Faculty of Electronic & Computer Technology and Engineering

DEVELOPMENT OF OPTICAL MICROFIBER SENSOR FOR COCONUT WATER CONCENTRATIONS USING A TAPERING METHOD

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I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology with Honours.

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Date : 11/02/2024

ABSTRACT

Fiber-optical sensing refers to using fiber-optic cables to measure physical or chemical parameters in various applications. This project aimed to detect different parts of coconut using a tapering approach by employing microfiber optics as a sensor. The single-mode fiber will be tapered using the tapering method, and the best size of microfiber optics will be used forfurther investigation as a liquid sensor. Furthermore, three samples of coconut parts, such aswater, coconut milk, coconut oil, and coconut water, each with a different concentration, will be evaluated. The graph's sensitivity, correlation, and coefficient of determination all rely entirely on the part of coconut concentration, and the light source will be used to summarise the experiment's results.

ABSTRAK

Penginderaan serat optik merujuk kepada penggunaan kabel serat optik untuk mengukur parameter fizikal atau kimia dalam pelbagai aplikasi. Projek ini bertujuan untuk mengesan bahagian kelapa yang berbeza menggunakan pendekatan yang meruncing dengan menggunakan Optik Mikrofiber sebagai sensor. Serat mod tunggal akan meruncing menggunakan kaedah tirus, dan ukuran Optik Mikrofiber Terbaik akan digunakan untuk penyelidikan lebih lanjut sebagai sensor cecair. Selanjutnya, tiga sampel bahagian kelapa, seperti air, santan, minyak kelapa, dan air kelapa, masing-masing dengan kepekatan yang berbeza, akan dinilai. Sensitiviti grafik, korelasi, dan pekali penentuan semuanya bergantung sepenuhnya pada bahagian kepekatan kelapa, dan sumber cahaya akan digunakan untuk meringkaskan hasil eksperimen.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to offer my thanks to Dr Aminah binti Ahmad, my supervisor, for his invaluable assistance, wise words, and patience during this project. Additionally, I am thankful to Universiti Teknikal Malaysia Melaka (UTeM) for providing the financial support necessary to complete the research. Not to mention my coworkers, classmates, and family members for their unwavering support during the completion of this bachelor's degree Project. Additionally, I would like to express my gratitude to my bachelor's degree Project panel member, Ts. Dr. Norhashimah binti Mohd Saad and Dr. Vigneswaran Narayanamurthy, for their constructive criticism and suggestions on my Bachelor's Degree Project.

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n_1	-	the mediums that will impact the refraction entering
n_2	-	the mediums that will impact the refraction leaving
θ_1	-	the angle of incidence
θ_2	-	the angle of refraction
μm	-	Micrometer

LIST OF ABBREVIATIONS

SMF - Single mode fiber

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CHAPTER 1

INTRODUCTION

1.1 Background

A fiber optic sensor is a type of sensor that uses optical fibers to transmit and detect signals from the sensing element to the measurement electronics. The sensing element can be a material that changes its optical properties in response to a physical or chemical parameter, such as temperature, pressure, strain, or chemical composition. Fiber optic sensors were first developed in the 1960s, but it was not until the 1980s that they began to be widely used in industrial and scientific applications. Since then, the field of fiber optic sensing has grown rapidly, and fiber optic sensors are now used in a wide range of applications, including structural health monitoring, oil and gas exploration, medical diagnostics, and environmental monitoring. One of the key advantages of fiber optic sensors is their ability to operate in harsh environments, such as high temperatures, electromagnetic interference, and corrosive environments. Fiber optic sensors can also be used for remote sensing, meaning that they can be installed in hard-to-reach places and monitored from a remote location.

Optical microfibers are a type of optical fiber that has a very small diameter, typically on the order of a few micrometres or less. They are typically made from glass or other transparent materials and are used for a variety of applications, including sensing, communications, and photonics. The concept of optical microfibers was first proposed in 2003 by Liang et al. at the University of Sydney. The researchers demonstrated that tapering a conventional optical fiber down to a very small diameter could create a new type of fiber with unique optical properties, such as strong light confinement and low propagation losses.

1.2 Problem Statement

Currently, there is no reliable and efficient method for measuring coconut water concentration in various applications, such as in the food industry, which can affectthe quality and safety of products. Conventional methods for detecting part of coconut concentration, such as titration and refractometry, can be time-consuming, require complex instrumentation, and are prone to errors. Existing fiber-optic sensing systems for detecting various parameters are often limited by their sensitivity, accuracy, and robustness in harsh environments, such as high temperatures or corrosive environments. Therefore, this research aims to develop an innovative fiber-optic sensing system using microfiber optics for the reliable and accurate detection of coconut liquid concentration. By employing a tapering approach, microfiber optics as sensors can achieve high sensitivity, compact size, and immunity to electromagnetic fields, making it ideal for harsh environments. This research will contribute to the development of an efficient and reliable method for measuring coconut liquid concentration that can be used in various applications, including the food industry, to ensure product quality and safety.

1.3 Project Objective

After the problem statement has been determined, the project objectives are as follows:

a) To investigate microfiber optics as a liquid sensor using the tapering method.

b) To develop microfiber optics as a liquid sensor to detect various types of coconut liquid concentrations using the tapering method.

c) To analyse the performance of the optical microfiber as liquid sensors to detect various types of coconut liquid concentrations.

1.4 Scope of Project

Microfiber optics is used as a liquid sensor to detect coconut liquidconcentration. The liquid sensor is developed by using the tapering method at different sizes.Furthermore, all different sizes will be tested, and the best size is determined based on sensitivity. As the best liquid sensor will be developed, further investigation will be carriedout on coconut liquid concentrations. There will be three samples of different concentrations of coconut liquid, such as coconut water, coconut milk and coconut water tested. Before each test, the fiber would be dipped in the samples and then measured. In a line graph, each measurement would have different results. The experiment's findings will be described in terms of sensitivity, correlation, and coefficient of determination of the graph, all of which are completely dependent on the coconut liquid concentration and light source.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the past 50 years, fiber-optical sensing has been a highly successful application of fiber optics and sensing technology. Recently, there has been a focus on miniaturising fiber-optic sensors due to advancements in micro/nanotechnology and the need for sensors with better performance and versatility. Reducing the size of a sensor is important for achieving faster response, higher sensitivity, lower power consumption, and improvedspatial resolution. One promising solution for achieving miniaturisation is the use of optical microfibers, which are made by taper-drawing glass or polymer materials such as optical fibers. Optical microfibers combine fiber optics with nanotechnology and have become a new platform for exploring fiber-optic technology on a micro or nanoscale. They guide light with low optical loss and offer excellent mechanical flexibility, tight optical confinement, and large fractional evanescent fields. These properties make them ideal for optical sensing, providing advantages such as faster response, higher sensitivity, and lower power consumption. Researchers have already demonstrated various types of physical, chemical, and biological optical sensors based on microfibers. In this review, we examine the recent advancements in microfiber optical sensors, including their waveguide properties, fabrication methods, and applications in sensing. However, microfiber optical sensors offer unique advantages and have been widely explored in various sensing applications. This chapter will thoroughly describe microfiber optic sensing, microfiber fabrication, and microfiber optic applications in various fields, as well as some important works related to this topic.

2.2 Optical Microfiber

Microfiber optics possess several distinct characteristics that make them highly desirable for various applications. These properties include strong optical confinement, customisable flexibility, high optical confinement, and a wide evanescent field. These features make microfiber optics well-suited for physical sensing applications such as surface absorption spectroscopy with exceptional sensitivity, hydrogen detection, as well as chemical and refractive index sensors (Chen, G. Y., Ding, M., Newson, T., & Brambilla, G. (2013)). The propagation of microfibers generates significant evanescent waves due to their sensitivity to changes in the surrounding refractive index. As the proportion of power transmitted in the evanescent field increases, the refractive index of the surrounding material also increases. This characteristic enables effective evanescent coupling with other waveguides, including metal, semiconductor, and substrate, thereby facilitating robust sensing capabilities. The refractive index, core diameter, and operating wavelength of a fiber can influence the type and number of modes that can propagate through it. While most of the light energy remains confined within the fiber, with some extending into the clad, a small fraction exponentially decays towards the edge of the core-cladding region. Tapering common single-mode fibers (SMF) can enhance the low amplitude evanescent fields, increasing their interaction with transmitted light in the taper area.

2.2.1 Single-mode fiber

Single-mode fiber is commonly used for longer distances due to its smaller glass fiber core diameter. The reduced diameter results in lower attenuation, minimising signal power loss along the transmission. By concentrating the light into a single beam through the smaller core, the signal is provided with a more direct path, enabling it to travel greater distances. Moreover, single-mode fiber exhibits a significantly larger bandwidth compared to multimode fiber. Consequently, laser light is frequently employed as the light source for single-mode fiber. However, it is important to note that the production of laser light within a narrower core requires precise calculations, making single-mode fiber generally more expensive.

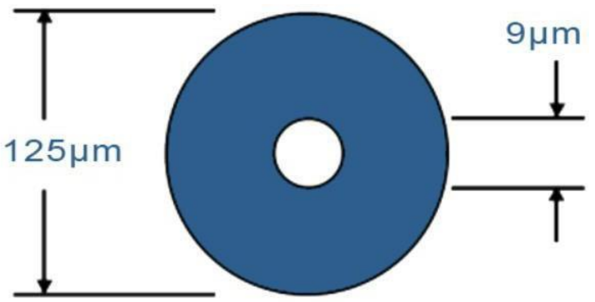

Figure 2.1 Fiber Optic Internal Structure of Single Mode

An optical fiber consists of three essential components: the core, cladding, and coating or buffer. Among these, the core holds the utmost significance as it serves as the pathway for light transmission. In comparison to multi-mode fibers, single-mode fibers possess a significantly smaller core. The core diameter of single-mode fibers typically measures around 9 micrometer (μm). Surrounding the core is the cladding, which enlarges the overall diameter of the optical fiber to 125 μm. By confining the light to a single light wave, the small core effectively eliminates any overlap or distortion of light pulses, resulting in minimal signal attenuation and the highest transmission speed possible.

Figure 2.2Single Mode for Light Path

Single mode is quicker than multimode across long distances since it requires fewer switches or routers in the mid-span. Almost limitless bandwidth capacity. Furthermore, this cable can transfer data at up to 40Gb across hundreds of kilometres with minimum integrity loss, and it can transport data at up to 10Gb over longer distances, such as thousands of kilometres. Single-mode cable and connections are less costly than multimode cable and connectors.

2.2.2 How fiber optic working

Fiber optics function based on the principle of total internal reflection, enabling the transmission of light signals through glass or plastic fibers. When a light signal is injected into the fiber optic cable, it undergoes multiple internal reflections as it travels down the fiber(Srinivasan, B., & Venkitesh, D. 2017). Total internal reflection occurs when the angle at which light hits the boundary between the core and cladding exceeds a critical angle(Zhang, S., Liu, H., Coulibaly, A. A. S., & DeJong, M. 2021). This reflection keeps the light signal confined within the core, preventing significant signal loss. At the receiving end, the light signal is detected by a photosensitive device, such as a photodiode, which converts it into an electrical signal for further processing. Fiber optics offer advantages such as high bandwidth, low signal loss, resistance to electromagnetic interference, and the ability to transmit signals over long distances. This makes fiber optics an essential technology for applications in telecommunications, internet connectivity, medical imaging, and more.

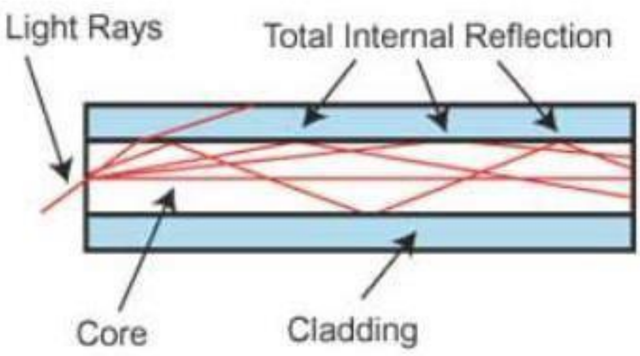

Figure 2.3 Total internal reflection inside the core

2.3 Properties of Optical Microfiber

Microfiber possesses a range of fascinating optical characteristics, including a robust evanescent field. The evanescent field effectively distributes fractional power at the external boundary of microfibers with small radio. This attribute plays a crucial role in the production of resonators with high quality factors (Q) and facilitates the efficient transmission of light into high Q micro-resonators. Moreover, microfiber demonstrates significant near-field interaction with its surroundings, exhibiting favorable evanescent coupling between the microfiber and other waveguides like substrates, semiconductors, and planar waveguides. Consequently, this property enables the creation of numerous optical devices, such as resonators, sensors, and lasers.

Propagation loss is a significant characteristic to consider when it comes to microfiber. This loss occurs due to various factors, such as cracks, impurities attached to the surface of the micro/nano fiber, and imperfections on the surface. As the radii of the microfiber decrease, the propagation loss increases. Researchers have conducted theoretical studies on non-adiabatic intermodal transitions to determine the minimum diameter of the microfiber waist that can effectively transmit signals. It has been observed that the transmission mode disappears when the rate reaches a threshold value that is typically smaller than the wavelength of the radiation. Additionally, it has been discovered that small-sized microfibers degrade more quickly in air when cracks form at the facet as a result of water absorption.

Furthermore, because to its small mass, microfiber is very sensitive to momentum changes of photon guides through mechanical displacement or vibration mass. This enable a development of compact optomechanical components or devices. It also provides for reduced loss when transferring light via sharp bends. As a result, microfiber is formed by extending the optical fibers till they reach the necessary waist diameter. This enables low-loss splicing with other standard-size optical fibers. It can also be bent to build compact devices with a small bending radius. Outside of the microfiber, the small waist fiber transmits a significant amount of power and overlaps with external parts. Any changes in the surrounding attributes result in a change in the output. As seen in Figure 2.4. (Brambilla, G. 2010).

