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Preface

On behalf of the Jabatan Kejuruteraan Petrokimia, Politeknik Kuching Sarawak. I want to express my sincere gratitude to all the DGP50242: Project 2 final-year students in the year 2024/2025, who completed and successfully presented their project findings at the Green Technology & Petrochemical Engineering Mini Conference Volume 2, 2024. The Journal of Petrochemical Engineering was broadly based on each selected publication, and, again, those subjects are related to the general subjects of petrochemical products, either directly or indirectly. Finally, the editorial teams would like to thank and acknowledge all the reviewers and supervisors assigned to this technical journal writing.

Dr Muhamad Nazri Abu Shah
Chief Editor
Journal of Petrochemical Engineering
Jabatan Kejuruteraan Petrokimia
Politeknik Kuching Sarawak

Abstract

This volume contains the technical writing of the final year project, which was participated in and presented their work in the Green Technology & Petrochemical Engineering Mini Conference Volume 2, 2024, which was organized by Unit Projek Pelajar and co-organized by the UPIK and Projek Pelajar, Jabatan Kejuruteraan Petrokimia, Politeknik Kuching Sarawak. The technical writing theme was centered on the field of Petrochemical Engineering, which is required by the course requirements for DGP50242. The Journal of Petrochemical Engineering's main goal is to provide a platform for final-year students, lecturers, and researchers at the Department of Petrochemical Engineering, Politeknik Kuching Sarawak to contribute and share their knowledge, information, new ideas, and experience in person with their peers for anticipated research and innovation in the Petrochemical Engineering field. This platform will help the participants, especially final-year students and lecturers, establish their technical research papers. We hope that the Journal of Petrochemical Engineering outcomes will result in significant contributions to the knowledge base and research exposure in related fields.

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THE DEVELOPMENT OF EFFICIENT MINI HYDROGEN

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ABSTRACT

Hydrogen generators, especially those using hybrid renewable energy systems, face design challenges due to the integration of various energy sources and complex storage requirements. Although hydrogen is a clean energy alternative, production remains costly and energy-intensive, limiting its economic viability. The current hydrogen infrastructure relies on existing technologies, and expanding production capacities while lowering costs could encourage broader adoption. As fossil fuels decline and costs rise, hydrogen's potential as a sustainable alternative grows, though challenges in production and storage need addressing. An affordable, continuous, small-scale hydrogen generator could be an effective solution. The construction of an effective Mini-Hydrogen Generator is examined in this article. By researching materials and using stainless-steel electrodes because of their low cost and corrosion resistance, the project seeks to develop an economical and effective design. Journal reviews, laboratory testing, and quantitative analysis were all used in the data collection process. According to the results, certain materials and chemical combinations are essential for producing hydrogen efficiently. The report's recommendations for automotive and educational applications encourage students and community members to have firsthand knowledge of hydrogen production. The efficiency of hydrogen production in water electrolysis was investigated using several important techniques. This involved doing statistical analysis to evaluate hydrogen generation rates, establishing controlled experimental conditions, and examining the manufacture of electrode materials. In an inverted bottle immersed in water, gas generation displaced water, allowing gases to be collected using the water displacement method. Also, the "pop test" was employed to verify if hydrogen was present. By guaranteeing precise measurements and reproducible outcomes, these techniques offered insightful information for enhancing hydrogen production in subsequent studies. This study concludes that water electrolysis using stainless steel electrodes is an efficient and economical method of producing hydrogen. A good option for producing hydrogen sustainably was the use of stainless steel, which is renowned for being inexpensive and non-corrosive. The findings show that hydrogen generation rates can be significantly increased by altering the sodium hydroxide content and optimizing the electrode configuration. A two-rod electrode configuration is especially successful in increasing current flow and lowering resistance, which helps produce hydrogen more reliably.

Key words: *Hydrogen, mini hydrogen generator, stainless steel, non-corrosive, pop test*

1.0 INTRODUCTION

Hydrogen is widely recognized as a clean and sustainable energy source with immense potential to replace fossil fuels in various applications. As global energy demands continue to rise and concerns about climate change intensify, hydrogen production methods have gained significant attention. Among these methods, electrolysis stands out as an efficient way to generate high-purity hydrogen by splitting water molecules using electricity. However, the widespread adoption of hydrogen as an alternative energy source is hindered by challenges such as high production costs, energy-intensive processes, and complex storage requirements [1], [2].

This study focuses on developing an efficient mini hydrogen generator to address these challenges and enhance the feasibility of small-scale hydrogen production. Electrolysis offers a promising approach, particularly when combined with optimized electrode materials and configurations to improve efficiency while maintaining cost-effectiveness. By analyzing different electrode materials (stainless steel, copper, and brass), electrode configurations (parallel, stacked washer, and two-rod arrangements), and varying concentrations of sodium hydroxide (NaOH) as an electrolyte, this study aims to determine the most efficient combination for hydrogen generation.

While hydrogen is a clean energy alternative, current hydrogen generators, especially those integrating hybrid renewable energy systems, present significant design challenges. The production of hydrogen via electrolysis remains costly and energy-intensive, limiting its widespread adoption [3], [4]. Furthermore, storage and handling complexities add to the economic and safety concerns associated with hydrogen energy systems [5]. With fossil fuel resources declining and fuel prices continuing to rise, there is an urgent need for an efficient, affordable, and continuous small-scale hydrogen generator that eliminates the need for large-scale storage [6].

This study focuses on optimizing a mini hydrogen generator by evaluating electrode materials, electrode configurations, and electrolyte concentration. Stainless steel, copper, and brass will be tested to determine the most efficient material for hydrogen production, as electrode properties significantly impact conductivity and durability [7]. Different electrode arrangements, including parallel, stacked washer, and two-rod configurations, will be analyzed to identify the most effective setup for maximizing gas output while maintaining energy efficiency [8]. Additionally, the impact of varying sodium hydroxide (NaOH) concentrations (4g, 12g, and 20g) on hydrogen generation will be examined, as electrolyte concentration plays a crucial role in enhancing ionic conductivity and reaction stability [9]. The findings aim to develop a cost-effective and practical hydrogen generator for small-scale applications.

By systematically addressing these factors, this study seeks to contribute to the development of a cost-effective and practical mini hydrogen generator that can be applied in educational and small-scale industrial settings. The findings will not only enhance understanding of electrolysis efficiency but also support the transition toward sustainable hydrogen-based energy solutions. Thus, the main goal of this project is to design an efficient Mini Hydrogen Generator, and the specific objectives of this work are to study the different masses of sodium hydroxide in hydrogen processing, electrode arrangements design, time taken for hydrogen production

2.0 SUMMARY LITERATURE REVIEW

Table 1: Summary of Important keys in this work

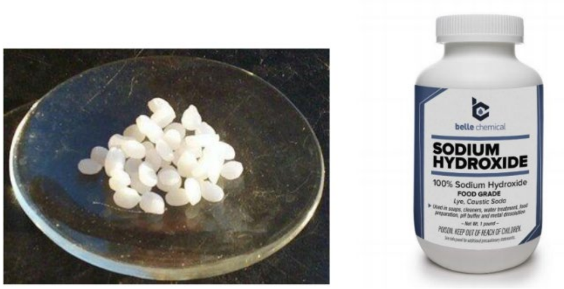
Author & Year	**Key Findings**	**Discussion & Relevance to This Study**
El-Shafie et al. (2023) [10]	Electrolysis is an efficient method for hydrogen production but requires cost optimization.	This study emphasizes the need to improve efficiency while reducing operational costs. Our research addresses this by testing different electrode materials and configurations to enhance hydrogen yield with minimal energy consumption.
Shams Anwar (2021) [11]	Electrode materials significantly impact hydrogen production rates; high-conductivity materials improve efficiency.	The selection of stainless steel, copper, and brass in our study aligns with this finding. Testing these materials will determine the most effective option for optimizing hydrogen generation.
Terlouw et al. (2022) [13]	Scaling up electrolysis for industrial applications remains a challenge due to high costs and infrastructure requirements.	This highlights the importance of small-scale hydrogen generators, like the one we are developing, which could serve as a practical and cost-effective alternative.
A.Z. Arsad et al. (2023) [9]	Increasing NaOH concentration enhances conductivity and hydrogen yield, but excessive concentration leads to energy losses.	This supports our investigation into the effects of varying NaOH concentrations (4g, 12g, 20g) to balance conductivity and efficiency without excessive power consumption.
U.S. Department of Energy (2024) [5]	Hydrogen storage requires specialized methods due to its flammability and low energy density per volume.	Instead of large-scale storage, our research focuses on an on-demand hydrogen generator, reducing the need for complex storage solutions.
Wang et al. (2021) [14]	Hydrogen fuel cells provide clean energy but require improved infrastructure for widespread adoption.	Our study contributes by developing an efficient mini hydrogen generator that can support small-scale applications in education and research.
Reinmold & Lühken (2023) [12]	The pop test is a reliable method for confirming the presence of hydrogen gas.	Our study adopts the pop test to verify hydrogen production, ensuring accurate experimental validation.
Till (2024) [15]	The pop test is an effective method for confirming the presence of hydrogen gas by igniting a small gas sample in a test tube.	Our study adopts the pop test as a verification method to ensure the successful production of hydrogen gas during electrolysis.

3.0 METHODOLOGY

3.1 Materials

These are the materials used in this project to develop an efficient mini hydrogen generator, as tabulated in Table 2. The selected materials were essential in ensuring the success of the electrolysis process and hydrogen production.

Table 2: Materials and Tools are used in this work

Reverse Osmosis Water 	12v Motorcycle Battery 
12v Motorcyle Battery 	Metal electrode 
Syringe Needle 	Jumper Wire And Alligator Clip 
Glass Jar 	Sodium Hydroxide 

3.2 Preparation Techniques

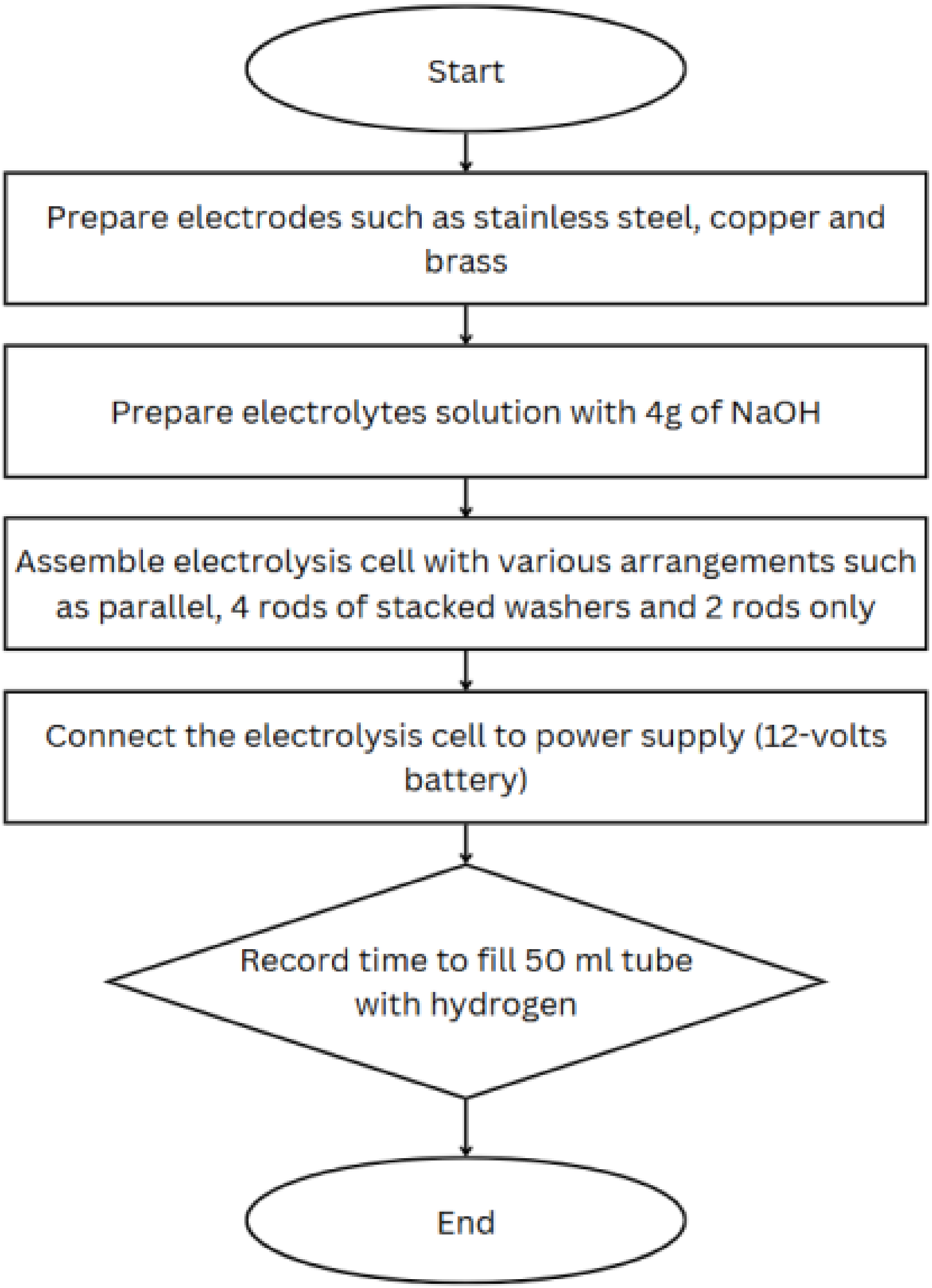


Figure 1 Flowchart of hydrogen production in this work

3.3 Characterization

The characterization of products in this project focused on evaluating the efficiency of hydrogen production through electrolysis. Various tests and observations were conducted to analyze the effectiveness of different electrode materials, electrode configurations, and sodium hydroxide (NaOH) concentrations.

One of the primary characterization methods was the water displacement method, where the volume of displaced water indicated the amount of hydrogen gas produced, allowing for a qualitative assessment of hydrogen generation efficiency [16]. Additionally, the pop test confirmed the presence of hydrogen gas, as a distinct “pop” sound was observed when a flame was introduced near the collected gas.

The performance of different electrode materials—stainless steel, copper, and brass—was evaluated by observing the rate and intensity of bubble formation during electrolysis. Stainless steel demonstrated the best performance due to its high conductivity and non-corrosive properties [17]. Furthermore, different electrode configurations (parallel, stacked washer, and two-rod arrangements) were tested to determine their impact on hydrogen generation. The two-rod arrangement exhibited the highest efficiency, producing the most hydrogen with minimal resistance [18].

The effect of NaOH concentration on electrolysis efficiency was also examined. Higher NaOH concentrations improved conductivity, leading to increased hydrogen production. However, excessively high concentrations caused excessive heating and instability, requiring careful optimization [19].

Through these characterization techniques, this study identified the most effective combination of electrode material, arrangement, and electrolyte concentration for efficient and cost-effective hydrogen production. The findings provide valuable insights into optimizing small-scale hydrogen generators for future applications.

4.0 RESULT & DISCUSSION

4.1 Effect of Electrode Material on Hydrogen Production

The experiment compared stainless steel, copper, and brass as electrode materials to determine their efficiency in electrolysis. Observation is recorded in Table 3

Table 3: Observation and time taken for 50 ml of hydrogen gas production

Type of material	Observation	Time taken (min)
Stainless steel	Fast reaction with many gas bubbles produced	26:03
Copper	Fast reaction with gas bubbles produced vigorously	25:53
Brass	Moderate reaction with gas bubbles produced moderately	41:30

These results indicate that stainless steel is the most suitable electrode material for a mini hydrogen generator due to its durability, conductivity, and non-corrosive properties. According to Lathifa Putri Afisna et al. (2024), copper electrodes produced higher hydrogen gas pressure than stainless steel electrodes during electrolysis. However, the study did not explore long-term performance or material degradation. In contrast, stainless steel is widely recognized for its corrosion resistance and stable conductivity over time, making it a more practical choice for long-term hydrogen generation systems despite copper’s higher short-term output.[20], [23].

4.2 Effect of Sodium Hydroxide (NaOH) Concentration

The effect of varying NaOH concentrations (4g, 12g, 20g) on hydrogen production was tested using stainless steel, copper, and brass electrodes. The results, shown in Table 3, indicate that hydrogen production time increased with NaOH concentrations.

Table 3: Hydrogen production time with different masses of Sodium Hydroxide

Electrode materials	Mass of NaOH (g)	Time taken (min)
Stainless steel	4	7:49
	12	16:15
	20	25:76
Copper	4	8:00
	12	16:66
	20	26:30
Brass	4	16:56
	12	25:22
	20	34:86

The optimal performance occurred at 12g NaOH, where the balance between conductivity and stability was best achieved. Higher concentrations, 20g resulted in longer production times, likely due to increased solution viscosity and heat generation, which reduced efficiency.

