EXAMINATION OF ADULTERATION OF EDIBLE OILS BY USING FIBER OPTIC DISPLACEMENT SENSOR

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This report is submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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DECLARATION

I declare that this report entitled "Examination of Adulteration of Edible Oils by using Fiber Optic Displacement Sensor" is the result of my own work except for quotes as cited in the references.

Signature : ....

Author : SITI NORAMINAH BINTI NORDIN

Date : 25 JUNE 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature	:	…………………………………
Supervisor Name	:	Dr Hazura binti Haroon
Date	:	25 June 2021

DEDICATION

This thesis is dedicated to express my highest gratitude especially to my beloved parents Nordin bin Yaman and Norizan binti Torgi.

ABSTRACT

A fiber optic sensor has been developed to detect the adulteration of edible oil. In this project, the sensing mechanism uses SMF-SMF and MMF-MMF based on displacement sensors by using lateral offset method. The distance offset for SMF-SMF is 6.47 µm,11.57 µm, and 14.64 µm, while for MMF-MMF is 4.42 µm,7.49 µm,7.83 µm. The refractive index for pure coconut oil, paraffin oil, and palm oil are found to be 1.4481,1.4585, and 1.4634. The sensitivity of each sensor determined by referring to the highest offset distance of each fiber. For SMF-SMF, the highest offset distance is14.64 µm and the sensitivity have been tested in two mixed solutions which is coconut oil with palm oil with sensitivity -0.286dBm/mol and for solution coconut oil with paraffin oil with sensitivity -0.045 dBm/mol. For MMF-MMF, the highest offset distance is at 7.83 µm highest and the sensitivity have been tested in two mix solution which is coconut oil with palm oil with sensitivity -0.406 dBm/mol and for solution coconut oil with paraffin oil with sensitivity -0.437 dBm/mol. It is proven that the larger the offset distance, the higher the sensitivity of the fiber sensor.

ABSTRAK

Sensor gentian optik telah dikembangkan untuk mengesan pemalsuan minyak yang boleh dimakan. Dalam projek ini, mekanisme penginderaan menggunakan SMF-SMF dan MMF-MMF berdasarkan sensor sesaran dengan kaedah offset lateral. Jarak offset untuk SMF-SMF adalah 6.47 µm, 11.57 µm, dan 14.64 µm, sementara untuk MMF-MMF jarak offset adalah 4.42 µm, 7.49 µm, 7.83 µm. Indeks bias untuk minyak kelapa , minyak parafin, dan minyak sawit didapati 1.4481,1.4585, dan 1.4634. Sensitiviti setiap sensor akan ditentukan dengan merujuk pada jarak offset tertinggi bagi setiap gentian. Untuk SMF-SMF, jarak offset tertinggi ialah 14.64 µm dan kepekaan telah diuji dalam dua larutan campuran iaitu minyak kelapa dengan minyak sawit dengan kepekaan -0.286dBm / mol dan untuk larutan minyak kelapa dengan minyak parafin dengan kepekaan -0.045 dBm / mol. Seterusnya untuk MMF-MMF, jarak offset tertinggi adalah tertinggi 7.83 µm dan kepekaan telah diuji dalam dua larutan campuran iaitu minyak kelapa dengan minyak sawit dengan kepekaan -0.406 dBm / mol dan untuk minyak kelapa larutan dengan minyak parafin dengan kepekaan - 0.437 dBm / mol. Ini telah membuktikan bahawa semakin besar jarak offset, semakin tinggi kepekaan sensor gentian.

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to Allah S.W.T, the Almighty, for showers His blessings throughout my journey in completing my Final Year Project, entitled "Examination of Adulteration of Edible Oil by Using Fiber Optic Displacement Sensor", successfully. Not to forget, a special appreciation to my supervisor, Dr. Hazura Binti Haroon, for her encouragement and valuable guidance in helping me in completing this project. I am beyond thankful to her for all the knowledge she has shared and helped me whenever I needed help. She has fully guided me as clearly as possible, and it is such an honor to study under her guidance. Not just that, to my beloved family, I would like to express my deep and sincere gratitude for their continued support, financially and morally, throughout the whole project. I extremely grateful for their love, care, and sacrifices for me to finish my study without facing any hardships is much appreciated. Their encouragement whenever times get rough while completing this project is such a relief and comfort to me. Not just that, special thanks to my friends and seniors of Master and Ph.D. students that have been very helpful and gave me guidance throughout my project. My whole journey in completing this project has been so meaningful and knowledgeable.

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LIST OF SYMBOLS AND ABBREVIATIONS

MMF	:	Multimode fiber
SMF	:	Single mode fiber
IoT	:	Internet of thing
LPG	:	Long Period of Grating
OPM	:	Optical Power Meter
OSA	:	Optical Spectrum Analyzer
FOS	:	Fiber Optic Sensor
RI	:	Refractive Index
dB	:	Decibels
μW	:	microWatt
%	:	Percentage

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CHAPTER 1

INTRODUCTION

In this chapter 1, it consists of an introduction, problem statement, objective, scope of work about this project which is the examination of adulteration of edible oils by using fiber-optic displacement sensor,

1.1 Introduction

Nowadays, the usage of fiber optics is in high demand and increasingly popular in today's culture because it is widely used in a variety of ways of applications such as medical, science, telecommunication networking, automotive, and other various industry. Moreover, optical fibers also can be used as a sensor to measure strain, temperature, pressure, concentration, and different quantities by modifying a fiber optic itself[1]. Fiber optic sensors are ideal for monitoring environmental changes, and they have a lot of useful features in electronic sensors.

Over the past two decades, fiber optic sensors have been used for contamination detection in food products. Edible oil such as coconut oil pays an important role in people's lives, and it is commonly used in tropical areas.Coconut oil is not only for cooking but also for medical and industrial porposes. Since pure coconut oil is well known for its smell, flavor, antioxidants, medium-chain fatty acids, vitamins, and easily digestible, it is very much prone to adulteration[2]. The most commonly used adulterants are paraffin oil and palm oil. Since paraffin oil is not an edible oil, it is a very good candidate for adulteration due to its characteristic which is being odorless, colorless, and tasteless. Petroleum, paraffin, paraffin oil, and propylene glycol are all derivatives of mineral oil that dissolve the natural oil of the skin, and hence skin becomes more dehydrated. In addition, liquid paraffin is indigestible and prolonged, and extremely hazardous to human health as it can ultimately lead to several health problems such as liver disorders or even cancer. Therefore, it is very important to check the purity of coconut oil [2].

This project involves the development of an optical fiber sensor which is single-mode fiber-optic (SMF) and multimode fiber-optic (MMF) based on method lateral offset displacement sensor to detect the amounts of paraffin oil and palm oil in coconut oil. The fabrication of lateral offset is easy, safe, and cost-effective.

As shown in Figure 1.1, the lateral offset is applied to the misalignment core connection between two fiber optic, whether SMF with SMF or MMF with MMF, so it can help in producing high sensitivity sensor to trace the amount of adulteration oil.

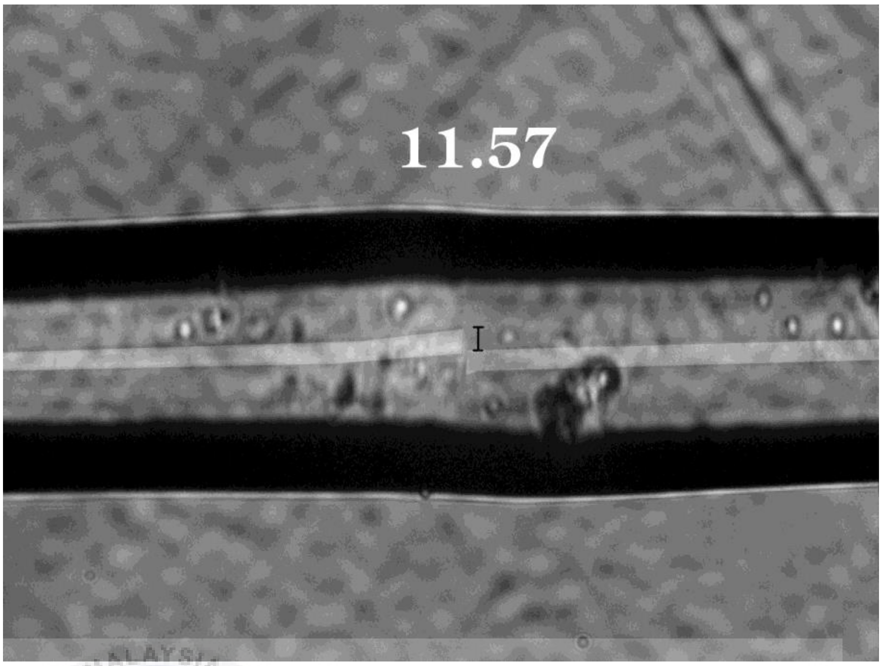


Figure 1.1: The Example Fabrication of Fiber Optic in Lateral Offset with Core Distance 11.57 μm

1.2 Problem Statement

Nowadays, edible oils are a very important food for daily life. Edible oils are used as cooking or food product formulation. They are essential from a nutritional point of view but ensuring their purity is a concern since old times. Edible oils such as coconut oils are very much prone to adulteration. Since it is in high demand, the adulteration concern has been a significant issue. Due to adulterants used in coconut oil, it can cause health problems to our system body. The commonly used as adulterant is paraffin oil and palm oil because it is good candidates for adulteration.

Adulteration oil is defined as the addition or subtraction of any substance to or from other oil so that the natural composition and quality of the original oil substance are affected. It is difficult for the consumer to detect the extent of adulteration.

Adulteration of foods can either be intentional, unintentional, or natural. Hence it is very important to check the purity of coconut oil. Thus, by using a fiber-optic displacement sensor it can be used to overcome the problem that can cause a health problem.

1.3 Objectives

The objective of this project is:

i. To design single-mode fiber and multimode fiber sensing devices based on fiber-optic displacement sensor method.

ii. To analyze the sensing response of the sensor towards the adulterants concentration in coconut oil.

1.4 Scope of Work

This project is to design and develop an optical fiber sensor which is single-mode fiber-optic (SMF) and multimode fiber-optic (MMF) based on method lateral offset displacement sensor to detect the amounts of paraffin oil and palm oil in coconut oil.

The sensing devices will be designed using single-mode fiber and multimode fiber using the displacement method for the detection of trace amounts of paraffin oil and palm oil in coconut oil. The working wavelength is 1550nm for single-mode fiber and 850nm for multimode fiber. A Digital refractometer will be used to measure the refractive index (RI) of each solution. This parameter is chosen based on the equipment and tools that available in the experimental laboratory. The input will be the light source or laser source and the output will be using an optical power meter to detect the value of power loss (dBm or Watt) in each of the experiments.

CHAPTER 2

BACKGROUND STUDY

This chapter discussed briefly in related research on the project of the fiber optic displacement sensor. Fiber optic sensor has been used to monitor the environmental parameters such as concentration, strain, temperature, chemicals, viscosity, and other various elements The theory and the study of journals were discussed in this chapter. Besides, this chapter explains about displacement sensor with method lateral offset that has been used to optimize optical fiber for sensing application and the losses of the optical fiber

2.1 Fiber Optic Application

Since their beginnings nearly four decades ago, fiber optic cables have changed the world of network communication. Traditional networking systems, which require copper wires, have nearly been eliminated by these cables [3]. The application of the fiber optic such as internet, computer networking, surgery and dentist, automotive industry, telephone, lighting and decoration, mechanical inspections, cable television, military, and space application. Fiber optic cables are used for lighting and imaging and as sensors to measure and monitor a vast array of variables. Furthermore, fiber optic cables are also used in research and development, and testing across all the above-mentioned industries [3].

2.2 Optical Technology

Fiber optic technology is based on the ability to convey a light beam along with a thin fiber that has been properly manufactured. A fiber optic cable consists of a glass or silica core. The core of the optical fiber is surrounded by a similar material such as glass or silica, called the cladding, which has a refractive index that is slightly lower than that of the core. It is found that even when the cladding has a slightly higher refractive index, the light passing down the core undergoes total internal reflection, and it is thereby contained within the core of the optical fiber [4]. The structure of glass fiber optic has been shown in Figure 2.1. Figure 2.2 showing the left side of the image is a bundled of fibers and with protective sheathing. This not only provides further protection but also serves to keep the optical fibers together. In the right image is a schematic drawing of three types of optical fibers, showing the propagation of light rays and refractive indexes [7].

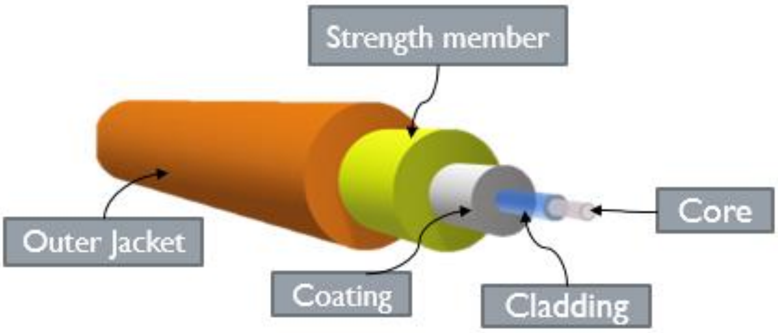


Figure 2.1: Structure of Glass Fiber Optic [4].

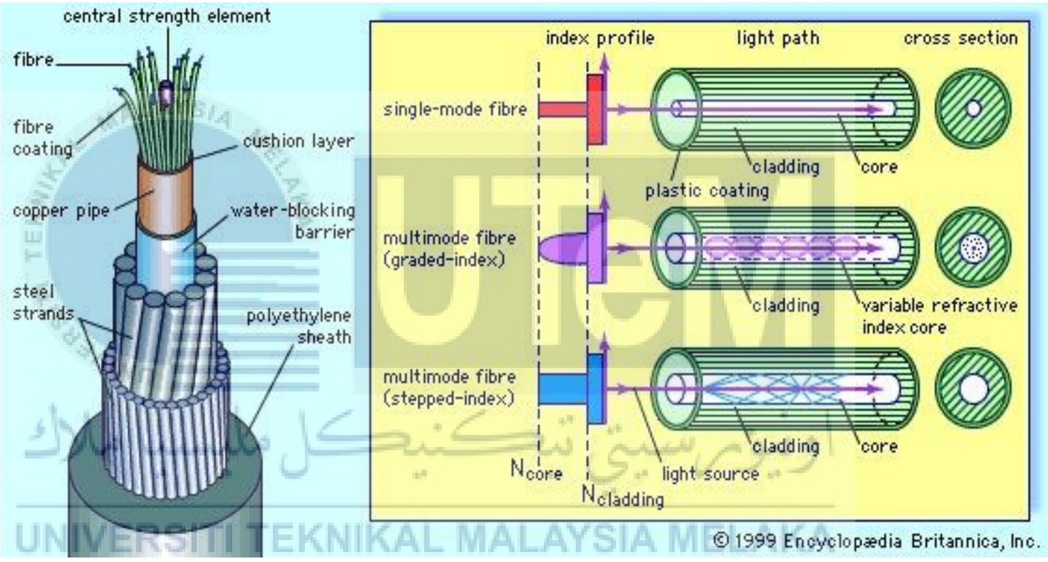


Figure 2.2: Cutaway Drawing of an Optical Fiber Optical [4].