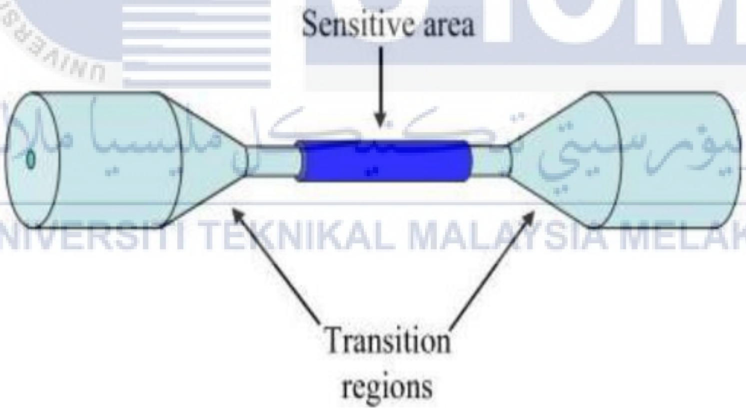

Figure 2.4 Sensitive area has a large fraction of power propagating to interact with the surrounding environment

2.4 Snell's Law Concept

When light transitions between different mediums, it undergoes bending and refraction. Bending can be determined using the law of refraction, which is more complex than the law of reflection but crucial for understanding lenses and their future applications. Snell's law, named after its discoverer Willow Broad Snell in 1621, describes the law of refraction. Similar to reflection, refraction depends on the angle of incidence, with rays refracted at points perpendicular to the surface of refraction. The medium through which light travels also influences refraction, just like reflection. Snell's law utilises the index of refraction to express this dependency. The index of refraction is determined by the wavelength of the light under examination. Certain materials exhibit a higher index of refraction for short-wavelength blue light compared to longer-wavelength light, such as red light.

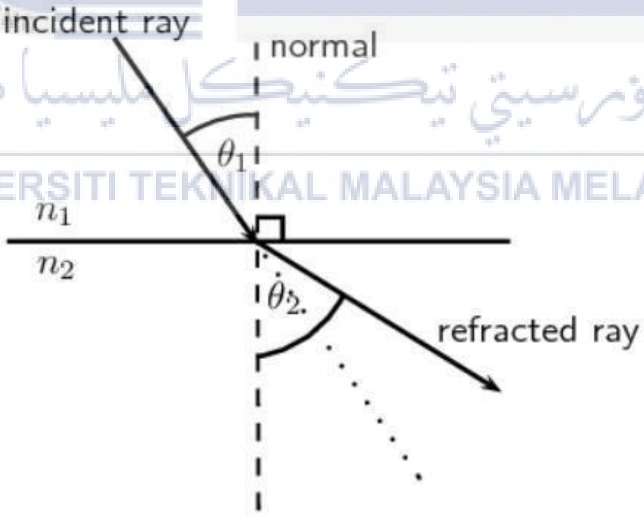

Figure 2.5Snell's Law Concept

Based on Figure 2.5 Snell's law can be represented as below:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Where:

n_1 are mediums that will impact the refraction entering.

n_2 are mediums that will impact the refraction leaving.

θ_1 is the angle of incidence.

θ_2 is the angle of refraction.

2.5 Tapering method

Tapering a single mode fiber involves pulling the end of the fiber while heating its waist to decrease the diameter of the cladding and core. During the tapering process, light travels through the core and extends into the cladding. This creates a new core, while the outer layer functions as a new cladding. To achieve a high signal-to-noise ratio and minimise optical loss, it is crucial to maintain surface smoothness and geometric uniformity throughout the microfiber production process. Furthermore, as the fiber is pushed through the tapering process, its radius decreases. The light transitions from the core to the cladding and propagates across the tapered region, affecting the mode as it interacts with the core, cladding, and surrounding air. The shape of the taper influences the mode behavior within the tapered fiber or microfiber. Excessive tapering can lead to non-adiabaticity, resulting in poor transmission. On the other hand, reducing the tapering angle promotes more adiabatic mode propagation. The distinction between adiabatically tapered fibers and non-adiabatic tapered fibers is illustrated in the diagram below.

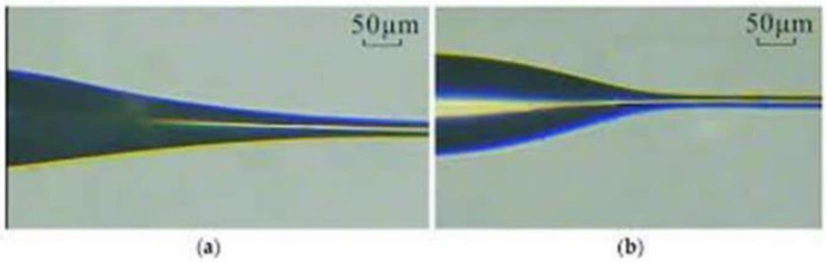

Figure 2.6 (a) Adiabatic tapered fiber and (b) Non-adiabatic tapered fiber

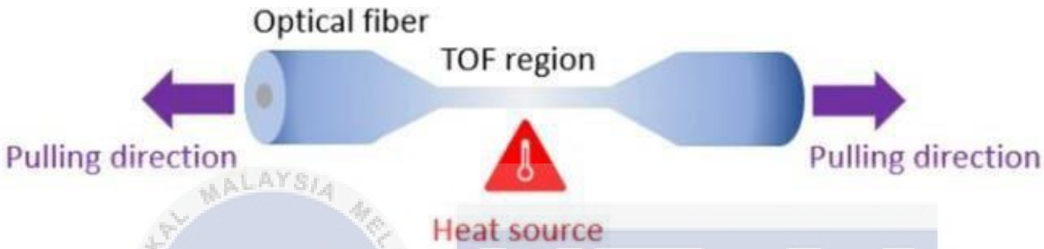

Figure 2.7 Illustration of the flame approach used for the fabrication of tapered optical fibers

2.6 Coconut

The coconut is a versatile fruit that is both nutritious and economically important. It is a dietary staple in tropical regions, and its various parts are used in a variety of industries. Coconuts are a good source of essential nutrients, including proteins, vitamins, and minerals. They also contain unique medium-chain triglycerides that have notable metabolic benefits. The different parts of the coconut liquid have been extensively studied for their benefits and drawbacks. (Anuradha, K., Sudha, M., & Srinivasan, K. 2013)

Table 2.1 Different part of coconut liquid

Part of Coconut Liquid	Benefit	Drawback
Coconut water	Coconut water is the clear liquid found inside immature coconuts. It's known for being a refreshing, natural beverage that's rich in electrolytes like potassium, making it an excellent choice for rehydration. Furthermore, due toits similar composition to human plasma, it has historically been used as a short-term intravenous hydration fluid.	While coconut water is a good source of electrolytes, it may not be suitable as a sports drink for intense, prolonged exercise due to its low sodium content, an essential electrolyte lost during sweating. Additionally, it contains sugars, which, if consumed excessively, could contribute to increased calorie intake and weight gain.
Coconut Milk	Coconut milk, derived from the grated meat of mature coconuts, is a rich source of nutrients, including vitamins C, E, B1, B3, B5, and B6 as well as iron, selenium, sodium, calcium, magnesium, and phosphorus. Coconut milk's creamy texture makes it a popular choice in many dishes, especially in vegan and dairy-free diets.	Similar to coconut oil, coconut milk is high in saturated fats, which may increase cholesterol levels if consumed in large quantities. Additionally, canned or processed coconut milk may contain additives or sweeteners that increase the sugar and calorie content.

2.7 Summary

This chapter will explore the techniques employed to create tapered microfibers, particularly optical microfibers. Extensively studied, these miniature fibers have shown remarkable properties for manipulating light at the micro and nanoscale. By reducingthe diameter of optical fibers to the wavelength scale, optical microfibers have openedexciting possibilities for both scientific research and technological advancements. With theirability to guide evanescent fields with minimal loss, strong near-field interaction, and compact sizes, these micro or nano fibers have facilitated the development of new applications in atom optics. These breakthroughs have the potential to extend the use of lightbeyond traditional optics, paving the way for an exciting future in fiber optics and technology.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the proposed methodology for this project, which consist of the methods that will be performed to achieve the right possible output. The importance of having the right method will determine and detect the project's fault. The main methodology principle will elaborate on the phase and step of this project. The proposed study aims to create a sensor that can detect the concentration of various types of coconut liquid.

3.2 Project Flow Chart

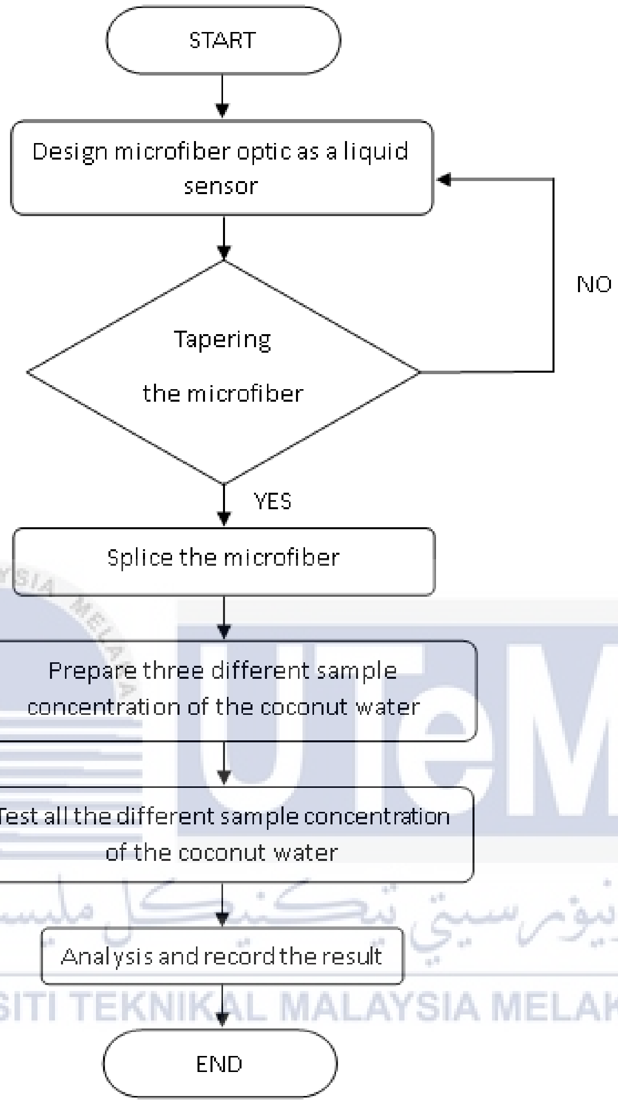


Figure 3.1 Process flow of project

To achieve the project objectives, a flowchart was devised to guide and summarise the step-by-step phases, as depicted in Figure 3.1. The project initiation involved designing a microfiber to function as a liquid sensor, with three distinct concentrations of Coconut Water as samples. A single-mode fiber (SMF) was chosen for use as the sensor. The subsequent step involved the fabrication of a tapered fiber, a process that entails reducing the diameter of the cladding (along with the core) by pulling the fiber's end while heating its waist.

Optimal sensitivity is achieved through smaller diameter taper waists. All microfibers were cut to the same length to minimise losses during experimentation. The mounting part, stripped for use as a sensor, was also cut to the same length. If the splice of the microfiber optic sensors proves effective, the process can proceed to the next step; otherwise, it moves to the fiber optic sensor setup.

The next step is to prepare three sample of different concentration of coconut water containers that will be used to conduct the experiment. At first, the container will be pierced to allow the fibers to fit inside. The container will then be filled with three sample of different concentrations of coconut water which is 25%, 50% and 75% coconut water.

Once the setup is complete, the Optical Power Level will project a beam onto the microfiber, and the resulting data will be collected using the Optical Power Meter. This data will be crucial in determining the reading values influenced by varying concentrations of coconut water. Subsequently, the experiment's outcomes will be scrutinised, focusing on sensitivity and linearity, which are contingent on both the coconut water concentration and the light source. The findings will be presented through tables and graphs. In summary, the performance of the microfiber optic as a liquid sensor is deemed outstanding, evaluated through factors such as transmitted power and wavelength shifting. The linearity, particularly in relation to the three different concentrations of coconut water, is also characterised as commendable.

3.2.1 Splicing Process

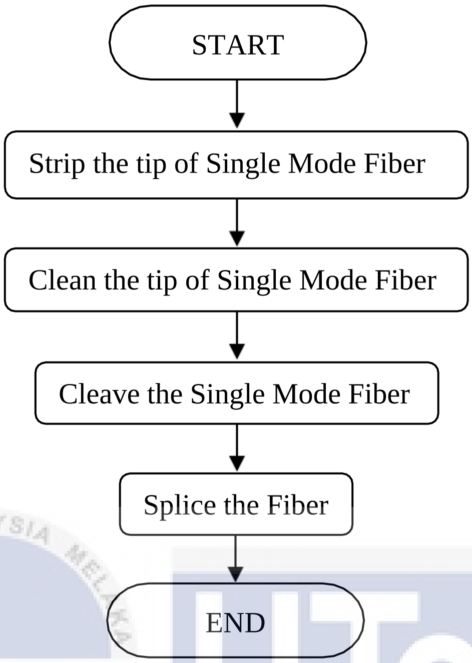
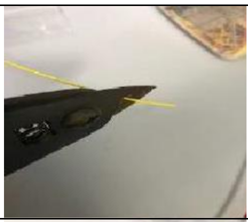
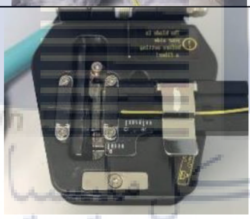


Figure 3.2 Flowchart of Splicing Process

The initial step involves the removal of the coating layer from the Single Mode Fiber using a fiber optic cable remover. Subsequently, the fibers were thoroughly cleaned with alcohol to eliminate any residual dust or coating. Next, the fibers are precisely cleaved using the high-quality Fujikura CT-30 cleaver to create flat faces. To connect two fibers that have been stripped and cleaned, the Fujikura FSM-18R splicing tool is utilised. The stripped fibers are carefully inserted into the splicer, ensuring that their orientations align in the same direction.

Table 3.1 Complete Steps for Splicing using Fujikura FSM-18R

No	Procedure	Description
1		Remove the outer layer of the optical cable.
2		Remove the optical cable's second layer (cladding).
3		Remove dust using alcohol and tissues.
4		Cut the optical cable with a high-precision cutter.
5		Place the cable on the separator and try to keep it in the same position.
6	  	Press the start button and wait until the connection is complete.
7		The connecting cable is now ready for installation on stage.

