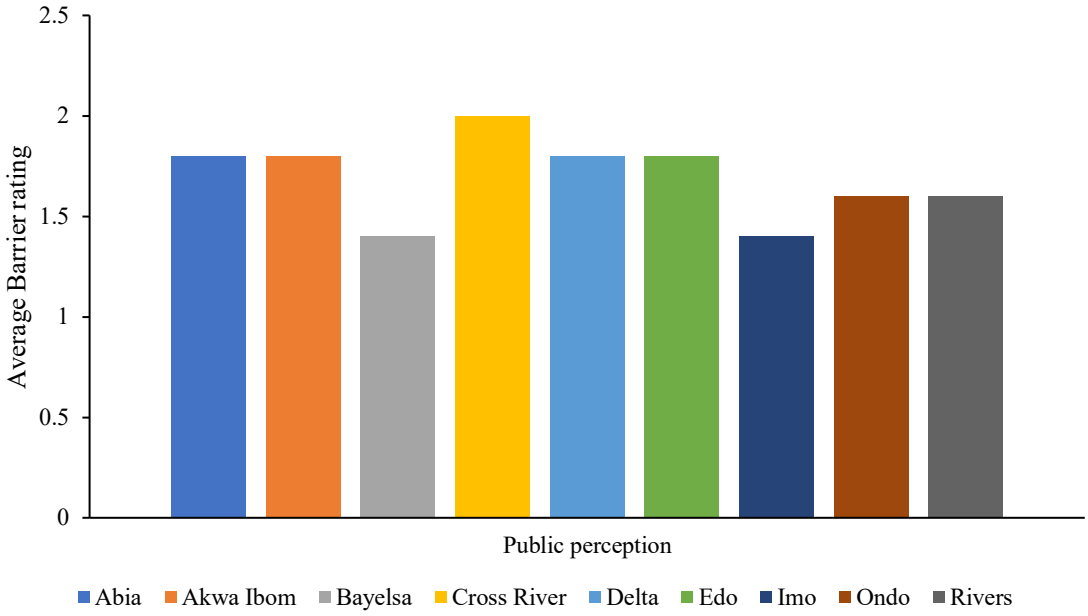


Figure 9.10: Average public perception impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.3.8. Regulatory Framework

Regulations play a crucial role in facilitating the transition of materials and products from a linear to a circular economy. They encompass various aspects such as health and safety considerations, material management practices, tax and penalty regulations, legal frameworks, transparency, and accountability. The regulatory framework serves as the fundamental basis for legally enabling and supporting the transition to a circular economy. Therefore, it is imperative to assess the current state of the regulatory framework to determine its ability to permit and facilitate this transition effectively.

Table 9.8 presents the average subcategory result for Cross Rivers State, which demonstrates the highest potential for achieving a circular economy, while Abia State's average result is also provided for comparison. Evaluating the regulatory framework in these states helps gauge its readiness and effectiveness in promoting circular practices.

Table 9.8: Assessment of Regulatory Framework (RF) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

RF Sub-category	State	No Potential (Level 0)	Some Possibility (Level 1)	Good Potential (Level 2)
RF1 Health and Safety: Are there any significant health and safety issues associated with this material?	Cross River		There are potential health issues with CFW if the disposal is not handled properly	
	Abia		Same	
RF2 Handling Requirements: Does the material require rigorous handling?	Cross River			CFW can be handled without many precautions
	Abia			Same
RF3 Taxes and Fines: Are there penalties associated with material if standard procedures are not adhered to?	Cross River		Fines can be imposed but they are not enforced	
	Abia		Same	
RF4 Legal requirements: Are there any regulations that will stop the Transition to a circular economy?	Cross River	There are regulations in place that can encourage other quick disposal options		
	Abia	Same		
RF5 Transparency and responsibility: Is it clear who is legally responsible for the material at the end of life?	Cross River		The Poultry Farms are responsible for the CFW EOL	
	Abia		Same	

The assessment scores of 0 and 1 reveal the absence of robust policies in all Niger Delta States that would effectively drive the advancement of the circular economy. Such policies play a

crucial role in promoting circular practices by encouraging the adoption of innovative business models, akin to the European Commission Circular Economy (EC CE) package and the green deals of the Netherlands.

The EC CE Package, introduced in 2014, has achieved significant milestones, including the increase in recycling of municipal waste between 2008 and 2016 and the improvement in the contribution of recycled materials. Similarly, the green deals of the Netherlands, launched in 2011, have seen the government initiate 229 Green Deals, with 169 successfully completed across various domains of the circular economy, encompassing energy, water, biodiversity, resources, construction, climate, and the bio-based economy (Van Langen, 2017; Ganzevles et al., 2016). Another critical concern highlighted by the assessment is the lack of awareness regarding the existence of the Nigeria Circular Economy Working Group (NCEWG). The NCEWG is a locally driven platform coordinated by the Government of Nigeria, aimed at fostering circularity and supporting the growth of the Nigerian economy. The key activities of the NCEWG include designing the Nigeria Circular Economy Road Map (NCERM) and the Nigeria Circular Economy Programme (NCEP) (afdb.org/Nigeria-circular-economy-working-group-ncewg).

9.3.9. Economic Viability

The transition to a circular economy necessitates commercial profitability as a fundamental aspect. Economic viability, influenced by factors such as monetization, the ability to transform waste into economically viable new products or raw materials, value and scale considerations, volume considerations, and contextual factors, plays a pivotal role in this regard. Each of these factors is essential in ensuring the economic feasibility of circular practices.

Table 9.9 provides the average subcategory result for Cross Rivers State, indicating its highest potential for achieving a circular economy, while Bayelsa State exhibits the lowest potential, as illustrated in Figure 9.11, which presents the Economic viability assessment results for all nine states.

Table 9.9: Assessment of Economic Viability (EV) negatively affecting or enabling Circular economy transition (Adopted model from CE Barriers assessment framework, Dieckmann et al, 2020)

EV Sub-category	State	No Potential (Level 0)	Good Potential (Level 2)	High Potential (Level 3)
EV1 Monetization: Can the material be processed into a new product or raw material for which there is a viable market?	Cross River			The CFW has substantial monetary value and a strong demand
	Bayelsa	There is no market demand within the location		
EV2 Value and Scale: Viability can be achieved but will this require major investment in scale, research development and processing to make it happen?	Cross River			There is value been realized using the existing value chain and linkages
	Bayelsa			
EV3 Amount: Are the total quantities materials available appropriate to the potential application(s)?	Cross River			There is sufficient CFW material
	Bayelsa	The total amount of CFW is low		
EV4 Context: Can the material be used directly without much transport and in a local context?	Cross River		The CFW is reused within a small distance, does not require long transports	
	Bayelsa	The CFW needs to be transported		

All Niger Delta States received assessment scores of 2 or 3, indicating a significant or substantial monetary value that can be realized even without meeting the demand of a growing market. These scores suggest that there is an abundant supply of waste feathers that can support various applications or the production of multiple goods. Additionally, value creation can be achieved on a small scale with minimal or no additional expenses, as existing infrastructure can be utilized. Furthermore, the local utilization of waste feathers eliminates the need for extensive transportation. Given the economic viability of the Niger Delta States, Cross River State exhibits the highest potential for transitioning to a circular economy.

On the other hand, an assessment score of 0 obtained in each state implies that waste feathers with minimal intrinsic value may not attract a thriving market. In this case, wealth generation can only be realized on a large scale, requiring significant expenditures.

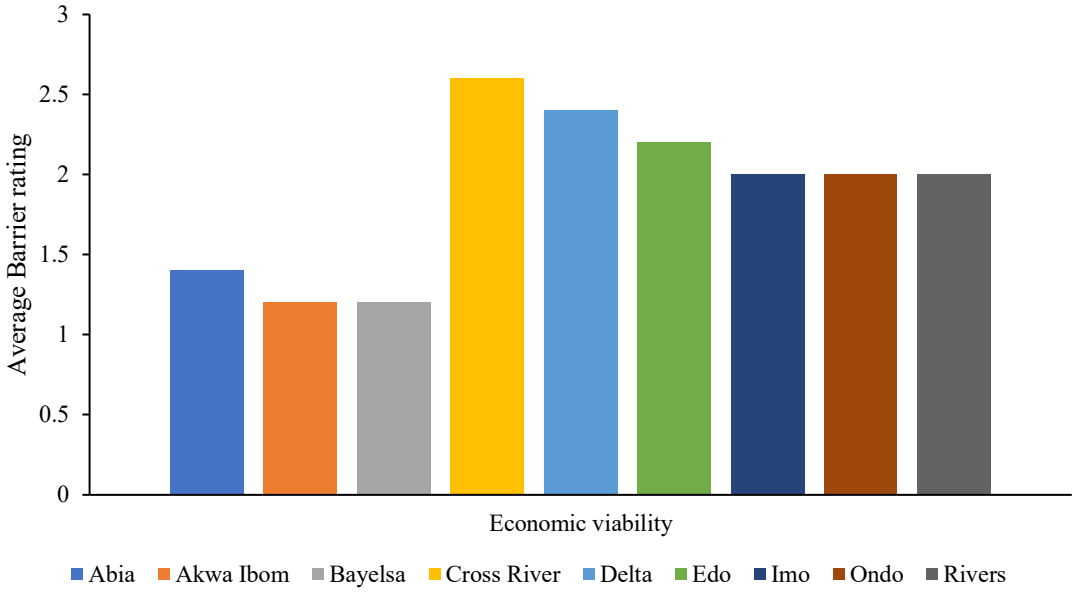


Figure 9.11: Average economic viability impact per State on a level of 0-3, where 0 is having least potential, and 3 is the highest potential for transitioning to CE.

9.4. Overall Assessment Result

The overall assessment score is distributed across the states, ranging from 9.2 for Abia State to 17.4 for Cross River State. Abia, Akwa Ibom, and Bayelsa received scores of 9.2/27, 9.6/27, and 9.8/27, respectively, indicating significant barriers to the circular economy across various categories.

In these states, the areas with the fewest barriers were related to materials and processing technology, suggesting that waste feathers possess valuable properties and there are available technologies for their reuse. However, the most substantial barriers were found in the organisational context, industry and supply chain, even though some states are organized, having companies that pay and collect their waste feathers as raw materials to produce other goods like beddings, cultural attires, and household decorations. Other states are not as organized and do not make any revenue from waste chicken feathers. Because of the peculiarity of the Niger Delta region, with crude exploration operations, it will be more beneficial to use waste chicken feathers for production of chicken feather pillows that the other options. Notably, the assessment score for the regulatory framework category was zero in all Niger Delta states, indicating existing issues in this area.

Comparatively, the other Niger Delta states (Imo, Ondo, Rivers, Delta, Edo, and Cross River) demonstrated higher potential for transitioning to a circular economy, with overall evaluation scores of 12.6/27, 13.2/27, 13.2/27, 14.6/27, 14.8/27, and 17.4/27, respectively. The assessment allowed participants to identify significant obstacles hindering the circular economy transition in their respective localities.

Cross River State has taken proactive steps toward sustainability and the circular economy through the initiation of the Green City Initiative. This endeavor focuses on creating environmentally friendly metropolitan regions by integrating waste management, green infrastructure, renewable energy, and circular economy concepts into urban design and construction. The state is dedicated to sustainable practices and embraces the principles of the circular economy.