2.3 Optical Fiber Types

There are a lot of various types of fiber optic cable that can be used, and they can be identified in a number of ways. There are two main categories to consider which are step-index fiber optic and graded-index fiber optic [4].

The term step-index cable refers to a cable in which the refractive index between the core and the cladding changes in a step. This is the type that is most typically used. The other variety, as the name implies, changes more gradually as the diameter of the fiber increases. The light is refracted towards the center of the cable when using this sort of cable.

Optical fibers or optical fibers can also be split into single-mode fiber and multimode fiber.

2.3.1 Single Mode Fiber Optic

The single-mode optical fiber (SMF) is designed to carry light with single-mode, which means that light wave travels in the same way or the same pattern and that gives us a single light ray of light. Features of single-mode fiber (SMF) are high transfer rates over long distances. A single-mode cable is a single strand of glass fiber with a measurement of 8.3 to 10 microns in diameter that has one mode of transmission. The width of a single human hair ranges from about 20 to 200 microns. It must use special equipment to see the core because with the naked eye it cannot see. Single-mode fiber has a narrow diameter, through which just a single mode will propagate typically 1310nm or 1550nm. Single-mode fiber carries higher bandwidth than multimode fiber requires a light source with a limited spectral width. Since single-mode fiber (SMF) can carry signals many miles before repeating so it's better for long-distance such as WAN connection for example internet backbone use a single-mode fiber [5].

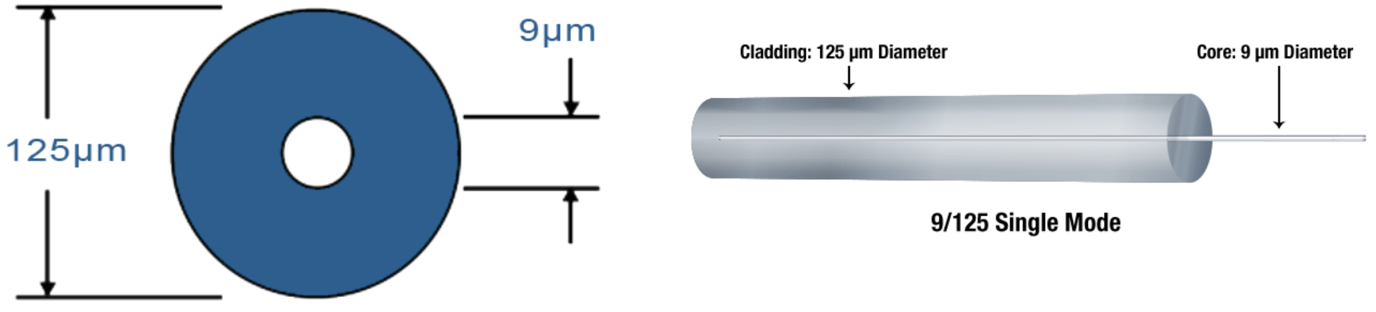


Figure 2.3: Dimension Single Mode fiber

2.3.2 Multimode Fiber Optic

Multimode optical fiber is mostly used for communication over short distances like within a building or on campus. Light waves are dispersed into numerous paths or modes as they travel through the cable core. Multimode links can be used for data rates up to 100 Gbps. Feature of multimode fiber it contains core with a larger diameter than single-mode fiber. Multimode fiber with a core of 50 µm or above. A larger core means multiple modes or rays of light can travel down the core simultaneously. Just like the single mode, the core is surrounded by a cladding that brings the overall diameter of the optical fiber to 125 µm [5].

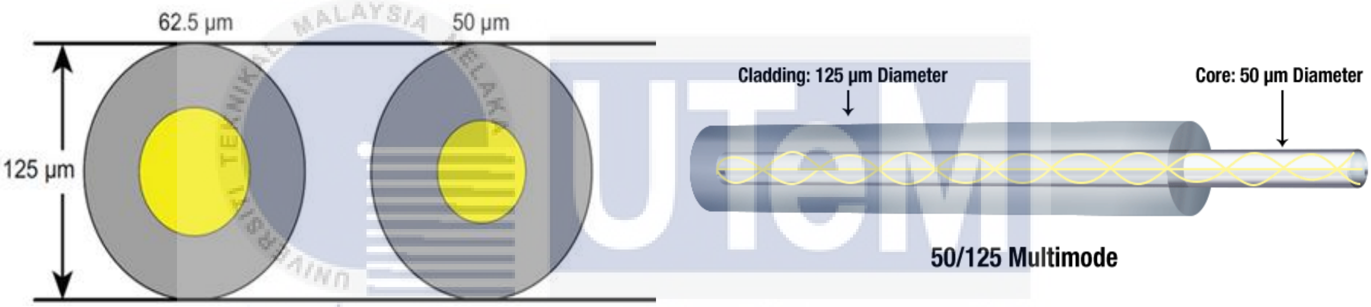


Figure 2.4: Dimension Multimode Fiber Optic [5].

2.4 Splicing

Fiber-optic cables might have to be spliced together for a number of reasons, for example, to realize a link of a particular length. Connecting two fiber-optic cables requires precise alignment of the mated fiber cores. This is required so that nearly all the light is coupled from one fiber-optic cable across a junction to the other fiber-optic cable [6].

There are two principal types of splices which are fusion and mechanical. Fusion splices use an electric arc to weld two fiber-optic cables together. Fusion splicing is the process of melting or fusing the ends of two optical fibers using targeted heat. Preparing each fiber end for fusion is the first step in the splicing procedure. All protective coatings on the ends of each fiber must be removed before fusion splicing. The score-and-break procedure is then used to cleave the fiber. A microscope is used to inspect the quality of each fiber end. In fusion splicing, splice loss is a direct function of the angles and quality of the two fiber-end faces [6]. Example of fusions splicing method is lateral offset, waist enlargement, fiber core mismatched, fiber tappers and other types of fusion splicing. From Figure 2.5 there is an example of how the fiber is splicing using fusion splicing.

Figure 2.5: Fiber Optical Fusion Splicing

The fibers are not permanently connected in mechanical splicing. Instead, the two fibers are properly aligned according to a specially built self-contained assembly. Between the fibers, an appropriate optical adhesive or gel is also utilized. The light can flow via two different fiber strands because of this configuration. There are a few different types of mechanical splices on the market such as rotary splices, elastomeric splices, v-groove splices, snug tube splices, and loose tube splice[7].

2.4.1 Lateral Offset Splicing Method

Fiber optic is offset from the longitudinal axis and usually spliced to form a solid structure. For example, by offset, the splicing of two single-mode fibers, both of fundamental and cladding modes are excited in a sensing fiber. This approach can be frequently to design a sensor for measuring the power loss (dBm).

The advantage of lateral offset is it allows long-distance optical signal transmission. It also has less reflection at the time of signal transmission. Furthermore, has high performance of the sensor is desirable in many sensing applications, including blood diagnosis, water quality control, and food industries. Next, for the disadvantage of lateral offset, sometimes the fiber losses are much higher than the acceptable limits. Splicing increases, the overall cost of the optical fiber communication system. Splicing provides permanent or semi-permanent joints. Sometimes the two fibers are joined temporarily. So connecting the two optical fibers temporarily is done by connectors.

2.4.2 Principle of Lateral Offset Fiber Sensor

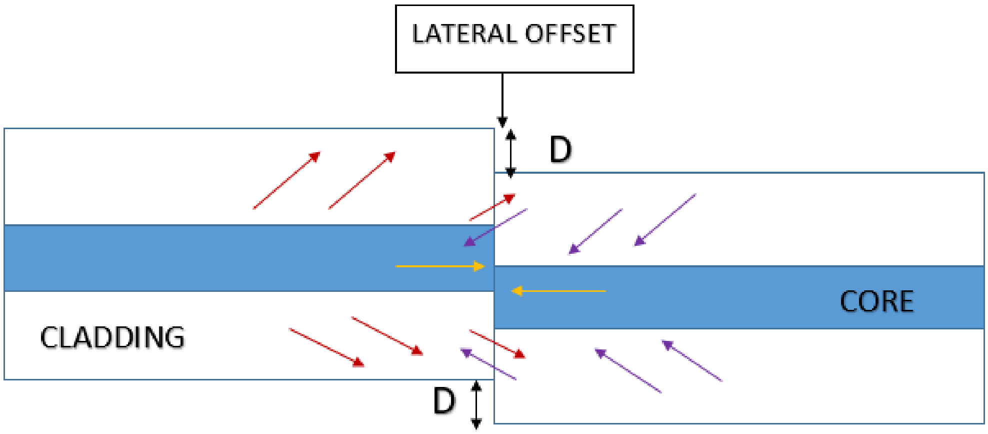


Figure 2.6: Schematic Diagram of Lateral Offset Method

Figure 2.6 shows the schematic diagram of lateral offset method. The principal source of loss in both connectors and splices is fiber-to-fiber end face misalignment [8].The fusion splicing method is used in order to combine the fiber in the lateral misalignment structure. In this project, a fusion-splicing method is used in developing and designing the fiber sensor. There are several types of structure that used the fusion-splicing method in which the method is using heat or electric arc to combine the fiber structure —for example, waist enlargement structure, lateral offset structure and etc. The first of these loss mechanisms, lateral misalignment, is the largest contributor to the total loss in a fiber connection[8]. Lateral misalignment is also known as lateral offset. Lateral offset structure by using the fusion splicing method has been used in designing the fiber sensor for this project. As for the first step, the two ends of the fiber are ready to be spliced. Then, the end of the fiber is cut off to produce flat end surfaces. The end surfaces are placed as for splicing in which that is they are positioned adjacent or abutting each other or abutting each other with their longitudinal axes parallel [9]. Lateral misalignment or lateral offset is the failure of the cross-sections of the two fiber cores to perfectly overlap that can cause power loss while transmitting the light inside the fiber.

In this step, the fibers are positioned in lateral offset which the fibers are aligned where the axes of the core of the fiber end with the outer surface of the cladding of the fiber end. Meaning that the direction of the position is perpendicular to the longitudinal axes of the fiber ends, in which the lateral offset by the offset distance between the core and the cladding of the two fiber ends. Then, the heat is applied to the offset in which causing them to fuse together. The lateral offset connection of fiber, cause an imperfect transfer of optical signal from the transmitter to the receiver of the fiber. The imperfect transfer of the optical signal is known as 'fiber loss' at the offset region, which will be the sensing region in this project.

2.5 Fiber Optic Sensor

The telecommunications sector has altered dramatically as a result of modern fiber-optic technological advancements. Optical fiber's ability to carry gigabits of data at light speed expanded their research potential. Simultaneous improvements and cost savings in optoelectronic components led to the rise of analogous new product categories Engineers combined fiber optic telecommunications product outgrowths with optoelectronic devices to build fiber optic sensors in a previous revolution. It wasn't long before it was discovered that, as material loss decreased and sensitivity to loss detection grew, phase, intensity, and wavelength changes from external disturbances on the fiber itself could be detected. Hence a sensor by using fiber optic was created [1].

2.6 Adulteration in Edible Oils

Food is necessary for human survival, but it has been prone to adulteration since ancient times. Food adulteration can take many forms, including mixing, substituting, concealing the quality of food through mislabeling, storing decomposed or expired food, and adding toxic substances[10]. Edible oils have both financial and nutritional advantages. Because they are the main sources of mono- and poly-unsaturated fats, these oils provide nutrients that are needed for human health. Furthermore, edible oils are used in both home and industrial food production. As a result, edible oils are in high demand all around the world [11].Adulteration in edible oils to increase producer profit becomes a major area of concern for consumers. Furthermore, adulteration in edible oils can result in a variety of health issues for consumers. As a result, the need for a sensitive, accurate, and appropriate method to detect adulteration is highly considered [11].

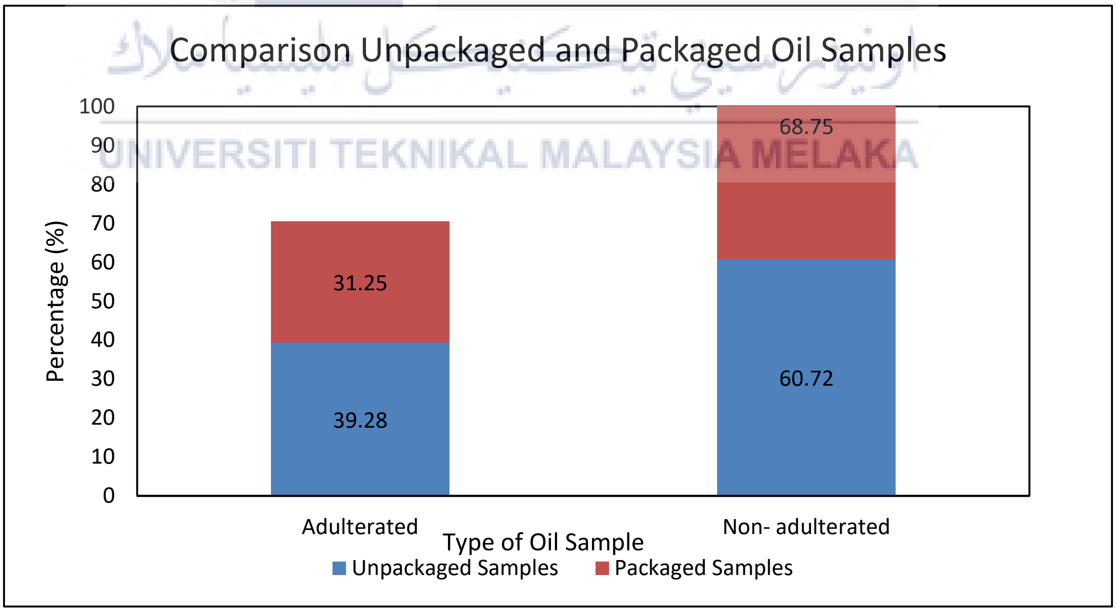


Figure 2.7: Comparison Unpackaged and Packaged Oil Samples[10]

A study in [10] shows that there is a comparison of adulterants in oil samples. It was observed that even though a higher percentage of adulteration was observed in unpackaged samples (39.28%), adulteration was also seen in packaged oil samples (31.25%). Taking into consideration, all the oil samples together for the presence of adulterants, a minor difference in percentage was observed between the unpackaged and packaged samples. It can be inferred that the term packaged does not necessarily mean that the content within is pure for consumption. The slight difference in percentage might be because of the easy practice of adulteration by the vendors in unpackaged or local oil samples. Food adulteration is the deliberate contamination of food material with low-quality, cheap, non-edible, or toxic substances. Adulteration is the addition of ingredients that are not permitted in food and are added solely for commercial gain. Finally, adulteration can cause a variety of issues in the application and manufacturing of edible oils. People should be made more aware and always check for standard certifications [10].