3.2.2 Tapering Process

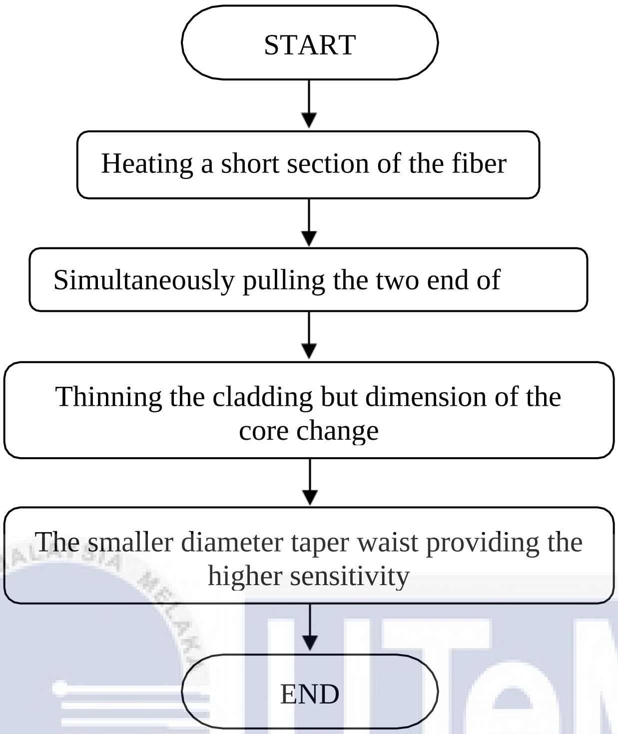


Figure 3.3 Flowchart of tapering process

The fabrication process for tapered optical microfibers typically involves heating a short section of the fiber while simultaneously bringing its two ends closer together. A gas burner flame is utilised as the heat source in this case. One of the main functions of cladding in single-mode optical fibers is to minimise the extent to which the electric field of the propagating mode penetrates into the surrounding medium.

Furthermore, the core and cladding diameters are reduced proportionally during the tapering process. As a result, light is transferred from the untapered fiber's fundamental mode to modes within the tapered region that may interact with the surrounding medium. Subsequently, the optical fiber cladding is thinned while maintaining the same core size. This thinning of the cladding increases the interaction of the propagating mode's electric field with the surrounding medium. It is important to note that the sensitivity of the taper increases with smaller diameter waists.

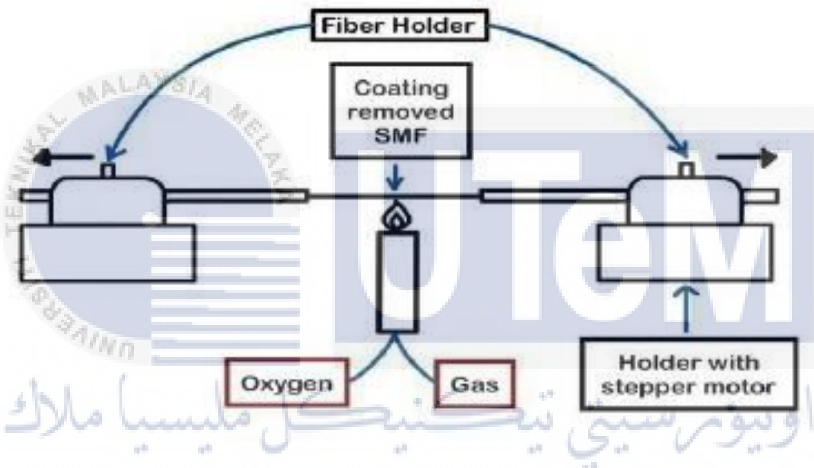


Figure 3.4 Schematic illustration of tapering process

3.2.3 Concentration Preparation Process

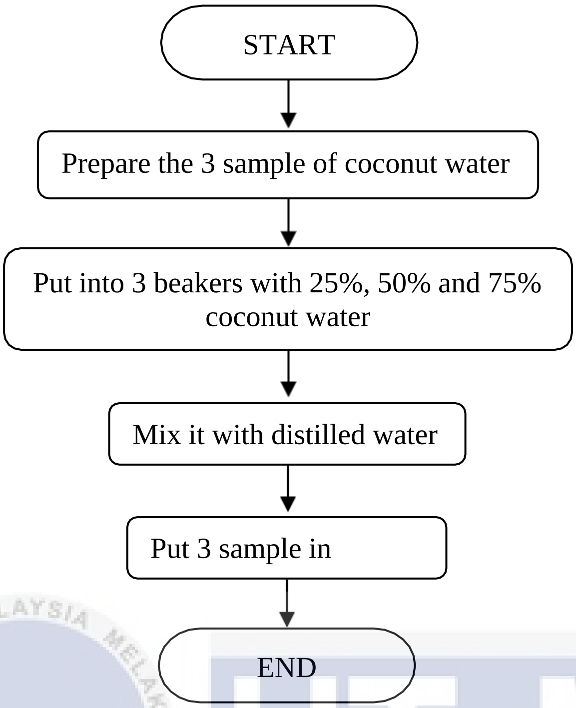


Figure 3.5 Concentration preparation Process

To conduct the experiment, three samples of coconut water were meticulously prepared. Each sample was accurately measured and placed in separate beakers, with concentrations representing 25%, 50%, and 75% of coconut water where 25% is 15 ml, 50% is 30 and 75% is 50ml. To ensure uniformity and facilitate the testing process, each sample was mixed with 10% distilled water which is 10ml. Subsequently, the prepared samples were carefully transferred into cuvettes, setting the stage for the forthcoming analysis. This systematic approach in sample preparation lays the foundation for a comprehensive investigation into the performance of microfiber optics as liquid sensors in detecting various concentrations of coconut water.

3.2.3.1 Experimental Setup Process

In the spectrophotometer process, we need to calibrate first to make sure there is no light in the spectrophotometer. This is to make sure the absorbance of light in the spectrophotometer is not disturbed by natural light from outside spectrophotometer make sure the value of transmittance, absorbance are 0 like in figure 3.6.

Figure 3.6 Calibrated Spectrophotometer

Once that's set, we insert the cuvette with our coconut water sample, and the spectrophotometer shines light through it.

Figure 3.7 Sample in cuvette tube

Figure 3.8 Cuvette tube in spectrophotometer

By measuring how much light gets absorbed at the same wavelengths 550 µm, it produces what we call an absorbance spectrum. Then analyse this data, comparing it to our calibration curve, to figure out the concentration of substances in our coconut water samples. Generally, higher absorbance values indicate higher concentrations. This whole process is crucial for understanding how well optical microfibers detect and measure different concentrations of coconut water, giving us valuable insights into their performance as liquid sensors.

3.3 Experimental Setup Process

Single-mode optical fiber sensors are connected to an Optical Power Level at the input to assess the concentration of coconut liquid. The Optical Power Level emits a wavelength of 1550 µm to the fibers, and the resulting optical power is measured in dBm using an optical power meter. Before conducting the experiment, a container is set up, and each drop of water is carefully poured into it. Subsequently, the sensor is placed in the prepared container for testing. The sensor is tested three times with the same type of water to obtain accurate measurements, and an average measurement is recorded. This procedure is repeated for each type of water being evaluated. The data collected is analysed based on the type of coconut liquid used and its concentration. The results are then utilised to create a graph representing the concentration of each coconut liquid.

3.3.1 Equipment

Table 3.1 Equipment that was used in project.

No.	Material Name	Equipment	Description
1.	SimpliFiber® Optical Power Level		• Source of input that is connected to the fiber. • The wavelength is set at 1550 µm
2.	SimpliFiber® Optical Power Meter		• The output is measured and sent to the display. • The device that displays the result is the output device.

3.	Commercial Splicer Fujikura FSM-18R		• Splice the fiber together
4.	Cleaver Fujikura CT-30		• To make the fiber tips flat
5.	Fiber Optic Stripper		• Remove the cladding on the • optical fiber.
6.	Single mode fiber		• Used in the development of sensor
7.	Single mode connector (pigtail)		• Use to connect the optical spectrum analyser to the sensor
8.	Rubbing Alcohol		• Remove the residual or dust after cleaving and before splicing
9.	Plastic container		• To place the sensor that immerses in the water

10.	Coconut liquid		• Main equipment for experimenting.
11.	Spectrophotometer		• To check concentration of coconut water
12	Cuvette Tube		• To put sample of coconut water

3.4 Summary

This chapter presents a proposed process for constructing optical microfiber sensors using various types of coconut liquid concentration. The main objective of this approach is to optimise the waveform output value obtained from the optical power level and optical power meters. The emphasis is placed on a less rigorous and more practical estimation method that does not significantly compromise the results' accuracy. The process allows for the creation of multiple varieties of coconut liquid using the same methodology. Instead of striving for the highest degree of precision, the ultimate goal of this technique is to maximise efficiency, ease of use and manipulation, and the practicality of microfiber optic sensors.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and analyses of developing a microfiber optic sensor using various types of coconut. Case studies were conducted to demonstrate the sensitivity of the microfiber optic cable. These studies aimed to determine the sensitivity of coconut water. The main objective of these case studies was to showcase a recommended approach applicable regardless of the coconut water used. The coconut underwent three tests to obtain an average outcome.

4.2 Results and Analysis

The following table and figure below are the analysis of coconut water testing results. These analyses are separated into several information: the time, number of tests, average value for each time taken, sensitivity, linearity and repeatability.

4.2.1 Size of Tappered Microfiber

The size of the microfiber is measured using a microscope at the FTKIP lab. It is important to determine the microfiber's size to analyse the microfiber's sensitivity level. The sizes found are 21.7 µm, 28.5 µm, and 10.8 µm. Sizes are investigated by measuring the range of axis-y.

The first sample showed the best tapered microfiber with the smallest size, resulting in the highest sensitivity compared to the two other samples. The smallest size of microfiber could make the microfiber very sensitive.

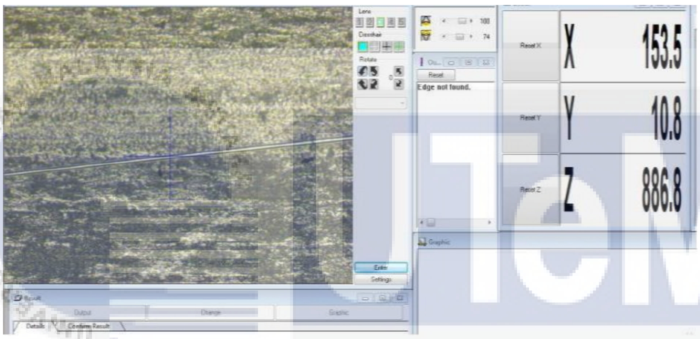


Figure 4.1 Sample A (10.8 µm)

The diameter of axis-Y for the second sample shows the biggest size among the three tapered sample sizes. Therefore, this sample will represent the lowest sensitivity among the two samples. Figure 4.2 below shows the size of the sample.

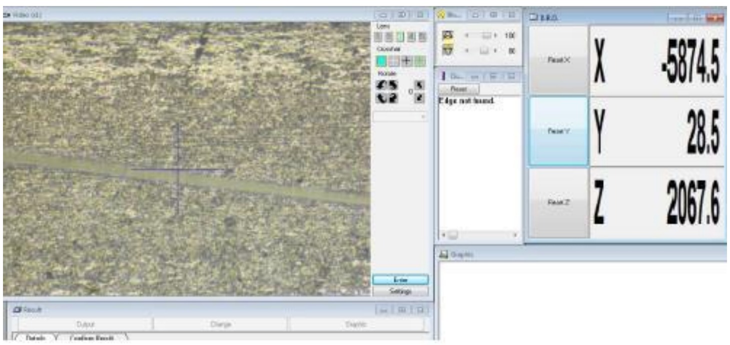


Figure 4.2 Size B (28.5 µm)

The last sample of microfiber has been tapered about 21.7 µm size diameter. This sample has been the second smallest in size that has been tapered. Figure 4.1 shows the screen of the microscope for size C.

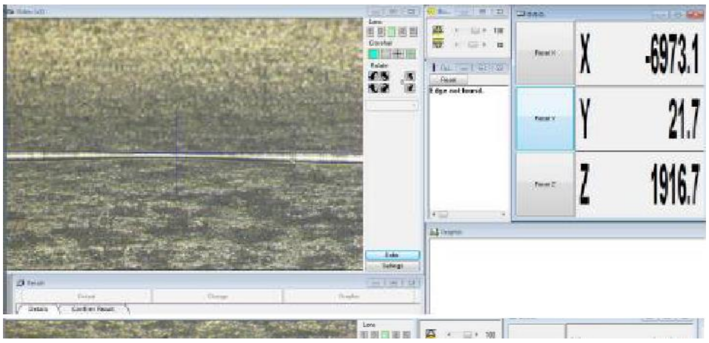


Figure 4.3 Size C (21.7 µm)

4.2.1.1 The Best Size of Microfiber

Size of Microfiber Optic Sensor	Diameter (µm)
A	10.8
B	28.5
C	21.7

Table 4.1 Size of Microfiber

Table 4.1 shows three different sizes of microfiber. Size A showed a smallest diameter value than other samples, obtaining a reading of 10.8 µm, followed by size C with value 21.7 µm, making size C the second smallest diameter. Size B was the biggest microfiber diameter with a value of 28.5 µm. This microfiber .will be used in the next experiment

4.2.2 Concentration of Coconut Water

The concentration of the coconut water is measured using a Spectrophotometer at the FTKE lab. It is important to determine the concentration of coconut water to analyse the benefit of coconut water in applications, including the food industry, to ensure product quality and safety. The concentrations found are 325mol, 362mol and 395mol.

Three samples of coconut water have been prepared to measure the coconut water concentration, which is 25%, 50%, and 75% coconut water mixed with 10% distilled water. The wavelength and the transmittance value are constant, where the wavelength is 550 nm and the transmittance is 1000. The concentration is shown in table 4.9 below.

Coconut water(%)	Transmittance	Absorbance	Factor	Concentration, mol
25	50.0	0.325	1000	325
50	42.7	0.362	1000	362
75	41.7	0.395	1000	395

Table 4.2 Concentration of Coconut Water

Table 4.2 shows the data for the concentration in three different samples of coconut water containing 10% of distilled water at wavelength 550 nm. Sample 3 showed a higher concentration value than other samples, obtaining a reading of 395 at wavelength 550 nm, followed by sample 1 and sample 2 with values of 325 and 362, respectively.

4.2.3 Sensitivity of microfiber optic sensor on 25% coconut water

The analysis is based on the sensitivity and linearity percentage of the performance on microfiber optics as a liquid sensor in different coconut water concentrations that were carried out during the test. Through this analysis, the output power was observed and recorded for every concentration using 1550 nm wavelengths, as shown in Table 4.3.

Sensitivity = slope (excluding the sign)
Linearity = ($\sqrt{R^2}$)

Table 4.3 Power Transmitted for 25% Coconut Water

Time (minutes)	Power Transmitted		
	Size A	Size B	Size C
1	-38.44	-39.60	-39.07
2	-39.22	-39.60	-41.03
3	-39.87	-40.00	-41.08
4	-40.05	-40.04	-41.12
5	-40.08	-40.06	-41.15
6	-40.11	-40.06	-41.15

Table 4.4 Sensitivity and Linearity of 25% Coconut Water

Size of Microfiber Optic Sensor	Sensitivity, Y	Linearity
A	0.3174	0.8850
B	0.1063	0.8711
C	0.3086	0.6935

From Table 4.4, sample size A showed the highest sensitivity compared to the two other samples, which is the smallest size of tapered fiber. The smallest size of microfiber could make the microfiber very sensitive. In comparison, we can see that sensor sizes A and B show a strong negative linear correlation. Meanwhile, size C shows a moderate negative linear correlation. The results indicate that the data have a good fit. This shows that the smallest size value will perform as the best microfiber optics liquid sensor.