The results show that NaOH concentration significantly impacts electrolysis efficiency. While higher concentrations, 20g, increased hydrogen production time, 12g NaOH provided the best results by optimizing conductivity without excessive heat or instability. The finding aligns with Diah Iswandari et al. (2022), who emphasized the importance of maintaining an optimal NaOH concentration.[21] as well as additional studies demonstrating that optimal NaOH levels enhance performance without increasing energy consumption [24],[25]. Therefore, 12g NaOH is recommended for efficient hydrogen production in future experiments or applications.

4.3 Effect of Electrode Arrangement on Hydrogen Production

Three different electrode arrangements were tested to analyze their impact on hydrogen production. The observations, efficiency, and ease of setup for each arrangement are summarized in Table 4.

Table 4 Observation of electrode arrangements to produce hydrogen

Electrode arrangement	Hydrogen Production Observation (Qualitative)	Efficiency	Ease of setup
Parallel	Moderate and steady gas bubbles	Moderate	Complex and takes a lot of space
4 rods of stacked washers	Very strong gas bubbles at first, but it gets slower over time	High, but requires more power	Complex, takes a lot of space
2 rods only	Strong and steady bubbles from each rod	High	Easy to set up, surprisingly efficient despite less surface area

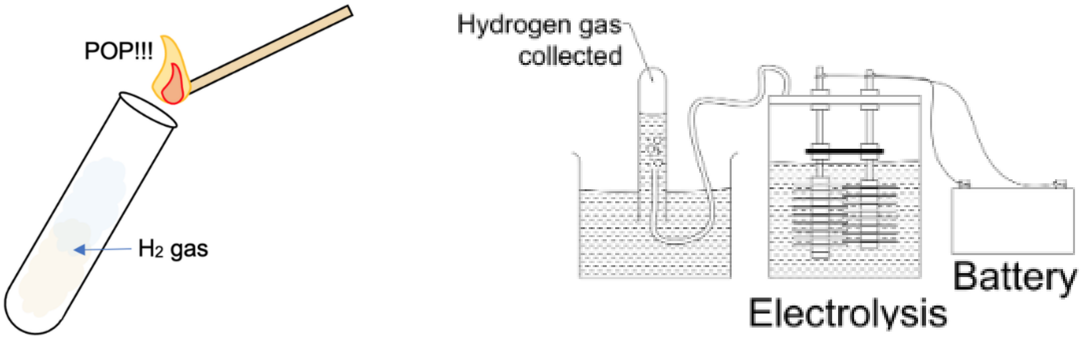
Based on observations, the 2-rods only arrangement demonstrated the highest efficiency, producing strong and steady hydrogen bubbles from each rod. Despite having a smaller surface area, this setup showed minimal resistance and was surprisingly effective. It was also the easiest to set up compared to the more complex parallel and 4-rod stacked washer arrangements.

The parallel arrangement produced moderate and steady gas bubbles but had moderate efficiency and was cumbersome to set up due to its large spatial requirements. Similarly, the 4 rods of stacked washer arrangement initially produced very strong bubbles, but the gas production slowed over time. This arrangement showed the highest efficiency in the beginning, though it required more power and was also space-intensive.

In conclusion, the 2-rods only configuration proved to be the most efficient and practical choice for hydrogen production. It offered high performance with minimal setup complexity and power requirements, reflecting the optimized configurations in industrial applications that balance efficiency with ease of setup [26], [27], [28].

4.4 Confirmation of Hydrogen Gas

To confirm the presence of hydrogen gas, the pop test was conducted. When a flame was introduced near the collected gas, a distinct “pop” sound was heard, confirming successful hydrogen production. Other than that, the water displacement method also demonstrated effective gas collection.[22].



Pop Test Method

Water Displacement method

Figure 2 Pop test method and water displacement method

In addition to the pop test, the water displacement method was used to collect and quantify the produced gas. By directing the hydrogen gas into an inverted test tube submerged in water, the gas displaced the water inside the test tube. This allowed for the measurement of the gas volume, effectively confirming its production.

The results from both methods provided clear confirmation of hydrogen gas generation. The pop test confirmed its presence through distinctive sound, while the water displacement method allowed for quantification of the hydrogen produced.

In conclusion, the experimental setup using stainless steel electrodes, a 2-rod arrangement, and 12g of NaOH resulted in the best conditions for small-scale hydrogen production. The efficiency of electrolysis was found to depend on optimizing electrode material, configuration, and electrolyte concentration to balance conductivity, reaction stability, and gas output.

These findings suggest that a mini hydrogen generator could be developed as a cost-effective and practical solution for small-scale applications, such as educational demonstrations or alternative fuel sources. Future improvements may include testing various electrode coatings, exploring alternative power sources, and investigating better storage methods to further enhance the efficiency and practicality of the system.

5.0 CONCLUSION

This study focuses on the development and evaluation of a hydrogen production system using electrolysis. The primary objective is to investigate the influence of different electrode materials and NaOH concentrations on hydrogen generation efficiency. Various materials, including stainless steel, copper, and brass, were tested to determine their effectiveness in optimizing hydrogen production. Additionally, the study explores the effect of NaOH concentration variations to enhance the conductivity of the electrolyte solution while maintaining energy efficiency. The pop test was employed to verify the presence of hydrogen gas, ensuring experimental reliability.

The purpose of this study was to develop a mini hydrogen generator capable of producing hydrogen efficiently on a small scale. The project aimed to explore the effectiveness of suitable electrode selection and the use of NaOH as an electrolyte to enhance hydrogen production. By demonstrating a simple and low-risk method of generating hydrogen, this study supports further research and development into small-scale hydrogen generation, especially as a preliminary step for industries or institutions exploring hydrogen as an alternative energy source.

For future research, it is recommended to explore alternative electrode materials such as platinum or nickel to enhance efficiency and investigate the impact of different electrolytes, like KOH or H_2SO_4, on hydrogen production rates. Additionally, a detailed study on energy consumption should be conducted to improve cost-effectiveness. The feasibility of scaling up the hydrogen generator for industrial applications should also be evaluated, along with advanced hydrogen storage methods and safety protocols for long-term applications. By addressing these aspects, future studies can contribute to the advancement of hydrogen technology, making it a more viable and efficient energy source.

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Thanks to Allah SWT because with His abundant grace, we managed to complete this project successfully.

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THE MAKING OF PANDAN PERFUME USING EXTRACTION AND EVAPORATION METHODS

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ABSTRACT

This study investigates the extraction and evaporation processes used in the production of pandan perfume. Pandan leaves (Pandanus amaryllifolius) possess a unique and appealing fragrance, which makes them an ideal candidate for perfume creation. The objective of this research is to explore sustainable methods for extracting and concentrating the aromatic compounds from pandan leaves to produce a natural pandan-scented perfume. The problem addressed by this study is the challenge of creating an eco-friendly, cost-efficient perfume that can retain the pandan fragrance without the use of synthetic chemicals, which often affect the longevity and quality of the scent. The scope of this project focuses on optimizing extraction parameters such as solvent type, extraction duration, and temperature to maximize fragrance yield and quality. The solvent extraction method, followed by evaporation using a rotary evaporator, is employed to obtain pandan essence. Analytical procedures are conducted to assess the chemical composition and quality of the extracted pandan EDP solution. The methodology involved the use of Soxhlet extraction and rotary evaporation techniques, which were tested and optimized for the most efficient extraction process. Various extraction parameters were altered, including solvent selection and extraction time, to determine the optimal conditions for producing a high-quality pandan essence. The evaporation process aimed to remove the solvent and enhance the fragrance profile. The findings of this work show that the pandan perfume produced through this process closely resembles the natural aroma of pandan leaves, while meeting consumer preferences for plant-inspired scents. The results also showed that despite the absence of synthetic fixatives, the perfume's scent could be sustained for a reasonable period, though further research is needed to address challenges related to scent longevity. In conclusion, this study demonstrates the feasibility of using natural pandan extracts to create an eco-friendly perfume. It highlights the potential for sustainable fragrance products that appeal to environmentally conscious consumers. The research contributes to the growing demand for green and natural fragrance products and suggests areas for future exploration, particularly in improving the longevity of the fragrance and expanding its applications in the perfume industry.

Keywords: *Pandan perfume, extraction process, Soxhlet extraction, rotary evaporation, pandan leaves*

1.0 INTRODUCTION

This project aims to develop a natural perfume infused with the fragrance of pandan (Pandanus amaryllifolius), utilizing environmentally friendly extraction techniques. Known for its distinctive aroma, pandan leaves are cherished for their fresh, mild, and slightly sweet scent. The study focuses on isolating aromatic compounds from pandan leaves through Soxhlet extraction, followed by using a rotary evaporator to concentrate these compounds into a pure pandan essence. The objective is to create a cost-effective, small-scale production of pandan perfume that excludes synthetic chemicals. By avoiding artificial additives, the project seeks to deliver a natural fragrance that reduces health risks and minimizes environmental impact, while maintaining high product quality and safety.

The study involves synthesizing and characterizing the produced pandan perfume, with particular emphasis on its effects on skin, its interaction with clothing, as well as its chemical composition. Characterization techniques include FTIR analysis, pH testing, and skin and fabric interaction studies. The specific objectives of this research are:

1. To produce pandan perfume using the extraction and evaporation methods.
2. To evaluate the effects of pandan-scented perfume on skin, cloth material and test its longevity.
3. To analyse the composition of the pandan perfume using FTIR.

1.1 Project Scope

The pandan leaves used in this project will be gathered from the surrounding areas of Politeknik Kuching, Sarawak, before being brought into the laboratory for further processing. In the lab, the leaves will undergo extraction using the Soxhlet method, with ethanol serving as the solvent to efficiently isolate the aromatic compounds. After extraction, the resulting pandan essence will be placed in a rotary evaporator to remove any remaining ethanol, yielding a pure pandan leaf extract. This extract will then be combined with other components or solutions to create the final pandan perfume.

1.2 Significance of the study

This study offers a safe and eco-friendly alternative to synthetic perfumes by developing a natural pandan-based fragrance. By excluding harmful chemicals known to cause skin irritation, burns, stains, and discoloration, the product is healthier and more practical for users. Furthermore, the research promotes sustainable production methods and provides valuable insights into the development of natural fragrances. It aligns with the increasing demand for safe, environmentally conscious cosmetic products and contributes to the growing trend of sustainable and green beauty solutions.

2.0 LITERATURE REVIEW

Soxhlet extraction is a widely used method for extracting substances from solid materials. Since its invention in 1879, it has remained a cornerstone technique in analytical laboratories. Despite being over a century old, it continues to serve as a benchmark for modern extraction methods. Researchers have made various modifications to the Soxhlet extraction process to improve efficiency, reduce extraction times, and minimize solvent use. These advancements include automated Soxhlet extraction and techniques utilizing auxiliary energies, such as microwaves and ultrasound. This section explores these innovations, outlining their principles, equipment, and practical applications in enhancing Soxhlet extraction. The Soxhlet extraction tools is illustrated in Figure 1.

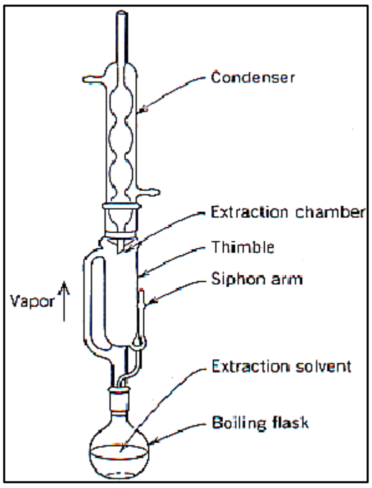


Figure 1: Soxhlet Extraction

This study examines how different extraction methods and solvents influence the yield, total phenolic content (TPC), and antimicrobial activity of aniseed extracts. Water-based Soxhlet extraction (SE) yielded the highest total content, but ultrasonic-assisted extraction (UAE) with diethyl ether or ethanol showed potential. Despite water-based extracts having high TPC, they exhibited low antimicrobial activity and phytochemical content. In contrast, ethanol extracts demonstrated the highest antimicrobial activity, which is potentially linked to the presence of petroselinic acid. This research suggests that ethanol is an effective solvent for extracting compounds with antimicrobial potential, especially for food industry applications. Besides, the production of ethanol is also achieved from the reaction of ethylene and water as presented in Figure 2. However, further studies are required to explore the toxicity of aniseed extracts and assess the potential of solvent mixtures to optimize extraction yields.

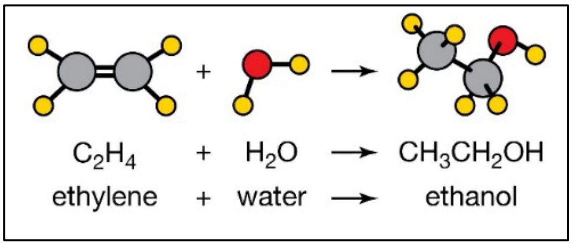


Figure 2: Production of Ethanol

Rotary evaporation, often referred to as "rotovap," is a key technique in organic chemistry used for the separation of solvents from compounds with higher boiling points. Developed by chemist Lyman C. Craig in 1950, this method revolutionized sample preparation processes. The primary function of rotary evaporation is to facilitate the drying and purification of samples, making them suitable for downstream applications. Its speed, efficiency, and capacity to handle large volumes of solvent have made it a widely adopted method in laboratories. Rotary evaporation is especially advantageous when dealing with substances that have low boiling points, and it plays a crucial role in organic synthesis and chemical research, enhancing the efficiency and productivity of scientific endeavors. The illustrated rotary evaporator is portrayed in Figure 3

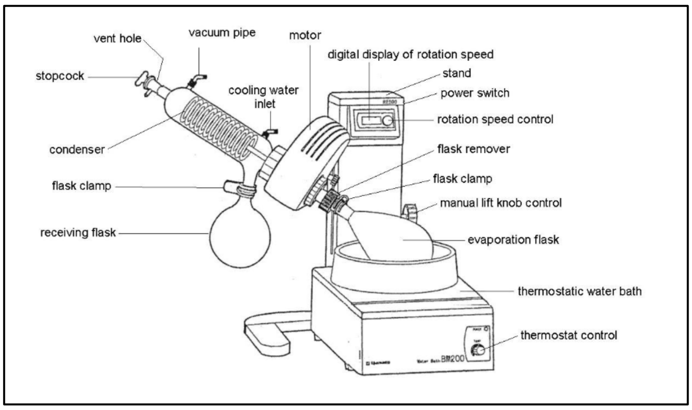


Figure 3: Rotary Evaporator

Synthetic fragrances are now common in many commercial products; however, research indicates that 95% of the chemicals in these fragrances are derived from crude oil, containing harmful compounds such as benzene, aldehydes, and toluene. These chemicals are linked to serious health issues, including cancer, birth defects, allergies, and nervous system disorders. The presence of such substances in everyday products can contribute to long-term health risks, underscoring the importance of exploring natural fragrance alternatives that do not pose these dangers.

Perfumes that contain fragrance oils, alcohol, or dyes have been known to cause stains on clothing when applied directly, as presented in Picture 1. These stains can darken over time, appearing as oily spots, particularly on bright fabrics. Darker-colored perfumes are more likely to cause staining, although it can be difficult to predict which perfumes will stain. This highlights the need for natural alternatives that avoid synthetic dyes and other potentially harmful ingredients, reducing the likelihood of staining and other undesirable effects.

Picture 1: Staining on fabric caused by a perfume

3.0 METHODOLOGY

In this section, the methodology employed in the production of pandan leaf perfume at Politeknik Kuching is elaborated, which comprises four main stages: collecting pandan leaves around the campus, conducting Soxhlet extraction to extract the essence from the pandan leaves, utilizing a rotary evaporator to separate the solution of pandan extract, and finally, employing preservation techniques to enhance and maintain the unique notes and essence of the perfume.

Figure 4: Materials and equipment for this work

The materials and equipment are illustrated in Figure 4, such as used including a rotary evaporator, Soxhlet extraction apparatus, pandan leaves, ethanol, and EDP solution.

3.1 Preparation techniques

The process begins with the collection of pandan leaves from the surroundings of Politeknik Kuching, where the leaves are carefully selected for their optimal aroma and quality. Only the best leaves, exhibiting the most fragrant and fresh characteristics, are chosen for extraction. The selected leaves are then cut into small pieces. This step is crucial as it prepares the pandan leaves for optimal fragrance extraction, ensuring that each batch of perfume maintains consistency and high quality.

Once the leaves are gathered, the extraction process takes place in the laboratory using the Soxhlet extraction method. The pandan leaves are placed into a specialized extraction apparatus, where they are repeatedly exposed to ethanol, the solvent chosen for its ability to effectively dissolve and extract the solid compounds present in the leaves. A solution of approximately 200 ml of ethanol is used for this process. Over time, the aromatic compounds in the pandan leaves are gradually dissolved into the solvent, resulting in the extraction of the pandan leaf essence.