Table 9.10: Average of Toptier Barrier assessments

Toptier Barriers	**Abia**	**Akwa Ibom**	**Bayelsa**	**Cross River**	**Delta**	**Edo**	**Imo**	**Ondo**	**Rivers**
Material Characteristics	1.6	2	1.8	2	2	2	1.4	1.6	1.6
Processing Technologies	0.8	0.8	0.8	1.2	1.2	1.2	1.2	1.4	1.4
Environmental Impact	1.6	2	2.2	2.4	2.4	2.4	2.2	2.2	2.2

Toptier Barriers	Abia	Akwa Ibom	Bayelsa	Cross River	Delta	Edo	Imo	Ondo	Rivers
Organisational Context	0.4	0.4	0.6	2	2	2	1.8	1.8	1.8
Industry and Supply Chain	0.6	0.6	0.6	2.2	2.2	2.2	1.6	1.6	1.6
External Drivers and Incentives	1	1	1	1	1	1	1	1	1
Public Perception	1.8	1.8	1.4	2	1.8	1.8	1.4	1.6	1.6
Regulatory Framework	0	0	0	0	0	0	0	0	0
Economic Viability	1.4	1.2	1.2	2.6	2.4	2.2	2	2	2
Total	9.2	9.8	9.6	15.4	15	14.8	12.6	13.2	13.2

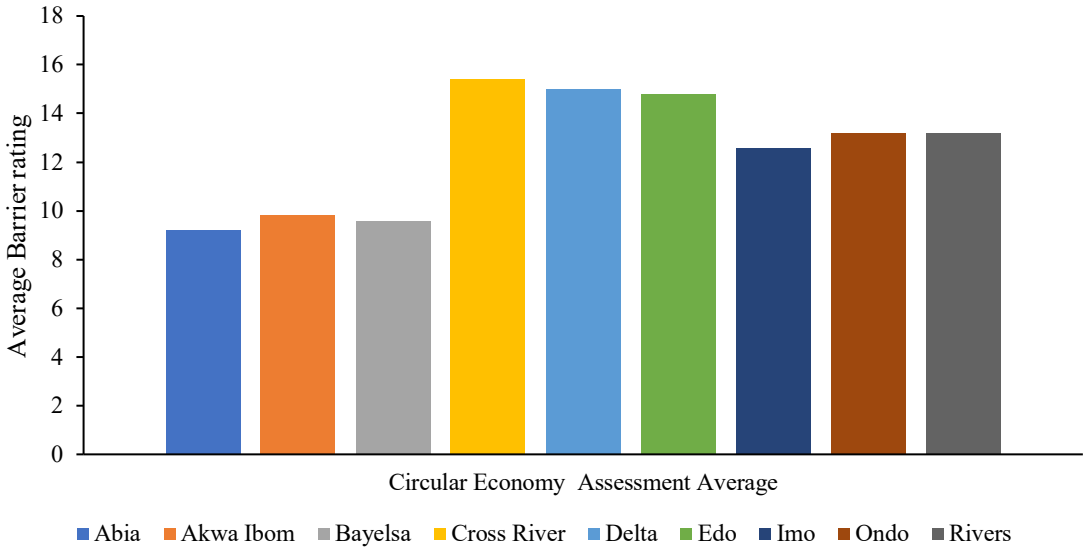


Figure 9.12: Average assessment impact per state on a scale of 0-27, where 0 is having the least potential to transition and 27 has a high potential to transition to circularity.

9.5. Conclusion

The study found that there is a favorable climate for circularity in the Niger Delta region, with several potential positive impacts such as resource preservation, environmental sustainability, business potential, climate change mitigation, sustainable agriculture, and innovation promotion.

The overall assessment scores for the different states were good, with the highest score of 17.4 for Cross Rivers State and the lowest score of 9.2 for Abia State. This indicates that some states have existing CE business models that can be leveraged for the promotion of chicken feather pillow as a sorbent for oil spill remediation and that some states may embrace the concept of CE quicker than others. All states had a low score level for external drivers and regulatory framework, which is a key success factor for any developing country to make progress in the concept of sustainability and Circular Economy. It is recommended that legislation and policies be strengthened to reduce other barriers.

There is a lack of awareness among the people about what the government is doing regarding CE. The Nigeria Circular Economy Working Group (NCEWG) has had no impact in the states assessed. It is suggested that education and awareness campaigns be prioritized to increase awareness of NCEWG and other government initiatives to support the development of circular economy ideas and boost public participation, particularly in Niger Delta communities. These organisations could create detailed recommendations or frameworks that support circular economy procedures for used chicken feathers. Partnerships between organisations exist, but they need to be maximized by developing strategic collaborations among stakeholders in the poultry sector, waste management organisations, researchers, and entrepreneurs in the Niger Delta states.

Chapter 10 - Conclusion and Recommendations

10.1. Conclusion

The findings of this research indicate that waste chicken feathers, an agricultural by-product, can be locally utilized in the manufacturing of oil pillows with comparable properties to conventional oil sorbents for remediating oil spills in Nigeria. These chicken feather pillows can be used for oil spill clean-ups for small-scale oil spills of both hydrocarbon and nonhydrocarbon origin. They can also be used in combination with booms for medium and large-scale oil spills in marine environments. The chicken feather pillow has a weight of 115g and a density of 0.865g/cm3. Remarkably, each pillow can absorb over ten times its weight, equivalent to 1035g or approximately 1.1 liters of vegetable oil. Field tests conducted at four different spill locations demonstrated sorption capacities of 1.9g/g for Diesel, 2.8g/g for Palm oil, 1.7g/g for Weathered oil, and 1.3g/g for Crude oil using the chicken feather pillow. Comparatively, under the same conditions, polypropylene pads exhibited sorption capacities of 2.5g/g for Diesel, 3.0g/g for Palm oil, 1.8g/g for Weathered oil, and 1.4g/g for crude oil.

The production chain of chicken feather pillows from sourcing to processing through to the packaging showcases a noteworthy cost-effectiveness achieved through the abundant availability of feathers, water, human resources, and the utilization of locally fabricated machinery and equipment. Remarkably, the unit cost price of a chicken feather pillow amounts to $4.59, positioning it favorably in comparison to the most competitively priced sorbent pillow, which is currently available at $10.0. This cost advantage highlights the potential of chicken feather pillows as a financially attractive option within the sorbent market.

The viability of the chicken feather pillow technology venture and the market readiness of chicken feathers were assessed utilizing the Cloverleaf model developed by Heslop, McGregor, and Griffith. The evaluation encompassed three key dimensions: Technology Readiness Level (TRL), Commercial Readiness Level (CRL), and Market Readiness Level (MRL). The findings revealed a TRL of Level 7, indicating a high degree of technological advancement and a robust foundation for further development. In terms of CRL, a Level 5 was attained, indicating substantial progress in commercialization efforts and a solid positioning for market entry. Notably, the MRL achieved Level 8, reflecting a strong market readiness with favorable conditions for successful deployment and use.

Through the application of a novel framework assessment method that defines 9 potential barriers to circularity on a level of 0-3 and the total barrier to be quantified on a scale of 0-27, the potential for circularity in the utilization of waste feathers from the poultry industry in the

Niger Delta region was evaluated. The assessment yielded an overall average score of 13 out of 27 for the nine states, indicating substantial potential for transitioning to circularity. The findings confirmed the economic viability of this transition, availability of materials, and processing technology. However, significant barriers related to the lack of a regulatory framework and external drivers were identified as key obstacles that need to be speedily addressed in order to achieve significant circularity advancements. The end-of-life option of chicken feather pillow for biodegradation, due to its biodegradability, leaves no secondary waste to the environment which promotes the business model of resource recovery in circular economy.

In conclusion, chicken feather pillow is a compelling choice to the widely used synthetic sorbent in promoting circular economy, a greener future and economic growth in developing countries.

10.2. Recommendations for Further Studies

As a novel technology, the chicken feather pillow sorbent necessitates additional studies and experiments to explore its potential thoroughly. A key area is the identification of the most suitable spill type, whether viscous or less viscous that chicken feather pillow can be used for. Another area is developing environmentally friendly and cost-effective modification technologies to optimize oil sorbency, oil recovery and oil reusability. Further studies are required for the End -of-life option to improve the slow degradation of chicken feathers, which currently inhibits the efficiency of anaerobic digestion. Finally, life-cycle analysis of chicken feather pillow is important. Life cycle analysis (LCA) offers several benefits, including a holistic understanding of the environmental impacts throughout its entire life cycle. It enables informed decision-making and will promote the improvement of chicken feather pillow product design. LCA supports eco-design initiatives and supplies end -users with information on environmental performance.

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11. APPENDIX

11.1. Published Journal Papers

1) Waste chicken as sorbents for hydrocarbon and Non-hydrocarbon Spills
   Kaine Chinwah, Juliet Gift-Onyesoh, Adewale Adeyemi 2022
   http://www.rsujnet.org/index.php/publications/2022-edition/2022-edition-6
2) Surface Energetics and Surface Chemistry of Chicken Feather Mat for Oil Spill Cleanup Application
   Kaine Chinwah, Majid Naderi, Sabiyah Ahmed, Reuben Okparanma, Christopher Cheeseman
   https://authors.elsevier.com/a/1isI4,RuCBUkIH

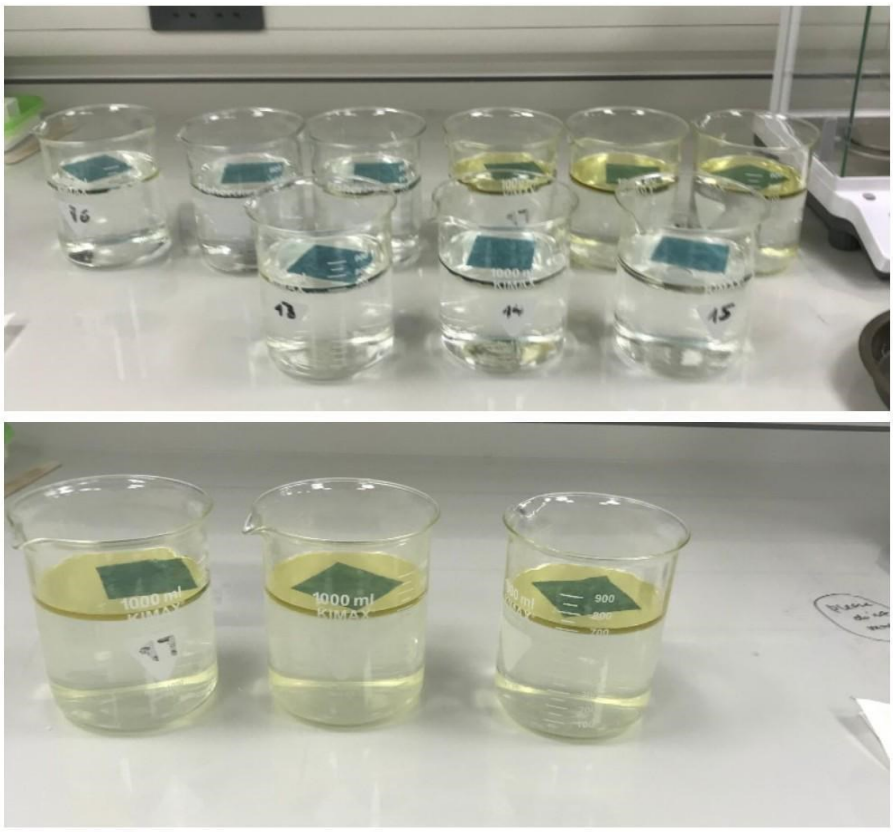
11.2. Laboratory Pictures

11.2.1.Sorption Capacity Test for Chicken Feather Fibre Mat



Sorption capacity test for chicken feather fibre mat

11.2.2.Sorption Capacity Test for Polypropylene Pad



Sorption capacity test for polypropylene pad

11.3. Chicken Feather Pillow Production



Produced chicken feather pillow and locally fabricated miller at the production location