Next for the study journal [2] which is detection and analysis of paraffin oil adulteration in coconut oil using fiber optic long period grating sensor. The sensing mechanism is based on the sensitive dependence of the resonance peaks of a long period of the grating (LPG) on the changes of the refractive index of the environmental medium surrounding the cladding surface of the grating. The wavelength shift of the attenuation bands of the LPG was measured with the sensor immersed in a mixture of paraffin oil and pure coconut oil in different proportions. The detection limit of adulteration was found to be 3% for coconut oil–paraffin oil binary mixture [2].

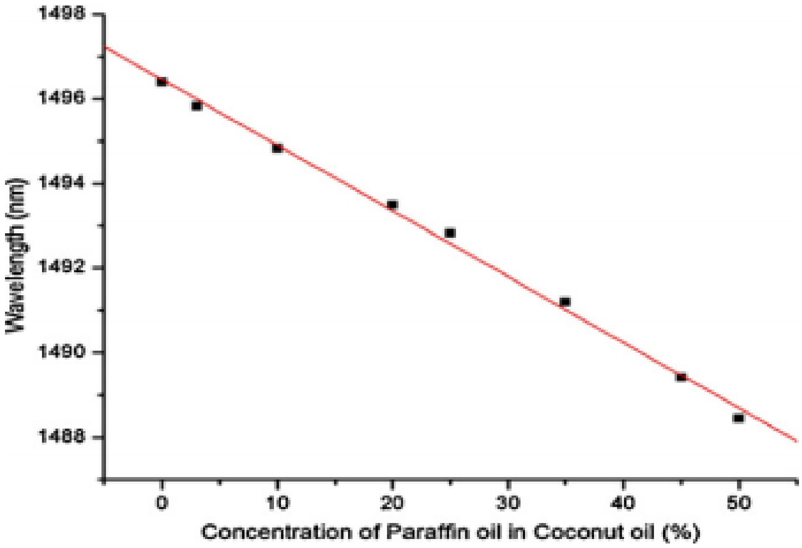


Figure 2.8: Peak Position of The Highest Order Resonance Band in The LPG Transmission Spectra as A Function Of Paraffin Oil Proportion [2]

Figure 2.8 shows the sensitivity of the LPG when used as a sensor for various volume percentages of paraffin oil in coconut oil. It can be seen from the results that the sensor is useful to determine paraffin oil concentration even up to 3% by volume with a good linear sensitivity between 3% and 50%. This region is very useful because most of the adulteration and malpractices using paraffin oil are within this range [2].

CHAPTER 3

METHODOLOGY

In this chapter, all methodology used for each part will be explained in detail. The details that cover the materials and equipment used in this project are described in this chapter. The method to fabricated the fiber optic sensor probe is also explained in this chapter.

3.1 Introduction

This project is to design and fabricate a fiber optic sensor by using method lateral offset method to detecting the liquid concentration of edible oils. The description of tools and components used, the process of making the sensor, the prototype design, and others are explained in this chapter. The use of fiber optic-based lateral offset splicing method for detecting the edible oils in coconut oil is recommended because it can produce high sensitivity and easily detect whether it contains other substances in the oil. For this part, the construction of this project's prototype will help with all the helpful information gathered regarding this project.

3.2 Project Flowchart

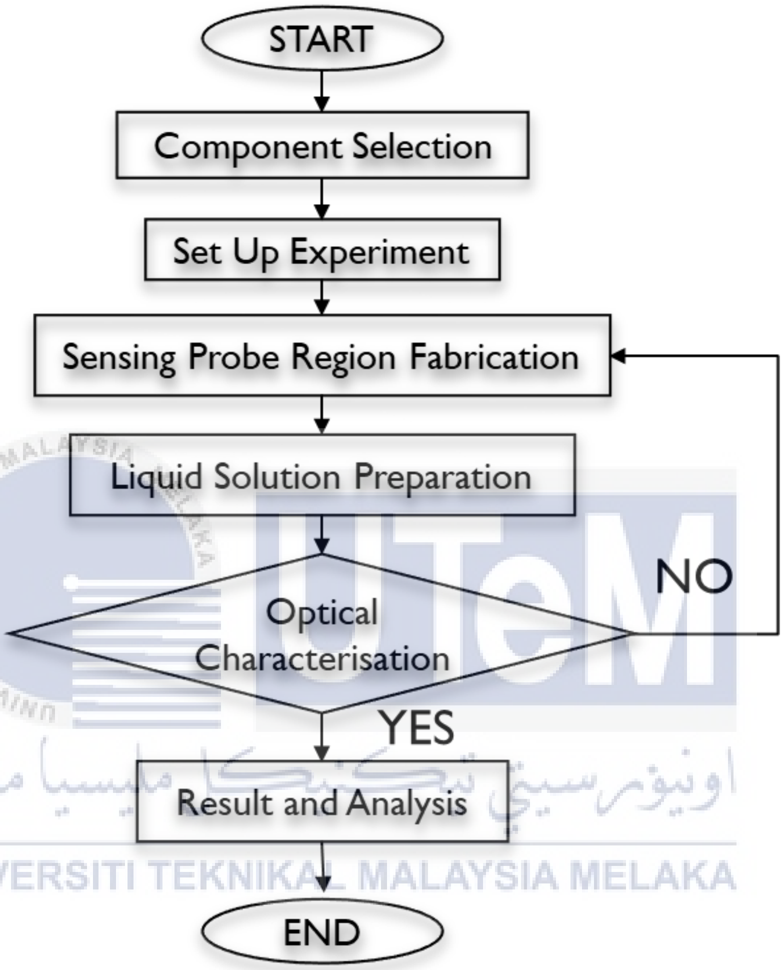


Figure 3.1: Project Flow Chart

Figure 3.1 shows the whole flowchart process of the project. As for the first part of the flowchart process, the component has been selected to identify a suitable material or equipment to be used while implementing this project. Not just that, the experiment also has been set up to know the flow of the operation in this project. An example of the experimental optical setup is shown in Figure 3.8 In designing the sensor part, the fiber optic sensor (FOS) will be developed by using Single-Mode Fiber (SMF) and Multimode Fiber (MMF). SMF is known as an optical fiber that carries a single mode of light, while MMF is known as an optical fiber that has multiple modes of light. As we all know, optical fiber transmits "data" by light to a receiving end, where the light signal is decoded as data. Optical fiber sensors are well known for a wide range of applications in optics and photonics [15]. As a sensing part, the fiber sensor part is fabricated at the SMF and MMF center based on the lateral offset splicing method. There are variations in the sensing region, which Single Mode to Single Mode and Multimode to Multimode. Not just that, there are variations in the distance of the offset part of the sensing region. The sensing region's exposed area will act as a sensitivity part for the sensing element in this project after the fabrication process.

Next, the liquid solution preparation measures the volume of coconut oil, palm oil, and paraffin oil with different measurements in volume so that it can calculate the concentration of the solution. After that, the process will continue with the optical characterization. The Optical Power Meter (OPM) will be used to get the optical signal in this optical characterization process. Other than OPM, Optical Spectrum Analyzer (OSA), also can be used instead of OPM where OSA can measure not only the optical signal, but it can measure wavelength, power, and additional functions which can display the waveform. Though OSA is powerful, there are limitations to using it. The results taken from the OSA are inconsistent. Thus OPM is the tool that can rely on in taking the results. After obtaining the results from the optical characterization, every result will be taken into a graph to determine the mathematical modeling of each result in order to find the best sensitivity of the best linear fit line of the results.

3.3 Method and Project Implementation

There is two types of fiber that are used in this project which are single-mode fiber and multimode fiber. Both of these sensors are spliced with the lateral offset method to detect the sensitivity of fiber optic in the oil.

3.3.1 Splicing Process

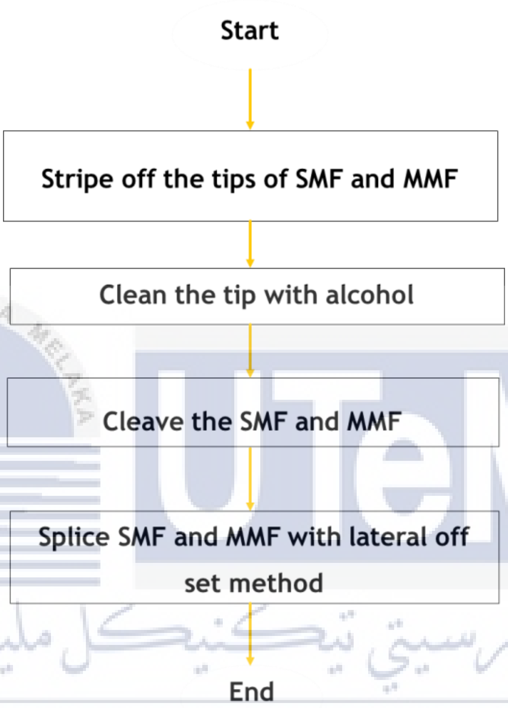


Figure 3.2: Fabrication of SMF and MMF

Figure 3.2 shows the flow chart for the fabrication of SMF and MMF. Fabrication of SMF and MMF is a process of making the fiber as a sensor probe. The fiber optic jacket must be removed by using a fiber cutter slowly and carefully stripe off the tip of the fiber optic. After removing the fiber optic jacket, the fiber optic area is cleaned by using an alcohol solution. After that, the fiber's cladding is removed to expose the core to act as the sensor. The fiber core will cleave by using a high-precision cutter so that the tip of the fiber optic is 90 degrees straight and need to clean it again with an alcohol solution before splicing in the splicing machine. After that, the fiber optic will be ready to splice by using the lateral offset method using the fiber splicing machine.

3.3.2 The procedure of Setting on Normal Splicing in Fujikura FSM-18R

Figure 3.3: Splicer Machine Fujikura FSM-18R

There is a variety type of splicing methods for fiber optic. One of the splicing methods is normal splicing. Normal splicing is the common one to joined the fiber optic with another fiber optic. The two types of sensor SMF and MMF will be splicing in a normal splicing part to compare the measurement with another type of splicing, which is the lateral offset method. The process of normal splicing is by using Fujikura FSM-18R.

The first step for the process of normal splicing by using Fujikura FSM-18 R is turning splicer "ON". Press ON/OFF the key and hold it until the green LED on. The following warning screen is displayed. It is displayed in 3 or 30 times when the splicer power on. The READY screen is displayed after all the motors are reset to their initial positions when you select [Agree]. The power source type is then identified.

After that, the monitor will have displayed a “Splice Mode”. Select appropriate splicing mode for the specific fiber combination. The current mode is displayed on the “READY “screen.

Next, loading fiber to splicer, open wind protector and sheath clamps, Place prepared fiber on to splicer section, and closed wind protector. In the 'Home' screen, after switching on, the splice mode is automatically set to SM AUTO (SM 1), which performs normal splicing. Next, press the SET button for fiber optic alignment, and the screen will appear the "GAP SETTING" and press the SET button for another time, and the fiber optic is ready spliced. The “ARC” will appear on the home screen and it already starts to splice. The splicing process is finished, and the fiber optic can take out from the splicer section.

3.3.3 The procedure of Setting on Lateral Offset Method in Sumitomo Type-36

Figure 3.4: Splicer Machine Sumitomo Type-36

The crucial part of this project is to analyze the performance of fiber optic sensors at different core distances of fiber optic sensors by using the method of lateral offset. The two types of sensor SMF and MMF are constructed at a variety of distances. The process of this method is done by using fusion splicer fiber optic Sumitomo TYPE-36.

The first step for the process of lateral offset splicing by using machine Sumitomo Type -36 turning on the push-button start in AC. Next, make sure the monitor is connected to the splicing machine. Next, for fiber optic placement, gently lay the fiber in the guides on the splicer. The position of the end of the buffer coating at 16 mm mark and check the position of the fiber end and should be near the electrodes, then close the clamp that holds the fiber and close hood on fiber. The display should show “SPLICE MODE MENU” and be set for “Manual Mode”. To set to “Manual Mode” it needs to press “1” at the front-mounted keypad. This keypad allows easy control through user-friendly and has drop-down menu selection and splicing operation. Next “SET” to begin splicing. Spicer will move fiber into place and show the fiber on screen. During the process, the screen will show fiber placement and a message will display to shows progress which is at the home screen “L FIBER/SPATTERING Y” and “R FIBER /SPATTERING Y”. This part is to adjusting fiber optic in manual mode. All the distance needs to do adjust in manual at the front-mounted keypad. After adjusting the fiber distance, fiber optic is ready for the splice. When finished running the program, the splicer will show a splice loss estimate at top of the screen and say “OPEN HOOD”. The splicing process is finished.

3.3.4 Procedure for Image Analyzer "Axioskop 2 MAT"

Figure 3.5: Image Analyzer Axioskop 2 MAT

This image analyzer is to measures the distance offset of the fiber optic by using an optical microscope "Axioskop 2 MAT". This machine is available at FKM. The first step for using image analyzer Axioskop 2 MAT, push the push button on "Green" to on the machine. Next, place the fiber-optic under the multiple ranges of the lens and then set for taking the measured distance offset by using the best range of the objective lens. Adjust the image viewer by using a coarse adjustment to get the best image and clear to see the distance between two fibers. Lastly, take the picture and save it.