After the extraction process, the solution containing the pandan leaf extract is further refined using a rotary evaporator. This equipment plays a vital role in separating the pandan extract from the ethanol solvent. The rotary evaporator operates under controlled conditions, applying gentle heat to the solution, which evaporates the ethanol and water, leaving behind a concentrated and pure pandan leaf essence. This process ensures that the final perfume is free from any residual solvents or impurities, resulting in a fragrance of high quality.

In the final stage, preservation techniques are applied to enhance and preserve the unique notes and essence of the perfume. The pandan leaf essence is carefully blended with ethanol, water, and an EDP solution. The EDP solution is selected specifically for its ability to prolong the fragrance's longevity, ensuring the perfume retains its pleasant aroma over time. The mixture is then divided into two jars for marination, each containing a different concentration of EDP solution. Jar 1 contains 15ml of EDP solution, while Jar 2 contains 30ml, with both jars containing equal amounts of pandan essence and water. The varying concentrations of EDP solution allow for the development of different fragrance profiles, offering options for the final perfume. The jars are carefully sealed, and the mixture is left to mature. Over time, the fragrance evolves and strengthens, and the preservation process ensures that the perfume maintains its authentic pandan aroma, providing a long-lasting and captivating scent.

4.0 RESULT & DISCUSSION

4.1 Effect on skin

Fifteen classmates will serve as primary respondents to evaluate the pandan perfume. They will complete a Google Form designed to gather structured feedback on their experience with the product. The form will ask respondents to indicate any reactions they experienced after using the perfume, such as burning, irritation, or no effect. In addition, the form will include options for respondents to note any other relevant effects, ensuring that a comprehensive range of responses is captured.

The feedback collected will provide insights into the safety and user experience of the perfume. By analysing the responses, the study will assess whether the perfume causes any adverse reactions, such as skin irritation or discomfort. Positive feedback will also help evaluate how well the perfume is received in terms of its scent and overall performance, as presented in Figure 5. This will give a clearer understanding of the perfume’s market potential and user acceptability.

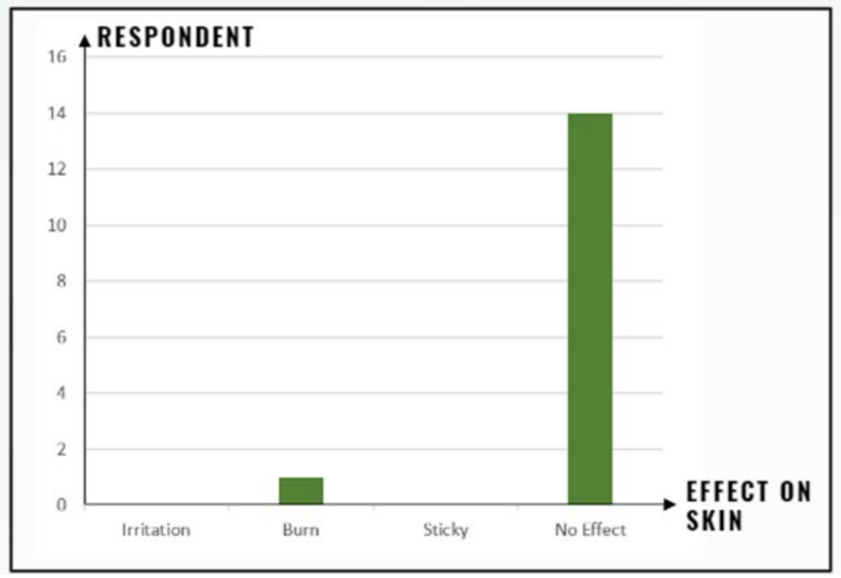


Figure 5: User feedback on the effect on skin after using pandan fragrance.

4.2 Long-lasting effect

Fifteen classmates will be invited to participate as respondents to provide feedback on the longevity of two different fragrance samples, each containing a unique proportion of Eau de Parfum (EDP) solution. Using a Google Form, each respondent will rate the fragrance duration for each sample, with the options ranging from 1 to 5 hours. The result of the long-lasting effect from 15 respondents is presented in Figure 6. The feedback will allow for a comparison between the two samples, helping to determine how the varying EDP concentrations affect the fragrance's lasting power. This analysis will provide valuable insights that can guide the formulation's refinement, aiming to optimize the perfume's longevity.

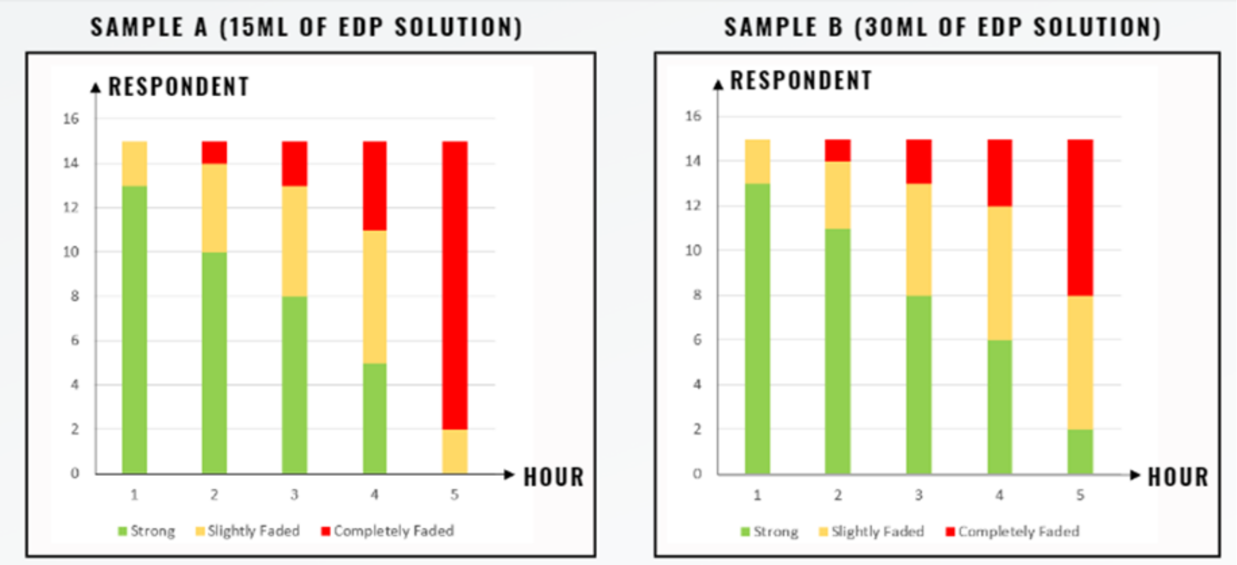


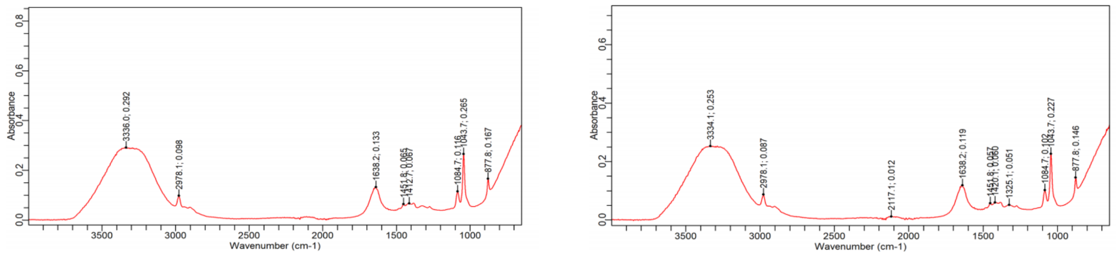
Figure 6: The results from 15 respondents for each sample

4.3 FTIR Analysis

The final pandan perfume samples were sent to "Craun's Research" for FTIR (Fourier Transform Infrared) analysis to examine the chemical composition. Two samples were submitted:

1. **Sample A**: 20ml of pandan essence, 75ml of water, 50ml of ethanol, and 15ml of EDP solution.
2. **Sample B**: 20ml of pandan essence, 75ml of water, 35ml of ethanol, and 30ml of EDP solution.

FTIR analysis helps identify the molecular components of each sample, focusing on how the varying ethanol and EDP concentrations affect the aromatic profile of the pandan essence. The resulting spectra as presented in Figure 7, show that the samples can be detected, the functional group may significantly affect the fragrance intensity and longevity, providing valuable insights into the best formulation for optimal fragrance quality.



Peak Number	Wavenumber (cm^{-1})	Intensity
1	877.8	0.167
2	1043.7	0.265
3	1084.7	0.116
4	1412.7	0.067
5	1451.8	0.065
6	1638.2	0.133
7	2978.1	0.098
8	3336.0	0.292

Sample A

Peak Number	Wavenumber (cm^{-1})	Intensity
1	877.8	0.146
2	1043.7	0.227
3	1084.7	0.102
4	1325.1	0.051
5	1420.1	0.060
6	1451.8	0.057
7	1638.2	0.119
8	2117.1	0.012
9	2978.1	0.087
10	3334.1	0.253

Sample B

Figure 7: Comparison of FTIR spectrum and wavelength table results between Sample A and B

4.4 Effect on cloth

The effect of cloth on the color mark by sample A and B is tabulated in Table 2. After three days, jersey and cotton garments perfumed with pandan-scented Eau de Parfum (EDP) showed stains but no discoloration, which probably means that the oils in the perfume had seeped into the fabric without changing its color. Because of their absorbency, these textiles may retain aroma oils, leaving behind residue or stains without obvious discoloration. The EDP's oils might not completely dissipate, leaving behind a faint stain that isn't pigment-based. This effect may be influenced by elements like as the oil concentration in the scent and the porosity of the cloth. It's best to test materials and apply perfume to the skin in advance to avoid this.

Table 1: Results of the effect of cloth on the color mark by samples A and B

	Sample A			Sample B		
Day	Effect	Type of Cloth		Effect	Type of Cloth	
		Jersey	Cotton		Jersey	Cotton
1	Discoloration	X	X	Discoloration	X	X
	Stains	X	X	Stains	X	X
2	Discoloration	X	X	Discoloration	X	X
	Stains	X	X	Stains	X	X
3	Discoloration	X	X	Discoloration	X	X
	Stains	/	/	Stains	/	/

4.5 pH value

After 4 weeks, the pH values of sample A (6.96) and sample B (6.04) from pandan-scented Eau de Parfum (EDP), as presented in Figure 8, indicate slight acidity, typical for perfumes. Sample A's pH of 6.96 is closer to neutral, suggesting that it is relatively stable or has maintained its formulation well. Sample B, with a pH of 6.04, is slightly more acidic, possibly due to minor chemical changes or evaporation of alcohol over time. Both pH levels are within the acceptable range for perfumes (4-7), but the difference may reflect slight variations in ingredient composition, stability, or interaction over the weeks.

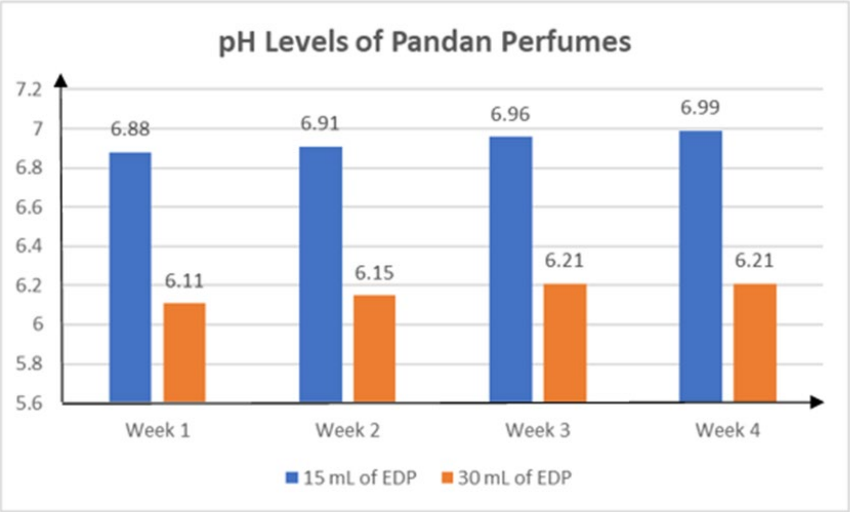


Figure 8: pH level of Pandan perfumes over time.

5.0 CONCLUSION

The results obtained from the analysis of the pandan perfume samples indicate that the project successfully developed a natural perfume using pandan essence and eco-friendly ingredients. The formulation effectively addresses health and environmental concerns by incorporating water, which minimizes staining and discoloration, making the perfume suitable for practical daily use. While the product meets the demand for eco-friendly and natural products, maintaining scent longevity without synthetic fixatives remains a challenge.

Although the objectives of creating a natural, sustainable pandan perfume were achieved, further research and development are necessary to enhance fragrance longevity while preserving the natural integrity of the formula. To improve longevity, other natural materials, such as resins (e.g., benzoin or frankincense), plant-based fixatives (like orris root or ambergris alternatives), and essential oils with longer-lasting scents (such as sandalwood or patchouli), could be explored. These ingredients may help to extend the fragrance's retention without compromising its eco-friendly nature. The insights gathered in this project provide a foundation for future work to refine the formulation, optimize scent retention, and ensure the perfume’s longevity while maintaining its natural and sustainable qualities.

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POLYMER CERAMIC MEMBRANE FOR THE PHOTOCATALYTIC TREATMENT OF OIL REMOVAL

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ABSTRACT

This study examined the effectiveness of a photocatalytic membrane reactor (PMR) for oil removal from water under conditions of ceramic to polymer material ratio, bed height, and distance of UV light source; it was found that higher polymer ratios and bed height increased oil removal while higher UV intensity distance decreased efficiency through lower photocatalytic activity, highlighting the importance of membrane composition optimization, filtration, and UV exposure to achieve effective oil-water separation. The PMRs mechanism involves membrane filtration and photocatalytic degradation, with oil being separated by the membrane while photocatalysis breaks down contaminants under UV irradiation.

Keywords: Photocatalytic membrane reactors (PMRs), UV light, ceramic polymer

1.0 INTRODUCTION

Photocatalytic membrane reactors (PMRs) consist of a system that integrates photocatalysts with membrane filtration. This project is focused mainly on oil removal as the pollutant. In this study, synthetic wastewater is prepared using cooking oil and water. The kaolin clay as ceramic is obtained from the market, and the plastic waste as polymer is collected from the dustbins in the Politeknik Kuching, Sarawak. This study is intended to investigate the effect of ceramic polymer membrane ratio, UV intensity, and bed height of the membrane on the oil removal percentage.

2.0 LITERATURE REVIEW

2.1 Oily Wastewater

Nowadays, many industries generate a great quantity of oily wastewater, which causes various adverse impacts on the surrounding environment and sanitary conditions[1], [2]. In fact, oily wastewater adversely affects our drinking water, groundwater resources, aquatic resources, human health, and crop production. Many countries such are US and Mexico, are setting regulatory limits on the maximum oil concentration in oily wastewater discharge to be within the 5–100 mg/L range. Some of the region-specific limits are listed in Table 1. Thus, the development of an effective strategy and less expensive means to treat oily wastewater is a crucial environmental need.[3]

Table 1: Region-specific oil discharge in wastewater.

Bodies or Regulation Being Followed	Limits of Oil Discharge	References
Oslo–Paris (OSPAR) Convention in North Sea region	Upper limit to the sea: 30 mg/L	[4]
Paris Convention	Upper limit to the sea: 40 mg/L Upper limit to offshore fields and on-land fields: 5 mg/L	[5]
Environmental Protection Agency (EPA) in United States	Upper limit: 72 mg/L	[6], [7]
Department of Environment, Environment Quality Act 1974 in Malaysia	Oil and grease discharge limit: 10 mg/L	[8]
China Government	Upper limit: 10 mg/L	[9]
UAE Environmental Regulation	Oil and grease content of industrial effluent: 100 mg/L	[10]
Central Pollution Board of India (CPCB)	Permissible limit for oil and grease: 35 mg/L	[11]

2.2 Kaolin Clay

Kaolin are white raw materials, their essential constituent being fine grained white clay, which are amenable for beneficiation that make them ideal for an assortment of industrial applications. Kaolin deposits can be classified into two types, primary (residual) and secondary (sedimentary). The main commercially important kaolin resources at the present time are the primary deposits of Cornwall in England and the sedimentary deposits in Georgia and South Carolina in the USA.[12] Malaysia also has kaolin resources, mainly in Perak, Johor, Kelantan, Pahang, and Sarawak. Kaolin has an important role in ceramic, paper, paint, and rubber industry, and has potential in the treatment of oily wastewater due to its adsorption properties, providing economic and environmental benefits for the country.