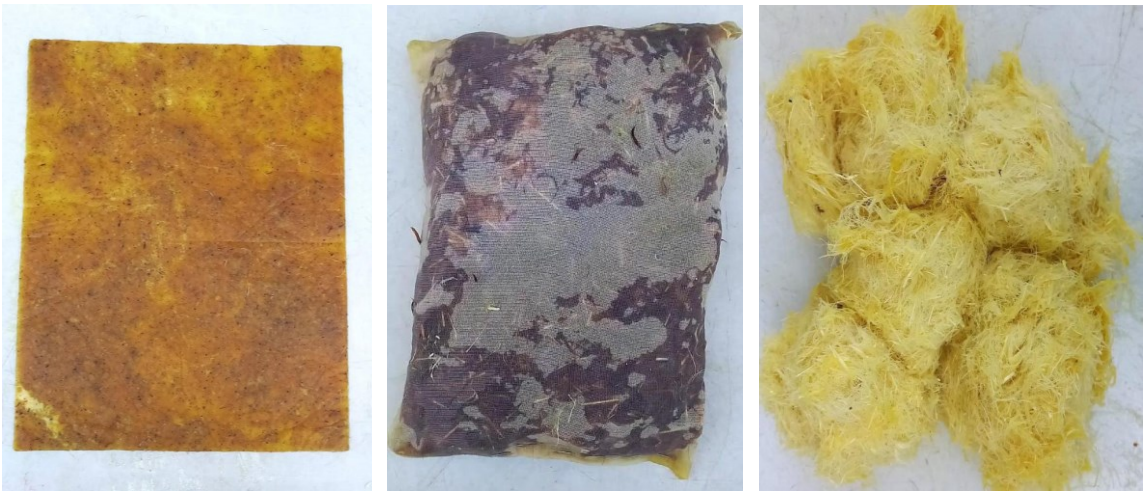
11.4. Field Test Trial

11.4.1.Tank Trial Showing Polypropylene Pad, Chicken Feather Fibre Mat, and Chicken Feather Pillow



Field test tank trials for various samples

11.4.2.Oil Saturated Polypropylene Pad, Chicken Feather Pillow, and Chicken Feather Fibre Mat



Oil-saturated polypropylene pad, chicken feather pillow, and chicken feather fibre mat respectively, after 3 cycles each.

11.5. Field Location Pictures

11.5.1.Accessing Spot for Sampling at Weathered Oil Location



Accessing spot for sampling at weathered oil location.

11.5.2.Diesel Oil Spill Location



Diesel oil spill location

11.5.3.Palm Oil Spill Location



Palm oil spill location

11.5.4.Crude Oil Spill Location



Ebube Stream Crude Oil Spill

11.6. Quantitative Study for Circular Economy

11.6.1.Questionnaire for Business Organizations that can use Chicken Feather

Survey on the use of Waste Chicken Feathers (Business organizations that can use Chicken Feather)

Introduction: Thank you for your interest in participating in our research study. Before you begin, please carefully read and understand the following consent statement. By proceeding with this survey, you are indicating your informed consent to participate in this research study.

Objective of the Study: The objective of this interview is to collect Data on the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

This research is ongoing and it would be beneficial to get your view and opinion as a Business organization that can use Chicken Feather. Kindly note that your name, position, and state may be cited because it is a personalized interview.

Procedure: Your participation in this survey will involve answering a series of questions related to the use of waste chicken feathers for oil spill remediation in the Niger Delta States. The survey will take approximately 20 minutes to complete. Your responses will remain confidential, and your identity will be kept anonymous.

Voluntary Participation: Participation in this survey is entirely voluntary. You are not obligated to participate, and your decision to do so will not affect any current or future

relationship with Engr. (Mrs) Kaine. You may withdraw from the survey at any time without penalty.

Confidentiality: Your responses will be treated with strict confidentiality. No personally identifiable information will be collected, and all data will be reported in aggregate form. Only authorized researchers will have access to the survey data.

Risks and Benefits: There are no foreseeable risks associated with participating in this survey. The potential benefits include contributing valuable information to our research, which may lead to a better understanding of the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

Questions and Contact Information: If you have any questions about the survey, you may contact Engr. (Mrs) Kaine at dallasba04@gmail.com.

Consent: By clicking the "I Agree" button below, you acknowledge that you have read and understood the information provided in this consent statement. You voluntarily agree to participate in this survey. If you do not wish to participate, please exit the survey now.

☐ I Agree (I consent to participate in the survey)

☐ I Do Not Agree (I do not wish to participate in the survey)

Thank you for contributing to this research work.

Bio-Data

1. Full Name *

2. In what state is your organization located? *

Survey Questionnaire

Ø Select YES or NO, where appropriate and as indicated in any question.

Ø Select the answers for any question as indicated.

Ø Please respond to all questions.

5. Do you frequently use any oil cleanup materials?*

Yes / No

6. For what kind of spills? *

Major / Minor

7. What kind of oil spill cleanup material do you use? *

8. How do you dispose of your oil spill cleanup material after use? *

9. What factors can make you completely substitute chicken feather pads for conventional materials used? *

Efficiency Cost / Government Policy / Environment Concerns / Other

10. Are you willing to promote the use of waste chicken feathers for oil spill remediation? *

Yes / No

11. What specific contribution / enabling environment do you suggest can be provided by the Government to support this initiative? *

12. Do you know and understand the concept of circular economy? *

Yes / No

13. Is there any ongoing project for circular economy you are aware of in your organization? *

Yes / No

11.6.2.Questionnaire for Poultry/Slaughterhouse Owners or Senior Managers

Survey on the use of Waste Chicken Feathers (Poultry/Slaughterhouse Owner / Senior Manager or Staff)

Introduction: Thank you for your interest in participating in our research study. Before you begin, please carefully read and understand the following consent statement. By proceeding with this survey, you are indicating your informed consent to participate in this research study.

Objective of the Study: The objective of this interview is to collect Data on the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

This research is ongoing and it would be beneficial to get your view and opinion as a Poultry/Slaughter House Owner / Senior Manager or Staff. Kindly note that your name, position, and state may be cited because it is a personalized interview.

Procedure: Your participation in this survey will involve answering a series of questions related to the use of waste chicken feathers for oil spill remediation in the Niger Delta States. The survey will take approximately 20 minutes to complete. Your responses will remain confidential, and your identity will be kept anonymous.

Voluntary Participation: Participation in this survey is entirely voluntary. You are not obligated to participate, and your decision to do so will not affect any current or future

relationship with Engr. (Mrs) Kaine. You may withdraw from the survey at any time without penalty.

Confidentiality: Your responses will be treated with strict confidentiality. No personally identifiable information will be collected, and all data will be reported in aggregate form. Only authorized researchers will have access to the survey data.

Risks and Benefits: There are no foreseeable risks associated with participating in this survey. The potential benefits include contributing valuable information to our research, which may lead to a better understanding of the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

Questions and Contact Information: If you have any questions about the survey, you may contact Engr. (Mrs) Kaine at dallasba04@gmail.com.

Consent: By clicking the "I Agree" button below, you acknowledge that you have read and understood the information provided in this consent statement. You voluntarily agree to participate in this survey. If you do not wish to participate, please exit the survey now.

☐ I Agree (I consent to participate in the survey)

☐ I Do Not Agree (I do not wish to participate in the survey)

Thank you for contributing to this research work.

Bio-Data

1. Full Name *

2. In what state is your Farm located? *

Survey Questionnaire

Ø Select YES or NO, where appropriate and as indicated in any question.

Ø Select the range of answers for any question as indicated. e.g. a. b.

Ø Tick a number that represents your level of agreement/ support or disagreement with each statement/ question.

Keys: 1 = Strongly disagree 2= Moderately disagree 3= Slightly disagree 4 = Neither dis- agree or agree 5 = Slightly agree 6= Moderately agree 7= Strongly agree

Ø Please respond to all questions.

5. How old is the farm?*

0 - 5 years / 6 - 10 years / 11 - 20 years / > 20 years

6. What is the capacity of your poultry farm? *

0 - 100 birds / 101 - 500 birds / 501 - 1000 birds / > 1000 birds

7. How many birds do you slaughter annually? *

< 100 birds / 101 - 500 birds / 501 - 1000 birds / > 1000 birds

8. What is the percentage contribution of waste chicken feathers to solid waste in the farm? *

0 – 25 / 26 – 50 / 51 – 75 / 76 -100

9. What quantity of waste chicken feathers is generated annually on your Farm?*

< 1000 Kg / 1001 - 2000 Kg / 2001 - 5000 Kg / > 5000 Kg

10. How do you dispose the waste chicken feathers? *

11. Are you part of any association or group of Poultry Farmers?*

Yes / No

12. Is there any existing Policy for waste chicken feather use or disposal?*

Yes / No

13. Are you willing to support the use of waste chicken feathers for oil spill remediation? *

Yes / No

14. Do you know and understand the concept of circular economy? *

Yes / No

15. Is there any ongoing project for circular economy you are aware of in the farm? *

Yes / No

11.6.3.Questionnaire for Individuals/Heads of Community

Survey on the use of Waste Chicken Feathers (Individual / head of community)

Introduction: Thank you for your interest in participating in our research study. Before you begin, please carefully read and understand the following consent statement. By proceeding with this survey, you are indicating your informed consent to participate in this research study.

Objective of the Study: The objective of this interview is to collect Data on the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

This research is ongoing and it would be beneficial to get your view and opinion as an individual/head of community. Kindly note that your name, position, and state may be cited because it is a personalized interview.

Procedure: Your participation in this survey will involve answering a series of questions related to the use of waste chicken feathers for oil spill remediation in the Niger Delta States. The survey will take approximately 20 minutes to complete. Your responses will remain confidential, and your identity will be kept anonymous.

Voluntary Participation: Participation in this survey is entirely voluntary. You are not obligated to participate, and your decision to do so will not affect any current or future relationship with Engr. (Mrs) Kaine. You may withdraw from the survey at any time without penalty.

Confidentiality: Your responses will be treated with strict confidentiality. No personally identifiable information will be collected, and all data will be reported in aggregate form. Only authorized researchers will have access to the survey data.

Risks and Benefits: There are no foreseeable risks associated with participating in this survey. The potential benefits include contributing valuable information to our research, which may lead to a better understanding of the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

Questions and Contact Information: If you have any questions about the survey, you may contact Engr. (Mrs) Kaine at dallasba04@gmail.com.

Consent: By clicking the "I Agree" button below, you acknowledge that you have read and understood the information provided in this consent statement. You voluntarily agree to participate in this survey. If you do not wish to participate, please exit the survey now.

☐ I Agree (I consent to participate in the survey)

☐ I Do Not Agree (I do not wish to participate in the survey)

Thank you for contributing to this research work.

Bio-Data

1. Full Name *

2. In what state are you located? *

Survey Questionnaire

Ø Select YES or NO, where appropriate and as indicated in any question.

Ø Select the answers for any question as indicated.

Ø Please respond to all questions.