3.3.5 Preparation for Solution

The solution is prepared by determining the volume of each solution that needs to be tested in this project. The solution that been used is coconut oil, palm oil, and paraffin oil. The solutions are prepared by determining the mass of the solute by utilizing a formula stated in equation 3.1. However, before finding the solution mass, the solution molar mass must be determined first by referring to the periodic table of an element [12]. The number of moles can be set up based on user preference. After finding the mass of solute needed, the solute is mixed with another solution. The choice of the user also determines the volume of solvent. Therefore, the concentration of the solution, which is the mixture of the solution, can be determined by using the formula in equation 3.2. Finally, the solution refractive index is determined by using a digital refractometer.

$$Number\ of\ Moles = \frac{Mass\ of\ Solute}{Molar\ Mass\ of\ Solute} \tag{3.1}$$

$$Concentration\ of\ Solution = \frac{Number\ of\ Moles}{Volume\ of\ Solution} \tag{3.2}$$

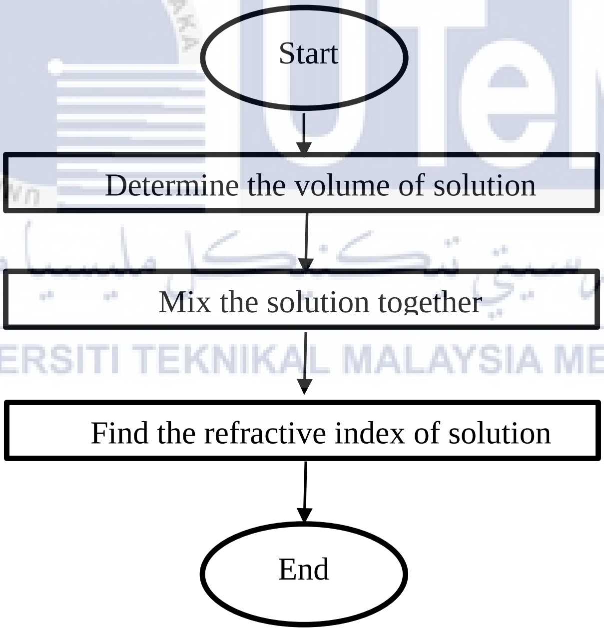


Figure 3.6 Step in Preparing Solutions

3.4 Experimental Setup

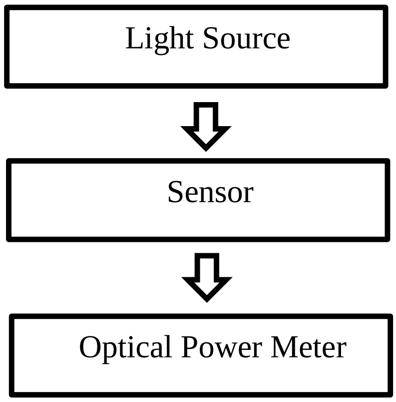


Figure 3.7: Optical Measurement Block Diagram

Figure 3.7 shows the optical block diagram for this project. Basically, for the input, whether 850 nm for multimode or 1550 nm for single-mode is connected to the probe that already splicing and the output is the optical power meter to detect the power loss in the fiber optic. The exposed area spliced based on lateral offset will act as a sensing head (sensor) in this project. It will be submerged into the different concentrations of solutions for sensing before it dipped the fiber optic in solution, the value of the refractive index is already taking out before the experiment is carried out using a digital refractometer. The results obtained from the OPM, which is an optical signal, are transmitted to the optical power meter to get the reading.

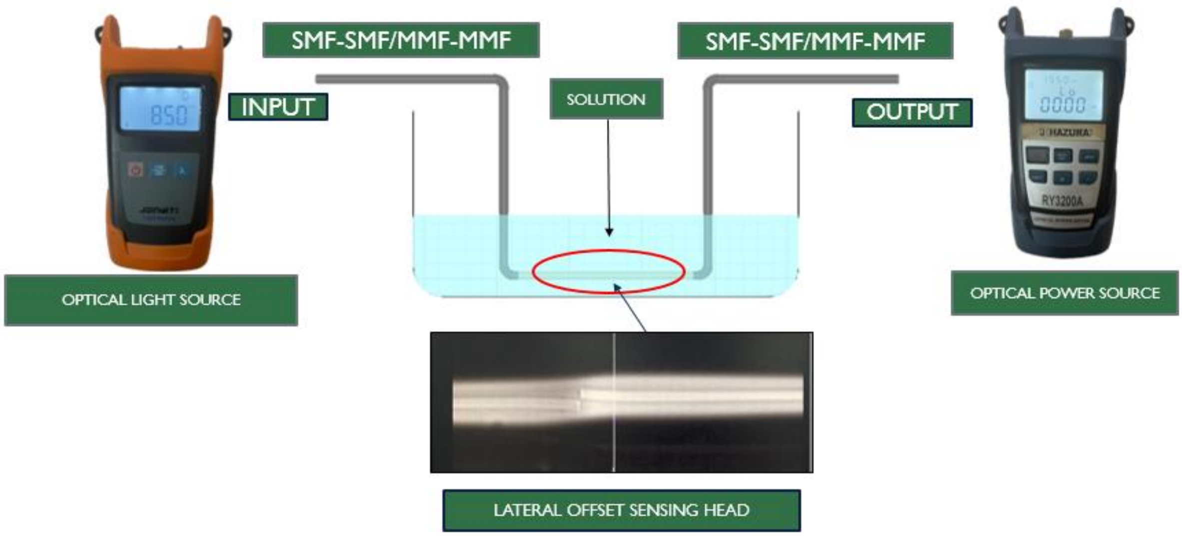


Figure 3.8: Experimental Setup

Figure 3.9: Equipment and Materials Setup

3.5 Equipment and materials

The main part of materials and equipment used in this project are multimode glass fiber-optic (MMF), single-mode glass fiber-optic (SMF), digital refractometers, splicer Fujikura FSM-18R, splicer machine SUMITOMO TYPE 36, image analyzer ZEISS Axioskop 2 MAT, optical light sources, and optical power meter.

Figure 3.10: Multimode Glass Fiber Optic

Figure 3.10 shows multimode glass fiber optic. The uses of multimode glass fiber optic as a sensing area for MMF-MMF. The wavelength transmitted is 650nm to less than 1300nm.

Figure 3.11: Single-Mode Glass Fiber Optic

Figure 3.11 shows a single-mode glass fiber optic. The uses single-mode glass fiber optic as a sensing area for SMF-SMF. The wavelength transmitted is 1310nm to less than 1550nm

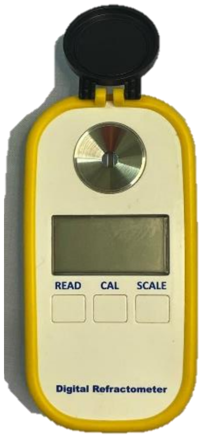


Figure 3.12: DR-101 Digital Refractometer

Figure 3.12 shows DR-101 digital refractometer use to measure the refractive index value in each of the solutions.

Figure 3.13: Splicer Fujikura FSM-18R

Figure 3.13 shows the splicer machine Fujikura FSM-18R that use to construct fiber sensor for normal fusion splicing with distance offset at 0µm.

Figure 3.14: Splicer Machine SUMITOMO TYPE-36

Figure 3.14 shows the splicer machine SUMITOMO TYPE-36 that uses to construct fiber sensor with method lateral offset distance.

Figure 3.15:ZEISS Axioskop 2 MAT

Figure 3.15 shows the image analyzer ZEISS Axioskop 2 MAT that uses to measure the offset distances of the fiber sensor.

Figure 3.16: Optical Power Meter

Figure 3.16 shows the optical power meter to observe and analyze the power output for SMF-SMF and MMF-MMF optic sensors. The wavelength is set for 850 nm for MMF-MMF and 1550 nm for SMF-SMF.

Figure 3.17: Optical Light Sources

Figure 3.17 shows the optical light source as an input source for the MMF-MMF sensor. It can operate at wavelength 850 nm and 1310 nm.

Figure 3.18: Optical Light Sources

Figure 3.18 shows the optical light sources as an input source for the SMF-SMF sensor. It can operate at wavelength 1550 nm.

CHAPTER 4

RESULTS AND DISCUSSION

Chapter 4 includes the results and discussion of the overall system. The results of this project have been recorded and tabulated.

4.1 Solution for Coconut Oil, Palm Oil, Paraffin Oil

All solutions have been prepared before the experiment begins by testing the refractive index, the volume of each solution, the concentration based on percentage and number of mol of each solution. Thirteen solutions have been prepared for this project which are pure coconut oil, pure palm oil, pure paraffin oil, five solutions for coconut oil mixed with palm oil, and five solutions with coconut oil mix with paraffin oil. The fixed volume taken for the main oil which is the coconut oil is 20 ml and for the mixture of a solution to see the adulteration occur in coconut oil either palm oil or paraffin, both of it has specific volume to mix with coconut oil which is

10ml,8ml,5ml,3ml,1ml and different volume of percentage range on 34%,29%,20%,13%, and 5% based on the mixture of which is coconut oil with palm oil or coconut oil with paraffin oil. The refractive index of coconut oil, palm oil, and palm oil are found to be 1.4481,1.4623 and 1.4540 respectively. Table 4.1 shows the list of the solution, volume, concentration, and refractive index.

Table 4.1: List of The Solution, Volume, Concentration, and Refractive Index

No	Solution	Volume (ml)	Concentration (100%)	Number of mol/g	Refractive Index
1.	Air	20 ml	100%	-	1.000
2.	Distilled Water	20 ml	100%	1.0824	1.333
3.	Coconut Oil	20 ml	100%	0.0329	1.4481
4.	Palm Oil	20 ml	100%	0.0214	1.4623
5.	Paraffin Oil	20 ml	100%	0.0484	1.4540

4.1.1 Mixture Solution of Coconut Oil with Palm Oil

The main oil to test the adulteration is coconut oil and the adulterant oil is palm oil. The fixed volume for coconut oil is 20 ml, and for the adulterant oil the volume is 1ml,3ml,5ml,8ml, and 10ml and, concentration volume in percentage, number of mol of each solution, and refractive index by using a digital refractometer have been recorded in the table shown in Table 4.2. Figure 4.1 shows the refractive index response towards the volume percentage of palm oil in coconut oil has been increased depending on the percentage of the palm oil added into coconut oil. The higher the amount of volume of palm oil in coconut oil, the higher the refractive index.

Table 4.2: List of Solution Coconut Oil With Palm Oil, Concentration, and Refractive Index

No	Solution	Concentration Coconut Oil in Volume (100%)	Number of mol/g	Refractive Index
1.	Coconut + Palm Oil	95%	0.0193	1.4533
2.	Coconut + Palm Oil	87%	0.0179	1.4539
3.	Coconut + Palm Oil	80%	0.0164	1.4549
4.	Coconut + Palm Oil	71%	0.0149	1.4551
5.	Coconut + Palm Oil	66%	0.0136	1.4560

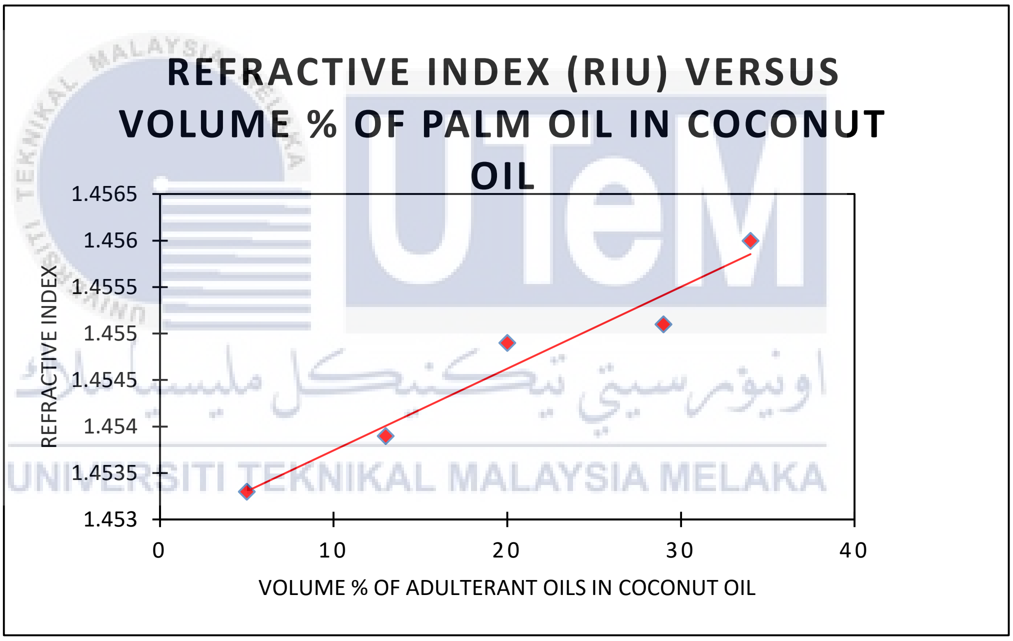


Figure 4.1: Refractive Index Versus The Volume Percentage of Palm Oil in Coconut Oil

4.1.2 Mixture Solution of Coconut Oil with Paraffin Oil

For the solution coconut oil with palm oil. The main oil to test the adulteration is coconut oil and the adulterant oil is paraffin oil. The fixed volume for coconut oil is 20 ml, and for the paraffin oil the volume is 1ml,3ml,5ml,8ml, and 10ml and, concentration volume in percentage, number of mol of each solution, and refractive index by using refractometer have been recorded in the table shown in Table 4.3. Figure 4.2 shows the graph of refractive index response towards the volume percentage of paraffin oil in coconut oil has been increased depending on the percentage of the paraffin oil added into coconut oil.