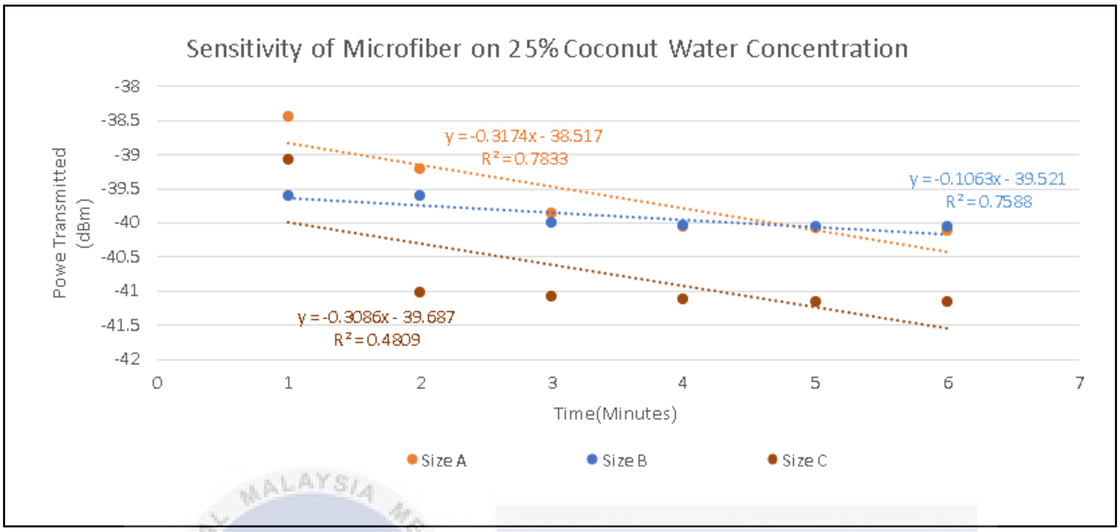


Figure 4.4 Graph for Sensitivity of 25% of Coconut Water

Based on Figure 4.4, shows three different lines for sensitivity with the total outcome percentage of 25% coconut water concentration. Each experiment was checked every 1 minute for a total of 6 minutes, with the output measured in decibels (dBm). The optical microfiber acts as a sensor to detect the coconut water and perform in size microfiber optic sensor. Sensitivity and linearity were used as observed parameters. According to the investigation, based on the parameters, at a microfiber optic sensor size A, it will show that the optical microfiber sensor has better performance. There is a strong negative linear correlation between time and power (dBm). As the time increases, the power decreases. This experiment also determines that the microfiber optics as a liquid sensor is used to sense the sensitivity.

4.2.4 Sensitivity of microfiber optic sensor on 50% coconut water

Table 4.5 Power Transmitted for 50% Coconut Water

Time (minutes)	Power Transmitted		
	Size A	Size B	Size C
1	-39.32	-40.05	-38.52
2	-40.55	-40.57	-39.67
3	-40.55	-40.67	-40.21
4	-41.01	-40.72	-40.50
5	-41.02	-40.76	-40.72
6	-41.06	-40.78	-40.77

Table 4.6 Sensitivity and Linearity of 50% Coconut Water

Size of Microfiber Optic Sensor	Sensitivity, Y	Linearity
A	0.3020	0.8521
B	0.1220	0.8276
C	0.0286	0.8426

Table 4.6 shows that sample size A has the highest sensitivity value, indicating the best performance as a microfiber optics liquid sensor. Microfiber optic sensors for all sizes have a strong negative linear correlation, showing the data fit well.

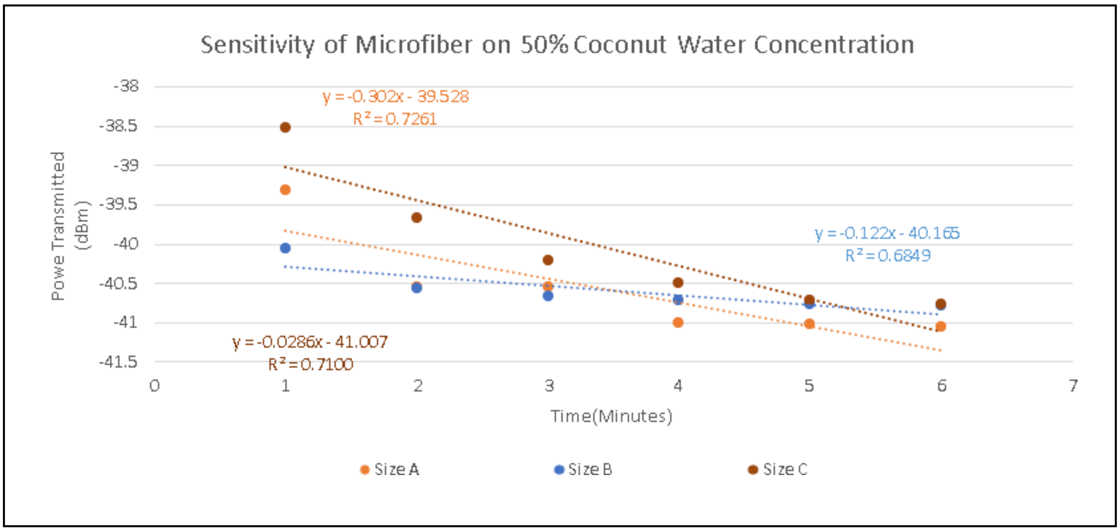


Figure 4.5 Graph for Sensitivity of 50% of Coconut Water

Based on Figure 4.5, shows three different lines for sensitivity with the total outcome percentage of 50% coconut water concentration. Each experiment was checked every 1 minute for a total of 6 minutes, with the output measured in decibels (dBm). The optical microfiber acts as a sensor to detect the coconut water and perform in size microfiber optic sensor. Sensitivity and linearity were used as observed parameters. According to the investigation, based on the parameters, a microfiber optic sensor size A will show that the optical microfiber sensor has better performance. There is a strong negative linear correlation between time and power (dBm). As the time increases, the power decreases. This experiment also determines that the microfiber optics as a liquid sensor is used to sense the sensitivity.

4.2.5 Sensitivity of microfiber optic sensor on 75% coconut water

Table 4.7 Power Transmitted for 75% Coconut Water

Time (minutes)	Power Transmitted		
	Size A	Size B	Size C
1	-40.82	-41.38	-39.85
2	-40.89	-41.38	-40.09
3	-40.92	-41.45	-40.28
4	-40.95	-41.45	-40.32
5	-40.96	-41.47	-40.33
6	-40.96	-41.47	-40.34

Table 4.8 Sensitivity and Linearity of 75% Coconut Water

Size of Microfiber Optic Sensor	Sensitivity, Y	Linearity
A	0.0269	0.9194
B	0.0206	0.9104
C	0.0174	0.8758

Furthermore, from Table 4.6, we can clearly see that sensor size A has the greatest sensitivity. This shows that the smallest size in diameter will perform the best microfiber as a liquid sensor. All microfiber optic sensors at different sizes have a strong negative linear correlation, indicating the data have a good fit.

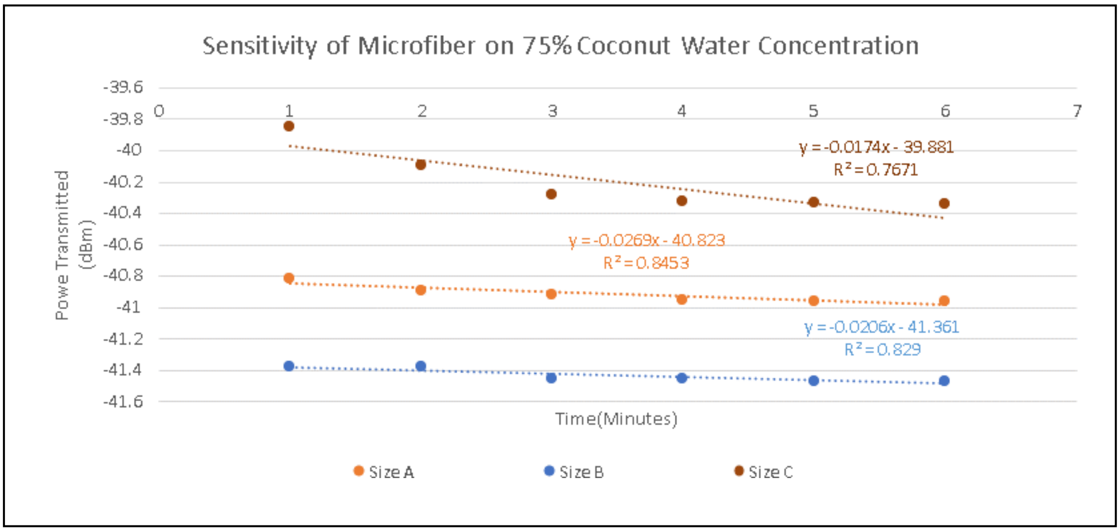


Figure 4.9 Graph for Sensitivity of 75% of Coconut Water

Based on Figure 4.9, shows three different lines for sensitivity with the total outcome percentage of 75% coconut water concentration. Each experiment was checked every 1 minute for a total of 6 minutes, with the output measured in decibels (dBm). The optical microfiber acts as a sensor to detect the coconut water and perform in size microfiber optic sensor. Sensitivity and linearity were used as observed parameters. According to the investigation, based on the parameters, at a microfiber optic sensor size A, it will show that the optical microfiber sensor has better performance. There is strong negative linear correlation between time and power (dBm). As the time increases, the power also decreases. This experiment also determines that the microfiber optics as a liquid sensor is used to sense the sensitivity.

4.2.6 Result for sensitivity and linearity on 3 Sample Coconut Water for Size A

Coconut Water (%)	Sensitivity (dBm)	Linearity
25	0.3174	0.8850
50	0.3020	0.8521
75	0.0269	0.9194

Table 4.9 Result for sensitivity and linearity on 3 Sample Coconut Water for Size A

Based on table 4.6 shows sensitivity and linearity for the microfiber optics in 3 sample coconut waters at different concentrations. The experiment shows that the optical microfiber sensor performs better at the first 25% coconut water. It has the highest sensitivity at the first sample compared to other samples, with a value of 0.3174, followed by 50% and 75%, with values of 0.3020 and 0.0269. In terms of linearity, all samples have a strong negative linear correlation. Furthermore, the linearity value indicates that the data have a good fit.

4.3 Summary

In this chapter, we showcased practical examples to illustrate how the proposed microfiber optic sensor development system can be applied to different concentrations of coconut water through a tapering method. The case study involved testing three samples with varying concentrations of coconut water, which were 25%, 50%, and 75%. The process included placing a drop of each coconut water sample on the microfiber, which had been previously prepared with the respective concentrations. The analysis involved observing and recording the output power for each concentration using the same input wavelength. Evaluating the microfiber optics water sensor's performance at identical wavelengths demonstrated favourable outcomes, as evidenced by the positive results in sensitivity, linearity and repeatability analyses.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the outlined project objectives focus on exploring the application of microfiber optics as a liquid sensor through the tapering method, with a specific emphasis on detecting different concentrations of coconut liquid. The primary goal is to investigate, develop, and analyse the performance of optical microfibers in this context. By employing the tapering method, the study aims to contribute valuable insights into the effectiveness of microfiber optics as liquid sensors, particularly in discerning various concentrations of coconut liquid. This research holds significance for advancing our understanding of microfiber optics and bears practical implications for potential applications in liquid concentration detection, particularly in the realm of coconut liquids. Overall, the project seeks to bridge the gap between theoretical exploration and practical implementation in the field of liquid sensing using microfiber optics.

Overall, the research presented in this thesis has helped us comprehend the importance of sensors in microfiber optics. The presented technique generates rapid, compelling, reflective, and correct results while making reasonable use of a limited set of data and information types, using straightforward mathematical operations, and requiring fewer complex calculations. Additionally, the research concentrated on creating strategies that would facilitate the creation of inexpensive sensors that simply rely on optical microfiber sensing. As a result, it prepares the groundwork for the suggested additional research.

5.2 Future Work

For future improvements, the accuracy of the sensor in sensing results could be enhanced as follows:

i) Using microfiber optic sensor to measure other variables such as temperature, pressure, and humidity. Because the main construction of both sensors is glass, they are resistant to harmful interference such as electromagnetic interference (EMI) and can tolerate harsh conditions such as high temperatures and pressure.

ii) Microfiber optic sensors can be linked to the Internet of Things (IoT) for even greater ease and convenience in monitoring sensor output. IoT enables remote monitoring since authorised users may access the system from anywhere globally. Additionally, extending the detecting zone might boost sensor sensitivity. The sensors may provide a greater resonant output when an optical signal passes through them.

iii) This research will be useful in the future for the food industry to determine the quality of coconut water during distillation and purification. This innovation provides a more dependable and efficient solution by overcoming the drawbacks of traditional methods like titration and refractometry. The high sensitivity, compact size, and resistance to electromagnetic fields of microfiber optics make them particularly well-suited for the challenging environments often encountered in food processing.

iv) This, translates to an uplift in overall product quality and safety. The system's adaptability to diverse compositions and its resilience in corrosive or high-temperature settings enhance its versatility in the food industry. Furthermore, the potential cost-effectiveness and scalability of the microfiber optic sensors promise increased operational efficiency and reliability, establishing this technology as an asset for ensuring top-notch quality and safety standards in coconut-based products within the food sector.