4. Are you self-employed? *

Yes / No

5. If self-employed, in what area?

6. Do you work in an organization? *

Yes / No

7. Your organization is in what industry?

8. Do you work in a Government establishment? *

Yes / No

9. What Government establishment?

10. Do you live close to a poultry slaughterhouse? *

Yes / No

11. Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you? *

Yes / No

12. Can you suggest any means to tackle this problem?

13. Do you use the waterways for transportation to your workplace or community? *

Yes / No

14. Do the Boat drivers pour oil into the river or other water bodies? *

Yes / No

15. Is there any other oil pollution you frequently observe around your Environment?

16. Is oil Spill a common occurrence in your community or neighbourhood? *

Yes / No

17. How is this oil spill addressed?

18. Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment? *

Yes / No

19. Is there any existing Policy that supports the Reuse of waste chicken feathers? *

Yes / No

20. What specific contribution / Enabling Environment can the Government provide to support this initiative?

21. Do you know and understand the concept of circular economy? *

Yes / No

22. Is there any ongoing project for circular economy you are aware of in your environment? *

Yes / No

11.6.4.Questionnaire for Government Officials and Policy Makers in the Agricultural Sector

Survey on the use of Waste Chicken Feathers (Government official / senior official in ministries linked with agriculture / or policy-making/officials in NGOs / sustainable sectors)

Introduction: Thank you for your interest in participating in our research study. Before you begin, please carefully read and understand the following consent statement. By proceeding with this survey, you are indicating your informed consent to participate in this research study.

Objective of the Study: The objective of this interview is to collect Data on the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

This research is ongoing and it would be beneficial to get your view and opinion as a Government official / senior official in ministries linked with agriculture / or policy-

making/officials in NGOs / sustainable sectors. Kindly note that your name, position, and state may be cited because it is a personalized interview.

Procedure: Your participation in this survey will involve answering a series of questions related to the use of waste chicken feathers for oil spill remediation in the Niger Delta States. The survey will take approximately 20 minutes to complete. Your responses will remain confidential, and your identity will be kept anonymous.

Voluntary Participation: Participation in this survey is entirely voluntary. You are not obligated to participate, and your decision to do so will not affect any current or future relationship with Engr. (Mrs) Kaine. You may withdraw from the survey at any time without penalty.

Confidentiality: Your responses will be treated with strict confidentiality. No personally identifiable information will be collected, and all data will be reported in aggregate form. Only authorized researchers will have access to the survey data.

Risks and Benefits: There are no foreseeable risks associated with participating in this survey. The potential benefits include contributing valuable information to our research, which may lead to a better understanding of the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

Questions and Contact Information: If you have any questions about the survey, you may contact Engr. (Mrs) Kaine at dallasba04@gmail.com.

Consent: By clicking the "I Agree" button below, you acknowledge that you have read and understood the information provided in this consent statement. You voluntarily agree to participate in this survey. If you do not wish to participate, please exit the survey now.

☐ I Agree (I consent to participate in the survey)

☐ I Do Not Agree (I do not wish to participate in the survey)

Thank you for contributing to this research work.

Bio-Data

1. Full Name *

2. Name of Ministry *

3. State *

Survey Questionnaire

Ø Select YES or NO, where appropriate and as indicated in any question.

Ø Select the range of answers for any question as indicated. e.g. a. b.

Ø Tick a number that represents your level of agreement/ support or disagreement with each statement/ question.

Keys: 1 = Strongly disagree 2= Moderately disagree 3= Slightly disagree 4 = Neither dis- agree or agree 5 = Slightly agree 6= Moderately agree 7= Strongly agree

Ø Please respond to all questions.

4. How many Commercial Poultry Farms do you have in your State?*

< 10 / 11 – 50 / 51 – 100 / > 100

5. What is the capacity of poultry farming annually in your State? or Nigeria *

< 100,000 birds / 100,001 - 200,000 birds / 200,001 - 500,000 birds / > 500,000 birds

6. What is the percentage contribution of waste chicken feathers to solid waste in the state? *

0 – 25 / 26 – 50 / 51 – 75 / 76 -100

7. What quantity of waste chicken feathers is produced annually in your state?*

< 10,000 Kg / 10,001 - 20,000 Kg / 20,001 - 50,000 Kg / > 50,000 Kg

8. Are there any regulations or guidelines for poultry/slaughter houses in regard to the disposal of chicken feathers in your state?*

Yes / No

9. Is there any value chain in existence for waste chicken feathers? *

Yes / No

10. Is there an existing association for poultry farmers in the state?*

Yes / No

11. Do you think farmers and agribusinesses can play a role in helping to address the issue of waste chicken feathers?*

12. Do you think it is important for the Ministry of Agriculture to prioritize finding sustainable solutions for waste chicken feathers disposal?*

13. Is there any existing policy for waste chicken feathers? *

Yes / No

14. Are you willing to support the use of waste chicken feathers for oil spill remediation? *

Yes / No

15. How can you support or promote the use of waste chicken feathers for oil spill remediation? *

16. Do you know and understand the concept of circular economy? *

Yes / No

17. Is there any ongoing project for circular economy you are aware of in your state or country? *

Yes / No

11.6.5.Questionnaires for Expert Interviews on the Barriers to Circularity

Survey on Barriers to Transitioning to Circular Economy

The objective of this interview is to collect Data on the use of waste chicken feathers for oil spill remediation in the Niger Delta States.

This research is ongoing and it would be beneficial to get your view and opinion as an entity that can use Chicken Feather. Kindly note that your name, position, and state may be cited because it is a personalized interview.

Thank you for contributing to this research work.

Personal Information

Kindly provide the required personal information

1. First Name *

2. Last Name *

3. Email Address *

4. What Niger Delta State do you reside in? *

Abia / Akwa Ibom / Bayelsa / Cross River / Delta / Edo / Imo / Ondo / Rivers

5. Position *

Toptier Barrier Questionnaire for Material Characteristics

Kindly select option that applies.

6. Can chicken feathers' composition stop the transition to circularity? *

- No Potential (Level 0) - Components are difficult to separate.
- Some Possibility (Level 1) - Components can be separated with little effort.
- Good Potential (Level 2) - Simple composition
- High Potential (Level 3) - Homogenous and Simple Composition

7. Do you think chicken feathers have economic value? *

- No Potential (Level 0) - No value
- Some Possibility (Level 1) - Low value
- Good Potential (Level 2) - Intermediate value
- High Potential (Level 3) - Potential to have relative value.

8. Does the material contain many different components that are difficult to separate and can stop the transition to a circular economy? *

- No Potential (Level 0) - It has many different components.
- Some Possibility (Level 1) - Limited amount of different components
- Good Potential (Level 2) - Few components that have the potential to be separated.
- High Potential (Level 3) - Single material with no impurities or compatible mixed materials.

9. Does the material have aesthetic value that can be beneficial to the move from a linear to a circular economy? *

- No Potential (Level 0) - No aesthetic value.
- Some Possibility (Level 1) - Material has little aesthetic value.
- Good Potential (Level 2) - Material has some aesthetic value.
- High Potential (Level 3) - Material has significant aesthetic value.

10. Does the chicken feather material degrade in new ways that will stop the transition to the circular economy? *

- No Potential (Level 0) - Is it volatile and/or odorous and properties degrade rapidly
- Some Possibility (Level 1) - Material does degrade but stability can be achieved with some processing.
- Good Potential (Level 2) - Material does not rapidly degrade and is stable.
- High Potential (Level 3) - Material is completely inert with no potential health or environmental concerns.

11. What do you think about the chicken feather waste? Is this hazardous and would stop the transition to a circular economy? *

- No Potential (Level 0) - Material is Hazardous
- Some Possibility (Level 1) - Problematic Waste with some potential for adverse health and environmental hazard
- Good Potential (Level 2) - Stable neutral waste with some potential for adverse health and environmental hazard
- High Potential (Level 3) - Safe, inert material with no potential health or environmental concerns

12. Is the chicken waste material Contaminated by other components that will stop the transition to a circular economy? *

- No Potential (Level 0) - The material is extensively contaminated.
- Some Possibility (Level 1) - The material has intermediate levels of contamination.
- Good Potential (Level 2) - Material is relatively consistent.
- High Potential (Level 3) - Materials is consistent, uncontaminated and comparable to virgin sources.

Toptier Barrier Questionnaire for Processing Technology

Kindly select option as applies.

13. Is technology readily available, for the reuse of Chicken Feather, to allow the transition to circularity? *

- No Potential (Level 0) - Technology to reuse the material does not exist.

- Some Possibility (Level 1) - Technology exist in different technical contexts and analogous processing is possible.
- Good Potential (Level 2) - Variety of technical options available
- High Potential (Level 3) - All required technology is standard and freely accessible.

14. Are there resulting processing wastes, that would stop the transition to circularity?*

- No Potential (Level 0) - Residues generated are likely to be highly problematic, requiring expensive linear disposal.
- Some Possibility (Level 1) - Residues can be managed.
- Good Potential (Level 2) - Disposal is unlikely to cause problems.
- High Potential (Level 3) - Only minor or no residues are created.

15. Is processing simple enough to allow the transition to circularity? *

- No Potential (Level 0) - The material needs a combination of mechanical, chemical, and thermal treatments.
- Some Possibility (Level 1) - The material requires a combination of 2 treatments.
- Good Potential (Level 2) - The material requires 1 of the treatments.
- High Potential (Level 3) - The material does not require treatment.

16. Are the suggested processes resource efficient to allow the transition to the circular economy? *

- No Potential (Level 0) - Transition requires significant use of other resources Some Possibility (Level 1) - The conversion of the products requires resources.
- Good Potential (Level 2) - The conversion of the products requires only very limited.
- use of other resources
- High Potential (Level 3) - The processing technology is standard in most cases.

17. Is it easy to implement the processing which allows the transition to a circular economy? *

- No Potential (Level 0) - The processing technology is difficult to implement.
- Some Possibility (Level 1) - Processing technology can be implemented with efforts.
- Good Potential (Level 2) - Processing technology can be implemented easily.
- High Potential (Level 3) - Processing technology is standard in most cases.

Toptier Barrier Questionnaire for Environmental Impact

Kindly select option as applies

18. What is the embodied carbon in the materials being considered? *

- No Potential (Level 0) - The material has low embodied carbon and energy.
- Some Possibility (Level 1) - The material has intermediate embodied carbon and energy.
- Good Potential (Level 2) - The material has a higher level of embodied carbon and energy.
- High Potential (Level 3) - The material has very high levels of embodied carbon and energy

19. Is the current disposal option having a significant adverse effect on the environment? *

- No Potential (Level 0) - Current linear disposal produces no adverse environmental impacts.
- Some Possibility (Level 1) - Current linear disposal is associated with some adverse environmental impacts.
- Good Potential (Level 2) - Linear disposal could cause significant adverse environmental impact.
- High Potential (Level 3) - Linear disposal causes drastic, irreversible and long-term damages and impacts environment dramatically.

20. Does the new proposed option significantly reduce the environmental impact of the material? *

- No Potential (Level 0) - Changes to the current linear disposal management methods may adversely impact the environment.
- Some Possibility (Level 1) - Changes to are likely to reduce the environmental impact of the material only minimally.
- Good Potential (Level 2) - Changes would reduce the environmental impacts associated with this material.
- High Potential (Level 3) - Changes would significantly reduce the environmental impacts associated with this material.