Table 4.3: List of Solution Coconut Oil with Paraffin Oil, Concentration, and Refractive Index

No	Solution	Concentration Coconut Oil in Volume (100%)	Number of mol/g	Refractive Index
1.	Coconut + Paraffin Oil	95%	0.0286	1.4533
2.	Coconut + Paraffin Oil	87%	0.0273	1.4535
3.	Coconut + Paraffin Oil	80%	0.0262	1.4538
4.	Coconut + Paraffin Oil	71%	0.0227	1.4541
5.	Coconut + Paraffin Oil	66%	0.0213	1.4551

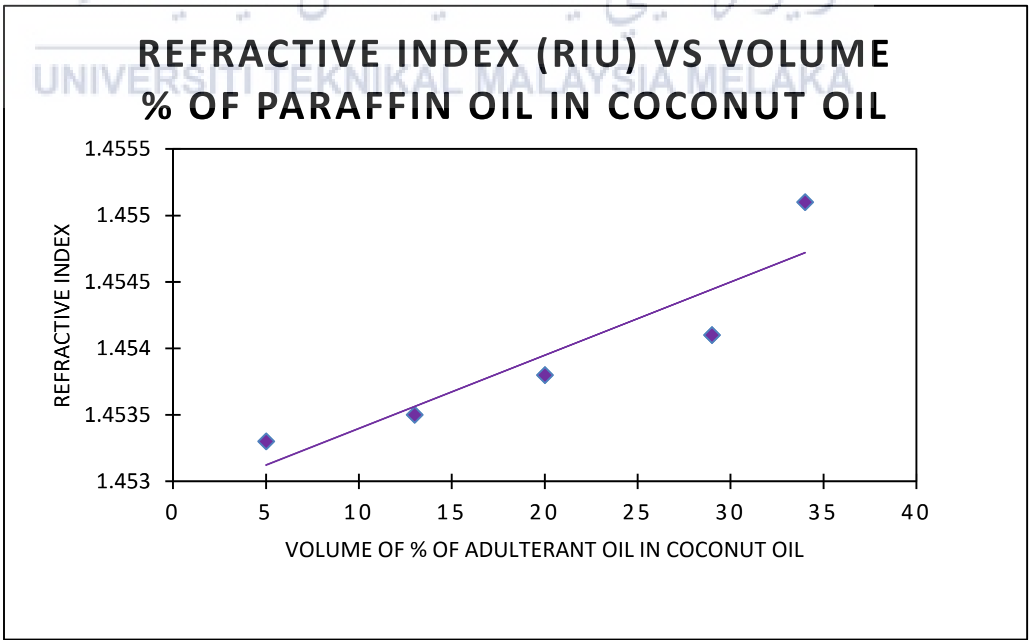


Figure 4.2: Refractive Index Versus The Volume Percentage of Palm Oil in Coconut Oil

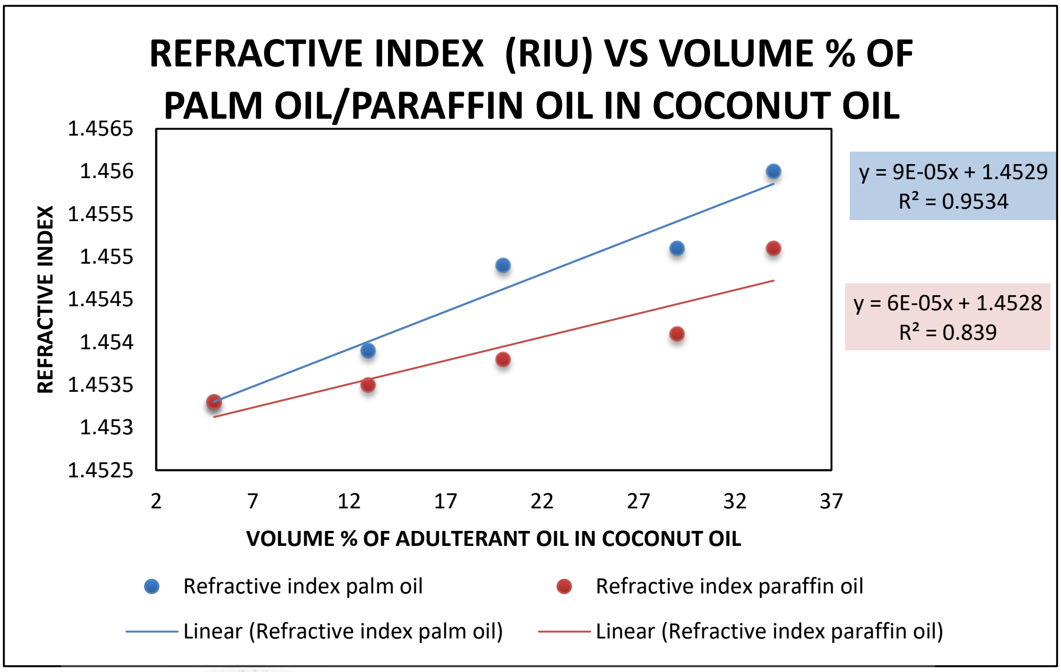


Figure 4.3: Refractive Index of The Volume Percentage Of Palm Oil and Paraffin Oil in Coconut Oil

In figure 4.3 shows a graph of the refractive index of the volume percentage of palm oil and paraffin oil in coconut oil. It can be seen that as the volume of adulterants increases, the RI is increasing as well. Pure palm oil has a refractive index of 1.4623 and pure paraffin oil has a refractive index of 1.4540. Therefore, the adulterant is predicted for RI other than that. In addition, the graph shows that the slope of the refractive index of palm oil with coconut oil is higher than the slope of coconut oil with paraffin oil because palm oil has similar physical and chemical properties to coconut oil, and it bends similarly to coconut oil [13]. The sensitivity of the fiber sensors has been observed and analyzed from the results obtained from the optical power meter (OPM). The steepest slope in the graph represents the highest sensitivities of the fiber sensor. Each graph has a best-fit linear line that represents in the general mathematical equation is:

$$y = mx + c \quad \textbf{(4.1)}$$

Where y is the output power, x is the refractive index value of the solution, m is the gradient of the graph and c is the y-intercept of the graph. Based on the graph the sensitivity for palm oil is 9E-05 RIU/% and for sensitivity, paraffin oil is 6E-05 RIU/%.

Sheeba et al.[14] developed fiber optic sensors to determine the concentration of adulterants, such as palm and paraffin oils, in a coconut oil sample. The results obtained by Sheeba et al. [14] also showed an increase in the refractive index of the medium surrounding the sensor head and a decrease in the output intensity with an increase in the number of adulterants.

4.2 Distance Measurement of Fiber Optic Sensor

The fiber optic has been a measure for each offset distance using an image analyzer. There are 3 different offset distances based on lateral offset displacement sensor and also normal splicing which include single-mode fiber and multimode fiber optic. The fiber optic sensor has been developed to see the variation of the sensitivity of output based on the offset distance of fiber optic. With the increase of the offset distance, the light entering the cladding gradually increases. The longer the offset distance is, the higher the energy loss. If more light energy enters the cladding, the energy difference between the cladding and the core becomes smaller, which improves the extinction ratio and forms multi-path interference effectively [15].

For SMF-SMF the distance that has been taken is for normal splicing in Figure 4.4 is 0µm, and for the lateral offset distance, is shown in Table 4.4 for of each the distances which are 6.47µm and 11.57µm and 14. 64µm.Next, for MMF-MMF the distance that has been taking for normal splicing is 0µm and for the lateral offset distance is 4.42µm, 7.49µm and 7.83µ has been shown in Table 4.5.

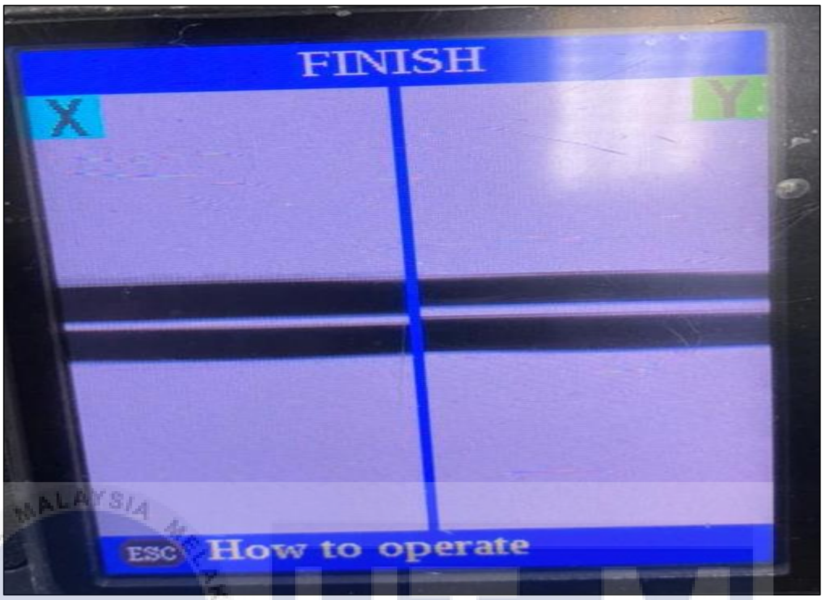


Figure 4.4: Shows The Image of Normal Splicing for Distance 0µm

Table 4.4: Image of Distance Measurement of Single-Mode Fiber Optic

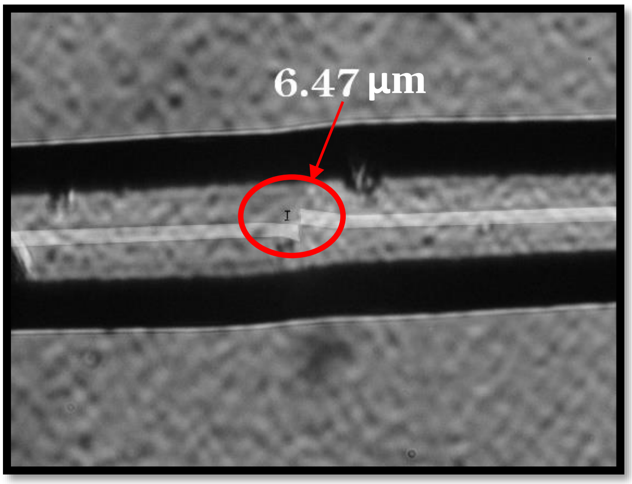
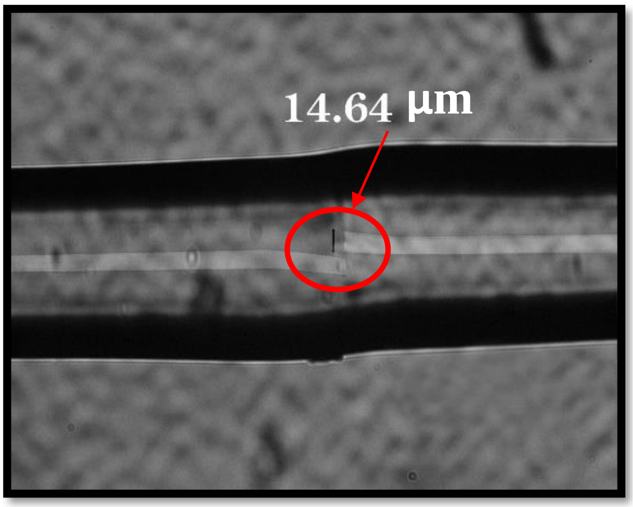
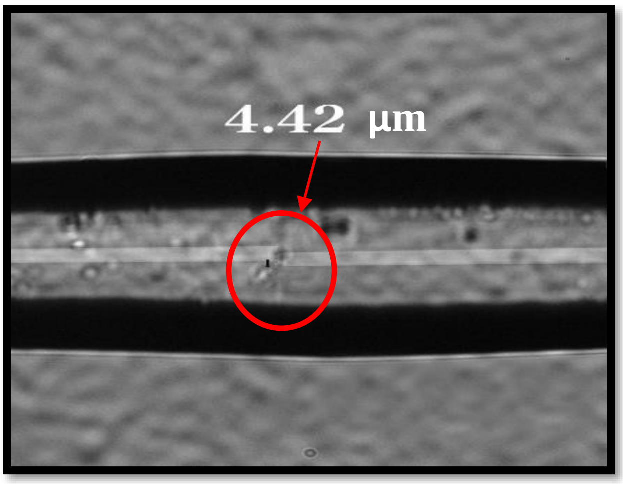
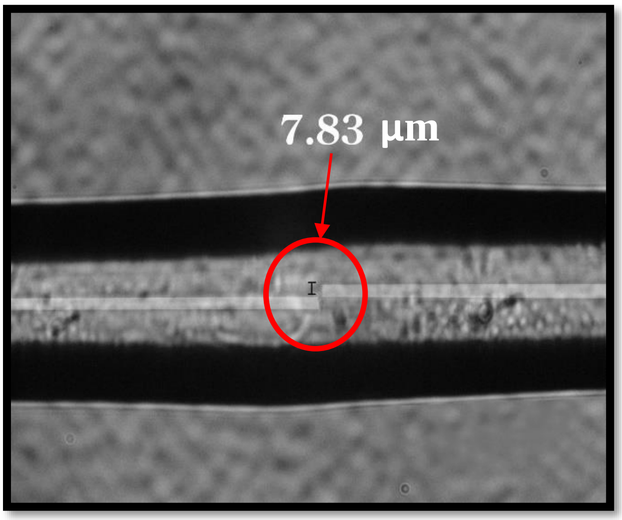
No	Image	Distance (um)
1.	Single-mode 1 	Distance: 6.47 µ m
2.	Single-mode 2 	Distance: 11.57µ m
3.	Single-mode 3 	Distance:14.64µ m

Table 4.5: Image of Distance Measurement of Multimode Fiber Optic

No	Image	Distance (um)
1.	Multimode 1 	Distance: 4.42 µ m
2.	Multimode 2 	Distance: 7.49µ m
3.	Multimode 3 	Distance:7.83µ m

4.3 Optical Measurement Analysis

For optical measurement analysis, two types of sensors have been used based on lateral offset, which are Table 4.6, Table 4.7, Table 4.8, and Table 4.9 for SMF-SMF, Table 14, Table 15, Table 16 and Table 17 for MMF-MMF show all the measurements taken with different variations of distance and solution. Each of the sensors has a different type of distance. For SMF-SMF, the distance used is 0µm,6.47µm, 11.57µm, and 14. 64µm and for MMF-MMF the distance offset used are 0µm,4.42µm, 7.49µm, and 7.83µm. All the explanations and discussion will be discussed in each part according to the table and graph based on the fiber sensor, distance, and solution used.

4.3.1 Single Mode Fiber Optic

For single-mode fiber optic, based on lateral offset distance SMF-SMF, the distance used is 0µm,6.47µm, 11.57µm, and 14. 64µm. Thirteen solutions have been tested which is pure coconut oil, pure palm oil, and pure paraffin oil, five mix solution which is pure coconut oil with palm oil, and another mixed solution is pure coconut oil with paraffin oil. The number of mols that have been calculated for each solution, refractive index measurement, and the output power, have been recorded in Table 4.6, Table 4.7, Table 4.8, and Table 4.9.