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APPENDICES

Appendix A : Gantt Chart

NO	TITLE	(BDP 1) SEM 2 2022/2023													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title selection and BDP Registration								MID TERM BREAK						
2	Background study: Search for papers related to the project														
3	Evaluate of Work Progress 1														
4	Complete report for Chapter 1 (Introduction)														
5	Complete report for Chapter 2 (Literature Review)														
6	Complete report for Chapter 3 (Methodology)														
7	Evaluate of Work Progress 2														
8	Submit report with turnitin <30%														
9	BDP 1 Presentation														
10	Submission and evaluation of BDP 1 final report on ePSM report														

Appendix B : Gantt Chart

NO.	TITLE	(BDP 2) SEM 2 2022/2023													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Continue with study while start the project: Search for papers related to the project, stripping the fiber, splicing fiber with connector input and output								MID TERM BREAK						
2	Evaluate of Work Progress 1														
3	Start working on the project: Stripping the fiber, Splicing and Tapering														
4	Complete report for Chapter 4 (Results)														
5	Collect data results, conclusion, and draft report														
6	Evaluate of Work Progress 2														
7	Submit first draft report to SV, report correction														
8	Submit report with turnitin <30%														
9	BDP 2 Presentation														
10	Submission and evaluation of BDP 1 final report on ePSM report														

PSM_2

by muhammad 1

Submission date: 15-Jan-2024 06:37PM (UTC-0800)
Submission ID: 2271655724
File name: PSM_2_FINALREPORT_SYARIL_Turnitin.pdf (948.21K)
Word count: 7906
Character count: 42125

UNIVERSITITEKNIKAL MALAYSIA MELAKA

culty of Electronic & Computer Technology and Engineering

DEVELOPMENT OF OPTICAL MICROFIBERSENSOR FOR COCONUT WATER CONCENTRAT IO NS USIN G A TAPERING METHOD

MUHAMMAD SYARILIHNJLAI A

Bachelor of Electronics Engineering Technology with Hononrs

2023

ABSTRACT

Fiber-optical sensin g refers to using fiber-optic cables to mea sure physical or chemical parameter s in various applications. This project aimed to detect different parts of coconut us ing a ta pering approach by employing ic rofiber cs as a sensor. The sin gle -mode fiber will be tapered using the tapering method, and the 6est size of mic rofiberJiptics will be use d orfu rtherJrniestigation as a liquid sensor. Furthermore, three sample s of coconut parts, such aswater, coc onut milk, coc and coconut water, each with a different concentration, will be eva uated. The graph's sensifivi y, correlation, and coefficient of determination all rely entirely on the part of coconut concentration, and the li ght source will be used to summ arise the expe riment's results.

ABSTRAK

enginderaan · - - - : else ra 'bptk u k lne ngukur parameter iz1 a i atau kimia dalam pelbagai aplikasi. Projek ini bertujuan untuk mengesan ah a · i kelapa yang berbeza menggunakan pendekatan yang meruncing dengan menggunakan Optik Mikrofiber sebagai sensor. Serat mod tunggal akan meruncing menggunakan kaedah tirus, dan ukuran Optik Mikrofiber Terbaik akan digunakan untuk penyelidikan lebih lanjut sebagai sensor cecair. Selanjutnya, tiga sampel bahagian kelapa, seperti air, santan, minyak kelapa, dan air ' e apa, masin katan yang berbeza, aka n dini lai. Sensitiviti grafik, korelasi, dan pekali penentuan semuanya bergantung sepenuhnya pada bahagian ke pekatan kelapa, dan sumber cahaya akan digun akan untuk merin gkaskan hasil eksperimen.

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LIST OF SYMBOLS

	the mediums that will imp act the refraction enter in g
n2	the mediums that will imp act the refraction leaving
	the angle of incidenc,
	the angle ofrefraction
µm	Mic romete r

LIST OF ABBREVIATIONS

SMF	-	Single mode fiber

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Background

A fiber optic sensor is a type of sensor that uses optical fibers to transmit and detect signals from the sensing element to t9 measurement electronics. The sensing element can be a material that changes its optical propertie s m response to a physical or chemical parameter , such as tem perature, pressure, stra in, or chemical compos ition. Fiber optic sensors were first developed in the 1960s, but it was not until the 1980s that the y began to be widely used in industrial and scie ntific applications. Since then, the field of fiber optic sensing has grown rapidly, and fiber optic sensors are now used in a wide range of applications, in clud in g structu ral health monitoring, oil and gas exploration, medical diagnostics, and environmental monitoring. One of the key advantages of fiber optic sensors is their ability to operate in harsh environments, such as high tempe ratures, electromagnetic in terfere nce , and corrosive environments. Fiber optic sensors can also be use d for remote sensing, meaning that they can be installed in hard -to-reach places and monitored from a remote location.

Optical · crofibersh a t,ype of optical fiber that has a very smal1 diameter, typically on the order of a few mic rome tre s or le ss. They are typic ally made from glass or other transparen t materials and are used for a variety of applications, including sensing, communications, and photo nics. he concept of optical microfiber was first proposed in !003 by Liang et al. at th e University of Sydney. The researchers demonstrated that tapering a conventional optical fiber down to a very small diameter could create a new type of fiber with unique opt.ical propert.ies, such as strong light confinement and low propagation losses.

1.2 Problem Statement

Currently , there is no reliable and efficient method for measuring coconut water concentration in various applications, such as in the food industry, which can affect the quality and safety of products. Conventional methods for detecting part of coconut concentration, such as titration and refractometry, can be time-consuming, require complex instrumentation, and are prone to errors. xisting fiber-optic sensing systems for detecting arious parameters are often limited by their sensitivity, accuracy, and robustness in harsh Si vi ronments, such as high temperatures or corrosive environments. efore, this research aims to develop an innovative fiber-optic sensing system using m1c rofiber Jhp,t.ics for the reliable and accurate detection of coconut liquid concentration. By employing a tapering approach, ic rofibet}opt ic s as sensors can achieve high sensitivity, compact size, and immunity to electromagnetic fields, making it ideal for harsh environments. This research will contribute to the development of an efficient and reliable method for measuring coconut liquid concentration that can be used in various applications, including the food industry, to ensure product quality and safety.

1.3 Project Objective

After the problem statement has been determined, the project objecti ves are as follows :

a) To in vestiga te ic rofiberppt.ics as a liquid sensor us in g the ta perin g method.

b) To develop crofiber)p'.tics as a liquid sensor to detect various types of cocon ut liquid conce ntrations using the taperi ng method.

c) To analyse the performance of the optical [:licrofiberk. liquid sensors to detect various type s of coconut liquid concentrations.

1.4 Scope of Project

crofiber}.ptics is used as a liquid sensor to detect coconut li quidc oncentration e iquid sensor is deve oped by using the tapering method a ditferent sizes.t<!Ht herm ort-"a-11 different sizes will be tested, and the best size is determined based on sensitivity. As the best liquid sensor will be developed, further investigation will be arrie doutlcm..c oconut liquid conce ntrations . There will be three sample s of different concentrations of coconut liquid, such as oconu [7]water coconut milk and coconut water tes ted . Before each tes t, the fiber would be dipped in the samples and the n meas ured. In a l i ne graph,eac h meas ureme nt wo uld have d ifferen t res u l ts. T he exper imen t's find in gs will be desc ribed in te rms of sens itivity, correlation, and coe fficien t of dete rmination of the grap h, all of whic h are comple tely depe nde nt on the coconut liquid concen tra tion and li gh sou r_ce.

CHA.l'Tl!:K2

LITERATURE REVIEW

2.1 Introduction

Over the past 50 years, fiber -opt ic al sensing has been a highly successful application of fiber optics and sensing technology. Rece ntl y, there has been a focus on miniaturising fiber-optic sensors due to advance ment s in micro/na no tec hnolo gy and the need fo r sensors with better perfo rmance and versa ti lit y. Reducing th e size of a sensor is important for achieving fas ter response , highe r se nsitivit y, lo wer power cons umption, and improved spati al resolu tion. ne promising solution for achieving miniaturisation is the use of optical

nicro fiber ic h are made by ta er-d raw in o olass or olymer materials such as o tical fibers. Optical microfibers 1bine fiber optics with nanotechnology and have become a new platform for exploring fi6er -opt ic technology on a micro or nanoscale. They guide light with low optical loss and offer excellent mechanical flexibility, tight optical confinement, and large fractional evanescent fields. These properties make them ideal for optical sensing, providing advantages such as faste1 response , higher se nsiti vi ty, and lo wer power consumption. Researchers have alread demonstrated various types of physical, chemical, and biological optical sensors based on crofibers this review, we examine the recent advancements in mic rofiber tic al sensors, inc uaing their waveguide properties, fabrication methods, and applications in sensing. However, micro fiber)!ptical sensors offer unique advantages and have been widely explored in various sensing applications. This

chapt r will thoroughly describ Ec rofi berftptic se nsi ng, mic rofibe.r abrication, and microfiber optic applications in var iou s fi lds, as w ll as some important works related to this topic.

2.2 Optical Microfiber

c rofiber ic s possess several disti nct characteristics th at make them highly desirable for vari ous applica ti ons. These propert ie s include strong optical confinement, customisable flexibility, high optical confinement, and a wide evanescent fie ld. These features make rof cs well-suited for physical sensing applications such as surface absorption spectroscopy wi th excep tional sens itivi ty, hydrogen detection, as well as chemical and refractive index senso rs (Che n, G. Y., Ding, M., Newson, **T.,** & Brambilla, G. (20 I 3)). T he propagation of mic rofibers)generates significant ev anesce nt waves due to their sensitivity changes in the surroundm g refractive index . As the proportion of power transmitted int e evanescent field increases, the refractive index of the surrounding material also i ncreases. This characteristic enable s effective evanescent coupling with other waveguides, including metal, semiconductor, and substrate, there by fac ili tatin g robus t sensing capab ilitie s. T he refractive index, core diameter, and operating wavelength of a fiber can influence the type and number of modes that can propaga te through it. While most of the light energy rema in s confined within the fiber, with some extending in to the clad, a small fraction ex ponen ti ally decays towards the edge of the core -cladd i ng region. Taperi ng common sin gle-m ode fibers **(SMF)** can en hance the low amp litude evanescent fields, inc reasing the ir interaction with trans mitted I ight in the taper area.

22 .1 Single -mode fiber

Sin gle -mode fiber is commonly use d for longe r distances due to its smaller glass fibe r core diameter. **The** reduced diameter resul ts in lower attenuati on, minimising signal power loss along the trans missi on. By concentra ting the light into a sin gle beam through the smaller core, the signal is provided wi th a more direct path , enabling it to trave l grea ter d is tances. Moreover, e ngle -mod , lftbe exhibi ts a significantly larger bandw idth compared to multimode fiber. Consequently, laser light is frequently employed as the light source for single-mode fiber. However, it is important to note that the production of laser light within a narrower core requires precise calculations, making single-mode fiber generally more expensive.

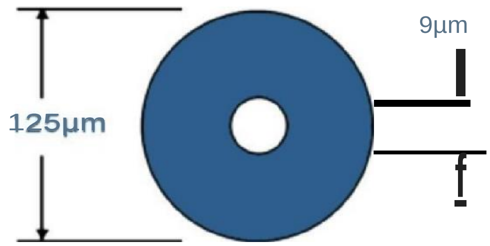


Figure 2.1 Fiber Optic Internal Structure of Single Mod

An optical fiber consists of three essentia l components: the core, cladding, and coating or buffer. Among these, the core holds the utmost significance as it serves as the pathway for light transmission. In comparison to mu lti-mode fibers, single-mode fibers possess a significantly smaller core. The core diameter of single-mode fibers typically measures around 9 micrometer (µm). Surrounding the core is the cladding, which enlarges the overall diameter of the optical fiber to 125 µm. By confin ing the light to a si ngle light wave, the small core effectively eliminates any overlap or distortion of light pulses, resulting in minimal signal attenuation and the highest transmission speed possible.

Figure 2.2Single Mode for Light Path

Single mode is quicker than multimode across long distances since it req uires fewer switche s or routers in the mid-span. Almost li mitless bandw idth capacity. Furthermore, this cable can transfer data at up to 40Gb across hundred s of kilometres with minimum inte grity loss, and it can transp ort data at up to 10Gb over longer distances, such as thousands of kilometres . Single-mode cable and connections are less costly tha n multimode cable and connectors.

22.2 How fiber optic working

Fiber optics function based on the principle of total internal reflection, enabling the transmiss ion of li ght s ignals through gla ss or plastic fibers. Whe n a l ight signal is injected into the fiber optic cable, it und ergoes multiple in ternal reflections as it travel s down the fiber(Srinivasan, B., & Venkitesh, D. 2017). Tota l internal reflection occurs when the angle at whic h light hi ts the boundary between the core and cladding exceeds a critical angle(Zhang, S., Liu, H., Coulibaly, A. A. S., & Delong, M. 2021). This reflection keeps the light si gna l confined within the core, preventin g significant signal loss. At the receiving end, light signal is detected by a photosensitive device, such as a photodiode, which converts it into an electrical signal for further processing.Fib er optics offer advan tages such as high bandwidth , low signal loss, resistance to elec omagne tic interference, and the ability to transmi t s ignals over long distances. This make s fiber optics an essential tec hnology for appl ications in telecommunic ations, int e rnet connectivity, med ical im aging, and more .

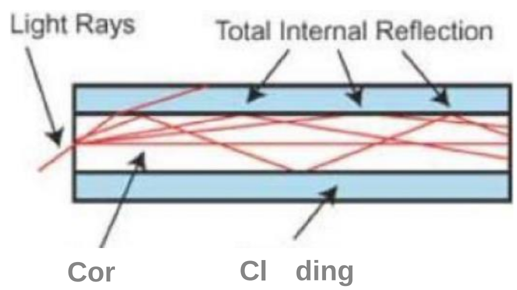


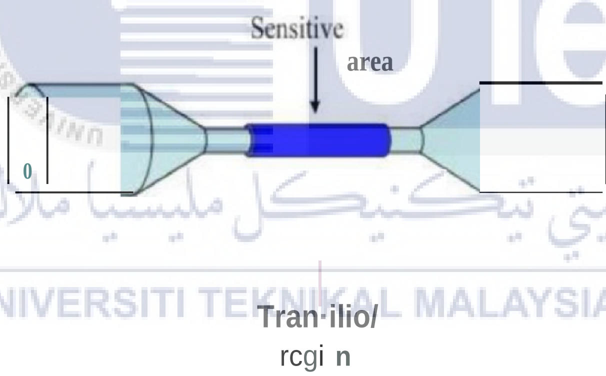
Figure 2.3 Total internal reflection inside the core

2.3 Properties of Optical Microfiberh

ic rofiber)ru sesses a range of fascinating optical characteristics, including a robus t evanescent field. fie evanescent field effectively distributes fractional power at the external boundary of cro fibers small radio.This attribute plays a crucial role in the production of resonators with high quality factors (Q) and facilitates the efficient transmission of light into high Q m ic ro-resonators. Moreover, mic rofiberB:!'&mo nstra tes significant near-field in terac tion with its surroundings, exhibiting favorable evanescent coupling between the 1.ic rofiber other waveguides like substrates, semiconductors, and planar waveguides. Consequently, this property enables the creation of nume rous optical dev ice s, s uch as resonators, sensors, and lasers.