Toptier Barrier Questionnaire for Organizational Context

Kindly select option as applies.

21. Does the organization owning the material encourage development and change? *

- No Potential (Level 0) - The organization does not promote new ideas and is highly reliant on staying in within given constraints.
- Some Possibility (Level 1) - The organization does allow some flexibility and new ideas, however the main business is always in focus.
- Good Potential (Level 2) - The organization is agile to some degree and regularly tests new processes and ideas.
- High Potential (Level 3) - The organization is very agile and seeks constant adaption and change.

22. Are the senior management in the organization supportive of the change to a circularity? *

- No Potential (Level 0) - Senior management does not support new ideas.
- Some Possibility (Level 1) - Senior management is not against new ideas but stresses the importance of business as usual.
- Good Potential (Level 2) - Senior management supports and rewards new ideas, if they do not conflict with the overall business strategy.
- High Potential (Level 3) - Senior management is very flexible and adaptive to trying new things and testing even if there is uncertainty.

23. Does organization place priority on sustainability and corporate social responsibility (CSR)? *

- No Potential (Level 0) - Sustainability is not important for the vision and there is no CSR.
- Some Possibility (Level 1) - Sustainability is included in the company vision, but not actively executed.
- Good Potential (Level 2) - Sustainability is important and measures are implemented.
- High Potential (Level 3) - Sustainability is the core value of the organization and there is a high level of CSR.

24. Are the resources available to support the transition to a circular economy? *

- No Potential (Level 0) - There is no room for resources to be diverted, resources are scarce.

- Some Possibility (Level 1) - Resources are available; however accessing them needs extensive justification
- Good Potential (Level 2) - Resources are available, and they are accessed easily.
- High Potential (Level 3) - Resources are available, and they are accessed easily, and can be increased with minimal effort.

25. How does the organization view risk? *

- No Potential (Level 0) - The organization is highly risk averse.
- Some Possibility (Level 1) - The organization is taking measures to manage risks, however risks are ideally avoided.
- Good Potential (Level 2) - The company is used to taking risks to some degree.
- High Potential (Level 3) - The company is not risk averse, can effectively manage risks and often takes risks.

26. How important is innovation to the organization? *

- No Potential (Level 0) - The organization does not promote innovation, especially when related to sustainability.
- Some Possibility (Level 1) - The company does promote innovation, but it is not a main driver for the business.
- Good Potential (Level 2) - The company rewards innovators and encourages innovation.
- High Potential (Level 3) - The company rewards innovators highly and seeks innovation and innovation/research is a priority.

Toptier Barrier Questionnaire for Industry and Supply Chain Issues

Kindly select option as applies

27. How does current Industry and supply chain issues influence transition from linear to circular? *

- No Potential (Level 0) - Current linear disposal is acceptable to the industry.
- Some Possibility (Level 1) - Some participants of the supply chain show interest in engaging in new activities related to the material.
- Good Potential (Level 2) - Most partners in the value chain would contribute to find better solutions and transition to circularity.

- High Potential (Level 3) - All organizations in the supply chain want to see the material transition to a circular economy.

28. Does the industry show a willingness to change and do they want to transition this material to a circular economy? *

- No Potential (Level 0) - The industry has no interest for circular economy.
- Some Possibility (Level 1) - Current linear disposal is being questioned as viable in the long-term
- Good Potential (Level 2) - A linear model is considered as problematic and change requested.
- High Potential (Level 3) - The status quo is considered total unacceptable.

29. Do the people who control the material consider the current linear disposal model to be acceptable? *

- No Potential (Level 0) - Producers consider the current situation as acceptable and are not liable for any damages/inefficiencies.
- Some Possibility (Level 1) - Product/ material owners/users face problems with the current situation.
- Good Potential (Level 2) - The material owner is clearly identifiable.
- High Potential (Level 3) - The material owner is clearly identifiable and subject to strict regulations for sustainability standards.

30. Does the nature of the industry allow sufficient quantities of the material to be collected? *

- No Potential (Level 0) - No existing infrastructure to handle the material.
- Some Possibility (Level 1) - Current infrastructure to collect and transport the material requires significant amount of additional resources.
- Good Potential (Level 2) - The material can be transported in a variety of modalities without problems with existing infrastructure.
- High Potential (Level 3) - The material can be reprocessed in-situ or does not need to be transported.

31. Can the material be easily stored and handled? *

- No Potential (Level 0) - The material storage is extremely problematic, time- sensitive, and condition-critical and requires significant space.

- Some Possibility (Level 1) - The material storage requires space and needs constant monitoring.
- Good Potential (Level 2) - The material storage is not problematic and requires only limited space.
- High Potential (Level 3) - The material can be stored indefinitely, with minimal space usage.

32. Is the material highly distributed and difficult to locate/access? *

- No Potential (Level 0) - The material is widely distributed and therefore difficult to collect.
- Some Possibility (Level 1) - The material is distributed, but central hubs of collection can be organized/ is available.
- Good Potential (Level 2) - The material is available from well-defined locations or collected in few central locations.
- High Potential (Level 3) - It is very easy to collect the material and locations are accessible.

33. Is it clear who can be held responsible for the material and disposal impacts? *

- No Potential (Level 0) - It is not clear who is responsible for the material at end-of- life (EOL)
- Some Possibility (Level 1) - Someone is responsible for the EOL of the material.
- Good Potential (Level 2) - There is a chain of responsibility available for inputs and outputs of the value chain.
- High Potential (Level 3) - There is a chain of responsibility available for each step of the supply chain.

34. Is the supply chain well connected to accommodate increased communication effort to transition to circularity? *

- No Potential (Level 0) - The supply chain is not connected and exchange of information is not possible or difficult
- Some Possibility (Level 1) - Communication measures could be implemented with some effort.
- Good Potential (Level 2) - The supply chain is well connected and communication is possible if requested

- High Potential (Level 3) - All partners in the supply chain are connected, they can easily communicate digitally and have access to storage/information about processes and materials.

Toptier Barrier Questionnaire for External Drivers and Incentives

Kindly select option as applies.

35. Are there significant drivers and incentives for the industry to change the current linear lifecycle of this material? *

- No Potential (Level 0) - No government drivers to re-use or rethink the current material life cycle.
- Some Possibility (Level 1) - Some drivers from government available to re-use or rethink the current material lifecycle.
- Good Potential (Level 2) - Government offers subsidies and support to transition to circularity.
- High Potential (Level 3) - Government heavily subsidizes and gives incentives to develop a circular economy for this material.

36. Is the material holder/producer aware of the importance of moving towards a circular economy? *

- No Potential (Level 0) - No end-user drivers to re-use or rethink the current material lifecycle.
- Some Possibility (Level 1) - Some drivers for industry to re-use or rethink the current material lifecycle.
- Good Potential (Level 2) - Drivers/incentives for the industry to re-use or rethink the current material lifecycle.
- High Potential (Level 3) - Significant drivers/incentives for the industry to re-use or rethink the current material lifecycle.

37. Is the material currently part of a research and development programs? *

- No Potential (Level 0) - No scientific or technical development to re-use or rethink the current material lifecycle.

- Some Possibility (Level 1) - Some scientific and technical development to re-use or rethink the current material lifecycle.
- Good Potential (Level 2) - The scientific and technical development exists High Potential (Level 3) - Main research area at universities and companies.

38. Are there overall industrial trends and drivers, which impact the transition to circularity? *

- No Potential (Level 0) - No industrial drivers to re-use or rethink the current material lifecycle.
- Some Possibility (Level 1) - End-users are somewhat motivated to re-use or rethink the current material lifecycle.
- Good Potential (Level 2) - End-users are motivated to re-use or rethink the current material lifecycle.
- High Potential (Level 3) - End-user is highly motivated to re-use and rethink the current material lifecycle.

Toptier Barrier Questionnaire for Public Perception

Kindly select options as applies.

39. What is the public perception of the current linear disposal of this material? *

- No Potential (Level 0) - The current end-of-life scenario is accepted by the public, media and government.
- Some Possibility (Level 1) - The end-of-life issues associated with the material have a very low or no profile with the public, media and government.
- Good Potential (Level 2) - Most of the public has a neutral perception towards re- using the material in a novel context.
- High Potential (Level 3) - Most of the public has a positive perception towards re- using the material in a novel context.

40. What is the level of public discussion and concern associated with this material? *

- No Potential (Level 0) - Discussion on the current management of this material is avoided and not encouraged.

- Some Possibility (Level 1) - There is no discussion on the current management of this material.
- Good Potential (Level 2) - The material has some coverage in the media and the public is aware of issues.
- High Potential (Level 3) - The material has a lot of public interest and the current end of life options are widely discussed

41. Are the public aware of this material and where it comes from? *

- No Potential (Level 0) - The origin of the material is not clear, and the issues are not known to the general public.
- Some Possibility (Level 1) - The origin of the material is traceable, and the public is aware of the current issues.
- Good Potential (Level 2) - The public may be aware of the end-of-life issues associated with this material.
- High Potential (Level 3) - Organizations associated with the material are known and the public is generally aware of the adverse impacts of linear disposal.

Toptier Barrier Questionnaire for Regulatory Framework

Kindly select options as applies.

42. Are there any significant health and safety issues associated with this material that could stop the transition to circularity? *

- No Potential (Level 0) - There are significant health and safety issues associated with this material, which are far-reaching, irreversible with lasting impact.
- Some Possibility (Level 1) - There are issues associated with the material, but they are localized, time-constraint or not severe.
- Good Potential (Level 2) - There are no issues associated with the material.
- High Potential (Level 3) - There are no issues associated with the material, if any, they are of positive nature.

43. Does the material require rigorous handling requirements? *

- No Potential (Level 0) - The material is dangerous and major requirements needs to be met to access the material.

- Some Possibility (Level 1) - Components of the material may be hazardous under certain conditions however can be mitigated with personal protection equipment.
- Good Potential (Level 2) - The material can be handled without many precautions; some basic training may be required.
- High Potential (Level 3) - The material can be handled without precautions, no training required.

44. Are there penalties associated with the material, if standard procedures are not adhered to? *

- No Potential (Level 0) - Fines for wrongful handling and disposal of the materials are very high and it is strictly controlled.
- Some Possibility (Level 1) - Fines can be imposed but they are usually not enforced.
- Good Potential (Level 2) - Fines are associated with the mismanagement of this material.
- High Potential (Level 3) - Fines are associated with the mismanagement of this material and these can be substantial.

45. Are there any regulations that will stop the transition to a circular economy? *

- No Potential (Level 0) - There are relevant regulations in place that will make the move to other disposal/ re-use ideas very problematic.
- Some Possibility (Level 1) - There are some regulatory barriers but there are components related to the material that may become an issue.
- Good Potential (Level 2) - There is little to no regulation with regards to the material High Potential (Level 3) - The material is not impacted by any regulation.

46. Is it clear who is legally responsible for the material at end of life? *

- No Potential (Level 0) - It is not clear who is legally responsible for the material at end of life.
- Some Possibility (Level 1) - It is clear who is legally responsible for the material at end of life, but there is not much documentation about it.
- Good Potential (Level 2) - It is clear who is legally responsible for the material at end of life and there is documentation in place.
- High Potential (Level 3) - It is not relevant/necessary to define responsibilities for the material.

Toptier Barrier Questionnaire for Economic Viability

Kindly select options as applies.