Table 4.6: Normal Splicing Single-Mode Fiber

No	Solution	Concentration %	No.of mol/g	Refractive Index	Power (dBm)	Power (μW)
1.	Air	100%	-	1.0003	-8.81	131.5
2.	Distilled Water	100%	1.0824	1.3333	-9.05	124.4
3.	Coconut Oil	100%	0.0329	1.4481	-8.15	153.1
4.	Palm Oil	100%	0.0214	1.4623	-8.28	148.6
5.	Paraffin Oil	100%	0.0484	1.4540	-8.30	147.91
6.	Coconut with Palm Oil	95%	0.0193	1.4533	-8.06	156.31
7.	Coconut with Palm Oil	87%	0.0179	1.4539	-8.14	153.46
8.	Coconut with Palm Oil	80%	0.0164	1.4549	-8.34	146.55
9.	Coconut with Palm Oil	71%	0.0149	1.4551	-8.38	145.21
10.	Coconut with Palm Oil	66%	0.0136	1.4560	-8.64	136.77
11.	Coconut with Paraffin Oil	95%	0.0286	1.4533	-8.83	130.91
12.	Coconut with Paraffin Oil	87%	0.0273	1.4535	-8.88	129.42
13.	Coconut with Paraffin Oil	80%	0.0262	1.4538	-8.92	128.23
14.	Coconut with Paraffin Oil	71%	0.0227	1.4541	-8.94	127.64
15.	Coconut with Paraffin Oil	66%	0.0213	1.4551	-8.97	126.77

Table 4.7: Single Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 6.47 μm

No	Solution	Concentration %	No.of mol/g	Refractive Index	Power (dBm)	Power (μW)
1.	Air	100%	-	1.0003	-18.00	15.84
2.	Distilled Water	100%	1.0824	1.3333	-17.94	16.14
3.	Coconut Oil	100%	0.0329	1.4481	-17.79	16.63
4.	Palm Oil	100%	0.0214	1.4623	-17.82	16.52
5.	Paraffin Oil	100%	0.0484	1.4540	-18.35	14.62
6.	Coconut with Palm Oil	95%	0.0193	1.4533	-17.75	16.79
7.	Coconut with Palm Oil	87%	0.0179	1.4539	-17.72	16.90
8.	Coconut with Palm Oil	80%	0.0164	1.4549	-17.7	16.98
9.	Coconut with Palm Oil	71%	0.0149	1.4551	-17.94	16.07
10.	Coconut with Palm Oil	66%	0.0136	1.4560	-18.03	15.73
11.	Coconut with Paraffin Oil	95%	0.0286	1.4533	-18.09	15.52
12.	Coconut with Paraffin Oil	87%	0.0273	1.4535	-18.11	15.45
13.	Coconut with Paraffin Oil	80%	0.0262	1.4538	-18.18	15.21
14.	Coconut with Paraffin Oil	71%	0.0227	1.4541	-18.2	15.14
15.	Coconut with Paraffin Oil	66%	0.0213	1.4551	-18.22	15.07

Table 4.8: Single-Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 11.57µm

No	Solution	Concentration %	No.of mol/g	Refractive Index	Power (dBm)	Power (µW)
1.	Air	100%	-	1.0003	-20.50	8.912
2.	Distilled Water	100%	1.0824	1.3333	-20.61	8.689
3.	Coconut Oil	100%	0.0329	1.4481	-20.90	8.128
4.	Palm Oil	100%	0.0214	1.4623	-20.93	8.072
5.	Paraffin Oil	100%	0.0484	1.4540	-21.45	7.161
6.	Coconut with Palm Oil	95%	0.0193	1.4533	-20.86	8.203
7.	Coconut with Palm Oil	87%	0.0179	1.4539	-20.85	8.222
8.	Coconut with Palm Oil	80%	0.0164	1.4549	-20.89	8.147
9.	Coconut with Palm Oil	71%	0.0149	1.4551	-21.18	7.620
10.	Coconut with Palm Oil	66%	0.0136	1.4560	-21.25	7.499
11.	Coconut with Paraffin Oil	95%	0.0286	1.4533	-20.49	8.933
12.	Coconut with Paraffin Oil	87%	0.0273	1.4535	-20.82	8.279
13.	Coconut with Paraffin Oil	80%	0.0262	1.4538	-20.85	8.222
14.	Coconut with Paraffin Oil	71%	0.0227	1.4541	-20.93	8.072
15.	Coconut with Paraffin Oil	66%	0.0213	1.4551	-21.07	7.816

Table 4.9: Single Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 14.64 µm

No	Solution	Concentration %	No.of mol/g	Refractive Index	Power (dBm)	Power (µW)
1.	Air	100%	-	1.0003	-21.67	6.807
2.	Distilled Water	100%	1.0824	1.3333	-21.89	6.471
3.	Coconut Oil	100%	0.0329	1.4481	-21.86	6.426
4.	Palm Oil	100%	0.0214	1.4623	-21.89	6.471
5.	Paraffin Oil	100%	0.0484	1.4540	-21.92	6.516
6.	Coconut with Palm Oil	95%	0.0193	1.4533	-21.9	6.457
7.	Coconut with Palm Oil	87%	0.0179	1.4539	-22.04	6.251
8.	Coconut with Palm Oil	80%	0.0164	1.4549	-22.72	5.346
9.	Coconut with Palm Oil	71%	0.0149	1.4551	-22.86	5.176
10.	Coconut with Palm Oil	66%	0.0136	1.4560	-22.92	5.105
11.	Coconut with Paraffin Oil	95%	0.0286	1.4533	-21.95	6.382
12.	Coconut with Paraffin Oil	87%	0.0273	1.4535	-22.04	6.252
13.	Coconut with Paraffin Oil	80%	0.0262	1.4538	-22.08	6.194
14.	Coconut with Paraffin Oil	71%	0.0227	1.4541	-22.11	6.152
15.	Coconut with Paraffin Oil	66%	0.0213	1.4551	-22.14	6.109

4.3.1.1 Solution Pure Coconut Oil, Paraffin Oil and Paraffin Oil

Table 4.10: List of Fiber Optic and Offset Distance

Fiber Optic	Distance (D)
Normal Splicing (NS)	0µ
Single Mode 1 (SM1)	6.47µ
Single Mode 2 (SM2)	11.57µ
Single Mode 3 (SM3)	14.64µ

Table 4.10 shows the list of SMF-SMF fiber optic and offset distance. Normal splicing (NS) the offset distance is 0µm, by using method lateral offset, single-mode 1 (SM 1) the offset distance is 6.47µm, single-mode 2 (SM 2) the offset distance is 11.57µm, and single-mode 3(SM 3), the offset distance is 14.64µm. Table 10 shows the output power in (dBm) for each solution which is pure coconut oil, pure palm oil, and pure paraffin oil-based on a number of mols. So based on the output power with the different offset distances, it will show which of the best length will detect the adulteration in coconut oil.

Table 4.11: Output Power in (dBm) Single-Mode Fiber Optic With Lateral Offset Displacement Sensor With Distance 0 µm,6.47 µm,11.57 µm,14.64 µm for Pure Coconut Oil, Palm Oil and Paraffin Oil.

	D= 0µ	D= 6.47µ	D= 11.57µ	D= 14.64µ
Number of mol/g	Output Power NS (dBm)	Output Power SM 1 (dBm)	Output Power SM 2 (dBm)	Output Power SM 3(dBm)
0.0329	-8.15	-17.79	-20.90	-21.86
0.0214	-8.28	-17.82	-20.93	-21.89
0.0484	-8.30	-18.35	-21.45	-21.92

Table 4.11 shows that each of the solutions has been tested according to the number of mols for each solution for pure coconut oil the number of mols is 0.0329 mol/g, pure palm oil is 0.0214 mol/g, and pure paraffin oil is 0.0484 mol/g.

The result for the output power in (dBm) based on Table 4.11 it shows the longer distance will produce high power loss with method lateral offset distance for distance 14.64 µm the output power for pure coconut oil is -21.86 dBm/mol, pure palm oil is -21.89 dBm/mol and for pure paraffin oil is -21.92 dBm/mol compared to the other shorter offset distance. For the output power with method lateral offset distance with distance 11.57µm, the output power for each solution for pure coconut oil is -20.90 dBm, pure palm oil is -20.93 dBm and for pure paraffin oil is -21.45 dBm.Lastly, for the output power with method lateral offset distance with the shorter distance which is 6.47µm, the output power for each solution for pure coconut oil is -17.79 dBm, pure palm oil is -17.82 dBm and for pure paraffin oil is -18.35 dBm.

For the normal splicing output power loss with a distance of 0µm, pure coconut oil is -8.15 dBm, pure palm oil is -8.28 dBm and pure paraffin oil is -8.30 dBm. Therefore, it can conclude that the longer the offset distance is, the higher the energy loss will produce.

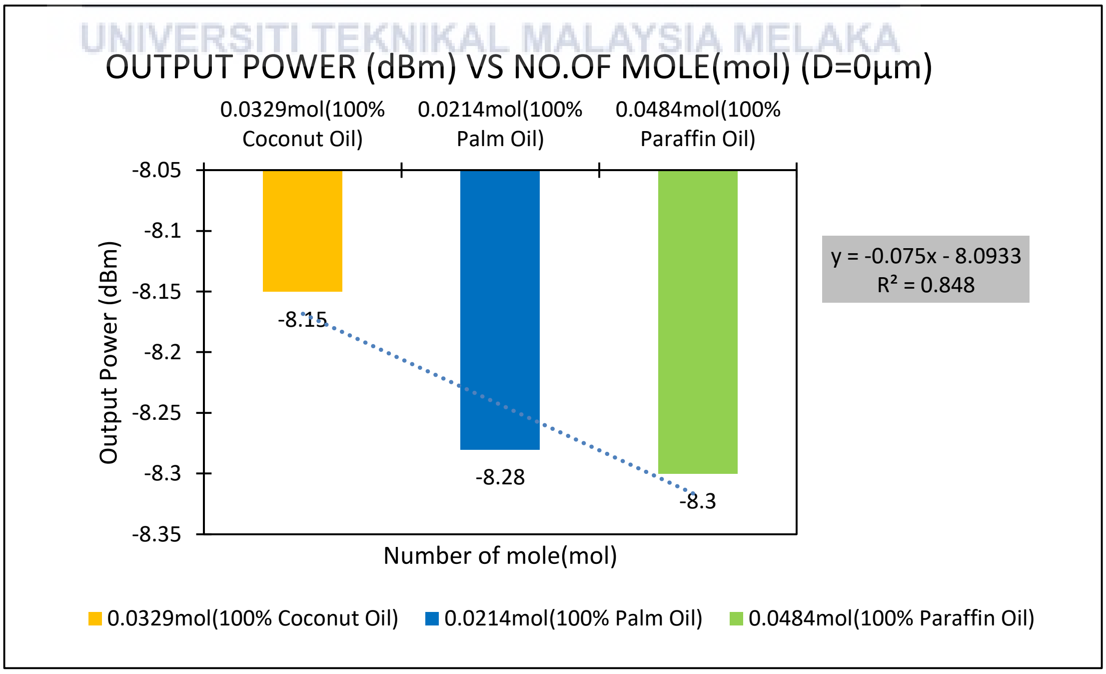


Figure 4.5: Graph For Output Power Versus Number of Mole (mol) Coconut Oil, Palm Oil, Paraffin Oil for Distance 0µm using Normal Splicing SMF-SMF

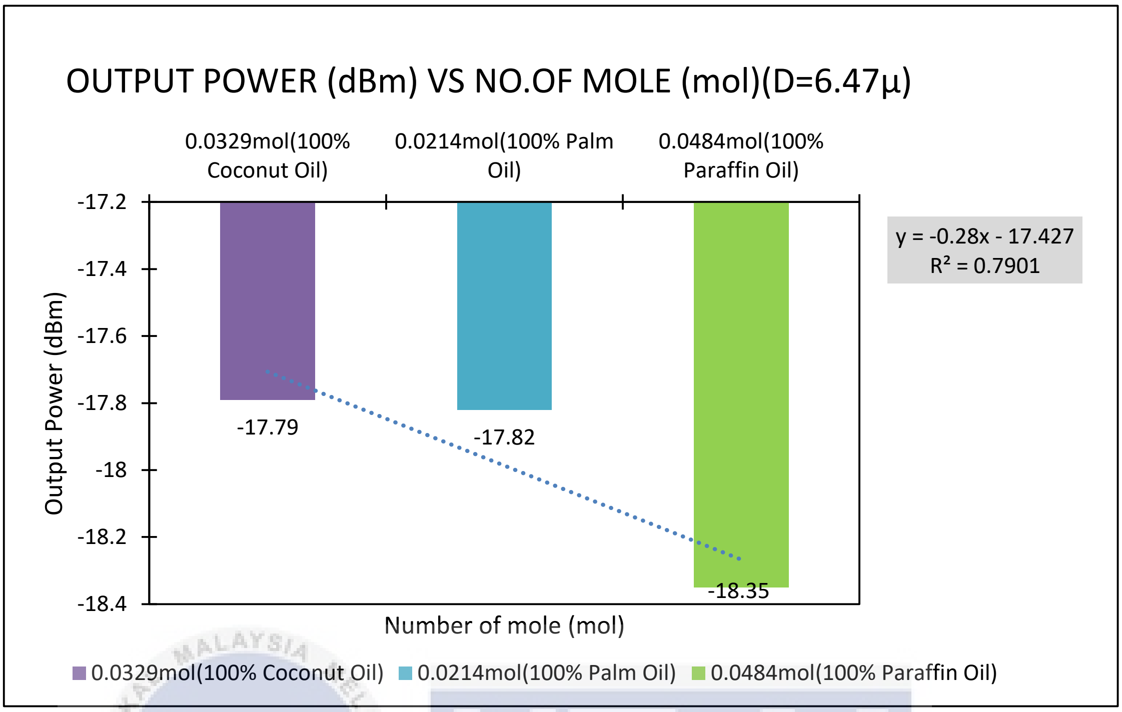


Figure 4.6: Graph for Output Power Versus The Number of Mole (mol) Coconut Oil, Palm Oil, Paraffin For Distance 6.47µm using SMF-SMF

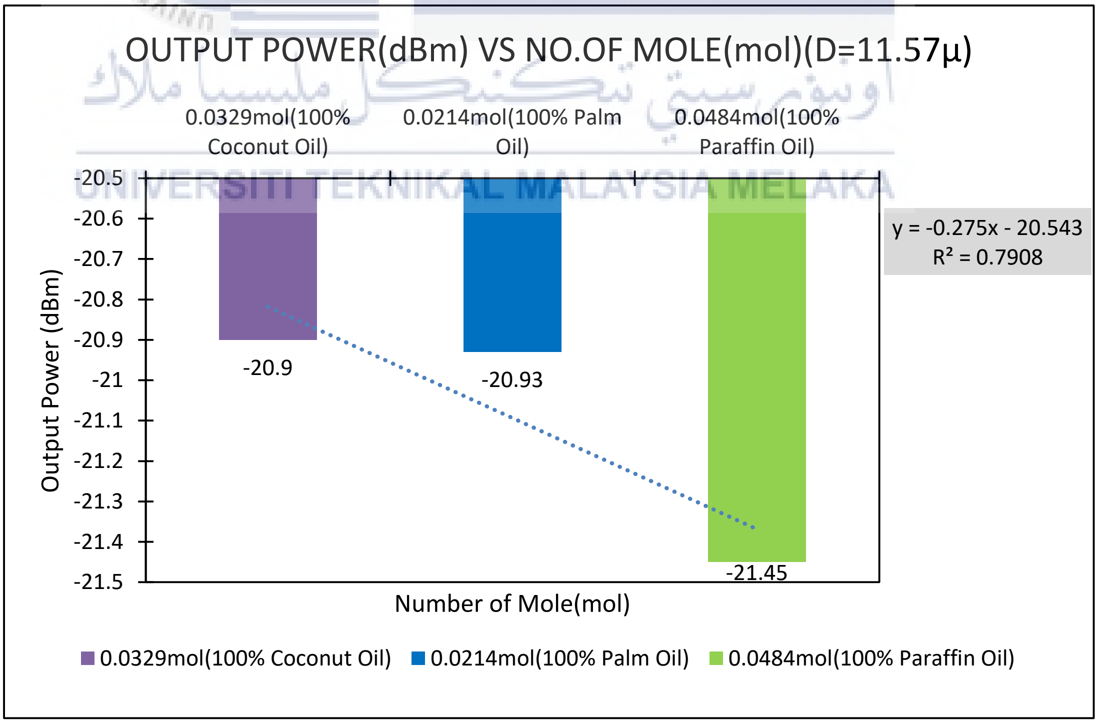


Figure 4.7: Graph for output power (dBm) versus the number of mole(mol) coconut oil palm oil, paraffin oil for distance 11.57 µm using SMF-SMF