Propagation loss is a significant characteristic to consider when it comes to 'crofiber. This 1 ss occurs due to various facto rs, such as cracks, imp urities attached to the surface of tfie micro/nano fiber, and imperfec tions on the surface. As the rad iiM.. the · crofiber'1te-cre a e, the propagation loss increases. Researchers have conducted theoretica studies on non-adiabatic intermodal trans i tions to determine the minimum diameter of the nicrofiber waist that can effectively transmit signals. It has been observed that the transmission mode disappears when the rate reaches a threshold value that is typically smaller than the wavelength of th9 rndiati.on.Additionally, it has been discovered that small-sized mic rofi bers rade more quickly in a1i when cracks f rm at the facet as a result of water absorption.

Furthermore, because to its small mass, mic rofibe1 e ry sensitive to momentwn changes of photon guides through mechanical displacement or vibration mass. This enable a development of compact optomechanic albn pone nts or device s . It also provides for reduced los s when transferring light via sharp en s. As a result, mic rofibcr f s-.fo rmed by end in g the o tical fiberi till they reach he necessary waist d iame ter. 1fN s enables lo w-loss splicing with other st ard-size optical fibers. It can also be ben to build compact devices with a small bending radius. Outside of the microfiber, the small waist fiber transm its a significant amount of power and overlaps with extema l parts. Any changes in the su rround i ng attributes result in a change in th output. A seen in Figure 2.4. (Bran1billa, G. 2010).



' igur , 2.4 Sensitive area has a laroe fraction of ower propagating to interact with the surroundino- env i ronment.

.4 Snell's Law Conce l

hen light ansitions between different mediums, it undergoes bending and ract ion j Ben ·ng can be determined using the law of refract ion, which is more complex than the law of reflection but crucial for understanding lenses and their future applications. Snell's law, named after its discoverer Willow Broad Snell in 1621, describes the law of refraction. Similar to reflection, refraction depends on the angle of incide nce , wit rn1s refracted at poi nts perpendicular to the surface of refraction. The medium through which ig t travel s also i nflue nce s refraction, just like reflection. Snell's law utilises the index of refraction to express this dependency. he index of refraction is determined by the avelength of the light under examination. ain materials exhibit a higher index of refraction for short-wavelength blue light co! pared to longer-wave len gth light , such as red light.

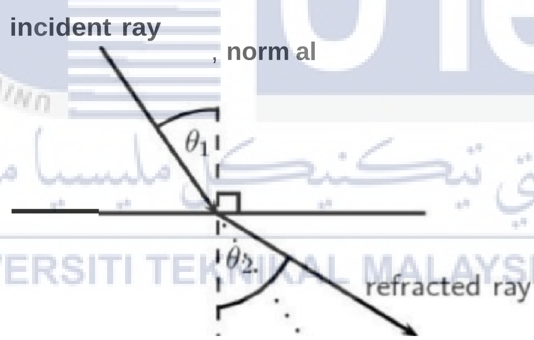


Figure 2.SSnell's Law Concept

Based on Figure 2.5 Sne ll's law ca n be represented as below:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

Where:

n1 are medi um s that will impact the refraction ente ri ng.

n2 are mediums that will impact the refraction le avin g. 01

is the ang le of inci dence .

02 is the ang le of refraction.

2.5 Tapering method

Tapering a single mode fiber involves pulling the e nd of the fiber while heati ng its waist to decrease the diameter of the cladding and core . During the tapering process, light travels through the core and extends into the cladding. This creates a new core, while the outer layer func tions as a new cladding. To achieve a high signal-to-noise ratio and minimiseopt.ical loss, it is cruc ial to maintain urfac smoothness and geome tric uni formity throughout the mic rofiber duction process. Furt ermore, as the fibe r is pushed through the taperin g process, its radius dec reases. The light trans i tions from the core to the cladding and propagates across the tapered region, affecting the mode as it interacts with the core, cladding, and surround i ng air. The shape of the taper influences the mode behavior within the tapered fiber or ro cess ive taper in g can lead to no n-adiabatici ty, resu l ti ng in poor transmiss ion. On the oth ana , reducing the tapering ang le promotes more adiaba tic mode propagation. The distinction between adiabatically tapered fibers ~~and non-adiabatic tapered fibers is illustrated~~ in the diagram below.

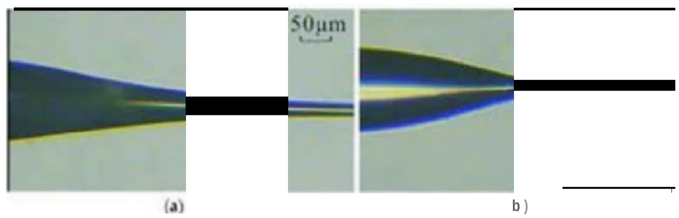


Figure 2.6 (a) Adiabati tapered fiber and (b) Non-adiabatic tapered fiber

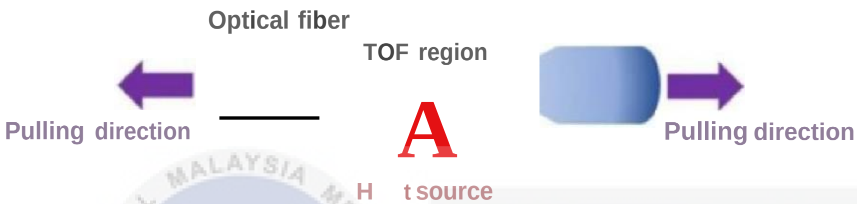


Figure 2.7 mustration of the flame approach used for the fabrication of tapered optical fibers

2.6 Coconut

The coconut is a versatile fruit that is both nutritious and economically important. It is a dietary staple in tropical reg ion s, and its various parts are used in a variety of industries. Coconuts are a good source of essential nutrients, incl uding protein s, vitamins, and mine rals . They also contain unique med i um -cha i n trig lyceride s that have notable metabolic benefits. The different parts of the coconut liquid have been extensively studied for their benefits and drawbacks. (Anuradha , K., Sudha, M., & Srinivasan, K.2013)

Table 2.1 Different part of coconut liquid

Part of Coconut Li uid	Benefit	Drawback
Cocon ut water	Coconut wate r is the clear liquid found inside immature coconuts. known for being a refreshing, natur al beverage tha t's rich in 'electro ytes ilce potassium, kin g it an excellent choice for hydration f lFurthe rmore, due toits" simj]ar compo sifio n to human plasma, it has historically been use d as a short-term intravenous hyd ration fluid.	While coconu t water is a good sourc1 o electrolytes it may not be e as a sports drink for intense, prolonged exercise due to its low sodium content, a essential electrolyte lost during sweating. Add itioil'äll y, it contains sugars, which, if con sume d excessively, could contribute to increased calorie int ake and weight gam.
Cocon ut Milk	Coconut milk, derived from the grated meat of mature coconuts, is a §_h source of nutrients, ·ncluding vitamins C, E, BI, B3, 5, and B6 as well as iron, selenium, sodium, calcium, agnesiu, Coconut millc's creamy texture makes it a popular choice in many dishes, especially in vegan and	Similar to coconut oil, coconut mjlk is high in saturated fats, which may increase cholesterol levels if consumed in large quan tities! Additionally, canned or processed coconut milk may additives or sweeteners th at increase the sugar and calorie content.

dairy-free diets.

2.7 Summary

This chapter will explore the techniques employed to create tapered microfibersL particularly optical crofibers. tensively studied, these miniature fibers have shown remarkab le propert ie s for m ati ng light at the micro and nanoscale. By educingtheb. diameter of optic al fibers 1t the wavelength scale, optical mic rofibersltM,,e openedexcitin possibilities for both sc ien tific research and technological advanceme nts. With theirabil i tyRh guide evanescent field s with minimal loss, strong near-field interaction, and compact sizes, s mic ro or nano fibers have facilitated the development of new applications in atom optics. These reakthroughs ha ve the potential to extend the use of lightbeyon d traditional opt.ics, paving the way for an exciting future in fiber optics and technology.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the proposed methodology for this project, which consist of the methods that will be performed to achieve the right possible output. The importance of having the right method will determine and detect the project's fault. The main methodology principle will elaborate on the phase and step of this project. The proposed study aims to create a sensor that can detect the concentration of various types of coconut liquid.

3.2 Project Flow Chart

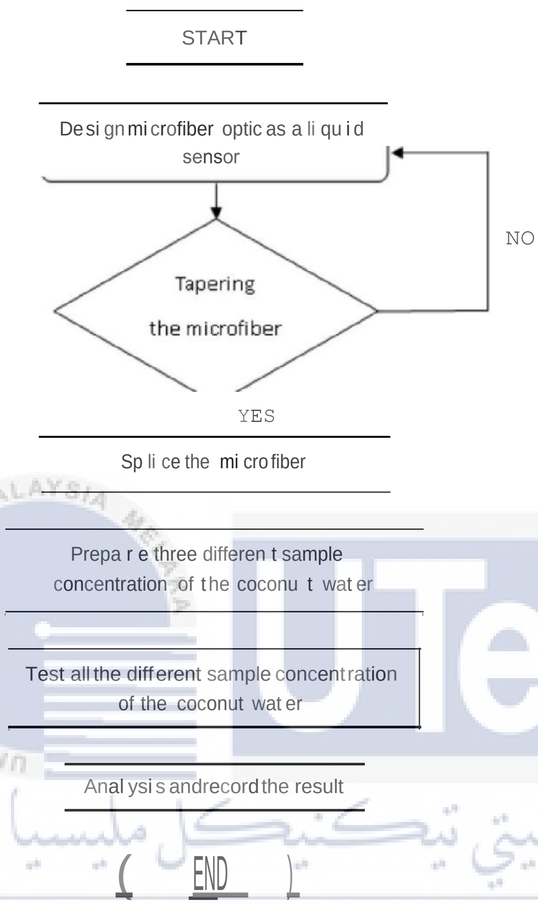


Figure 3.1 Process flow of projec

To achieve the project objecti ves, a flowc hart was devised to guide and summari se th e step- by-step phases, as depicted in Figure 3.1. The project initiation involved designing a · croftber) mction as a liquid sensor, with three distinct concentrations of Coconu t Water as samp le s. A single -mode fiber **(SMF)** was chosen for use as the sensor. The subseq ue nt step involved the fabrication of a tapered fiber, a process that entails reducing the diameter of the cladding (along with the core) by pulling the fiber's end while heating its waist.

Optimal sensitivity is achieved through smaller diameter taper waists. All micr ofibers e cut to the same length to minimise losses during experimentation. The mounting part, stripped for use as a sensor, was also cut to the same length. If the splice of the microfiberL opt.ic ens ors)ffective, the process can proceed to the next step; otherwise, it moves to the fiber optic sensor setup.

The next step is to prepare thre1 s amp le of different concentration of coconut water containers that will be used to conduct t e expenment. At first, the containe r will be pierced to allow the fibers to fit inside. The container will then be filled with thre1 ample of differe nt concentrations of coconut wate ·:,xhic h is 25 o, 50% and 75% coconut water.

Once the setup is comp e e, tfie Optical Power Level will project a beam onto the · crofiberJ1md the resulting data will be collected using the Optical Power Meter. This data will be crucial in determining the reading values influenced by varying concentrations of coconut water. Subsequently, the experiment's outcomes will be scrutinised, focusing on sensitivity and linearity, which are contingent on both the coconut water concentration and the light source. The findings will be presented th rough tables and graphs. ln sum mary , the performance of the crofiber)p,t.ic as a liquid sensor is deemed outstanding, evaluated through factors such as transmitted power and wavelength shifting. The linearity, particularly in relation to the three different concentrations of coconut water, is also characterised as commendable.

3.2.1 Splicing Process

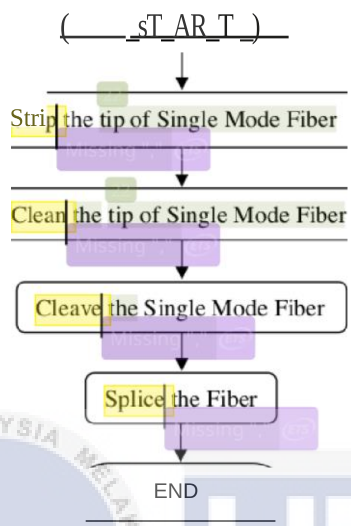
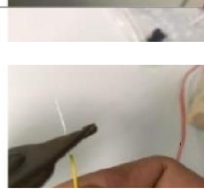
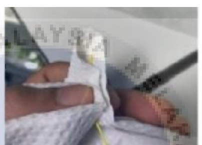
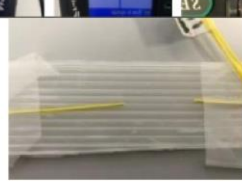


Figure 3.2 Flowchart of Splicing Process

The initial step involves the removal of the coating layer from the Single Mode Fiber using a fiber optic cable remover. Subsequently, the fibers were thoroug y c eaned with alcohol to el imi nate any residual dust or coatin g. Nex t, the fibers are precisely cleaved using the high-quality ujikura CJ:-30 cleaver to create flat faces. To connect two fibers that have been stripped and cleaned, the Fujikura ... 8R splicing tool is utilised. The stripped fibers are carefully inserted into the splicer, ensuring that their orientation alig · the same direction.

Table 3.1 Complete Steps for Splicing using Fujikura$M -i8R

No	Procedure	Description
		Remove the outer layer of the optical cable.
2		Remove the optical cable's second !aye (cladding).
3		Remove dust usmg alcohol and tissues.
4		Cut the optical cable with a high-precision cutter.
5		Place the cable on the separator and try to keep it in the same position.
6		Press the start button and wait until the connection is complete.
7		**The** connecting cable is now ready for installation on sta e.

3.2.2 Tapering Process

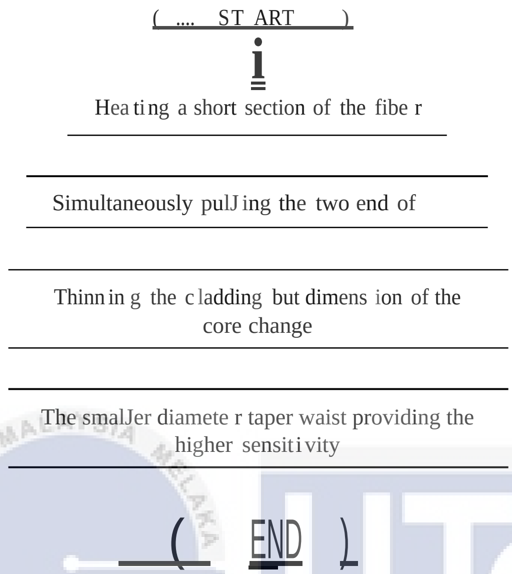


Figure 33 Flowchart of ta perin g process

The fabrication process for tapered optic al mic rofibershµ ic ally i nvolves heating a sho rt section of the fiber whi le si mult aneo usl y brin gin g it s two enas closer togethe r. A gas burner flame is utili se d as the heat source in this case. One of the main func tions of claddingin sin gle -mode optic al fibers is to minimise the extent to which the electric field of the propagatin g mode penetra tes i nto the su rrou nding med iu m.