2.3 Titanium Dioxide (TiO_2)

Titanium Dioxide (TiO_2) photocatalysis is widely used in a variety of applications and products in the environmental and energy fields, including self-cleaning surfaces, air and water purification systems, sterilization, hydrogen evolution, and photoelectrochemical conversion. The development of new materials, however, is strongly required to provide enhanced performances with respect to the photocatalytic properties and to find new uses for TiO_2 photocatalysis. In this review, recent developments in TiO_2 photocatalysis research, in terms of new materials from a structural design perspective, have been summarized. The dimensionality associated with the structure of a TiO2 material can affect its properties and functions, including its photocatalytic performance, and more specifically its surface area, adsorption, reflectance, adhesion, and carrier transportation properties. We provide a brief introduction to the current situation in TiO_2 photocatalysis and describe structurally controlled TiO_2 photocatalysts which can be classified into zero-, one-, two-, and three-dimensional structures. Furthermore, novel applications of TiO_2 surfaces for the fabrication of wettability patterns and for printing are discussed.[13]

2.4 Fly Ash

Fly ash (FA) is the principal industrial waste byproduct from the burning of solid fuels. FA is a powdery solid that is constituted mostly of unburned carbon (UC), metal oxides (Si, Fe, Ca, and Al), and other inorganic substances. UC is an inexpensive source of activated carbon that plays an important role in FA adsorption capacity. Due to the broad variability in its composition, FA characterization is challenging. Accordingly, FA is categorized into class F, and class C according to the maximum and minimum % of SiO_2, Al_2O_3, Fe_2O_3, and SO_3. X-ray diffraction, fluorescence, and scanning microscopy with an energy dispersive spectroscopy are the common techniques employed to characterize FA. FA was used to remove hazardous contaminants, organic and inorganic chemicals, and dyes from wastewater. Furthermore, investigations revealed that FA has promising potential beneficial usage in the construction industry, particularly in cement and concrete production. FA has been added to cement in a reduced nano size form giving good durability and minimizing concrete pores size to resist adverse environment. In this article, significant properties, characterization methods and applications of FA were summarized.[14]

2.5 Polyvinyl Alcohol (PVA)

Polyvinyl alcohol (PVA) is a versatile synthetic polymer, used for the design of hydrogels, porous membranes and films. Its solubility in water, film- and hydrogel-forming capabilities, non-toxicity, crystallinity and excellent mechanical properties, chemical inertness and stability towards biological fluids, superior oxygen and gas barrier properties, good printability and availability (relatively low production cost) are the main aspects that make PVA suitable for a variety of applications, from biomedical and pharmaceutical uses to sensing devices, packaging materials or wastewater treatment. However, pure PVA materials present low stability in water, limited flexibility and poor biocompatibility and biodegradability, which restrict its use alone in various applications. PVA mixed with other synthetic polymers or biomolecules (polysaccharides, proteins, peptides, amino acids etc.), as well as with inorganic/organic compounds, generates a wide variety of materials in which PVA's shortcomings are considerably improved, and new functionalities are obtained. Also, PVA's chemical transformation brings new features and opens the door for new and unexpected uses. The present review is focused on recent advances in PVA-based hydrogels.[15]

2.6 UV Light

Ultraviolet light has become more important in recent years as the various technologies necessary to provide practical UV laser imaging and beam delivery systems have progressed, especially the light sources. Historically, UV light has been available only from relatively low power lamps, thereby restricting the usefulness of the technology. The discovery and development of the excimer laser in the 1980s made possible, for the first time, the availability of intense ultraviolet light. Researchers explored and uncovered the unique properties of this new light source. As various phenomena involving UV energy and material interactions were discovered and optimized, practical applications emerged.[16]

2.7 PMR mechanism

Photocatalytic membrane reactors (PMRs) are a promising treatment technology for degradation of organic compounds discharged from wastewater treatment facilities. This review presents information about TiO_2 nanoparticles, which are the widely used photocatalyst semiconductors in PMRs, and how doping can be used to make TiO_2 able to absorb part of the visible spectrum.

3.0 METHODOLOGY

3.1 Materials

The list of materials that are used in this work are :-

- Acrylic sheets
- TiO_2
- Kaolin
- PVA
- UV lamp
- Mash
- Fly ash
- Filter sponge

3.2 Fabrication of PMRs

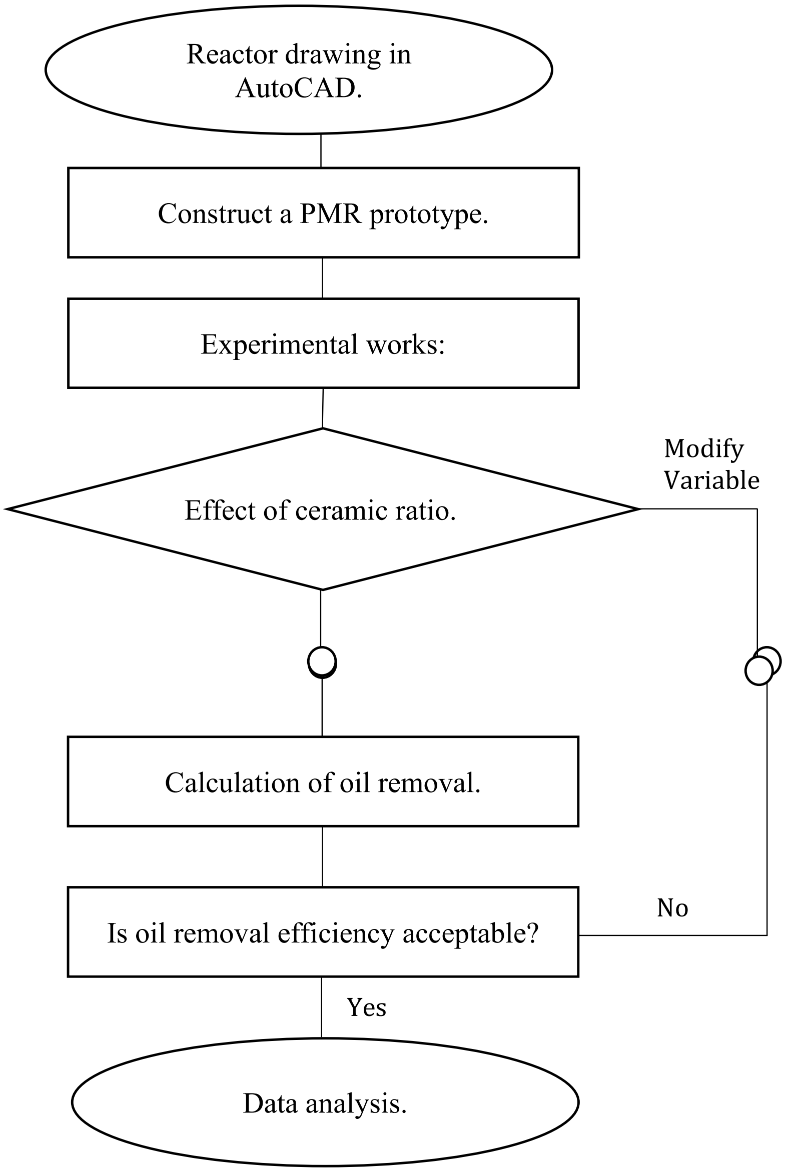

Figure 1: Overall Flowchart of Experimental Works

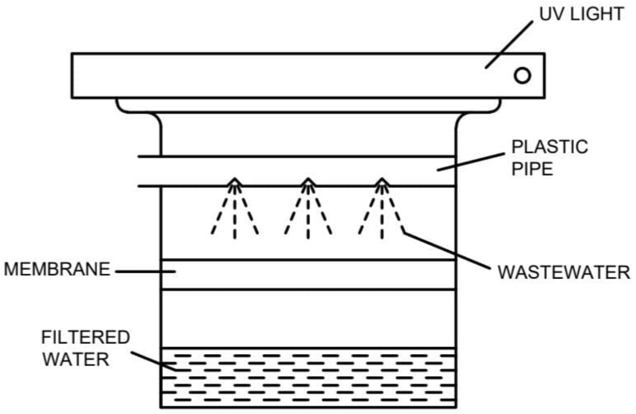

Figure 2: Reactor drawing in AutoCAD

The PMRs prototype construction involves creating a reactor drawing in AutoCAD and building the prototype. Key experimental factors include analyzing the effect of ceramic and polymer ratios, UV intensity, and membrane bed height on performance. The process will also include calculating oil removal efficiency and conducting data analysis to interpret the results.

3.2 Production of Membrane

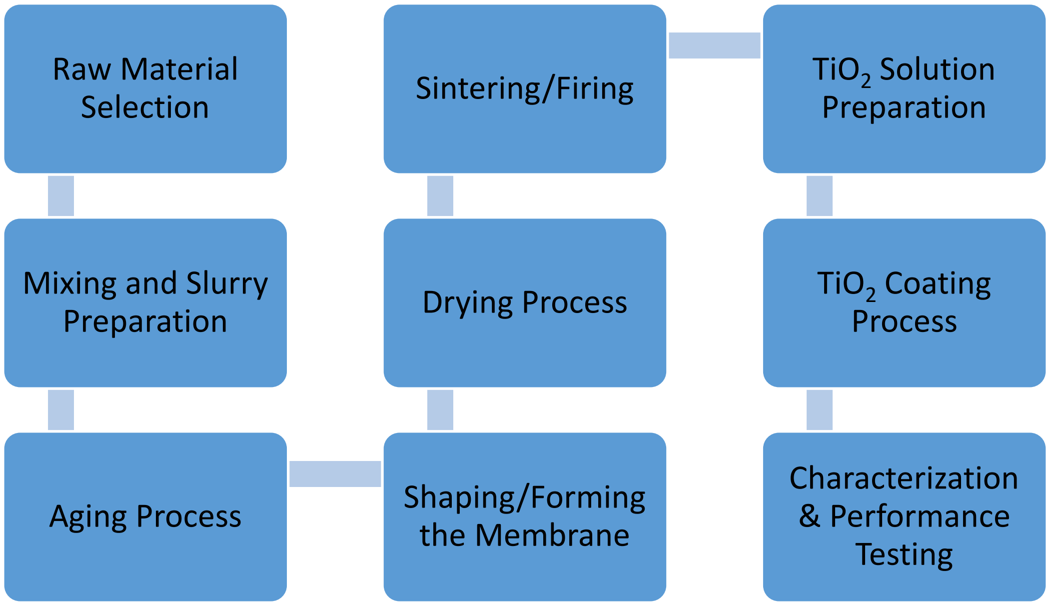

Figure 3: Process flow of PMR Membrane Productions

3.3 Preparation of Titanium Dioxide (TiO_2) Suspension

A Titanium Dioxide (TiO_2) suspension for dip-coating can be prepared by mixing 20 g of Titanium Dioxide (TiO_2) powder with 200 mL of distilled water and 4 mL of acetone, followed by thorough stirring to achieve a homogeneous solution. The dip-coating process involves immersing a cleaned substrate into the suspension at a controlled rate of 10 cm/min, allowing the solution to adhere to the surface, and withdrawing it at the same rate. The coated substrate is then dried for 30 minutes to remove excess solvent and stabilize the coating. This method ensures uniform film deposition and is widely used for applications like photocatalysis due to its simplicity and cost-effectiveness.[17], [18], [19]

3.4 Calculation of oil removal

To determine the final oil weight after irradiation, the weight of the beaker containing oil after irradiation is subtracted by the weight of the empty beaker. The oil removal percentage is calculated by taking the difference between the initial oil weight and the final oil weight, then dividing it by the initial oil weight and multiplying by 100 percent. To convert the oil mass to volume, the oil mass is divided by the oil density in g/ml.

Final Oil Weight Calculation: $Beaker\ Weight\ of\ Oil\ after\ Irradiation\ (g) - Empty\ Beaker\ (g)$

Oil Removal Percentage (%): $\frac{Oil\ Weight\ (g) - Final\ Oil\ Weight\ (g)}{Oil\ Weight\ (g)}$

Mass Convert to Volume: $\frac{Mass\ (g)}{Density\ \left(\frac{g}{ml}\right)} = Volume\ (ml)$

4.0 RESULT & DISCUSSION

4.1 Fabrication of Photocatalytic Membrane Reactors (PMRs)

The fabrication of Photocatalytic Membrane Reactors (PMRs) begins with purchasing the necessary materials, such as acrylic sheets, UV lamps, glue, filter sponge and mash. The acrylic is then cut into the desired shape, and all the cut pieces are assembled and glued together. Finally, holes are drilled into the acrylic walls to allow for the adjustment of the UV lamp height later.

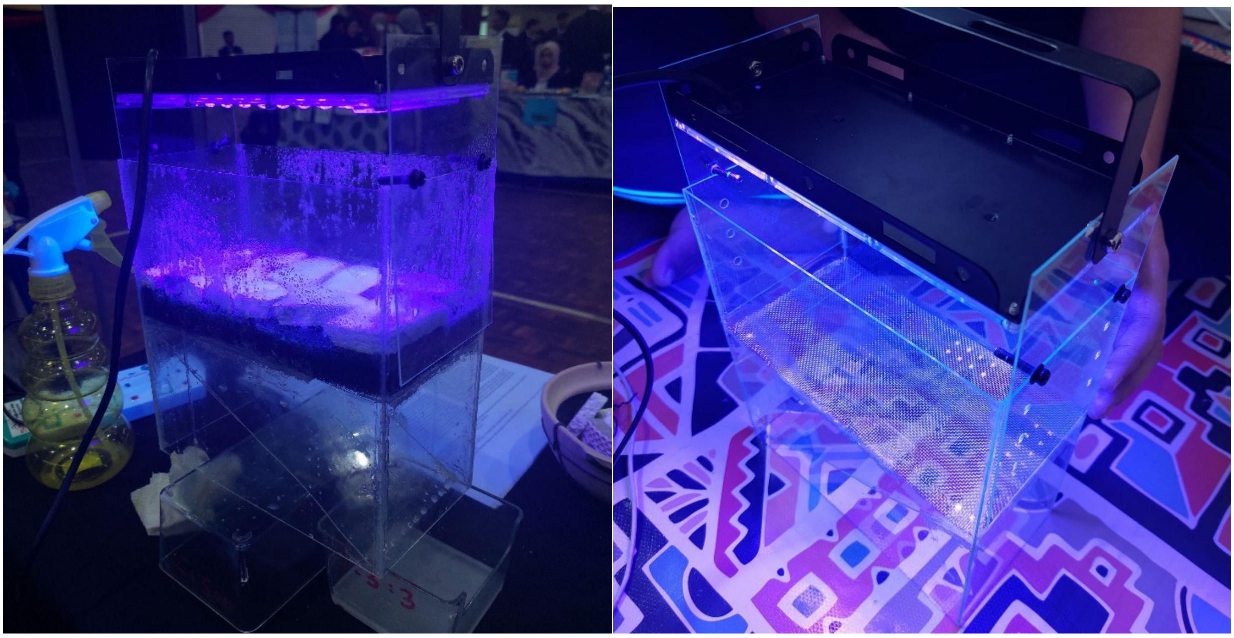

Figure 4: Photocatalytic Membrane Reactors (PMRs)

4.2 Effect of the membrane's ceramic ratio on oil removal

Based on Table 2 and Figure 5, the experimental results reveal a trend between the ceramic ratio and oil removal efficiency. As the ceramic ratio increased from 1:1:1 to 1.2:1:1, the oil percentage decreased from 95.55% to 93.60%. Further increases in the ceramic ratio to 1.3:1:1, 1.5:1:1, and 1.7:1:1 resulted in a continued decline in oil removal efficiency, reaching 86.55%, 84.45%, and 82.44%, respectively.

Based on Table 2 and Figure 5, The initial increase in the ceramic ratio to 1.2:1:1 resulted in a slight reduction in oil removal, which may be attributed to the increased density of the membrane structure, potentially limiting the accessibility of oil contaminants to the photocatalytic sites. As the ceramic ratio further increased, the reduction in oil removal efficiency became more pronounced. This suggests that excessively high ceramic content leads to a less porous structure, reducing the effective surface area for adsorption and hindering the diffusion of oil molecules to the TiO_2 photocatalyst. This is consistent with the general understanding that the membrane becomes more brittle with increased ceramic content.