47. Can the material be processed into a new product or raw material for which there is a viable market? *

- No Potential (Level 0) - The material has no or very low inherent value, which could be monetized with no market/ demand existent.
- Some Possibility (Level 1) - The material low inherent value, which could be monetized immediately, there is little demand.
- Good Potential (Level 2) - The material has a certain monetary value, which can be realized even without processing and there is certain demand.
- High Potential (Level 3) - The material has significant monetary value, which can be realized even without processing with strong demand of a thriving market.

48. Do Economic viability can be achieved but this will require major investment in scale, research, development and processing to make it happen? *

- No Potential (Level 0) - The value creation can only be realized on large scale, requiring major investment.
- Some Possibility (Level 1) - The value creation can be realized only at scale, but can be grown successively to size.
- Good Potential (Level 2) - The value creation can be realized already on medium sizes scale requiring small investment.
- High Potential (Level 3) - The value creation can be realized already on very small scale, existing infrastructure can be used without any investment

49. Are the total quantities of material available appropriate to the potential application(s)? *

- No Potential (Level 0) - The total amount of waste is very low compared to potential applications.
- Some Possibility (Level 1) - The total amount of waste is medium compared to potential applications.
- Good Potential (Level 2) - There is a significant amount of material available to allow production of more than one product type.

- High Potential (Level 3) - There is sufficient material available to be used in a wide range of applications.

50. Can the material be used directly without much transport and in a local context? *

- No Potential (Level 0) - The material/product cannot be re-used for in a local context and needs to be transported far.
- Some Possibility (Level 1) - The material/product cannot be re-used for in a local context, but transport can be organized within reason.
- Good Potential (Level 2) - The material/product can be used within a smaller radius and does not require long transports.
- High Potential (Level 3) - The material can be re-used on spot and no transport is involved.

11.6.6.Summary of Responses from 60 Respondents on Questions for Use of Chicken Feather

ID	1	2	3	4	5	6	7	8	9	
In what state are you located?	Edo	Rivers	Rivers	Edo	Edo	Edo	Edo	Rivers	Rivers	Rivers
Position										
Are you self-employed?	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
If self-employed, in what area?									Essential productions	Law
Do you work in an organization?									No	No
Your organization is in what industry?										
Do you work in a Government establishment?									No	No
What Government establishment?										
Do you live close to a poultry slaughterhouse?	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No
Can you suggest any means to tackle this problem?	Proper sanitation.	Proper and regular clean up with enclosed environment and treatment .	I don't experience it	Govt should help in waste disposal		Using the feathers for pillow making.		Proper recycling of the waste.	I feel like slaughter house should be a bit far from Residential areas as it produces both Noise, Air & land pollution	
Do you use the waterways for transportation to your workplace or community?	No		No	No	No	No	No	No	No	Yes
Do the Boat drivers pour oil into the river or other water bodies?	No	No	No	Yes	No	Yes	No	Yes	Yes	No
Is there any other oil pollution you frequently observe around your Environment?	Noise from the birds		No			No		Mechanical engineers waste.	Yes	
Is oil Spill a common occurrence in your community or neighbourhood?	No	Yes	No	No	No	No	No	No	No	No
How is this oil spill addressed?		Effect is being ignored.							Through gorvernmental agencies	
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is there any existing Policy that supports the Reuse of waste chicken feathers?	No	No	No	No	Yes	No	No	No	Yes	No
What specific contribution / Enabling Environment can the Government provide to support this initiative?		The right Policy				Discourage the spillage of waterways by enforcing laws to punish offenders	Finance it		Financial assistance to those who birthed the initiative as it is environmentally friendly to the ecosystem and habitats at large.	
Do you know and understand the concept of circular economy?										
Is there any ongoing project for circular economy you are aware of in your environment?										

ID	11	12	13	14	15	16	17	18	19	
In what state are you located?	Rivers	Rivers	Ogun	Rivers	FCT	Rivers	Benue	Rivers	Rivers	Rivers
Position										
Are you self-employed?	Yes	No	Yes	No	No	Yes	Yes	No	No	No
If self-employed, in what area?	Graphics designer		Legal Practice			Culinary	Farming			
Do you work in an organization?	No	No	No	Yes	Yes	Yes	No	No	No	No
Your organization is in what industry?				Information Technology	Agrotorism	Culinary				
Do you work in a Government establishment?	No	No	No	No	No	No	No	No	No	No
What Government establishment?						None				
Do you live close to a poultry slaughterhouse?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No
Can you suggest any means to tackle this problem?				Recycling Used as feeds	Burial of such waste	Constant cleaning	Recycling		Livestock areas should be away from residential areas(Proper distancing)	
Do you use the waterways for transportation to your workplace or community?	No	No	No	No	No	No	Yes	No	No	No
Do the Boat drivers pour oil into the river or other water bodies?	No	No	No	No	No	No	Yes	No	No	No
Is there any other oil pollution you frequently observe around your Environment?	Oil sellers washing their containers in the water	Yes	None.	Yes Used engine oil from a generator	Yes I see heavy duty machine planted close to water leak oil into river	Not really	Old oil from mechanics	No	Not sure	
Is oil Spill a common occurrence in your community or neighbourhood?	No	Yes	No	No	No	No	Yes	No	No	No
How is this oil spill addressed?		As the occupants of the community, we have soured for other means of getting water and food. Since the our water and farmlands have been polluted.				Nothing is being done about it	Nothing tremendous is really done Just the use of nets			
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Is there any existing Policy that supports the Reuse of waste chicken feathers?	No	No	No	No	No	No	Yes	No	Yes	No
What specific contribution / Enabling Environment can the Government provide to support this initiative?	Providing grants and engaging more people in this regards	Working with various remediation facilities	None that I am aware of.		Provide a waste collection medium	I think they can get machines	Funding	A Station where all Poultry Waste Product can be kept after properly disposed	Grant permission & follow up with inspections	
Do you know and understand the concept of circular economy?				Yes	Yes	No	Yes	Yes	No	No
Is there any ongoing project for circular economy you are aware of in your environment?				Yes	No	No	Yes	No	No	No

ID	21	22	23	24	25	26	27	28	29	
In what state are you located?	Rivers	Rivers	Rivers	Delta	Rivers	Rivers	Kogi	Kaduna	Adamawa	Kogi
Position										
Are you self-employed?	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No
If self-employed, in what area?	Poultry		Graphics Designer, Tech Savvy, Project Assistant		Baking	Fashion		Tailor	Rivers	
Do you work in an organization?	No	Yes	Yes	No	No	No	No	No	Yes	No
Your organization is in what		Education	Insurance company					Baba fashion hub	Ibeto cement	
Do you work in a Government establishment?	No	Yes	No	No	No	No	No	No	No	No
What Government establishment?		RSU, Port Harcourt	nil							
Do you live close to a poultry slaughterhouse?	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	No	Yes	Yes	Yes	No	No	No	Yes	No	Yes
Can you suggest any means to tackle this problem?	No	Recycling	We can utilize this waste by turning it to something useful for example biofuel using any biochemical means that is efficient				Cleanup	Sited from river bank	Regeneration	
Do you use the waterways for transportation to your workplace or community?	Yes	No	Yes	No	No	No	No	No	Yes	Yes
Do the Boat drivers pour oil into the river or other water	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes
Is there any other oil pollution you frequently observe around your	Yes at Abuloma Water side	Yes	Bunkery local refining of petroleum products		Yes Crude oil spillage		No		No	
Is oil Spill a common occurrence in your community or neighbourhood?	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes
How is this oil spill addressed?	Not addressed	Not certain	Nothing is done Elders and the Elites are just taking all the money from it				Arrest		Not addressed	
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No

ID	31	32	33	34	35	36	37	38	39	
In what state are you located?	Rivers	Rivers	Bayelsa	Rivers	Taraba	Rivers	Lagos	Rivers	FCT	Rivers
Position										
Are you self-employed?	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No
If self-employed, in what area?	Igwuruta	Entertainment		Livestock farming		Consulting	Retail	Mile 3 port Harcourt		None
Do you work in an organization?	Yes	No	No	No	No	No	No	No	Yes	No
Your organization is in what industry?	Graphics	Entertainment		None				Nil	Management	None
Do you work in a Government establishment?	No	No	No	No	No	No	No	No	No	No
What Government establishment?	Non	None		None				Nil		None
Do you live close to a poultry slaughterhouse?	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	Yes	No	No	Yes	No	No	No	No	Yes	No
Can you suggest any means to tackle this problem?	By educating the workers on how to keep there environment clean	No idea on that		Develop adequate usefulness of the poultry feathers					Flushing waste	None
Do you use the waterways for transportation to your workplace or community?	No	No	No	Yes	No	No	No	Yes	No	No
Do the Boat drivers pour oil into the river or other water bodies?	No	Yes	No	No	No	No	No	Yes	No	No
Is there any other oil pollution you frequently observe around your Environment?	Yes	None	Crude oil spillage in the glutters	The business activities of the oil products dealers and the local refiners	No			It darkens the water	No	None
Is oil Spill a common occurrence in your community or neighbourhood?	No	No	No	Yes	No	Yes	No	Yes	No	No
How is this oil spill addressed?	Most of them are careless so they don't care about the effect of them spilling oil around	No idea		Stopping if illegal refining activities		Moderate		Nothing is being done about it actually		None
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is there any existing Policy that supports the Reuse of waste chicken feathers?	Yes	No	No	No	No	Yes	No	No	No	No
What specific contribution / Enabling Environment can the Government provide to support this initiative?	By educating and telling them the use and also the side effects of what they are doing because I believe some of them don't know what they are even doing so they end up doing it any how causing problems and other stuffs	Well around places that are yet to be developed	Waste bins should be provided Proper waste disposal orientations on disposing the waste products	Stopping the illegally refining activities and full support of the reuse of waste chicken feathers		Policy				None
Do you know and understand the concept of circular economy?	Yes	No	No	Yes	No	Yes	No	No	Yes	Yes
Is there any ongoing project for circular economy you are aware of in your environment?	Yes	No	No	Yes	No	No	No	No	No	No

ID	41	42	43	44	45	46	47	48	49	50
In what state are you located?	Lagos	Edo	Rivers	Rivers	Rivers	Rivers	Rivers	Delta	Rivers	Rivers
Position					Student	Citizen	Student	Student	Student	Student
Are you self-employed?	No	Yes	Yes	No	No	No	No	Yes	Yes	No
If self-employed, in what area?			Wellness, logistics					Fashion designer	Business	
Do you work in an organization?	Yes	No	No	No	No	No	No	No	No	No
Your organization is in what industry?	Finance									
Do you work in a Government establishment?	No	No	No	No	No	No	No	No	No	No
What Government establishment?										
Do you live close to a poultry slaughterhouse?	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No
Can you suggest any means to tackle this problem?	Burning			Always keep your poultry farm clean	To provide a scluded area as a slaughter	Caging the birds properly				
Do you use the waterways for transportation to your workplace or community?	No	No	No	No	No	No	Yes	No	No	No
Do the Boat drivers pour oil into the river or other water bodies?	No	Yes	No	No	No	Yes	No	No	Yes	No
Is there any other oil pollution you frequently observe around your Environment?	No	No		No	Oil spillage				yes	
Is oil Spill a common occurrence in your community or neighbourhood?	No	No	No	Yes	Yes	No	No	No	Yes	No
How is this oil spill addressed?					Poorly	Proper handling of equipments			It's a norms in my neighborhood	
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Is there any existing Policy that supports the Reuse of waste chicken feathers?	No	No	No	Yes	No	No	Yes	No	No	No
What specific contribution / Enabling Environment can the Government provide to support this initiative?					Community participation	Provide adequate space to contain the beds				
Do you know and understand the concept of circular economy?	Yes	No	No	Yes	Yes	No	Yes	No	No	No
Is there any ongoing project for circular economy you are aware of in your environment?	No	No	No	No	Yes	No	Yes	No	No	No