Furthermore, the core and cladding diameters are reduced proportionally during the taperin g process. As a res ul t, li ght is tran sfe rred from the untapered fiber's fu ndame nta l mode to mode s within the tapered region that may interact with the surroundin g medium. Subseque ntl y, the optical fiber claddin g is thin ned while maintaining the same core size. This thin ning of the cladd in g inc reases the interaction of the propagatin g mode 's electric field with the surroun ding medium . It is important to note that the sens i ti vity of the taper inc reases with smalle r diameter waists.

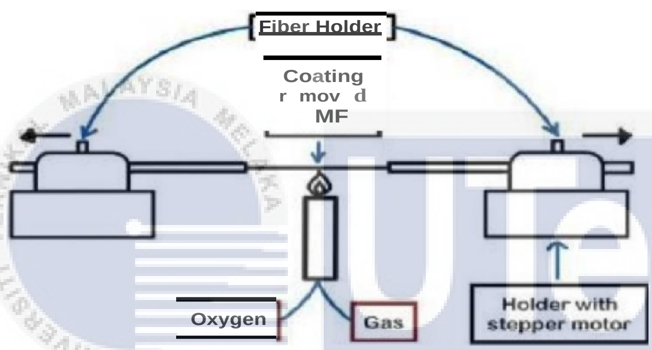


Figure 3.4 Schematic illustration of tapering process

32.3 Concentration Preparation Process

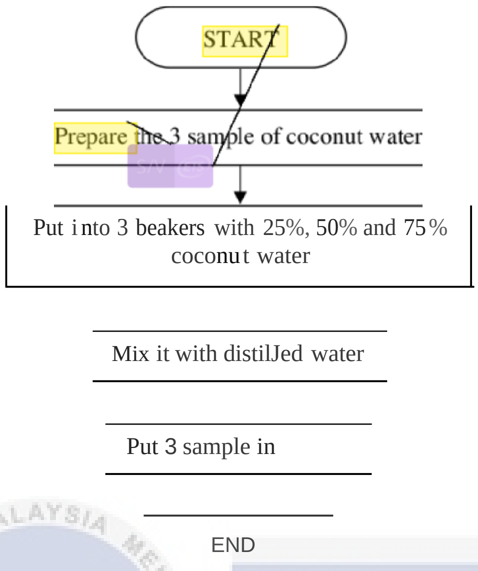


Figure 3.5 Concentration preparation Process

To conduct the experiment, three samples of coconut water were meticulously prepared. Each sample was accurately measured and placed in separate beakers, with concentrations representing 25%, 50%, and 75% of coconut water where 25% is IS ml, 50% is 30 and 75% is 50ml. To ensure uniformity and faci li tate the testing process, each sample was mixed wi th I 0 % distilled water which is 10ml. Subsequently, th repared..samples were carefully transferred into cuvettes, setting the stage for the forthc om ing an ysis . This systematic approach in sample preparation lays the foundation for a comprehensive investigation into the performance of c ro cs as liquid sen sors in detecting various concentrations of coconut water.

3.2.3.1 Experimental Setup Process

In the spectrophotometer process, we need to calibrate first to make sure there is no light m the spectrophotometer. his is to make sure the absorbance of light in the pectrophotometer is not disturbed by natural light from outside spectrophotometer make ure the value of transmittance, ab orbance 'b-file in figure 3.6 .

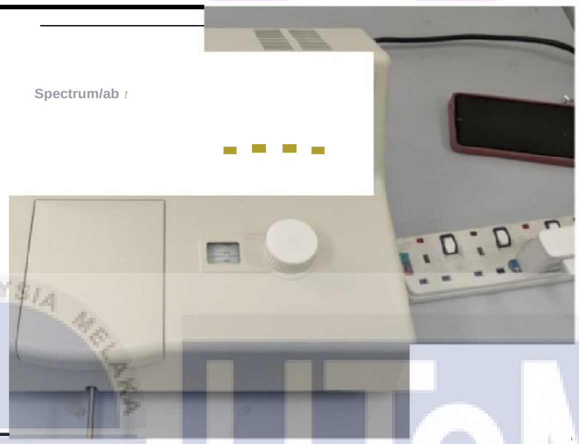


Figure 3.6 Calibrated Spectrophotometer

Once that's set, we insert the cuvette with our coconut water sample, and the spectrophotometer shine s light through it.

Figure 3.7 Sample in cuvett tube.

Figure 3.8 Cuvette tube in spectrophotometer

By measur i ng how much light gets absorbed at the same wavelengths 550 μm, it produces what we call an absorbance spectrum. Then analyse this data, comparing it to our calibration curve, to figure out the concentration of su bstances in our coconut water samp le s. Generally, higher absorbance values indicate higher conce ntrations. T his whole process is crucial for understanding how well optica l mic rofiberstre.tect and measure different concentrations of coconut water, giv ing us valuable insights into their perfomrnnce as liquid sensors.

3.3 Experimental Setup Process

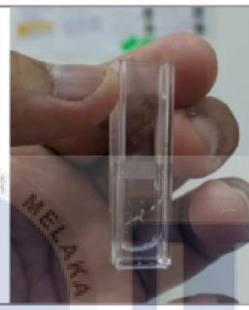
Single-mode optic al fiber sensors are connected to an Optical Power Level at the input to assess the concentration of coconut li quid. T he Optical Power Level emits a waveleng th of 1550 μm to the fibers, and the resu l tin g optic al power is measured in dBm usi ng an optic al power meter. Before conducting the experiment, a container is set u p, and each drop of wate r is carefully poured in to it. Subsequently, the sensor is placed in the prepared container for te s tin g. The sensor is tes ted three time s with th e same type of wate r to obtain accurate measurements, and an average measurement is recorded. **This** procedure is repeated for each type of wa ter being evaluated. The data collected is analysed based on the type of coconut liquid used and its concentration. The results are then utilised to create a graph representing the concentration of each coconut liquid.

3.3.1 Equipment

Table 3.1 Equipment that was used in project

No.	Material Name	Equipment	Description
I.	Simp liF iber® Optical Power Level		Source of input that is connected to the fiber. • The wavelength is set at 1550 μm
2.	Si mp liF iber® Optical Power Meter		• The output is measured and sent to the display. • The device that displays the result is the output device.

3.	Commercial Splicer Fujikura FSM-18R		• Sp!ice the fiber together
4.	Cleaver Fujikura CT-30		• To make the fiber tips flat
5.	Fiber Optic Stripper		• Remove the cladding on the • optical fiber.
6.	Single mode fiber		• Used in the development of sensor
7.	Single mode connector (pigtail)		• Use to connec t the optical spectrum analyser to the sensor
8.	Rubbing Alcohol		• Remove the residual or dust after cleaving and before splicing
	Plastic container		• To place the sensor that immerses in the water

10.	Coconut liquid		• Main equipment for experimenting.
11.	Spectrophotometer		• To check § ncent ratio of. coconut watet
12	Cuvene Tube		• To put sampl of coconut wate

3.4 Summary

This chapter presents a proposed process for constructing optical mic rofiber sors using various types of coconut liquid concentration. The main objective of this apJ oach is to optimise the waveform output value obtained from the optical power level and optical power mete rs. The emphasis is placed on a less rigorous and more practical estimation method that does not significantly compromise the resu lts' accuracy. The process allows for the creation of multiple varieties of coconut liquid using the same methodology. Instead of striving for the highest degree of precision, the ultimate goal of this technique is to maximise efficiency, ease of use and manipulation, and the practicality of mic roftber):lptic sensors.

CHAPT.li:K4

RESULTS AND DlSCUSSIONS

4.1 lntroduction

This chapter presents the resu1ts and analyses of developing a mic rofiberfiptic sensor us ing various types of coconut. Case studies were conducted to demonstrate the sensi tivity of the ic rofiberpPt ic cable. These studie s aimed to determine the sensi tivi ty of coconut water. The main o6jecti ve of the se case studies was to showcase a recomme nded approach applic able regardle ss of the coconut wa ter use d. T he coconut unde rwe nt three tests to obtain an aver age outc ome.

4.2 Results and Analysis

The following tab le and figure below are the analysis of coconut water testin g results. These analyses are separated into severa in ormation: the time, number o test , awrag alue for each time taken, sensitivity, linearity an repeata ility

4.2.1 Size of [!appered'1icrofiberh

The size of the icrofiber easured usin g a microscope at the FTKJ PJlab,. It is important to determine the microfi er s size to analyse the mic rofiberh nsi tivi ty leve . The sizes found are 21.7 *µm* , 28.5 *µm,* and 10.8 *µm.* Sizes are inves tigate 1Jy measuring the ange of ax

The first sample showed the best tapered microfiber with the smallest size, resultin in th e highest sensiti vity com ared to th two other sampl e s. The smalle st size of microfiberh could make the mic rofib er'vory sensiti ve .

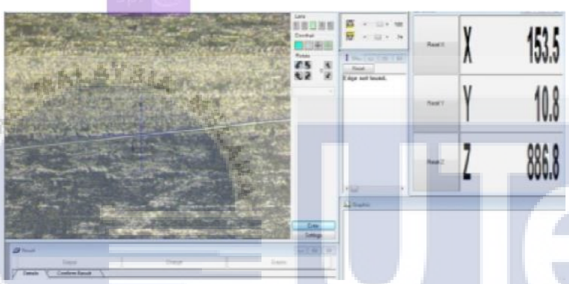


Figure 4.1 Sample A (10.8 *µm)*

The d iame te r of ax is-Y for the second samp le shows the biggest size among th e three tapered sample sizes. rf here fore, thi s sample will represen t the lowest sensiti vity amon th two sam les. Figure 4.2 below shows th e size of the sam le

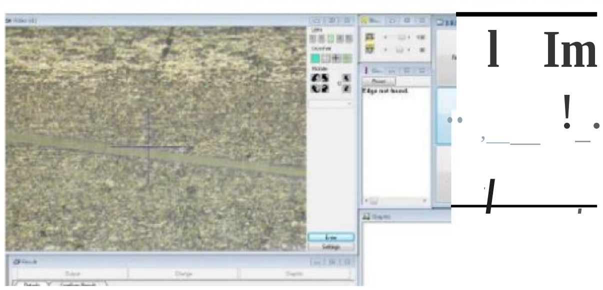


Figure *42* Size **B** (28.5 *µm)*

The last sample of icrofiber been tapered about 21.7 *µm* size diameter. This sample has been the second smallest in s ize that has been tapered. Figure 4.1 shows the screen of the microscope for size C.

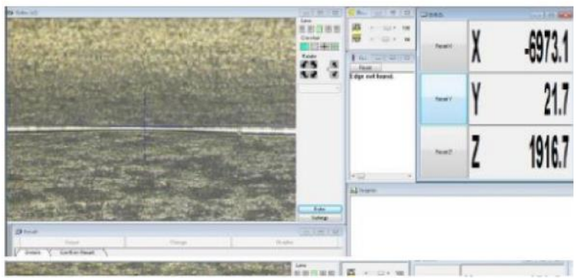


Figure 4.3 Size C (21.7 *µm)*

4.2.1.1 The Best Size of ;MicrofiberL.

Size of Microfiber Optic Sensor	Diameter *(µm)*
A	10.8
B	28.5
C	21.7

Table 4.1 Size of Microfiber

Table 4. 1 shows three differe nt sizes of mic rof :,,i.ze **A** showed a sma lle st diameter value than other samp le s, obtaining a reading of 10.8 *µm,* fo llo y size C with value 21.7 *µm,* making size C the second smallest diameter. Size B was the biggest microfiber eter with a value of 28.5 *µm.* This icrofiber .wuI be use d in the next experiment

4.2.2 Concentration of Coconut Water

The conce ntration of the coconu t water is meas ured using a Spectrophotome ter at the FTKE lab. It i s impo rtan t to dete rmine the conce ntration of coco nut water to ana lyse the benefit of coconut wate r in applications, including the food i ndu stry, to ensure product quality and safety. Theconce ntrations found are 325mol, 362mol and 395mol.

Three sample s of coconut water have been pre pared to meas u re the coconut wate r conce ntrat.ion, whic h is 25%, 50%, and 75% coconut wate r mixed with 10 % distilled water. The wave len gth and the trans mitta nce valu e are constant, where the wave len gth is 550 n1 and th.. transm ittance is 1000. The concen trat ion is shown in table 4.9 below.

Coconut water(%)	Transmittance	Absorbance	Factor	Conce ntrat io n , mo]
25	50.0	0.325	1000	325
50	42.7	0.362	1000	362
75	41.7	0.395	1000	395

Table 4.2 Concentration of Coconut Water

T able 4.2 shows the data for the concen trat ion in three differen t samp le s of coconut water con tainin g 10 % of distilled water at wav ele ngth 550 n . Sample 3 showed a higher concen tration value than other samp le s , obtaining a reading of 395 at wave engt 550 n , oUo We d b samp le I and samp le 2 with va l ue s of 325 and 362, respectively.

4.2.3 Sensitivity of rnk rofiber':o:p,:ic sensor on 25% coconut wate. ,.

The analysis is based on the sensitivity and linearity percentage of the performance on · c rofiberJJ_ptic s as a l iqu id senso r in different coconut wate r concentrations that were carried out during the est. Through this analys is, the output power was observed and recorded for every concentration using 1550 nm wavelengths, as shown in Table 4.3.

Sens1 v1 = s ope (excluding the sign)
Linearity = ({R2)

Table 4.3 Power Transmitted for 25% Coconut Water

Time (minutes)	Power Transmitted		
	Size A	SizeB	SizeC
1	-38.44	-39.60	-39.07
2	-39.22	-39.60	-41.03
3	-39.87	-40.00	-41.08
4	-40.05	-40.04	-41.12
5	-40.08	-40.06	-41.15
6	-40.11	-40.06	-41.15

Table 4.4 Sensitivity and Linearity of 25% Coconut Water

Size of Microfiber ic Sensor	Sensitivity, **Y**	Linearity
A	0.317 4	0.8850
B	0.1063	0.8711
C	0.3086	0.6935

From Table 4.4, sample size A showed the highest sensitivity compared to the two other samples, which is the smallest size of tapered fiber. The smallest size of microfiberL could make the E crofibekr y sensitive. In comparison, we can see that sensor sizes A and **B** show a strong negative linear correlation. Meanwhile, size C shows a moderate negative linear correlation. The results indicate that the data have a good fit. This shows that the smallest size value will perform as the best microfiber cs liquid sensor.