Table 2: Results of Ceramic Ratio

Ratio	Oil Weight (g)	Empty Beaker (g)	Beaker Weight with Oil after Irradiation (g)	Final Oil Weight (g)	Convert to Volume (mL)	Oil Percentage Removal (%)
1:1:1	20	126.55	127.44	0.89	0.98	95.55
1.2:1:1	20	128.77	230.05	1.28	1.41	93.60
1.3:1:1	20	125.91	128.60	2.69	2.96	86.55
1.5:1:1	20	115.69	118.80	3.11	3.42	84.45
1.7:1:1	20	105.56	109.08	3.52	3.82	82.44

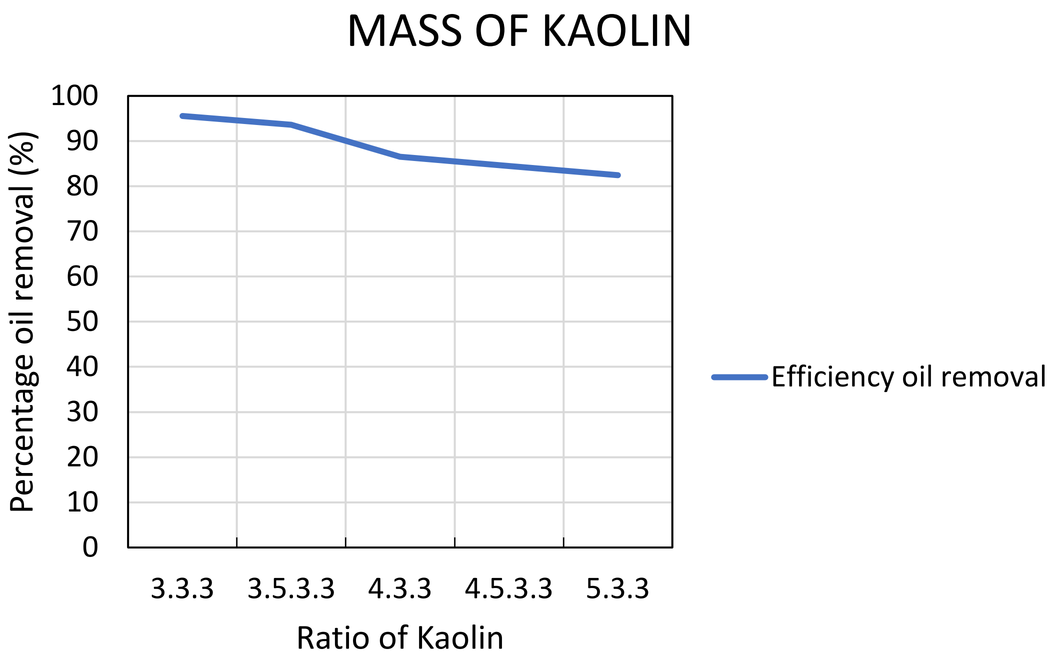

Figure 5: Chart of Kaolin Ratio

4.3 Effect of the membrane's polymer ratio on oil removal

Based on Table 3 and Figure 6, the experimental results reveal a trend between the polymer ratio and oil removal efficiency. As the polymer ratio increased from 1:0.75 to 1:0.875, the oil percentage removal increased from 75.55% to 80.50%. Further increases in the polymer ratio to 1:1, 1:1.125, and 1:1.25 resulted in a continued increase in oil removal efficiency, reaching 84.25%, 86.70%, and 89.75%, respectively.

The results suggest that increasing the polymer content generally enhances the oil removal efficiency. As the ratio of polymer (PVA) is increased, the membrane is likely becoming more porous, leading to greater accessibility for oil contaminants to reach the TiO_2 active sites. This aligns with the understanding that PVA promotes the formation of a porous structure, facilitating the transport of oil contaminants to the TiO_2 for photocatalytic degradation (refer 2.3).

Table 3: Results of Polymer Ratio

Ratio	Oil Weight (g)	Empty Beaker (g)	Beaker Weight with Oil after Irradiation (g)	Final Oil Weight (g)	Convert to Volume (mL)	Oil Percentage Removal (%)
1:0.75	20	125.91	130.80	4.89	5.37	75.55
1:875	20	127.13	131.03	3.90	4.29	80.50
1:1	20	127.72	130.87	3.15	3.46	84.25
1:1.125	20	117.31	119.97	2.66	2.92	86.70
1:1.25	20	106.90	108.95	2.05	2.25	89.75

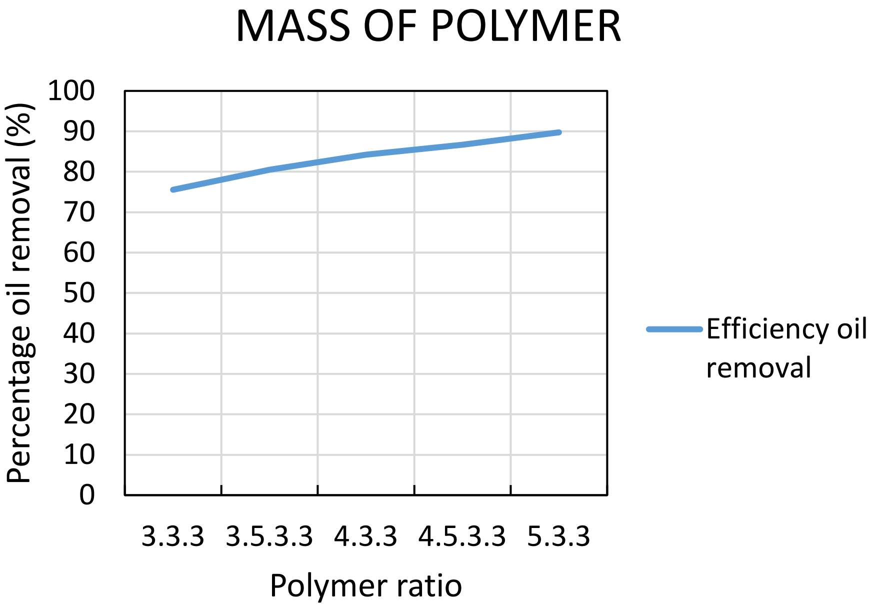

Figure 6: Chart of Polymer Ratio

4.4 Effect of the membrane's bed height on oil removal

Based on Table 4 and Figure 7, the experimental results reveal a trend between bed height and oil removal efficiency. As the bed height increased from 1 cm to 2 cm, the oil percentage removal increased from 95.55% to 96.45%. Further increases in bed height to 3 cm and 4 cm resulted in a continued increase in oil removal efficiency, reaching 97.35% and 98.90%, respectively.

The consistent increase in oil removal efficiency with increasing bed height indicates that a taller membrane bed provides more surface area for interaction between the oil and the membrane. This increased surface area allows for greater adsorption of oil contaminants onto the membrane and enhances the photocatalytic degradation process, leading to higher overall removal efficiency.

Table 4: Results of Membrane Bed Height

Height (cm)	Oil Weight (g)	Empty Beaker (g)	Beaker Weight with Oil after Irradiation (g)	Final Oil Weight (g)	Convert to Volume (mL)	Oil Percentage Removal (%)
1	20	126.55	127.44	0.89	0.98	95.55
2	20	125.86	126.57	0.71	0.78	96.45
3	20	126.36	126.89	0.53	0.58	97.35
4	20	105.59	105.81	0.22	0.24	98.90

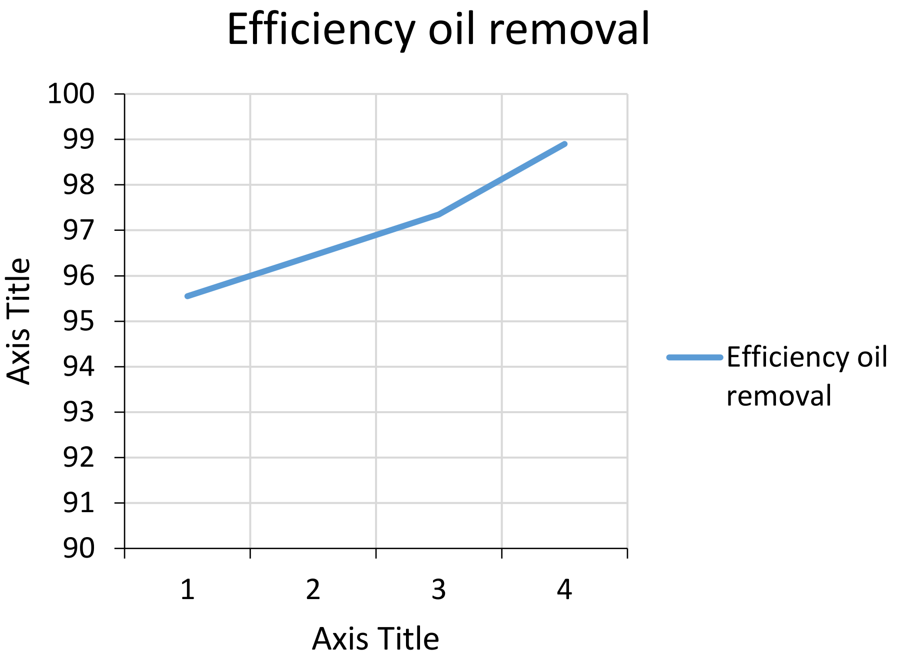

Figure 7: Chart of Membrane Bed Height

4.5 Effect of the membrane's UV intensity on oil removal

Based on Table 5 and Figure 8, the experimental results reveal a trend between the UV light intensity (represented by the height from the UV source) and oil removal efficiency. As the height from the UV source increased from 6.5 cm to 8.5 cm, the oil percentage decreased significantly from 98.40% to 87.40%. Further increases in the height from the UV source to 10.5 cm and 12.5 cm resulted in a continued decline in oil removal efficiency, reaching 63.10% and 44.35%, respectively.

The results suggest that higher UV light intensity, achieved by positioning the membrane closer to the UV source, leads to greater oil removal efficiency. As the height from the UV source increases, the intensity of UV light reaching the membrane decreases, resulting in lower photocatalytic activity. This is consistent with the principle that UV light activates the TiO_2 photocatalyst, generating electron-hole pairs that initiate a series of redox reactions leading to the degradation of organic pollutants. Reducing UV intensity would therefore lead to a lower rate of these reactions.

Table 5: Results of UV Intensity

Height (cm)	Oil Weight (g)	Empty Beaker (g)	Beaker Weight with Oil after Irradiation (g)	Final Oil Weight (g)	Convert to Volume (mL)	Oil Percentage Removal (%)
6.5	20	105.59	105.81	0.22	0.24	98.40
8.5	20	106.80	109.30	2.50	2.74	87.40
10.5	20	105.60	112.98	7.38	8.11	63.10
12.5	20	105.80	116.93	11.13	12.23	44.35

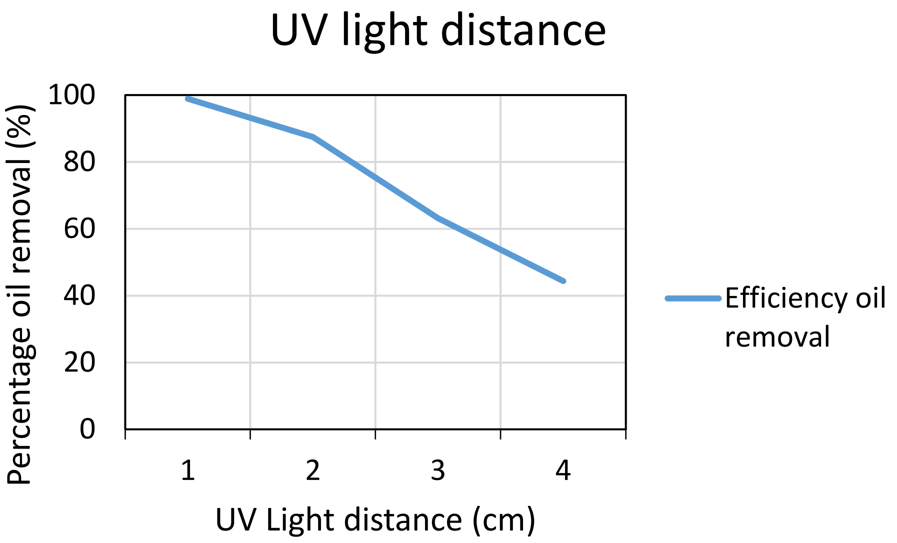

Figure 8: Chart of UV Intensity

5.0 CONCLUSION

The study of Photocatalytic Membrane Reactors (PMRs) in oil-contaminated wastewater treatment highlights the necessity of optimizing membrane composition and design parameters. Testing has confirmed that increasing the polymer content enhances adsorption capacity but makes the membrane more brittle. Conversely, higher ceramic (kaolin) content reduces adsorption efficiency as the denser structure provides fewer adsorption sites. Additionally, thicker membranes improve oil removal due to their larger surface area for contaminant interaction and their closer proximity to UV light which enhances photocatalytic degradation efficiency. Based on experimental results and analyses, conclusions have been drawn to assess the effectiveness of PMR technology. Recommendations for optimizing PMR design and further research directions are also provided. As the polymer content in the membrane increases, the adsorption capacity also increases; however, the membrane becomes more brittle.[20], [21] Conversely, increasing the kaolin content results in decreased adsorption capacity due to the higher density of the structure, which limits adsorption sites.[22], [23]A thicker membrane enhances adsorption, as it provides more surface area for contaminant interaction.[24] Additionally, closer proximity to the UV light source improves the membrane's photocatalytic reaction efficiency, enhancing pollutant degradation.[25]From an operational perspective, efforts should focus on optimizing PMR design parameters, such as the ceramic-to-polymer ratio, membrane thickness, and UV light positioning. Pilot-scale trials in industrial processes that produce oily wastewater-such as petrochemical industries-are necessary to evaluate the scalability and economic feasibility of this technology. Additionally, cost-effective manufacturing processes could further facilitate the widespread adoption of PMR systems. In summary, PMRs present a promising solution to water pollution. With optimized material composition and process conditions tailored to real-world applications, this technology holds great potential for sustainable wastewater treatment on a global scale. In the future, it could also be expanded into other markets for further development, contributing to environmental sustainability and the well-being of our planet.

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NATURAL PAINT PIGMENTS FOR KINDERGARTEN

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ABSTRACT

This study focuses on the formulation and characterization of a natural paint using beetroot powder as a plant-based pigment, aimed at developing a safer, eco-friendly alternative to commercial acrylic paints for kindergarten use. The paint was prepared by optimizing the ratio of beetroot pigment, distilled water, and acrylic polymer (1:5:2), and mixed using various techniques to ensure uniformity and smooth application. Among the methods tested, homogenization proved most effective in producing a consistent paint mixture. Physical property evaluations showed that the natural paint had a lower density (1.11 g/ml) and a near-neutral pH (6.21), making it lightweight and safe for skin contact, suitable for environments involving children. Performance assessments included color stability, tape adhesion, rub resistance, and water resistance. The natural paint demonstrated good adhesion and rub resistance, comparable to commercial acrylic paint, indicating strong film formation. However, it exhibited lower color stability and poor water resistance, primarily due to the absence of synthetic stabilizers and hydrophobic agents. Despite these limitations, the natural paint formulation offers considerable promise for indoor applications where non-toxicity and biodegradability are prioritized. This research supports the viability of plant-based pigments in educational paint products and highlights the need for further enhancements to improve long-term durability and moisture resistance.

Keywords: *Natural paint pigment, acrylic polymer, beetroot powder, plant-based pigment, eco-conscious paint, non-toxic formulation, kindergarten use*

1.0 INTRODUCTION

The increasing awareness of environmental sustainability has driven research into natural alternatives to synthetic pigments used in commercial paints [1]. Natural pigments derived from plant sources offer a viable alternative, particularly for children's art supplies [2]. This study focuses on developing a natural paint formulation incorporating beetroot powder as the primary pigment, combined with acrylic polymer to enhance stability and application properties [3].

The need for this research arises from concerns regarding the potential health and environmental risks associated with synthetic pigments. Many commercial paints contain heavy metals and volatile organic compounds (VOCs), which may pose risks to human health and contribute to environmental pollution [4]. The incorporation of plant-based pigments aims to mitigate these concerns by offering a biodegradable and environmentally conscious alternative for educational and recreational applications [5]. Emphasizing the limitations of conventional synthetic pigments, particularly regarding children's exposure to potentially harmful substances. Thus, it is necessary to investigate how natural pigments can be effectively stabilized and integrated into paint systems without compromising their eco-friendly characteristics.

This work aims to formulate a natural paint using plant-based pigment with red color and acrylic polymer as a binder, aimed at producing a non-toxic, child-safe alternative to conventional acrylic paints. Specific objectives include optimizing the pigment-to-binder ratio and mixing technique to ensure uniform texture and application quality and evaluating the physical and performance characteristics of the paint in comparison with a commercial standard. Key performance indicators include pH, density, color, color stability, tape adhesion, rub resistance, and water resistance. Besides, this work also focuses on indoor applications, particularly in kindergarten or educational settings, where paint safety and ease of handling are essential. The study employs natural plant pigments due to their natural colouring properties, ease of processing, and safety as a food byproduct. Supporting ingredients such as gum Arabic and castor oil are included to enhance dispersion, film stability, and spreadability. The findings aim to assess the feasibility of using natural pigments in practical paint applications while highlighting areas for further improvement in formulation and performance.