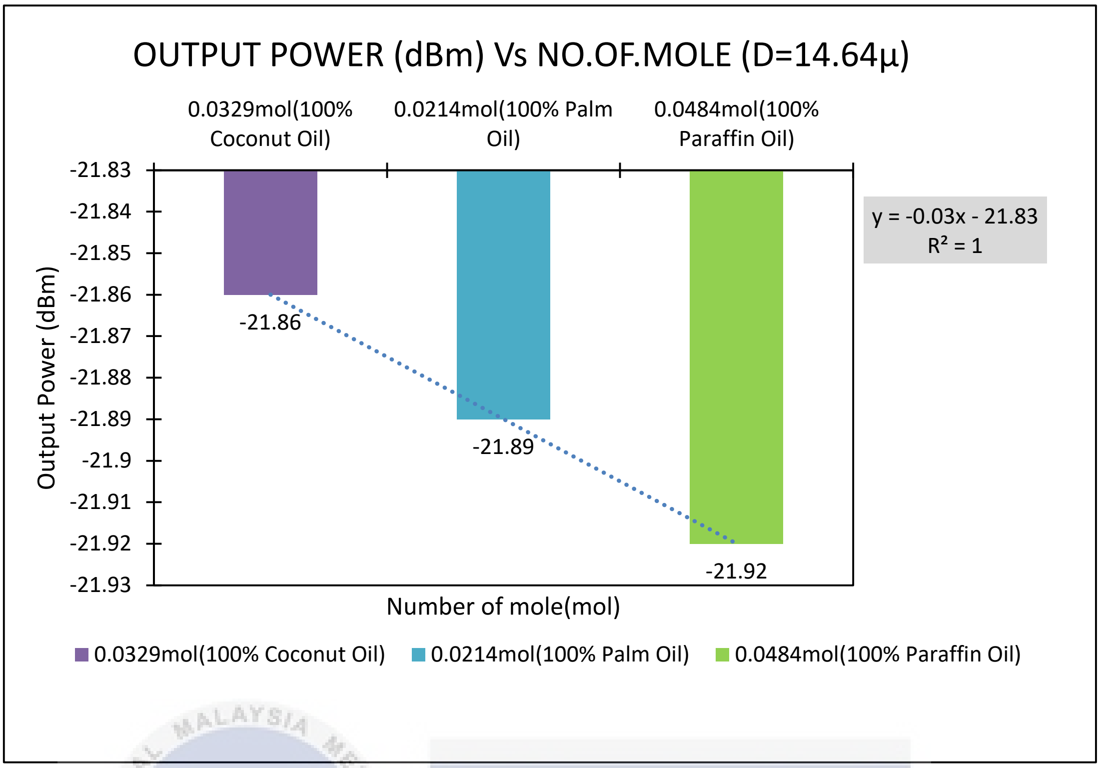


Figure 4.8: Graph for Output Power (dBm) Versus The Number of Mole (mol) Coconut Oil, Palm Oil, Paraffin Oil for Distance 14.64µm using SMF-SMF

For figure 4.5 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin oil for distance 0µm using normal splicing SMF-SMF is decreasing in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -8.3 dBm compare to pure palm oil is only -8.28 dBm and pure coconut oil is -8.15 dBm.

Next for Figure 4.6 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin for distance 6.47µm using method lateral offset distance SMF-SMF is the decreasing in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -18.35 dBm compare to pure palm oil is only -17.82 dBm and pure coconut oil is -17.79 dBm.

Next for Figure 4.7 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin for distance 11.57 µm using method lateral offset distance SMF-SMF is the decrease in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -21.45 dBm compare to pure palm oil is only -20.93 dBm and for pure coconut oil is -20.9 dBm

Next for Figure 4.8 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin for distance 14.64 μm using method lateral offset distance SMF-SMF is decreased in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -21.92 dBm compare to pure palm oil is only -21.89 dBm and pure coconut oil is -21.86 dBm.

Figure 4.5 until Figure 4.8 shows the trend of the graph is decreasing towards the output in (dBm). Paraffin oil has a higher output loss compare to the other solution because the characteristics of paraffin oil are used to be colorless and low absorbance towards the sensing elements. Furthermore, paraffin oil also can be easily mixed with coconut oil and there will not be any notable difference in the smell or color of coconut oil.

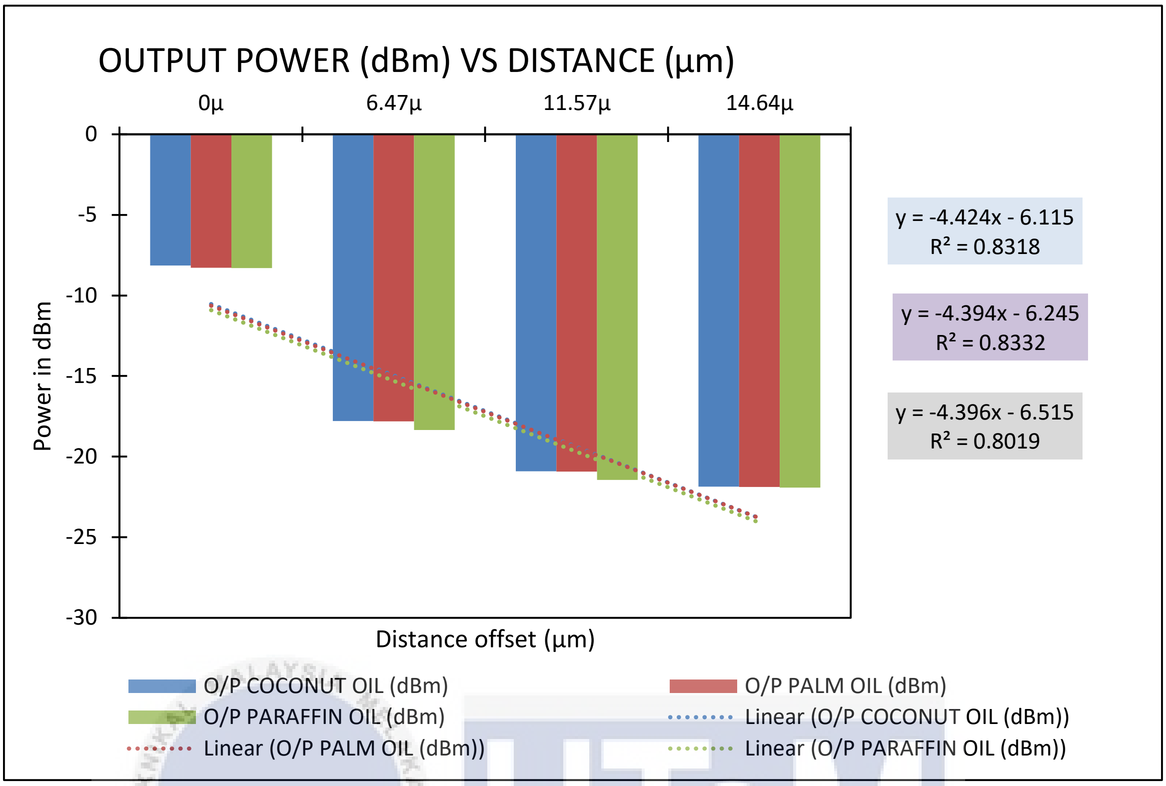


Figure 4.9: Graph of Output Power (dBm) Versus Distance (µm) Of Coconut Oil, Palm Oil, Paraffin Oil in Mole (mol) for All Distance (µm) using SMF-SMF

Figure 4.9 shows a graph of output power (dBm) versus distance (µm) of coconut oil, palm oil, paraffin oil in mole (mol) for all distances (µm) using SMF-SMF is a decrease in output intensity. The output power loss shows that pure paraffin oil has higher value output power loss in all tested distance compare to the other solution which is pure coconut oil and pure palm oil. The sensitivity for pure paraffin oil is -4.396 dBm/mol and R-value is 0.8019. Next for the sensitivity of pure palm oil is -4.394 dBm/mol and R-value is 0.8332 and lastly, pure coconut oil is -4.424 dBm/mol and R-value is 0.8318.

4.3.1.2 Mixture Solution Coconut Oil with Palm Oil

Table 4.12 Output Power in (dBm) Single-Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 0µm,6.47µm,11.57µm,15.64 µm

	D= 0µm	D= 6.47µm	D= 11.57µm	D= 14.64µm
Number of mol/g	Output Power NS (dBm)	Output Power SM 1 (dBm)	Output Power SM 2 (dBm)	Output Power SM 3(dBm)
0.019	-8.06	-17.75	-20.86	-21.9
0.018	-8.14	-17.72	-20.85	-22.04
0.016	-8.34	-17.7	-20.89	-22.72
0.015	-8.38	-17.94	-21.18	-22.86
0.014	-8.64	-18.03	-21.25	-22.92

Table 4.12 above shows the solutions have been tested according to the number of mol for mix solution for pure coconut with palm oil. There are five solutions with a different volume percentage of concentration which is 95% of coconut oil with 5% of palm oil with the number of mols is 0.019 mol/g. Next is 87% of coconut oil with 13 % of palm oil with the number of mols is 0.018 mol/g. Next for 80% of coconut oil with 20 % of palm oil with the number of mols is 0.016 mol/g. Next for 71% of coconut oil with 29% of palm oil, the number of mols is 0.015 mol/g, and lastly, for 66% of coconut oil with 34% of palm oil, the number of mols is 0.015.

The result for the output power in (dBm) based on Table 4.12 it shows the longer distance will produce high power loss with method lateral offset distance for distance 14.64 µm the output power for 66% of coconut oil mixed with 34% of palm oil with the number of mol 0.014 mol/g is -22.92 dBm, compare to the other of mixed solution and distance. For example, the distance offset 6.47µm with the same number of mol 0.014 mol/g, the output power loss is -18.03dBm and for distance offset 11.57µm the output, power loss is -18.03dBm. The result showed an increasing the output power based on the volume of adulterant in the coconut oil. The higher the volume of adulterant oil in coconut oil, the higher the output loss will produce based on the sensing head with the method of lateral offset. All the measurements that have been tested have been tabulated in Table 4.12.

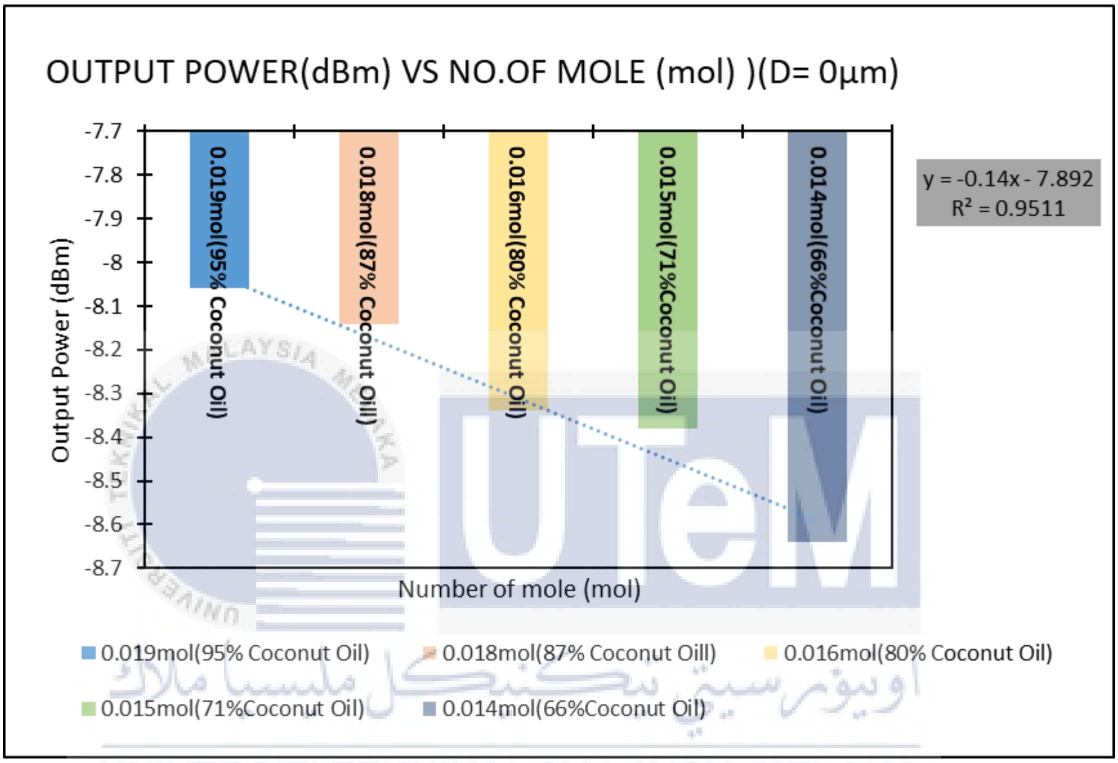


Figure 4.10: Graph of Output Power (dBm) Versus The Number of Moles (Mole) Coconut Oil With Palm Oil for Distance 6.47µm using SMF-SMF