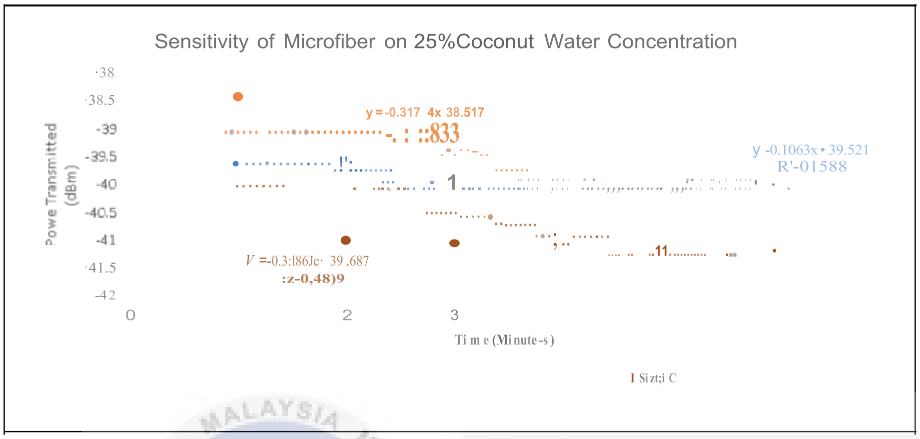


Figure 4.4 Graph for Sensitivity of 25% of Coconut Water

Based on Figure 4.4, shows three different lines for sensitivity with the total outcome percentage of 25% coconut water concentration. Each experiment was checked every I minute for a total of 6 minutes, with the output measured in decibels (dBm). The optical microfiberJacts as a sensor to detect the coconut water and perform in size microfiber}tpric ensor. Sensitivity and linearity were used as observed parameters. According to the investigation, ased on the parameters, at a ·ccofibe,k c sensm si,e **A,** it will show that the optical microfibcr sm has bette< performance. T ere is a strong negative linear correlation between time and power (c!Bm). As the time increases, the power decreases. This experiment also determines that th, mic..rofib e r optics as a liquid sensor is used to sense the sensitivity.

4.2.4 Sensitivity of microfiber optic sensor on 50% coconut water

Table 4.5 Power Transmitted for 50% Coconut Water

Time (minutes)	**Power Transmitted**		
	Size A	**SizeB**	**SizeC**
1	**-39.32**	**-40.05**	**-38.52**
2	**-40.55**	**-40.57**	**-39.67**
3	**-40.55**	**-40.67**	**-4021**
4	**-41.01**	**-40.72**	**-40.50**
5	**-41.02**	**-40.76**	**-40.72**
6	**-41.06**	**-40.78**	**-40.77**

Table 4.6 Sensitivity and Linearity of 50% Coconut Water

Size of Microfiber Sensor	Sensitivity, **Y**	Linearity
A	0.3020	0.8521
B	0.1220	0.8276
C	0.0286	0.8426

Table 4.6 shows that sample size **A** has the highest sensitivity value, indicating the best performance as a microfiber optics liquid sensor. Microfiber optic sensors for all sizes have a strong negative linear correlation, owing the data fit well.

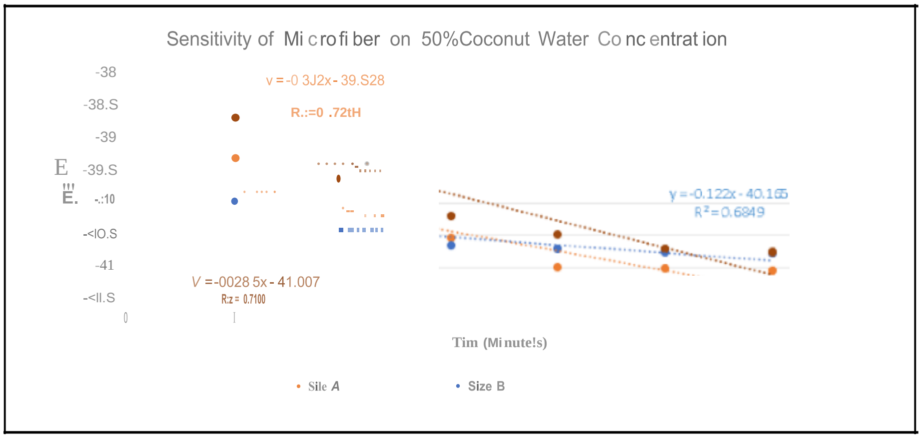


Figure 4.5 Graph for Sensitivity of 50% of Coconut Water

Based on Figure 4.5, shows three differe nt lin es for sensitivi ty with the total outcome percentage of 50% coconut water concent ration. Each experiment was checked every I minute fora total of 6 minutes, with the ou tput measured in dec ibels (dBm). The optic al mic rofiber as a senso r to detect the coconut water and perform in size mic rofiberJbptic sensor. Sensitivity and linearity were used as observed parame ters. According to the i nve stigation, ased on the para meters,a [:1ic rofiberjl'ptic sensor size A will show that the optic al mic rofiberJlm sor has better performance. T here is a strong negative li near correlation between time and power Bzj. As the time increases, the power decrea ses. This experiment also dete rmi nes that th microfiber optics as a liquid sensor is used to sense the sens iti vi ty.

4.2.5 Sensitivity of imicrofiber)p.tic sensor on 75% coconut water

Table 4.7 Power Transmitted for 75% Coconut Water

Time (minutes)	Power Transmitted		
	Size A	Size B	SizeC
1	-40.82	-41.38	-39.85
2	-40.89	-41.38	-40.09
3	-40.92	-41.45	-40.28
4	-40.95	-41 A5	-40.32
5	-40.96	-41 A7	-40.33
6	-40.96	-41.47	-40.34

Table 4.8 Sensitivity and Linearity of 75% Coconut Water

Size of Microfiber JC Sensor	Sensitivity, **Y**	Linearity
A	0.0269	0.9194
B	0.0206	0.9104
C	0.0174	0.8758

Furthermore, from Table 4.6, we can clearly see that sensor size A has the greatest sensitivity. This shows that the smallest size in diameter will perform the best microfiber liquid sensor. All microftberoptic sensors at different sizes have a strong negative lineart rrelation, indicating the data have a gocxl fit.

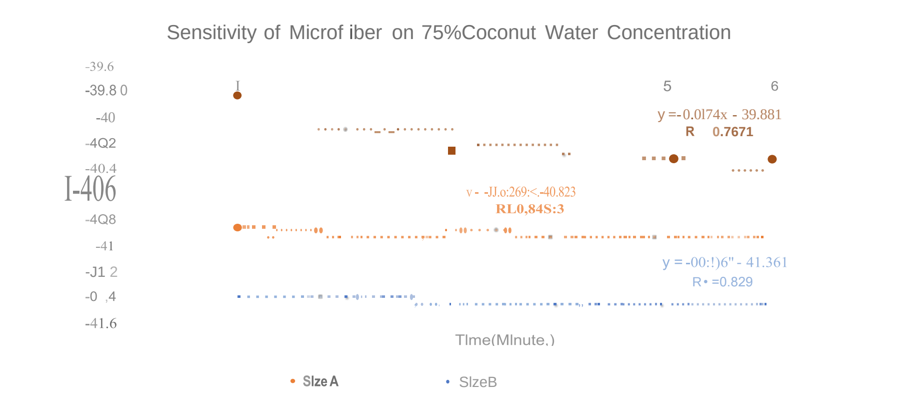


Figure 4.9 Graph for Sensitivity of 75% of Coconut Water

Based on Figure 4.9, shows three different lines for sensitivity with the total outcome percentage of 75 % coconut water concentration. Each experiment was checked every I minute for a total of 6 minute s , with the output measured in decibels (dBm). The optical mic rofiber"a-cts as a sensor to detect the coconut water and perform in size microfiber ic sensor. Sensitivity and linearity were used as observed parameters. According to the investigation, based on the parameters, at a · crofiberJhp.tic se nsor size A, it will show that the optical mic rof sor has better performance. Tnere is tron egati e linear correlation between time and power Bm . As the time increases, the power also decreases. Tnis experiment also determines that th1 m.icr.o cs as a liquid sensor is used to sense the sensitiv ity.

4.2.6 Result fo _sensitivi ty and linearity on 3 Sample Coconut Water for Size A

Coco nut Water (%)	Sensitivity (dBm)	Linearity
25	0.317 4	0.8850
50	0.3020	0.8521
75	0.0269	0.9194

Table 4.9 Result fo nsitiv ity and linearity on 3 Sample Coconut Water for Size A

Based on table 4.6 shows sensitivity and linearity for the microfiber ics in 3 sample coconut waters at different concentrations. The experiment shows that the optic a microfiber' s sor performs better at the first 25% coconut water. It has the highest sensi tivi ty at the first samp e compared to other sample s, with a value of0.3174, followed by 50% and 75 %, with values of0.3020 and 0.0269. [n te rms of line arity, all samp le s have a strong negative linear correlation. Furthermore, the linearity value in dic ates th at the da ta have a good fit.

4.3 Snrnmary

In this chapter , we showcased practical xamples co illustrate how the propos d mic rofibe rj.ip_tic se nso r deve lopment system can be applied to different concen tratio ns of coconut wate r through a tapering method. The case stud y i nvolved tes ting three samples with varyin g conce nt ration s of coco nut water, which were 25%, 50%, and 75%. The process includ d placing a drop of each coconut wat r sample on the rofi bcr, ich had been previously prepared with the respec tive concentrations. The analysis in vo1ved observing and recording the omput power for eac h concentration us in g the same input wavelength. Evaluating the E crofibe r]bprics water sensor's performance at iden tic al wavelengths demo nstrated favourable outcomes, as evicle nce d by the positive result s in sensiti vity , lin e arity and r p arability analyses.

CHAPTERS

CONCLUSIONS AND RECOMMENDATIO S

5.1 Conclusion

In conc lu sion , the outl i ne d project objectives foc us on ex plo ri ng the applic ation of mic rofiber cs as a liquid sensort hrough the tape ri ng method , with a specific emp hasi s on detecting different co nce ntrations of coconut liquid. The primary goal is to i nvestigate, develop, and analy se the petformance of optical · crofibe rsfh:iliis contex t. By emp loy ing the tapering metho d, the stud y aims to contribute valuable insights int o the e ffective ness of crofibe cs as li quid sensors, partic ul arly in dis cern i ng various conce ntrat ions of o"" ligo id. Th is re a h hd, "'""""" fm ad m ciog om ood stm dmg of m<rnfibr CS md bears practical im plic atio ns for potential a pplic ation s i n li quid co nce ntration detection , partic u arly in the realm of coconut liq u ids. Ove rall, the project see ks to bridge the gap betwee n theoretica .l e xploration and practical i mp le me ntatio n in the fiel d of l iqu id sensing using microfibertip::tics.

Overa ll, the researc h presented in this thesis has helped us comprehend the importance of s nso rs i n icrofiber optics. Th presen ted tech niqu e g ne rat s rapid, compe lli ng, re tlectiv , and co rrect r suits while making reaso nable use of a limited set of data and information types, usi ng s traight fo rw ard mat hemati cal ope ratio ns, and requ irin g fewe r co mplex calcuJations. Add i tio nally, the resea rch conce ntrated o n creating strategies that would fac ili tat the creat io n of inexpen sive senso rs that si mply rely on optical c rofiber i ng. As a result, it prepares the gro und wo rk for the sugges ted addi tio nal research.

5.2 Future Work

For future improvements, the accuracy of the sensor in sensing results could be enhanced as follows :

i) Using E crofiberJlP:l,ic sensor to measure other variables such as temperature , press ure, and hum id i ty. Because the ma in construct io n of both sensors is gla ss, they are resistant to hannful interference suc h as electroma gnetic i nterfe rence (EMI) and can tolera te harsh cond iti ons such as high temperatures and pressure.

ii) icrofi ber)ptjc sensors can be li nked to the In ternet of Thing s (IoT) for eve n greate r ease and convenience in mo n itoring sensor output. IoT enable s remote monitori ng since auth orised users may access the system from an ywhe re glob aJly . Add itionally , exte nd ing the detecting zone might boost sensor se nsi tiv ity. Th e sensors may provi de a greate r resonant output whe n an optical signal passes through them.

iii) This research will be useful in the future for the food i ndu stry to determine the qual ity of coco nut wate r during d is t illat ion an d purificat ion. This inn ovat ion provides a more depe nda ble a nd efficie nt sol ut io n by ove rcoming the drawbacks of tradit io naJ methods lik e tit rat ion and refractome try. The high sensi tiv it y, compact size, and resistan ce to electromagnetic fields of micro fiber illpt ic s make them part ic ul ar ly well-suited for the challe nging environme nts ofte n e ncounte red in food process ing.

iv) This, translate s to an upl if t in overaJI produc t quality and safety. T he system's adaptability to di verse composi tio ns and its resil ie nce in corrosi ve o r high-temperature setti ngs e nhance its versatility in the foo d i ndu stry. Furthe nnore , the potential cost -effective ne ss and scaJability of the ic rofiber}1pctic se nsors promise incr eased ope ration al e fficie ncy and re liab ili ty , estabI ishing this te hnol ogy as an asset for ensuri ng top-notch quality and safety standar ds in coconut-b ased products within the food sector.

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Prep. You may be using the wrong preposition.

Missing "," Review the rules for using punctuation marks.

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PAGE 8

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PAGE 9

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P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

PAGE 13

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Confused You have used either an imprecise word or an incorrect word.

Article Error You may need to use an article before this word.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

PAGE 17

Missing "," Review the rules for using punctuation marks.

PAGE 18

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Possessive Review the rules for possessive nouns.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

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PAGE 21

Run-on This sentence may be a run-on sentence.

Prep. You may be using the wrong preposition.

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PAGE 22

Missing "," Review the rules for using punctuation marks.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Hyph. Review the rules for using punctuation marks.

PAGE 23

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Run-on This sentence may be a run-on sentence.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Run-on This sentence may be a run-on sentence.

Verb This verb may be incorrect. Proofread the sentence to make sure you have used the correct form of the verb.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Wrong Form You may have used the wrong form of this word.

PAGE 30

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S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

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Article Error You may need to use an article before this word.

Garbled This sentence contains several grammatical or spelling errors that make your meaning unclear. Proofread the sentence to identify and fix the mistakes.

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Proper Nouns You may need to use a capital letter for this proper noun.

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