2.0 SUMMARY LITERATURE REVIEW

Table 1: Summary of Literature Reviews for Natural Paints Pigments for Kindergarten

Focus Area	Key Findings	Relevance to Current Study	Reference
Natural pigments in paints	Plant-based pigments show lower chemical stability compared to to synthetic ones	Confirms challenges in durability and color retention	[6]
Acrylic polymer as a binder	Acrylic enhances pigment dispersion and adhesion to surfaces	Supports the use of acrylic polymer for improved performance	[7]
Environmental impact of synthetic vs. natural pigments	Natural pigments reduce ecological impact but have a shorter lifespan	Emphasizes the need for optimization to balance sustainability and performance	[8]
Child-friendly paint formulations	Biodegradable natural pigments are safer alternatives in educational settings	Supports the application in kindergarten art supplies	[9]
Durability of plant-based pigments in coatings	Some natural pigments degrade faster under UV exposure	Reinforces the need for UV stabilizers when formulating natural paints	[10]
Water resistance of natural vs. synthetic paints	Synthetic paints show superior water resistance compared to natural pigments	Highlights the need for water-resistant additives in natural paint development	[11]
Adhesion properties of acrylic-based paints	Acrylic-based paints exhibit better adhesion compared to natural gum binders	Justifies the selection of acrylic polymer for improved performance	[12]
Pigment particle size and dispersion	Smaller pigment particles improve dispersion and color consistency	Suggests particle size reduction techniques for better quality natural paints	[13]

The gap analysis table and key findings of this work are summarized in Table 1. Previous studies on natural paint formulations have highlighted both the potential and limitations of using plant-based pigments as alternatives to synthetic counterparts. Plant-based pigments have been shown to possess lower chemical stability compared to synthetic ones, resulting in issues such as faster degradation and diminished color retention over time [6]. Despite this, they offer significant environmental and health benefits, particularly in applications where non-toxic and biodegradable materials are preferred.

To improve the performance of natural pigments, the use of acrylic polymer as a binder has been emphasized, as it enhances pigment dispersion and adhesion to surfaces more effectively than natural gums [7, 12]. This makes acrylic polymer a suitable choice in developing stable and user-friendly natural paint formulations. From an environmental standpoint, natural pigments reduce ecological impact compared to synthetic pigments, although they tend to have a shorter usable lifespan, emphasizing the need for formulation improvements to balance sustainability with durability [8].

In terms of child safety, natural pigments are more favorable as they are biodegradable and contain fewer harmful chemicals, making them ideal for kindergarten and educational settings [9]. However, issues related to durability persist. Some studies have reported that natural pigments, particularly those exposed to UV light, degrade faster unless stabilized with additives such as UV protectants [10]. Water resistance is another challenge, with natural paints generally performing poorly compared to synthetic paints unless enhanced with water-resistant additives [11].

Moreover, adhesion properties are better in acrylic-based paints than those using natural binders, justifying the use of acrylic polymer in this study to improve bonding performance [12]. Finally, pigment particle size plays a crucial role in color consistency and dispersion; smaller pigment particles tend to distribute more evenly, resulting in better visual and performance outcomes [13].

Collectively, these studies inform the current research by reinforcing the importance of binder selection, pigment optimization, and performance enhancement in developing a safe, effective, and eco-conscious natural paint suitable for educational environments.

3.0 METHODOLOGY

3.1 Materials

The materials used in this work are shown in Figure 1

Chilli powder (Provides the color in the paint)

beetroot powder (provides the colour in the paint)

roselle powder (provides the colour in the paint)

acrylic polymer (acts as a binder)

distilled water (acts as the solvent to dissolve and mix the ingredients)

Castorl oil (improves flowability, flexibility, and texture of the paint)

Arabic gum (stabilizes the pigement dispersion, thickens the paint, and improves texture)

thyme essential oil (preserves the paint by preventing microbial and fungal growth)

Figure 1: Materials for Natural Paint Pigments for Kindergarten

3.2 Preparation Techniques

3.2.1 Pigment Selection Process

The natural pigments used in this study are fine powders of beetroot, chili, and roselle. To determine the optimal pigmentation, formulations were prepared based on the weight ratio of pigments, distilled water, acrylic polymer, and a 1% additive such as a dispersing agent. The weight ratio of the three main component pigments, distilled water, and acrylic polymer—was maintained at 15:70:15.

For the evaluation of the natural pigments, each sample was spread thinly onto paper and left to dry at room temperature under natural lighting conditions. Observations focused on color intensity, homogeneity, the finest particle, and the stability of the paint mixture.

3.2.2 Optimization Process

Once beetroot was chosen as the pigment, an optimization process was undertaken to determine the ideal ratio of beetroot powder, distilled water, and acrylic polymer. The process is summarized in Table 2.

Table 2: Summary of the optimization process for beetroot pigment paint

Sample	Beetroot powder (g)	Distilled water (ml)	Acrylic polymer (ml)	ratio
1	10	50	15	1:5:1.5
2	10	50	20	1:5:2
3	10	50	25	1:5:2.5

3.2.3 Mixing method optimization

The mixing process was also optimized to ensure a uniform, smooth paint. The following methods were tested for their effect on dissolution and texture as tabulated in Table 3.

Table 3 Comparison of mixing methods to achieve uniform paint texture

Sample	Mixing method	Picture equipment
1	Manual stirring	Use a glass rod and a beaker by hand
2	Magnetic stirring	Use a hot plate and a magnetic stirrer
3	Homogenizer	Homogenizers

3.2.4 Preparation of formulation paint

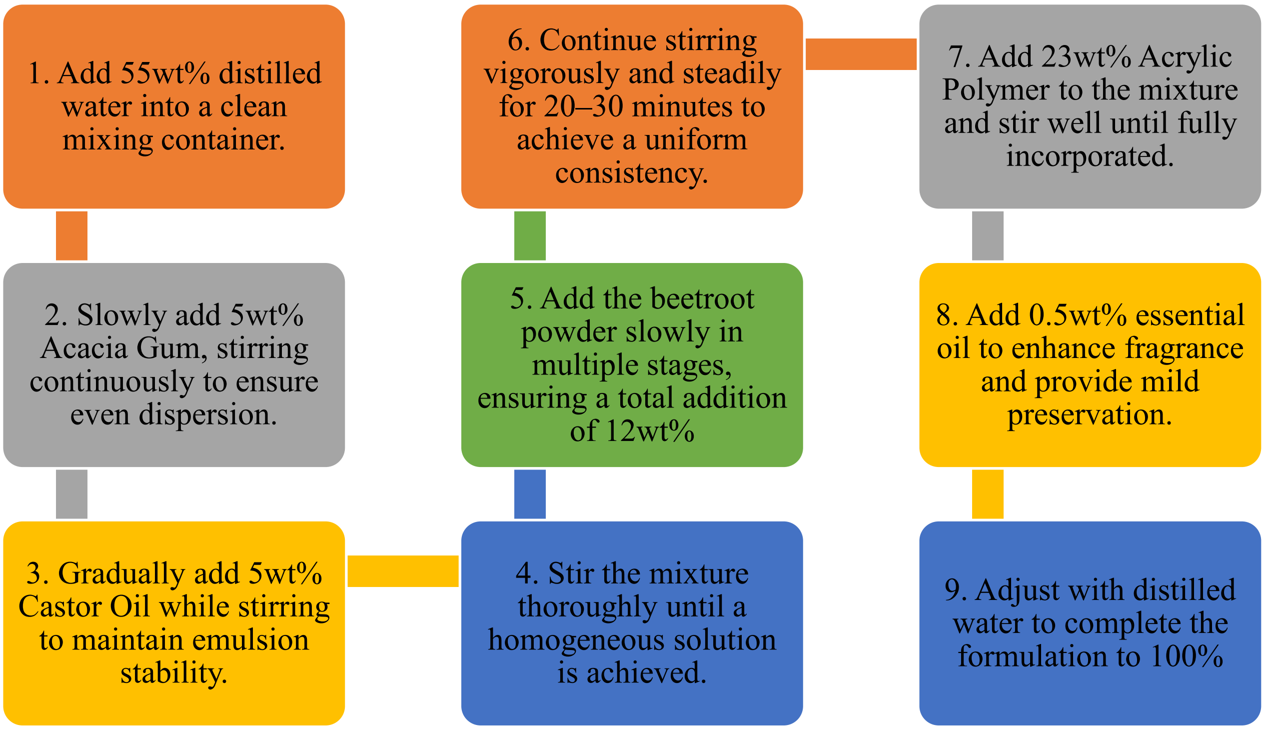


Figure 2: Preparation process flow of natural paint with acrylic polymer

3.3 Characterization of natural paint

The paint characteristics are examined through various tests, including density, pH, color difference, color stability, tape adhesion, rub resistance, and water drop resistance.

a) Density measurement

The density of the natural paint was determined using a measuring cylinder and a weighing balance. The procedures involved are

1. Weighing an empty measuring cylinder.
2. Weighing the measuring cylinder filled with the natural paint.
3. Applying the density formula.

b) pH value measurement

The pH of the natural paint was measured using a calibrated digital pH meter. The procedure involved:

1. Placing a small sample of the paint into a clean container.
2. Insert the pH probe into the sample and allow it to stabilize.
3. Recording the pH value displayed on the meter.

c) Color difference and color stability are observed.

The color difference and stability were evaluated by performing a side-by-side drawdown using both the commercial and natural paints applied with a brush. The initial color differences were recorded, and the color stability was monitored for one week.

d) Tape Adhesion Test

The adhesion of the paint was evaluated using a standard tape test. The test was performed as follows:

1. A layer of natural paint was applied to a test surface and allowed to dry completely.
2. A strip of adhesive tape was firmly pressed onto the painted surface.
3. The tape was then peeled off at a consistent angle and speed.
4. The degree of paint removal was assessed. The formulated paint successfully passed the adhesion test, demonstrating good bonding to the substrate.

e) Rub Resistance Test

The rub resistance of the natural paint was evaluated using tissue paper. The test involved:

1. Gently rubbing a piece of tissue paper against the dried paint surface.
2. Observing whether the paint transferred onto the tissue paper.
3. Comparing the results with commercial paint.

f) Water Drop Resistance Test

The water resistance of the natural paint was tested by applying water droplets onto the dried paint surface. The procedure included:

1. Using a dropper to apply water onto the painted surface.
2. Observing whether water spots or patches formed.
3. Comparing the resistance of the natural paint against commercial.

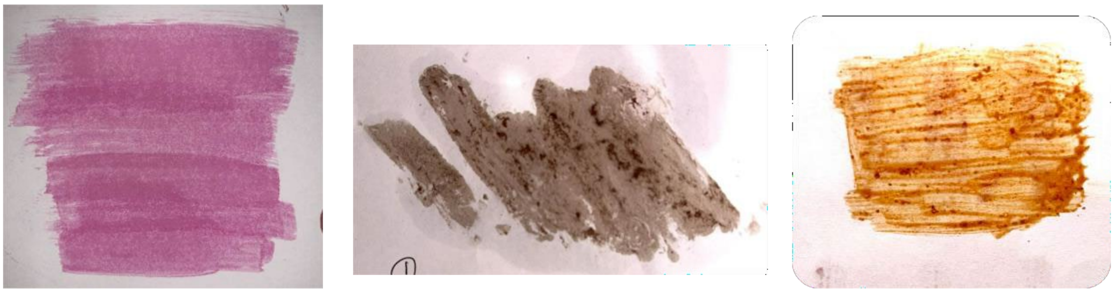
4.0 RESULT & DISCUSSION

4.1 Preliminary study on process selection and optimization

This work employed a systematic strategy to formulate and optimize natural pigment-based paints by selecting appropriate natural pigments, establishing optimal component ratios, and improving the mixing technique to achieve ideal paint qualities. The results presented in this section focus solely on color consistency, texture, and overall application performance.

a) Natural pigment selection

Three natural pigments, such as beetroot, chili, and roselle, were initially assessed based on visual observations of color intensity, particle fineness, homogeneity, and mixture stability. Figure 3 depicts the application of three natural paints using brushes.



(a) (b) (c)

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Figure 3: Application of synthesized paint from a) Beetroot, b) Roselle, and c) Red chilli

The application of three paints is illustrated in Figure 3. When applied thinly to paper, beetroot pigment demonstrated the most favorable characteristics, including strong coloration, minimal graininess, and consistent dispersion within the acrylic base. In contrast, chili and roselle pigments showed less homogeneity and tended to settle unevenly. Besides, the color appearance of chili abd roselle easily oxidizes after being applied rather than beetroot. This justified the selection of beetroot pigment for further formulation optimization.

b) Optimization of formula ratio of pigment, polymer and distilled water.

Three formulations incorporating beetroot pigment were evaluated with differing ratios of acrylic polymer, while maintaining constant quantities of beetroot powder and distilled water, as presented in Table 4. Sample 2, with a ratio of 1:5:2 (beetroot:water:acrylic), proved to be the most efficacious. It achieved equilibrium between viscosity and pigment dispersion, providing seamless application and adequate binding strength. Sample 1 demonstrated inadequate adhesion owing to insufficient acrylic content, while Sample 3 presented a marginally thicker and less manageable texture. In contrast, Sample 2 provided an ideal combination of flowability, color vibrancy, and structural robustness. The increased acrylic content in Sample 3 enhanced adhesion but diminished application ease, which is essential in consumer-focused paint products. Consequently, formulation Sample 2 was deemed the most optimal and chosen for further examination.

Table 4: Formulation ratio and observations

Sample	Formulation ratio	Observation
1	1:5:1.5	Achieved moderate dissolution with smooth texture. Reduced acrylic resulted in lower binding strength, affecting adhesion.
2	1:5:2	Good dissolution and smooth consistency were observed. Balanced ratio enhanced binding and dispersion for a user-friendly application
3	1:5:2.5	Effective dissolution, but a slightly thicker texture was noted. Higher acrylic improved adhesion but reduced flowability slightly.

c) Mixing Method Optimization

To enhance the uniformity of the paint, different mixing methods were evaluated, and the observation is recorded in Table 5. Manual stirring resulted in inadequate pigment dissolution and visible granules in the mixture, which would negatively impact the final paint finish. Magnetic stirring offered moderate improvement, reducing graininess but still falling short of complete homogenization. However, the homogenizer tool provided the best outcome, producing a fine, uniform, and well-integrated mixture. This method allowed for a better breakdown of pigment particles and ensured an even distribution throughout the medium, which is essential for consistent color output and surface smoothness during application. Therefore, the use of beetroot as a natural pigment, combined with a formulation ratio of 1:5:2 (pigment:water:acrylic) and the application of a homogenizer, represents the most effective optimization in this preliminary study. The following section will discuss the characteristics and performance of the resulting paint.

Table 5: Mixing method optimization and its observation

Sample	Mixing method	Observations
1	Manual stirring	Limited dissolution due to manual stirring. The resulting mixture had visible graininess and uneven texture.
2	Magnetic stirring	Improved dissolution with a smoother texture. Minor graininess present due to moderate shear from stirring
3	homogenizer	Excellent dissolution, with a consistent, smooth texture. Homogenization led to a well-integrated mixture.

4.2 Characteristics of natural paint

4.2.1 Physical properties of the paint

This section compares the physical properties, specifically the density and pH values, of natural paint using natural pigments and commercial acrylic paints. The properties of these two types of paint are important because they influence their usability, safety, and effectiveness in various applications, especially in environments like kindergartens where children will come into direct contact with the paint.

Table 6: Comparison of physical properties of natural and commercial paints

Type of Paint	Density (g/ml)	pH
Natural Paint	1.1	6.21
Commercial Paint	1.62	8.22

The comparison of physical properties between the natural pigment paint and commercial acrylic paint reveals notable differences, particularly in terms of density and pH value, which have important implications for practical use. The natural paint exhibited a lower density (1.11 g/ml) compared to the commercial acrylic paint (1.62 g/ml). This lower density indicates that the natural paint is lighter, which may enhance ease of handling, especially for young children. However, a lighter paint may also result in reduced opacity, potentially requiring multiple layers to achieve complete coverage. Generally, lower density is associated with diminished coverage capability, a trend that aligns with the findings of this study. This limitation should be carefully considered, and future formulations may aim to improve the opacity of the natural paint, such as by optimizing the binder-to-pigment ratio or incorporating natural fillers, without significantly increasing their density.

The natural paint recorded a pH of 6.21, which falls within the safe range for skin contact. This is particularly important in ensuring the safety of children, as a neutral or mildly acidic pH helps reduce the risk of skin irritation. In contrast, the commercial acrylic paint exhibited a higher pH of 8.22. Although not inherently harmful, this more alkaline nature may contribute to skin dryness or irritation, especially with prolonged exposure. In practical terms, the suitability of pH in children's products is well-documented, with many studies noting that pH values close to neutral (around 6–7) are optimal for safety. This observation is consistent with the findings of this study and reinforces the child-friendly nature of the natural paint formulation.