ID	51	52	53	54	55	56	57	58	59	60
In what state are you located?	Rivers	Rivers	Rivers	Rivers	Nassarawa	Rivers	Edo	Rivers	Rivers	Rivers
Position	Citizen	Student	Citizen	Citizen	Governor	Student	Citizen	Student	Student	Student
Are you self-employed?	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
If self-employed, in what area?			I have a farm	Business	Business	Baking	A fashion designer	Electrical installations		Because am a student and not working under anyone
Do you work in an organization?	Yes	No	No	No	No	No	No	No	Yes	No
Your organization is in what industry?	Photo studio				Commercial		I don't work in any organization		Education	
Do you work in a Government establishment?	No	No	No	Yes	No	No	No	No	No	No
What Government establishment?										
Do you live close to a poultry slaughterhouse?	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Do the feathers from the slaughterhouse cause any Waste Management /Environmental challenges for you?	Yes	No	No	No	Yes	No	No	Yes	No	Yes
Can you suggest any means to tackle this problem?	Convert the feathers into useful things as a wasteless cycle The benefits or nutritional value of it can be researched and worked upon but if non then it can be used in the place other things like clothing etc				By locating such industries where houses aren't common					The waste should be properly taken care of and disposed appropriately as the small from the slaughter house isn't good for the human health. It causes environmental hazards by altering
Do you use the waterways for transportation to your workplace or community?	Yes	No	No	No	No	No	No	Yes	No	No
Do the Boat drivers pour oil into the river or other water bodies?	Yes	No	Yes	No	No	No	No	Yes	No	No
Is there any other oil pollution you frequently observe around your Environment?	No		Yes		No			No	Oil from eateries waste products	
Is oil Spill a common occurrence in your community or neighbourhood?	Yes	No	Yes	No	No	No	No	No	Yes	Yes
How is this oil spill addressed?	I don't have an idea		Nothing is done about it						Not addressed, just waiting for rain to wash it away	No good response because the guys cooking the oil settles the people
Are you happy to promote Oil sorption Pillows made from Chicken feathers to clean water resources around your Environment?	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes
Is there any existing Policy that supports the Reuse of waste chicken feathers?	No	No	No	No	No	No	No	No	No	No
What specific contribution / Enabling Environment can the Government provide to support this initiative?	The government can support financially and enlighten persons who can handle this area and people who are involved in it The government can also lay down rules to be followed in line with feather waste and follow them to the latter		Sensitization						Proper Drainage	
Do you know and understand the concept of circular economy?	Yes	No	No	No	No	No	No	Yes	No	No
Is there any ongoing project for circular economy you are aware of in your environment?	No	No	No	No	No	No	No	No	No	No

11.6.7.Summary of Responses from the Expert Interviewees

Respondent 1

Ministry of Agriculture and Environment, Owerri

Material Characteristics

As a staff of Imo State Ministry of Agriculture and Environment who grew through the ranks to become a Director in the Civil Service, I have had the opportunity to assess different kinds of waste materials in the state. Hence, I have observed that waste chicken feathers are highly homogenous with limited amount of impurities that can be handled. However, if the material is poorly handled, it could become heavily contaminated. Thus, the ease of handling the material and stability of waste feathers are factors that can enhance transition to circularity in Imo State. By implication, so much resources will not be needed and the stability of the material makes it an environmental-friendly asset that can be deployed in environmental remediation. Therefore, material characteristics of waste feathers can be managed in the state to achieve circularity.

Processing Technology

The technology to reuse waste chicken feathers does not really exist in Imo State, and this is a potential factor that can hinder the transition to circularity. However, considering that the people are quick to learn and adopt new technologies, the technology to reuse the material can easily be developed. Also, residues resulting from the use of the material can be handled in the state because any technology being developed in line with the reuse of waste feathers will incorporate waste/residue management.

Environmental Impact

The current linear disposal of waste feathers in Imo State is associated with some adverse environmental impacts which include aesthetic nuisance. The situation needs urgent steps to find alternative methods of managing the material in the state. Thus, it is my opinion that changes to the current linear disposal methods would reduce the environmental impacts. The current linear disposal and the need for change would encourage the transition to circularity in the state.

Organizational Context

Some organizations that produce poultry feathers in the state do welcome new ideas and strive to ensure that the ideas are implemented. The management of these organizations are flexible and encourage innovations. The management attitude and flexibity are favourale towards achieving circularity for waste feathers in the state. These organizations also have the resources to support the innovations. These resources can easily be assessed. On the basis of organizational context, it can be concluded that the potential to create a circular economy for waste feathers exist in the state.

Industry And Supply Chain Issues

Organizations that produce waste chicken feather in the state are known to have infrastructural problems. These organizations of course have some infrastructures to collect and transport the materials. However, the infrastructures are not adequate and require significant amount of other resources in order to allow collection of sufficient material needed to enhance transition to circularity. Another factor that could constitute a problem towards achieving circularity in the state is the distribution of the material. The material is widely distributed such that creation of central collection hubs is needed to make it easier to assemble the materials.

External Drivers And Incentives

There are no government drivers and incentives that can enable the industry to change the current linear model to circular economy. It is true that the producers of waste feathers in the state understand the importance of moving to a circular economy, however, absence of government drivers and end-user drivers to rethink the current life cycle have hindered the benefits that would have accrued from this awareness.

Public Perception

The people of Imo State are neutral towards innovations relating to the material. In as much as they know that technology is advancing and that materials considered as waste in the past can now be put into useful applications, efforts have not been made to initiate discussions on the management of waste feathers. Therefore, little or nothing is known about the end-of-life issues associated with the material and hence, informed opinions about the material are not forthcoming. These issues can act as barriers towards creating circular economy for waste feathers.

Regulatory Framework

The material can be handled without precautions and with little training. Also, there are no specific laws or regulations guiding the use or management of waste feathers in the state. Since it is presently classified as waste, there are aspects of Imo State environmental laws and regulations that could apply to it. However, such laws will not restrict its applications in other areas and cannot also hinder transition to circular economy.

Economic Viability

In Imo State, there are harsh economic policies that can hinder production of poultry products. These policies lead to multiple taxation by ministries, departments and agencies of government including the local governments. These economic policies adversely affect the production of dairy products including the generation of waste feathers for industrial applications.

Respondent 2

JVC Group, Owerri

Material Characteristics

As a commercial poultry farmer in Imo State with over ten (10) years' experience in the industry, I have observed that the level of poultry consumption has increased tremendously in the state especially in the last five (5) years. This in my opinion is as a result of population increase. There has also been a tremendous surge in the production of waste feathers in the state. The high production rate of this waste material calls for concern and concerted effort towards realizing alternative method of utilizing the material and converting it to asset. Thus, the situation shows good potential for transition to circularity.

Processing Technology

All over the world, technology has improved, and science has also deepened. Nigeria in general and Imo State in particular have not been left out. As a commercial poultry farmer, it is my opinion that technologies that can redirect the use of this material exist and such technologies can easily be sourced and implemented in Imo State because the state is endowed with human resources that can be harnessed to achieve this goal.

Environmental Impact

Although the current linear disposal method that has significant adverse effect on the environment and the proposed changes which have the potential to reduce the environmental problems of the material are factors that can drive circularity, the current economic downturn is likely to serve as a barrier to the transition. This is because organizations may avoid engaging in new prospects while struggling to sustain their businesses.

Organizational Context

Issues relating to organizational context can also constitute some barriers to transition to circularity especially in the area of promoting new ideas. Most organizations that produce waste feathers in Imo State are afraid of taking risks especially for novel projects. The senior management in some of these organizations find it difficult to support new ideas thereby making it difficult to achieve circularity for the material. However, we also have in the state organizations that take measures to manage risks. These set of organizations also avoid risk especially when the prospect is new.

Industry and Supply Chain Issues

As a commercial poultry farmer in the state, I have observed that one of the major problems feather producing firms encounter is poor communication and exchange of information. The supply chain is not connected, thereby making the exchange of information and ideas impossible or difficult. Another problem is responsibility issues. It is not really clear who should be held responsible for the disposal impacts of the material.

External Drivers and Incentives

In Imo State, there are no industrial trends and drivers that can help to create a circular economy for the material. Second, the material is not part of any research and develop program that is designed to ensure circularity. Thus, it can be concluded that there is no scientific or technical development that can rethink the current material life cycle and enhance transition to circularity.

Public Perception

Citizens have become aware of the current technological trend across the globe. Although the end-of-life issues associated with the material have attracted very little government and media attention, it is believed that efforts to bring the current innovation to public knowledge will be

a welcome development. Besides, from the cultural and religious perspectives, there are no norms or beliefs that can work against the proposed innovation.

Regulatory Framework

There are virtually no government regulations that can hinder transition to circularity for waste feathers in the state or make reuse ideas very problematic. Although, as the material draws public and government attention as effort to develop and implement the innovation increases, there could be specific regulations to guide its applications. However, considering that the material is not associated with any serious environmental issues, it is unlikely that there could be strict regulations that can hinder its transition to circularity.

Economic Viability

Although, while discussing material characteristics, I stated that poultry consumption has increased tremendously over the last five (5) years due to population increase. A critical analysis of market demand for chicken in the last few months after fuel subsidy removal shows sharp fluctuation in the demand of the product not only in Imo State but in other parts of Nigeria. There are fears amongst poultry farmers that if the economic situation does not improve, consumption of chicken and dairy products will reduce significantly because many households may no longer afford it. As it is now, the material is highly abundant in the state and can be used in a wide range of applications. However, if the economy does not improve, there may be shortage of the material.

Respondent 3

Poultry Farm, Amala Ngor Okpala L.G.A., Imo State

Material Characteristics

Waste chicken feathers could be problematic and do not decompose easily. I am saying this based on my experience as a poultry farmer for the past 12 years who also runs a slaughterhouse. We normally burn or use it as landfill. Even when it is used as landfill and you excavate the land after some years, you will still see the waste feathers intact and undecomposed. Since the material is stable, it constitutes environmental problem. Sometimes, we see it as a great burden trying to dispose the feathers because of the quantity that is being produced on daily basis. The material is also odorous especially when it heaped in large quantity. When it is mixed with blood stains, micro-organisms get attached to it. These

problems are enough to make relevant organizations to look for alternative ways of handling the material.

Processing Technology

I do not think that the technology to reuse the material exist in Imo State or anywhere in Nigeria. As a poultry farmer and slaughterhouse owner for over ten (10) years, I often face problem of how to dispose waste feathers. I have interacted severally with officials from Ministry of Agriculture and Environment to find out if there is any way the material can be used to produce some other material, but the response has always been no. So if there is any technology or innovation coming at this point that can convert waste feathers to wealth which of course is possible, the poultry farmers in Imo State will key into it and also offer financial support in any way we can to make it a reality.

Environmental Impact

Like I stated earlier while discussing material characteristics, the current disposal method of waste feathers causes adverse environmental impacts which include bad odour. The impacts can also last for a very long time. When buried, it can cause foundation problems if a building or structure is erected on that land. The poultry farmers in Imo State have for long desired to have other applications of waste feathers developed anywhere in Nigeria so that we can adopt the innovation. This will help to reduce the problem of waste feather disposal in the state.