In conclusion, the natural paint formulation demonstrates favorable physical properties that support its suitability for child-friendly applications. Its lower density makes it easier to handle, particularly for young users, although further enhancement of opacity may be required to improve coverage. More importantly, the near-neutral pH of the natural paint offers a significant safety advantage, minimizing the risk of skin irritation compared to the more alkaline commercial acrylic paint. Together, these findings highlight the potential of natural paint as a safer and more user-friendly alternative for environments involving direct contact with children, such as kindergartens or educational settings.

4.2.2 Performance of natural paint

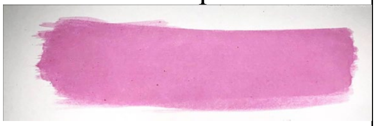
This section evaluates the performance characteristics of natural paint derived from beetroot pigments in comparison to commercial acrylic paint. The assessment focuses on key factors such as color durability, adhesion, rub resistance, and water resistance, all of which are critical in determining the suitability of paint for practical applications, and is presented in Table 7. These properties are especially important in environments such as kindergartens, where both safety and long-term durability are essential.

Table 7: Performance comparison of natural paint & commercial paint

Property	Natural paint	Commercial paint
Color different	Pink and fades faster	Purple and more durable and consistent
Tape adhesion	Passed	Passed
Rub resistance	Good rub resistance	Good rub resistance
Water drop test	Low water resistance	High water resistance

The natural paint derived from beetroot pigment initially exhibits a bright pink as presented in Table 8; however, it tends to fade more rapidly compared to commercial acrylic paint when exposed to environmental conditions such as light, air, and humidity. This faster fading is primarily attributed to the inherent instability of natural dyes, which are more prone to photodegradation due to the organic nature of their chemical structure. Unlike synthetic pigments, natural pigments like those in beetroot lack the chemical stability needed to resist prolonged exposure to ultraviolet (UV) light. In previous studies, chlorophyll-based paints have demonstrated improved color stability with the incorporation of stabilizing agents such as copper nitrate, highlighting the potential of additives to enhance the durability of natural pigments. This suggests that, although beetroot pigments offer an eco-friendly and child-safe alternative, their application in long-term or outdoor settings may require further optimization through the inclusion of stabilizers or protective coatings to maintain color integrity over time.

Table 8: Color observation and color stability

Type of paints	Color	Color stability
Natural paint 	Pink	Fade faster
Commercial Paint 	Purple	More durable and consistent

Both the natural paint and commercial acrylic paint passed the tape adhesion test as presented in Table 9, indicating that each formulation demonstrated sufficient bonding strength to the substrate surface. The success of the natural paint in this test is a positive indicator of its potential for practical application, especially considering its eco-friendly composition. The satisfactory adhesion suggests that the selected binder (acrylic polymer) in the natural formulation was effective in anchoring the pigment to the substrate, despite the absence of synthetic additives typically found in commercial paints. This result aligns with findings from previous studies, which noted that proper binder selection and mixing methods, such as homogenization, can significantly enhance adhesion in natural paints. Comparable performance to commercial paint in terms of adhesion reinforces the viability of the natural paint formulation for indoor use, including in educational settings where consistent coating performance is crucial.

Table 9: Adhesion test of natural and commercial paint

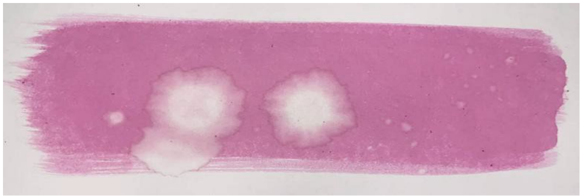
Types of paints	Adhesion test	Result
Natural Paint		Passed
Commercial Paint		Passed

Good rub resistance was demonstrated by both commercial acrylic paint and the natural paint as presented in Table 7, suggesting that neither formulation could be severely damaged or lose pigment when subjected to physical abrasion. This is a positive outcome for the natural paint, it indicates that a strong enough paint film was produced by the combination of the ideal mixing technique and formulation ratio of acrylic polymer and beetroot pigment.

Since natural paint formulations typically lack a chemical crosslinker, it is especially crucial to obtain rub resistance equivalent to commercial paint. The results show that even in the absence of these additives, a well-balanced natural formulation, especially with an appropriate ratio of binder and effective dispersion, can offer good rub resistance.

This finding challenges the commonly held view, from previous work usually that natural water-based paints generally have low rub resistance. In this case, the results imply that with proper formulation techniques, such as binder optimization and homogenized mixing, natural pigments can achieve performance levels close to or equal to commercial alternatives. This reinforces the potential of natural paint for broader application, including in environments like kindergartens, where both safety and durability are essential.

However, natural paint has low water resistance, while the commercial acrylic paint showed high water resistance, as Tabulated in Table 7 and illustrated in Figure 4. When exposed to water droplets, the natural paint surface showed signs of partial absorption and pigment disruption, indicating that the paint film lacks sufficient hydrophobic properties. This behaviour suggests that the film formed by the natural paint is more permeable and less cohesive, making it vulnerable to moisture exposure. In contrast, the commercial paint maintained its integrity and repelled water effectively, demonstrating its suitability for environments exposed to humidity or cleaning activities.



Natural Paint

Commercial Paint

Figure 4 Water drop test for natural paint pigments and commercial paint

The poor water resistance of the natural paint is likely due to the absence of waterproofing agents or surface sealants that are commonly used in commercial formulations. Since the natural paint relies on a simple acrylic binder and plant-based pigments, it lacks the chemical barriers that prevent water penetration. This result highlights a key limitation in the current natural formulation, particularly for use in areas where moisture resistance is crucial, such as kitchens, bathrooms, or outdoor applications.

To improve water resistance, future formulations of natural paint could incorporate eco-friendly waterproofing agents or apply a protective clear coat made from natural resins or waxes. Despite this limitation, the natural paint still holds promise for indoor use in dry areas or as an educational/artistic medium, especially where non-toxic and biodegradable materials are preferred.

5.0 CONCLUSION

This study successfully developed and evaluated a natural paint formulation using beetroot powder as a plant-based pigment to provide a safer, eco-friendly alternative to commercial acrylic paints, which use chemical pigmentation, particularly for kindergarten applications. The project met its objectives by formulating a non-toxic paint using a ratio of 1:5:2 (beetroot:water: acrylic polymer), optimized through systematic testing of component proportions and mixing techniques. The use of a homogenizer was found to produce the most uniform and smooth mixture, resulting in improved application quality.

In terms of physical properties, the natural paint demonstrated a lower density (1.11 g/ml) compared to commercial paint (1.62 g/ml), which makes it lighter and easier to handle for young children. Its pH value of 6.21 also falls within the skin-safe range, supporting its application in environments where direct contact is expected. These findings confirm that the natural paint meets basic safety and usability requirements for child-focused use.

Performance evaluations showed promising results in several aspects. Both the natural and commercial paints passed the tape adhesion and rub resistance tests, indicating that the optimized natural paint can form a stable, durable film despite the absence of synthetic hardeners. This challenges the perception that natural water-based paints are mechanically weak. However, a key limitation was observed in the water drop test, where the natural paint exhibited low resistance to moisture due to the absence of hydrophobic agents. While this restricts its application in high-humidity or outdoor settings, it remains suitable for indoor, dry environments such as classrooms or art corners.

In conclusion, the natural paint formulated in this study demonstrates considerable potential as a child-safe and environmentally friendly alternative to commercial paints. While it shows acceptable performance in terms of adhesion, rub resistance, and application quality, further improvements, particularly in enhancing water resistance, are needed. With continued refinement, plant-based pigments like beetroot could play a significant role in future sustainable paint technologies tailored for educational and artistic use.

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CELLULOSE ACETATE FROM OIL PALM EMPTY FRUIT BUNCH (OPEFB) FOR TEXTILE INDUSTRY

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ABSTRACT

The oil palm industry in Malaysia generates a substantial amount of agricultural waste, with Oil Palm Empty Fruit Bunches (OPEFB) representing one of the largest and most underutilized components, amounting to approximately 20 million tons annually. Despite its high lignocellulosic content, OPEFB is typically discarded post-harvest, contributing to environmental degradation. This study explores the valorization of OPEFB through its transformation into cellulose acetate, a biodegradable and flexible polymer with significant potential in textile applications. The research involves key processing stages, including pretreatment, cellulose isolation, and acetylation, with experimental variables comprising reaction temperature and chemical reagent ratios. The resulting cellulose acetate was evaluated based on visual inspection, water absorption, fire resistance, melting point, and Fourier Transform Infrared Spectroscopy (FTIR). Findings demonstrate that controlled adjustments to processing parameters yield cellulose acetate with improved thermal and structural properties. These outcomes affirm the feasibility of OPEFB as a sustainable feedstock for biopolymer production, offering a practical solution for waste management and contributing to the development of circular economy practices in the agro-industrial sector.

Keywords: *Oil Palm Fruit Bunch, Cellulose Acetate, Textile Industry, Fourier Transform Infrared Spectroscopy.*

1.0 INTRODUCTION

Handling OPEFB in Malaysia poses a serious environmental risk. Malaysia, one of the world's top producers of palm oil, produces enormous amounts of OPEFB as a byproduct of extracting palm oil. Due to the vast volume generated, this led to open dumping, uncontrolled burning and inefficient dumping. OPEFB has the potential to be a valuable resource, but it is primarily handled as garbage such as gas emission, land and water pollution which has negative effects on the environment and results in lost chances for sustainable use [1].

In cellulose acetate process it will undergo 4 processes (Activation, acetylation, hydrolysis and drying). The process begins with activation of cellulose acetate. The cellulose is treated to remove impurities and lignin. Next, the cellulose is then treated with acetic acid in the presence of sulfuric acid as a catalyst. This reaction results in the substitution of hydroxyl (-OH) groups in the cellulose molecule with acetyl ($-COCH_3$) groups. The excess acetic acid is removed from the cellulose acetate by hydrolysing it after acetylation. To break down any unreacted acetyl groups, the cellulose acetate is treated with water or a diluted acidic solution in this stage[2]. To achieve the correct moisture content, the refined cellulose acetate is dried to eliminate any remaining moisture. Lastly, depending on its intended use, the cellulose acetate may be formed into a variety of shapes, including fibers, flakes, or pellets. The procedures of extrusion, moulding, or spinning can accomplish this.

Additionally, the practice of burning OPEFB as a disposal method which is used to manage garbage and clear agricultural fields releases dangerous pollutants and particle matter into the environment, which aggravates respiratory issues and air pollution in the areas nearby. The careless burning and dumping of OPEFB affects both local and regional environments in addition to being a health risk to people[3].

The objective of this study is to produce cellulose acetate and to study the physical and chemical properties from the cellulose acetate from OPEFB produced.

2.0 LITERATURE REVIEW

2.1 Cellulose

Cellulose $(C_6H_{10}O_5)_n$ is one of the most ubiquitous organic polymers on the planet. It is a significant structural component of the primary cell wall of green plants, various forms of algae and oomycetes. It is a polysaccharide consisting of a linear chain of several hundred to many thousands of β (1 → 4) linked d-glucose units. There are various extraction procedures for cellulose developed by using different processes like oxidation, etherification and esterification which convert the prepared celluloses into cellulose derivatives. Since it is a non-toxic, bio-degradable polymer with high tensile and compressive strength, it has widespread use in various fields such as nanotechnology, pharmaceutical industry, food industry, cosmetics, textile and paper industry, drug-delivery systems in treating cancer and other diseases. As illustrated in Figure 1, the molecular structure of cellulose reveals these repeating glucose units and the extensive hydrogen bonding that stabilizes the chain alignment, forming microfibrils within plant cell walls.

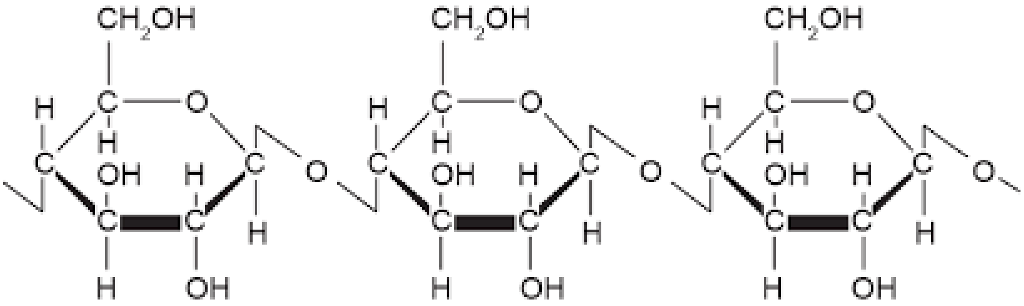

Figure 1: Molecular Chain Structure of Cellulose [4]

2.2 Cellulose Acetate

Cellulose Acetate $(C_6H_{10}O_5)_n \cdot x(CH_3COO)_m$ is a plant cell walls naturally contain cellulose, a naturally occurring polysaccharide, which is the source of cellulose acetate, a semi-synthetic polymer. It is created by reacting cellulose with either acetic acid or acetic anhydride in the presence of a catalyst, which causes the hydroxyl (-OH) and acetate (-OAc) groups in the cellulose molecule to be replaced. As shown in figure 2, the molecular chain of cellulose acetate consists of repeating glucose units with one or more hydroxyl groups substitutes by acetyl groups, reducing hydrogen bonding and enhancing solubility in organic solvent. This structural transformation makes cellulose acetate useful in various application such as films, fibers, and biodegradable plastics.

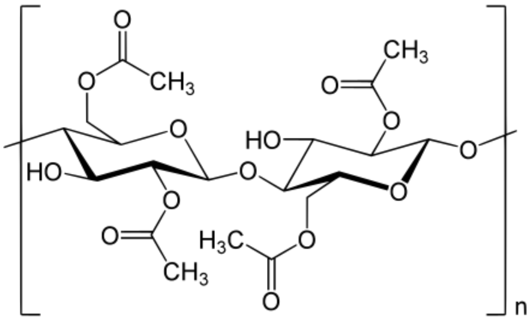

Figure 2: Molecular Chain Structure of Cellulose Acetate [4]

2.3 Cellulose Acetate Fibers as Raw Material in the Textile Industry

Cellulose acetate fibers, derived from natural cellulose through acetylation, provide textiles with softness, high gloss, moisture absorption, breathability, and durability. They're commonly used in clothing, linings, lingerie, and upholstery. Despite their advantages, their production involves chemicals, prompting sustainability efforts in the textile industry.

3.0 METHODOLOGY

3.1 Materials

The chemicals used are HNO_3, NaOH, Na_2SO_4, H_2O_2, CH_3COOH, and H_2SO_4. HNO_3 are used for Cellulose extraction in acid hydrolysis process. Meanwhile, NaOH and Na_2SO_4 are used in base hydrolysis process by doing this process it gives the highest cellulose production on EFB. CH_3COOH as acetylation agent, H_2SO_4 as catalyst and acetic acid as solvent.

3.2 Preparation Techniques

Figure 3 illustrates the process flow of the project work.

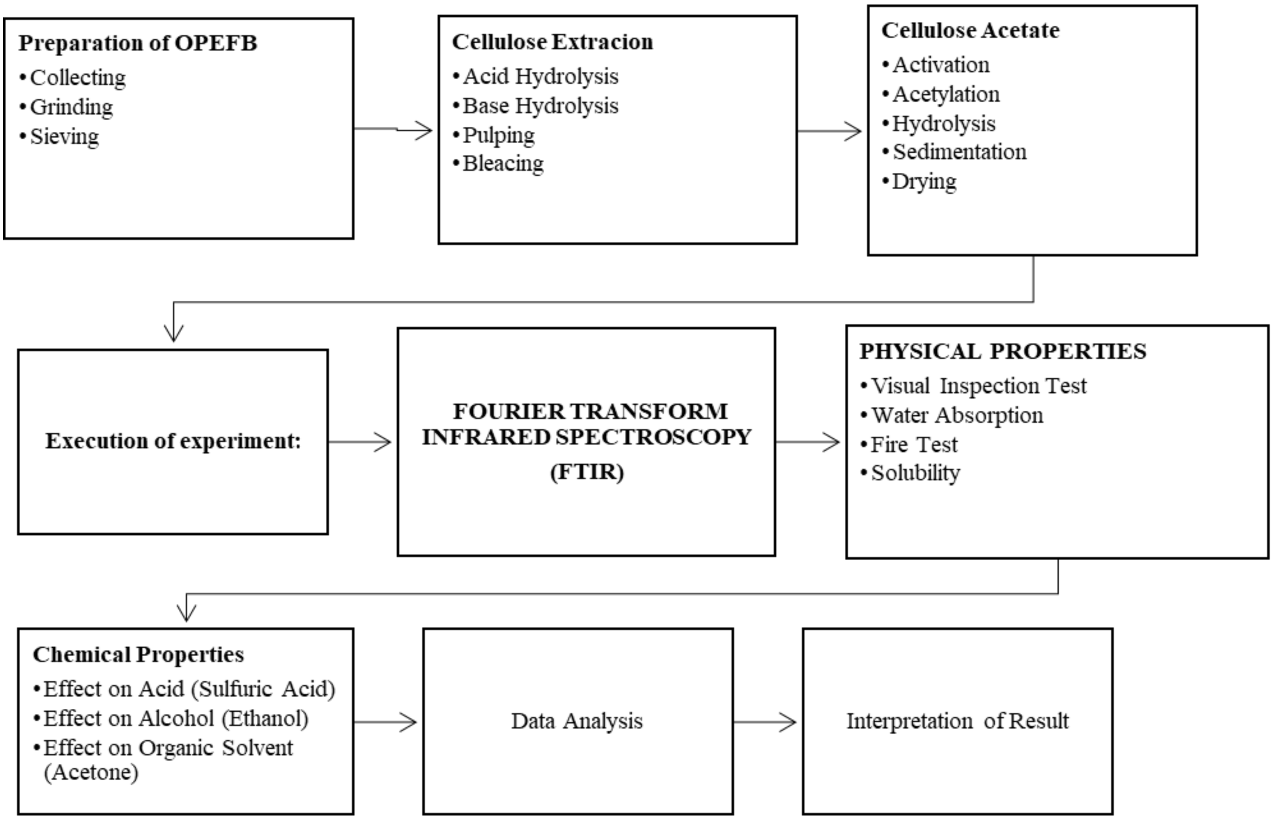

Figure 3: Process Flow of Project Work

3.3 Cellulose Production

The OPEFB waste in this study will first go through four steps in the cellulose extraction process (acid hydrolysis, acid hydrolysis, pulping and bleaching). OPEFB were manufactured by gathering from FELCRA Jaya Palm Oil Mill Kota Samarahan to initiate the reaction. Next, the OPEFB were sun-dried for 48 hours prior to being ground and sieved. Following drying and grinding, the EFB is combined with nitric acid and heated for two hours at 90°C. The OPEFB will undergo hydrolysis process once more using base acid, which is Sodium hydroxide and Sodium Sulphate, at 50°C for an hour. Next, the EFB will go through a pulping process in which it is combined with Sodium Hydroxide and heated at 80°C for three hours. Lastly, the OPEFB pulp will go through a bleaching process in which Hydrogen Peroxide is mixed with it at 60°C for 15 minutes. Acid hydrolysis, sometimes referred to as pre-treatment this process is for recrystallizing cellulose that used in production of regenerated cellulose materials like Cellulose acetate. Base acid, often referred to post-hydrolysis, where it is the second step in which the amorphous cellulose is converted to glucose. The purpose of the pulping process is to separate the fibers in water and release them from lignin that holds them together. Finally, bleaching is done during cellulose extraction to make the pulp whiter, brighter, and more absorbent than it would be.

3.4 Cellulose Acetate Produced from OPEFB

In cellulose acetate process it will undergo 4 processes (Activation, acetylation, hydrolysis and drying). The process begins with activation of cellulose acetate. The cellulose is treated to remove impurities and lignin. Next, the cellulose is then treated with acetic acid in the presence of sulfuric acid as a catalyst. This reaction results in the substitution of hydroxyl (-OH) groups in the cellulose molecule with acetyl (-COCH3) groups. The excess acetic acid is removed from the cellulose acetate by hydrolysing it after acetylation. To break down any unreacted acetyl groups, the cellulose acetate is treated with water or a diluted acidic solution in this stage. To achieve the correct moisture content, the refined cellulose acetate is dried to eliminate any remaining moisture. Lastly, depending on its intended use, the cellulose acetate may be formed into a variety of shapes, including fibers, flakes, or pellets. The procedures of extrusion, molding, or spinning can accomplish this.

3.5 Visual Inspection Test

The samples (Cellulose Acetate, Cotton, and Polyester) were prepared and examined each material for their unique characteristics. Next, findings are recorded separately for each material and summarized.

3.6 Water Absorption

The dry samples (cellulose acetate, cotton & polyester) are precisely weighed to establish the initial weight (W1) for comparison post-absorption. Next, completely submerge each sample in distilled water for a set duration. After immersion, remove excess water gently using filter paper and record immediate post-immersion weights (W2) to evaluate water retention. Lastly, calculate water absorption percentage using the formula

$$\text{Water Absorption Percentage}=(W1W3-W1)\times 100\% \quad \text{.................. Eq (1)}$$

where W1 is the initial weight and $W3$ is the final weight.

3.7 Fire Test

Small samples of cellulose acetate, cotton, and polyester fabrics are precisely measured to 0.2 grams each and cut into pieces approximately 1-2 cm in size. The test is conducted in a well-ventilated area with safety equipment nearby. Using tweezers, the samples are held near a flame, and their reactions are observed until fully burned, recording flame color, ash color, and ash characteristics. Results are compared with literature reviews for accuracy.

3.8 Melting Point

The melting point apparatus was set up, and clean samples of cellulose acetate, cotton, and polyester were obtained. Each sample was observed before heating. Starting with cotton, they were gradually heated, monitoring for signs of melting. Melting temperatures were recorded and compared with literature values to identify substances and assess purity.

3.9 Solubility

First, all the samples were placed inside individual tubes, and each tube was added a small amount of one solvent. The solvents used in this study were Sulfuric Acid, Ethanol and Acetone. Next, the tubes were stirred gently to facilitate dissolution. Lastly, the behavior of the samples in each solvent was observed and noted whether the material dissolved completely, partially, or remained insoluble.

4.0 RESULT & DISCUSSION

4.1 Production of Cellulose Acetate.

Figure 4 shows the Cellulose Acetate produced, and Figure 5 shows the cellulose acetate flakes used in the following experiment.

Figure 4: Cellulose Acetate Flakes

Figure 5: Cellulose Acetate Flakes After Hot Air Drying

4.2 Fourier Transform Infrared Ratio (FTIR) Analysis

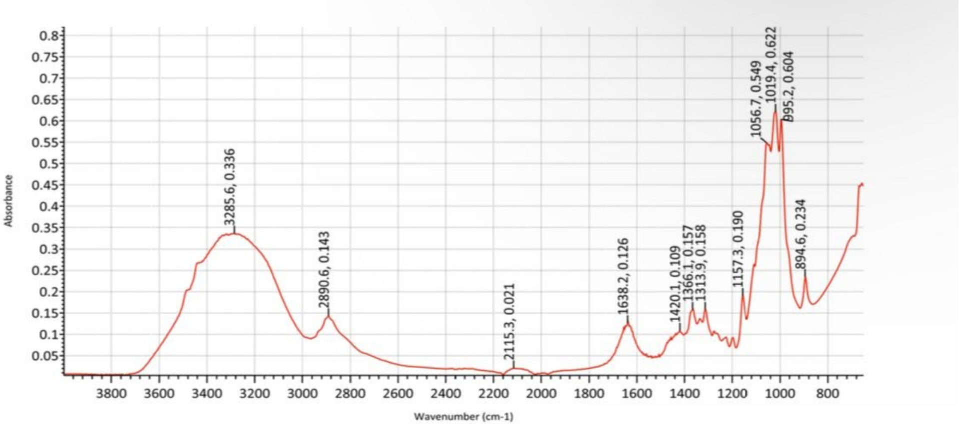

Figure 5: Cellulose FTIR

The FTIR plot of cellulose showed the presence of C-H stretching vibration at a wave number of 2899 cm^{-1}. this result is confirmed by X. Guo et al. [5]. They have succeeded in showing the formation of cellulose, which was confirmed by the peak appearance at a wave number of 2900 cm^{-1} that corresponds to the C-H stretching vibration. The peak formed at the wave number of 1638.2 cm^{-1} was identified as the water absorption area. This result is also confirmed by the results of research conducted by Lalu Suhaimi et al. [6]. Thus, based on the FTIR results, it was shown that cellulose was successfully extracted from OPEFB.

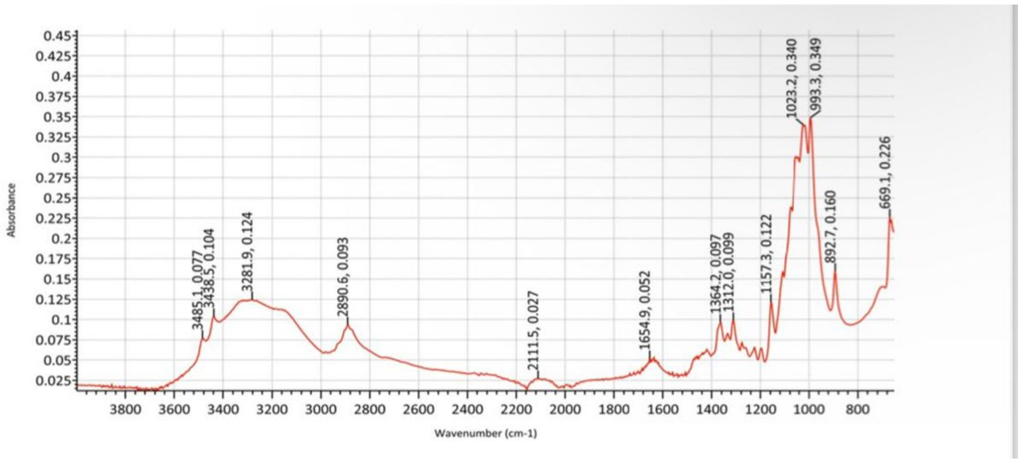

Figure 6: Cellulose Acetate FTIR

The FTIR plot of cellulose showed the presence of C-H stretching vibration at a wave number of 2899 cm^{-1} [5] have succeeded in showing the formation of cellulose, which was confirmed by the peak appearance at a wave number of 2900 cm^{-1} that corresponds to the C-H stretching vibration. The peak formed at the wave number of 1638.2 cm^{-1} was identified as the water absorption area. This result is also confirmed by the results of research conducted by Lalu Suhaimi et al. [6]. Thus, based on the FTIR results, it was shown that cellulose was successfully extracted from OPEFB.

4.3 Physical Properties

4.3.1 Visual Inspection Test

Table 1: Visual Inspection Results

Fibres	Appearance	Touch	Feel
Cellulose Acetate Flakes	Not smooth	Irregularly shaped flakes	Do not have a tactile feel
Cotton	Dull but lustrous when starched	Feel smooth and soft to touch	Warm to touch and not sticky when wet
Polyester	Lustrous acrylic fibres	Course and slippery to touch	Gives warm feeling, sticky when wet

Polyester fibre has a more lustrous appearance, is smoother, and slippery when it comes into contact with the skin, feels stretchy as compared to cotton fibre [7]. In comparison, cellulose acetate fibre flakes serve as the starting material to produce cellulose acetate-based textile products. They do not smooth as the finished cellulose acetate fabrics. In addition, cellulose acetate fabrics tends to have a smoother surface than both cotton and polyester[8] .

4.3.2 Water Absorption

Based on the water absorption test, 3 types of fabric are used to differentiate the water absorption rate of the product. The result is based on Table 2.

Table 2: Water Absorption Rate

Type of fibers	Cellulose acetate (time/minutes)		Cotton (time/minutes)		Polyester (time/minutes)	
	5	10	5	10	5	10
Water absorption (%)	42.80	46.29	46.20	48.82	52.30	61.25
Average water absorption (%)	44.55		47.51		56.78	

It was expected that the water absorption for cotton is higher than cellulose acetate and polyester. Polyester has lower water absorption compared to cotton due to its hydrophilic and chemical composition [9]. However, the experiment showed that the polyester has more water absorption percentage compared to cotton. It might be due to several reasons such as experimental conditions (temperature, humidity), fibre construction textures, fibre treatment and measurement methodology used to measure rate absorption percentage. Cellulose acetates are generally hydrophilic and does not exhibitive same level of water absorption as cotton and polyester [7]

4.3.3 Fire Test Data Analysis

Table 3: Fire Test Result

Parameters	Cotton	Cellulose Acetate Flakes	Polyester
Time (s)	27.67	15.50	21.00
Colour flame	Black	Black	Black
Melt	No	No	Melting
Burn	Burn	Burn	Burn
Smell	Smells like burning wood	Smells like burning paper and vinegar	Smells like a sweet chemical
Ash colour	Blackened flaky	Greyish black	Black

Cellulose acetate flakes typically burn at a moderate rate [10]. But depends on factors such as the thickness of the materials [11]. The cellulose acetate tends to produce minimal ash compared to cotton and similar or slightly more ash compared to polyester. The ash color for cellulose acetate is lighter [12]. The burning smell produced by cellulose acetate is typically vinegar-like [12].

4.3.4 Melting Point

Table 4 shows the melting point data from the execution experiment and the Material Safety Data Sheet (MSDS)

Table 4: Melting point data

Specimen	Melting point (Experimental)	MSDS
Cellulose Acetate Flakes	272	260
Cotton	148	149
Polyester	255	240

It was expected that cellulose acetate would have a higher melting point than cotton and polyester. This is because of its chemical composition and bonding. Cellulose acetate is a synthetic polymer generated from natural cellulose fibres. We took oil palm empty fruit bunches (OPEFB) and chemically modified them. During this procedure, cellulose's hydroxyl group is exchanged with an acetate group. Cotton has the lowest melting point because it is not a thermoplastic fibre. It has no glass transition temperature and remains flexible even at very low temperatures. At elevated temperatures, cotton decomposes instead of melting.

The chemical nature of cellulose acetate causes it to have a greater melting point than cotton and polyester. The acetate groups in cellulose acetate strengthen intermolecular forces. Cellulose acetate molecules are more organized and closely packed than the uneven structure of cotton and polyester, which contributes to their higher melting point. Cotton has a looser structure, resulting in weaker forces, whereas polyester, despite having stronger forces, often has a lower melting point than cellulose acetate due to structural variations.

4.3.5 Solubility

Table 5 shows the result of chemical properties testing in effect for acids, alcohol, and organic solvents.

Table 5: Results of chemical properties testing

Solvent	Cotton	Cellulose Acetate Flakes	Polyester
Acid (Sulfuric Acid)	Soluble	Burned and soluble partially	Soluble Completely
Alcohol (Ethanol)	Not soluble	Soluble partially	Not soluble
Organic Solvent (Acetone)	Not soluble	soluble	Not soluble

Cellulose acetate flakes are soluble in organic solvents like acetone [13]. Cotton and polyester are insoluble in acetone due to their natural cellulose composition and synthetic polymer composition, respectively. Cellulose acetate flakes, cotton, and polyester are generally insoluble in alcohol due to their chemical composition and molecular structures [14]. Cellulose acetate and polyester are generally resistant to sulfuric acid, while cotton is susceptible to degradation and weakening when exposed to sulfuric acid. However, prolapsed exposure may cause degradation to cellulose acetate and polyester [15].

4.4 Chemical Properties

4.4.1 Effect of Acids

Figure 7-9: Effect of Acids

Cellulose acetate flakes partially dissolve in sulfuric acid. Cellulose acetate flakes hydrolyse in sulfuric acid, break down the acetate ester groups, and release acetic acid. The sulfuric acids also hydrolyse the cellulose fibres in cotton [15].

4.4.2 Effect on Organic Solvent (Acetone)

Figure 10-12**:** Effect in Acetone

Acetone dissolves Cellulose Acetate flakes due to the similar polarity of the solvent. Acetone may not have a significant chemical reaction with polyester.

4.4.3 Effect of Alcohol

Figure 13-15**:** Effect in Alcohol

Cellulose acetate flakes, polyester and cotton were not dissolved in the ethanol. Ethanol does not have a significant chemical reaction effect on cellulose acetate flakes, cotton, and polyester. Ethanol is not typically used as a solvent for these materials [14].

5.0 CONCLUSION

The present study successfully demonstrated the production of cellulose acetate from oil palm empty fruit bunches (OPEFB) via the acetylation process. The resulting cellulose acetate flakes exhibited significant alterations in both physical and chemical properties compared to their original cellulose precursor. Key findings revealed that the degree of substitution (DS) achieved was within the optimal range for industrial-grade cellulose acetate, confirming effective acetylation. Physically, the cellulose acetate flakes displayed improved thermal stability, reduced moisture absorption, and increased transparency and the characteristics favorable for applications in biodegradable plastics and film-based materials. Chemically, FTIR analysis confirmed the presence of acetyl functional groups, indicating successful substitution of hydroxyl groups. Compared to cotton and polyester, the cellulose acetate from OPEFB showed intermediate hydrophobicity and biodegradability, making it a sustainable alternative with versatile application potential in textiles, packaging, and biomedical materials. These findings underline the viability of OPEFB as a low-cost, renewable feedstock for value-added cellulose derivatives.

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