Organizational Context

A large number of the organizations that produce waste feathers in Imo State do not promote ideas that has to do with sustainability. I am of the opinion that senior management of these organizations would not be willing to change the current trends and management practices to achieve circularity. The implication of the present situation of things is that achieving circularity for the material may be very difficult. However, we also have few organizations with good organizational culture that are willing to support efforts towards developing alternative use of this material in a manner that will enhance circularity.

Industry and Supply Chain Issues

I have observed that many of the firms that produce waste feathers in the state have issues relating to adequate storage of the material. This is because storage of the material is very problematic, and it is also sensitive to time especially long storage time. The material also

requires a lot of space and constant monitoring to achieve desired results. If there are processing technologies and good end-user drivers with a commitment to improve the supply chain inadequacies highlighted herein, the possibility of achieving circular economy for waste feather will be greatly enhanced.

External Drivers and Incentives

There are scientific and technical developments to rethink or reuse the current material life cycle. There is also government support in form of grants and subsidies in agricultural sector. These interventions can enhance transition to circular economy for waste feathers in the state. Another factor that can enhance transition to circularity is the level of awareness on the part of material producers on the importance of transition to circularity.

Public Perception

The end-of-life problems associated with waste feathers in Imo State are not considered to be a major issue by the people, the government, and the media. Hence, there is no discussion on how the material can be handled. But if the right information is passed to the people, I belief they will have a positive mindset towards the material as there are no cultural issues that can stop them from embracing any technology towards achieving circularity for the material.

Regulatory Framework

As a poultry farmer, I have interacted severally with officials from the state Ministry of Agriculture and Environment during their routine inspection of facilities. None of these officials has told me that there is a law regulating waste chicken feathers in the state. However, it should be noted that the material is considered as waste in the state and as such, its management is guided by waste management laws/policies of the state. It is also worthy to note that the state government has always enacted policies that will encourage ‘waste to wealth’. Thus, there cannot be any legislation that will hinder transition to circularity for this material.

Economic Viability

Waste chicken feathers are abundant in Imo State. The quantity being produced in the state on monthly basis is large enough for wide range of applications. The fact that at the moment, it is considered as waste and is being handled as such makes it even more abundant.

Respondent 4

Department of Environmental Management,

Federal University of Technology, Owerri

Material Characteristics

As a lecturer and researcher in Environmental Management with eight (8) years' experience, I have engaged in research to ascertain the chemical and microbial constituents of potential pollutants including waste feathers and other agricultural waste. In the course of the research, I observed that waste feathers are homogenous materials characterized by low level of impurities. Although, if it is not properly, handled, it has the tendency of being contaminated especially by microbes. The contamination can render it unfit for certain applications or cause it to have unpleasant smell. These attributes are supposed to enhance circular economy for the material.

Processing Technology

There are technologies to develop the material into other useful applications. However, the technology is not yet in Imo State. Even if the technology is in Nigeria, it should be a recent development. It is possible to develop industrial applications for the material in the area of oil clean up. These applications will require significant investment as a lot of research will be carried out before it could certified to be effective or not. Of course, such research will also take a considerable length of time.

Environmental Impact

The material has the potential to impact negatively on the environment. If it is dumped in the environment, micro-organisms will build up as a result of blood stains. If it is buried, it can cause foundation problems as structures erected on the land may not be strongly rooted to the ground. One of the ways of finding a lasting solution to this menace is to explore alternative ways the material can be handled. I think the best of all the options now is to develop probably, a novel method of using the material in the state and Nigeria in general.

Organizational Context

The senior management of many organizations that own feather materials in Imo State reward new ideas as long as these ideas do not conflict with the overall business strategies of the organization. These organizations consider sustaining their business strategies very important and are averse to ideas and innovations that are seen to affect their approach. Thus, in order to get the support of this set of organization in new prospects, proposals should be done and action plan mapped out in a manner that will not violate their business strategies.

Industry and Supply Chain Issues

One of the factors in relation to industry and supply chain issues that can enhance transition to circularity for waste feathers in Imo State is the fact that the current linear disposal is being questioned as being viable in the run long. It is also considered as a problematic model. Hence, there is urgent need for change in the form of creating alternative management practices for waste feathers in the state. Fortunately, organizations that produce waste feathers in the state have always shown willingness and are ready to support innovations that will transit this material to circular economy.

External Drivers and Incentives

As a university lecturer in the department of Environmental Management, and being privileged to know current research trends in the country, I can say that scientific and technical developments that can rethink the current material life cycle exists. Research on best ways to manage agricultural wastes including waste feathers is in progress in universities. There are also some drivers to rethink the current linear disposal model of the material. These drivers include tax incentives subsidies and grants for firms that are engaged in agriculture.

Public Perception

In Imo State, the end-of-life issues of waste feathers have very low profile with the public. This is because the government and the media have not really considered these problems as issues that deserve their attention. Hence, the result is the present situation in which an average citizen of the state knows very little or nothing about waste feathers other than being agricultural waste. This scenario can constitute obstacle to the effort to create circularity of the material in the state.

Regulatory Framework

I teach environmental laws to my students and I can say that any law that can hinder transition to circularity for waste feathers is yet to be enacted not only in Imo State but Nigeria in general. But I will also want to point out that there are environmental laws on waste management that can be presently used to regulate waste feathers in every state in Nigeria. However, such laws do not prohibit innovations that are aimed at recycling wastes or converting wastes to wealth or other applications.

Economic Viability

Waste feathers have monetary value because they can be incinerated and converted to manure. It can also be used as ornament and decoration material. The material is abundant in the state because of three reasons: first, the large number of poultry farms in the state; second, the very high consumption of chicken; and third, the material has no other use and is completely seen as waste material.

Respondent 5

Federal Controller of Environment,

Southeast Zone

Material Characteristics

As the Federal Controller of Environment, Southeast Zone, I have 29 years' experience as a staff of the Pollution Control Unit, Federal Ministry of Environment. I also embark on routine facility inspection not only in Imo State but in the entire southeastern states. Based on my experience, I can say that waste chicken feathers have good characteristics such as simple composition and aesthetic value. The material does not degrade easily. But it can be contaminated if it is carelessly handled. When the material is contaminated, its economic value reduces because resources will be required to clean it up for any industrial application. I believe the material has potential for circularity in Imo State.

Processing Technology

There are technologies to handle the material in Imo State. The technologies are for the use of feathers as feather fans, masks, costume accessories, bird ornaments and even earring and flowers. Some of these technologies are local technology and can be improved. The residues or wastes that originate from these processes are minimal and are not difficult to handle.

Environmental Impact

During some of my routine inspection tours in Imo State, I ran into large dumpsites composed mainly of chicken feather wastes. I made some observations and conclusions. First, I concluded that even though feather waste have aesthetic value, when handled in this manner, it becomes an eye sore. I also concluded that resources will be spent by government or whoever that may want to develop the land to evacuate the waste. Based on these observations, I can say authoritatively that feather wastes have adverse environmental impact if it is not handled properly.

Organizational Context

As a staff of the Federal Ministry of Environment, I am aware that some organizations that produce feather materials in the state encourage development and change. These organizations allow or tolerate new ideas and are flexible on issues relating to innovations. Two major

attributes of this set of organizations that can enhance circularity for waste feathers are their low level of risk aversion and culture of innovation. They are also willing to make resources available to test new ideas in order to transition to circularity.

Industry and Supply Chain Issues

The current linear disposal of waste feathers is acceptable to producers of the material in Imo State. This is because the producers are not to be held responsible for damages or inefficiencies that may arise at any time. Also, it is not clear who should be held for the material at end of life. It is my opinion that the current linear disposal has a high level of acceptance in the state which could hinder efforts to move the material to circularity.

External Drivers and Incentives

At the moment, there are no government drivers to reuse or rethink the current material life cycle in the state. There are also no industrial drivers. However, end-users are somehow motivated to rethink the current situation by trying to support innovations that will ensure circularity for the material. There also a good number of scientific and technical developments that can enhance circularity for this material.

Public Perception

By virtue of my position as the Federal Controller of Environment, Southeast Zone, I have observed that little or nothing is known about the end-of-life issues of the material in Imo State and beyond. If nothing is known about the material, how can it be discussed? It is not just possible. It is not too late to start educating the people on the end-of-life issues of the material. The state has no cultural or religious belief that can work against the application of the material in a novel context.

Regulatory Framework

As a staff of the Federal Ministry of Environment, I am aware that we do not have laws that apply specifically to waste chicken feathers because the material has always been generally classified as waste. So, the laws that apply to it are general environmental laws that were enacted to ensure safe and cleaner environment. I am also aware that the Imo State Ministry of Environment is yet to enact such laws.

Economic Viability

Under processing technology, I stated that technologies exist in the state to convert waste feathers into feather fans, masks, costume accessories, bird ornaments and even ear ring and flowers. One obvious conclusion one can make from this is that the material has economic value. It can be sold to generate income. I have also observed that the material is highly abundant in the state and can be harnessed into useful applications. Only a small proportion of the waste material is deployed into other uses as mentioned in this section.

11.7. Approval Letters for Research

11.7.1.Field Trial Approval Letter

RESEARCH, DEVELOPMENT AND PUBLICATION COMMITTEE
FACULTY OF ENGINEERING,
RIVERS STATE UNIVERSITY
PORT HARCOURT

Ref: RSU/FE/2021/Vol. I/06 7th July 2021

Engr. (Mrs.) Kaine Bene Chinwah
Department of Civil and Environmental Engineering
Imperial College London
South Kensington Campus,
London SW7 2AZ

Dear Engr. Kaine Chinwah,

APPROVAL FOR FIELD TRIAL FOR OIL SORPTION PERFORMANCE OF CHICKEN FEATHER PILLOW

Please refer to your application on the above subject dated 5th June 2021. As a collaborating University on your research work titled "Oil Spill Remediation using Waste Chicken Feathers as a Natural Sorbents" with the Civil/Environmental Engineering Department, Imperial College London, you have been approved for a field trial.

This is based on your fulfillment of risk assessment requirements for field work approval.

Engr Prof. J. G. Akpa
(Dean of Engineering Faculty)

Engr Prof (Mrs.) F.T. Ademiluyi
(Chairman RD and P)

11.7.2. Ethical Approval Letter

RESEARCH, DEVELOPMENT AND PUBLICATION COMMITTEE
FACULTY OF ENGINEERING,
RIVERS STATE UNIVERSITY
PORT HARCOURT

Ref: RSU/FE/2022/Vol. I/06 10th May,2022

Engr. (Mrs.) Kaine Bene Chinwah
Department of Civil and Environmental Engineering
Imperial College London
South Kensington Campus,
London SW7 2AZ

Dear Engr. Kaine Chinwah,

ETHICAL APPROVAL FOR RESEARCH STUDY

Please refer to your application on the above subject dated 5th March 2022. As a collaborating University on your research work titled "Oil Spill Remediation using Waste Chicken Feathers as a Natural Sorbents" with the Civil/Environmental Engineering Department, Imperial College London, you have been granted approval for research on human participants by the research ethics committee in the faculty.

This is based on your fulfillment of requirements for full unconditional ethical approval.

Engr Prof. J. G. Akpa
(Dean of Engineering Faculty)

Engr Prof (Mrs.) F. T. Ademiluyi
(Chairman RD and P)