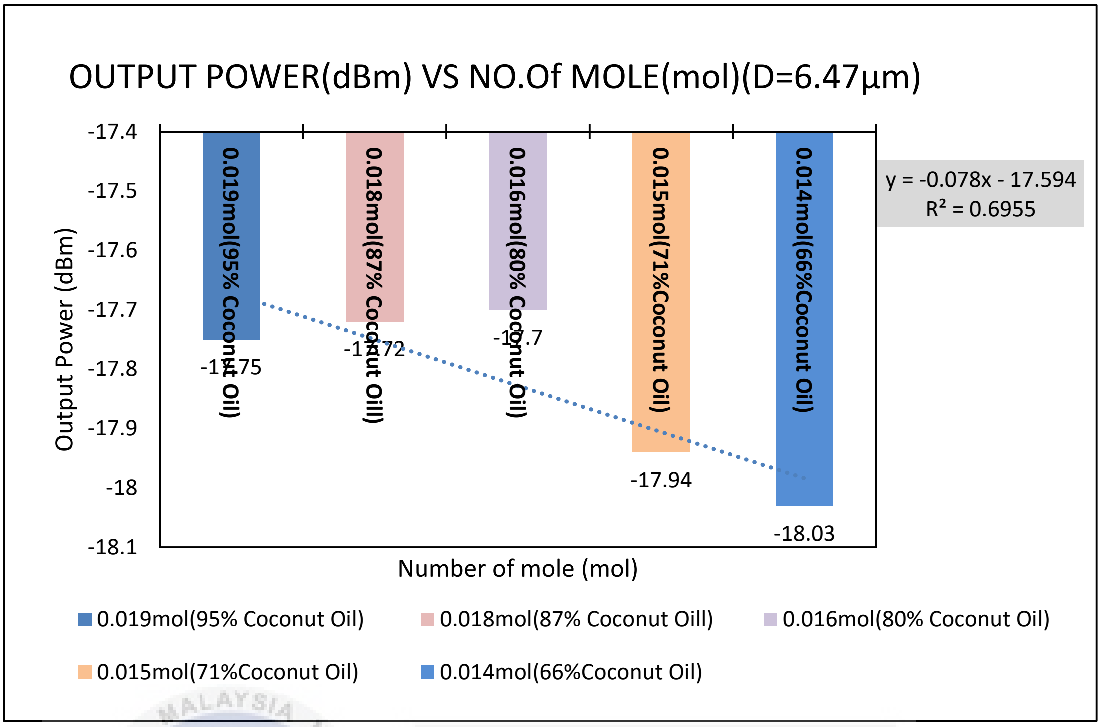


Figure 4.11: Graph of Output Power (dBm) Versus The Number of Moles (Mol) Coconut Oil With Palm Oil For Distance 6.47 Mm using SMF-SMF

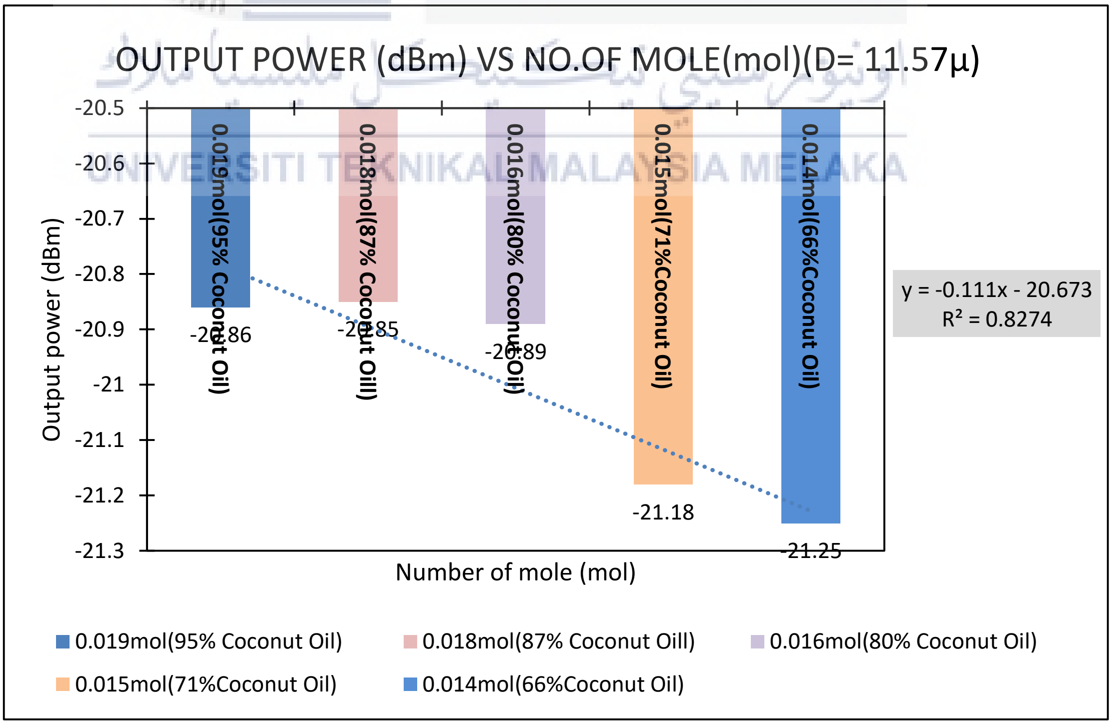


Figure 4.12: Graph of Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil With Palm Oil for Distance 11.57µm Using SMF-SMF

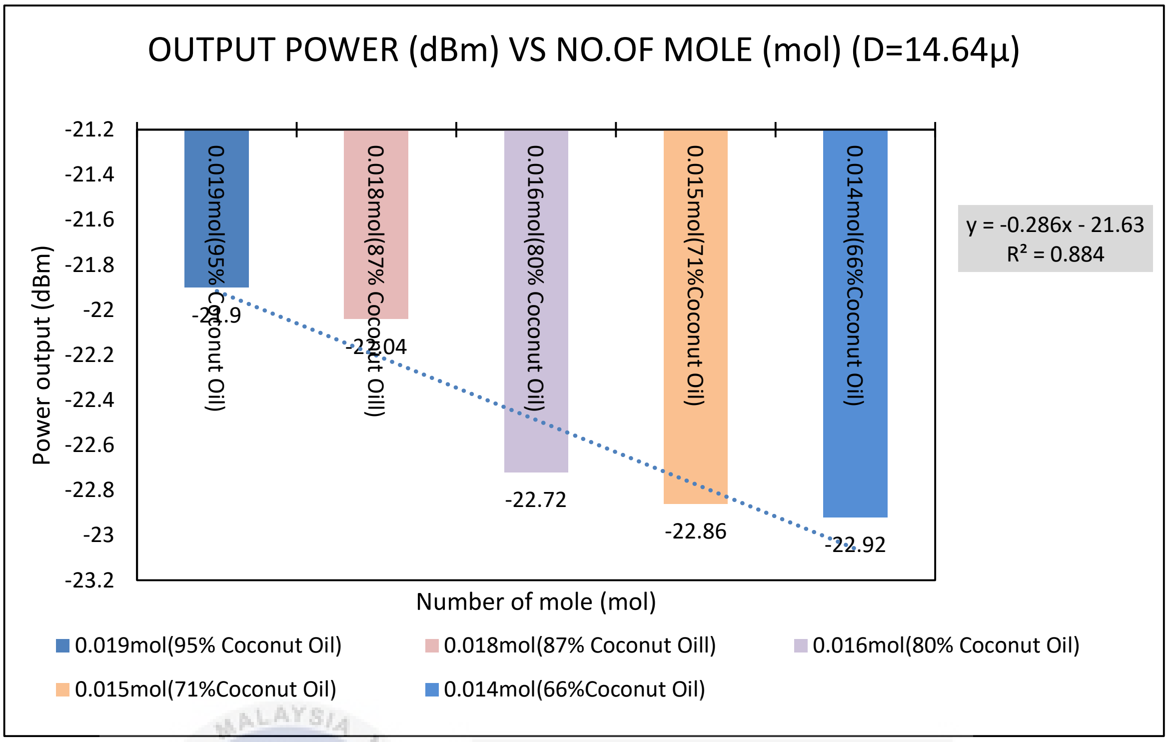


Figure 4.13: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil With Palm Oil For Distance 14.64 µm Using SMF-SMF

For figure 4.10 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with palm oil with a distance of 0µm using normal splicing SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.014 has a higher value which is -8.64 dBm compare to other mixed solutions.

For figure 4.11 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with palm oil with a distance of 6.47µm by using method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.014 has a higher value which is -18.03 dBm compare to other mixed solutions.

For figure 4.12shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with palm oil with distance 11.57µm by using method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.014 has a higher value which is -21.25 dBm compare to other mixed solutions.

For figure 4.13 shows the graph for output power dBm versus a number of moles (mol) mixed solution which is coconut oil with palm oil with a distance of 14.64 µm using the method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.014 has a higher value which is -22.92 dBm compare to other mixed solutions.

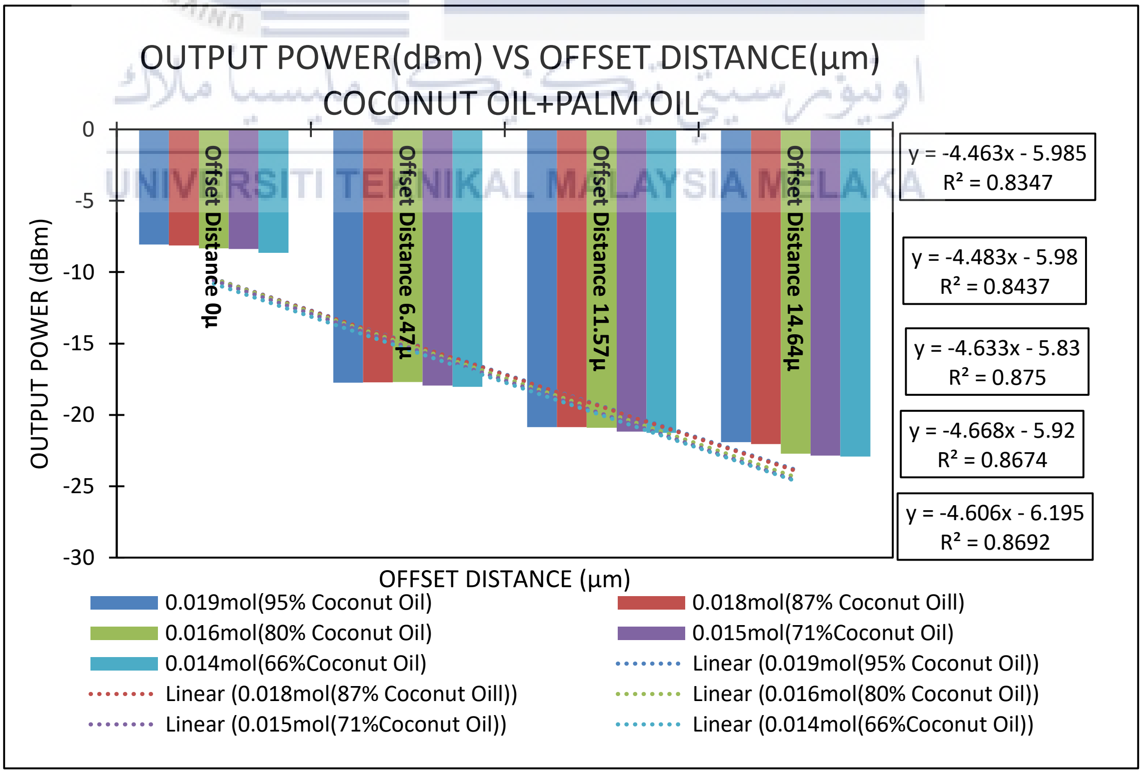


Figure 4.14: Graph of Output Power (dBm) Versus All Offset Distance (µm) Coconut Oil With Palm Oil In Mole (mol) Using SMF-SMF

Figure 4.14 shows a graph of output power (dBm) versus distance (μm) of coconut oil mixed with palm oil in mole (mol) for all distance (μm) using SMF-SMF is a decrease in output intensity. The output power loss shows that the larger distance has a higher value output power loss compared to the other distance. The larger gap of distance the higher output power loss will produce in the lateral offset method. The sensitivity for each of the solution coconut oil with palm oil has been shown in Figure 4.14 for 95% of coconut oil mixed with 5% of palm oil with 0.019 mol the sensitivity is -4.463 dBm/mol and the R-value is 0.8347. Next for 87% of coconut oil mixed with 13% of palm oil the sensitivity is -4.483 dBm/mol and the R-value is 0. 8437. Next for 80% of coconut oil mixed with 20% of palm oil, the sensitivity is -4.633 dBm/mol and the R-value is 0.875. Next for 71% of coconut oil mixed with 29% of palm oil the sensitivity is -4.668 dBm/mol and the R-value is 0.8647 and lastly, for 66% of coconut oil mixed with 34% of palm oil the sensitivity is -4.606 dBm/mol and the R-value is 0.869.

4.3.1.3 Mixture Solution Coconut Oil with Paraffin Oil

Table 4.13: Output Power in (dBm) Single-Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 0μ,6.47μ,11.57μ,14.64μ

	D= 0μ	D= 6.47μ	D= 11.57μ	D= 14.64μ
Number of mole/g	Output Power NS (dBm)	Output Power SM 1 (dBm)	Output Power SM 2 (dBm)	Output Power SM 3(dBm)
0.0286	-8.83	-18.09	-20.49	-21.95
0.0273	-8.88	-18.11	-20.82	-22.04
0.0262	-8.92	-18.18	-20.85	-22.08
0.0227	-8.94	-18.2	-20.93	-22.11
0.0213	-8.97	-18.22	-21.07	-22.14

Table 4.13 above shows the solutions have been tested according to the number of mol for mix solution for pure coconut with paraffin oil. There are five solutions with a different volume percentage of concentration which is 95% of coconut oil with 5% of paraffin oil with the number of mols is 0.0286 mol/g. Next is 87% of coconut oil with 13 % of paraffin oil with the number of mols is 0.0273 mol/g. Next for 80% of coconut oil with 20 % of paraffin oil with the number of mols is 0.0262 mol/g. Next for 71% of coconut oil with 29% of paraffin oil, the number of mols is 0.0227 mol/g, and lastly, for 66% of coconut oil with 34% of paraffin oil, the number of mols is 0.0213.

The result for the output power in (dBm) based on Table 4.13 it shows the longer distance will produce high power loss with method lateral offset distance for distance 14.64 µm the output power for 66% of coconut oil mixed with 34% of paraffin oil with the number of mol 0.0213 mol/g is -22.14 dBm, compare to the other of mixed solution and distance. For example, the distance offset 6.47µm with the same number of mol 0.0213mol/g, the output power loss is -18.22dBm and for distance offset 11.57µm the output, power loss is -21.07dBm. The result showed an increasing the output power based on the volume of adulterant in the coconut oil. The higher the volume of adulterant oil in coconut oil, the higher the output loss will produce based on the sensing head with the method of lateral offset. All the measurements that have been tested have been tabulated in Table 4.13.

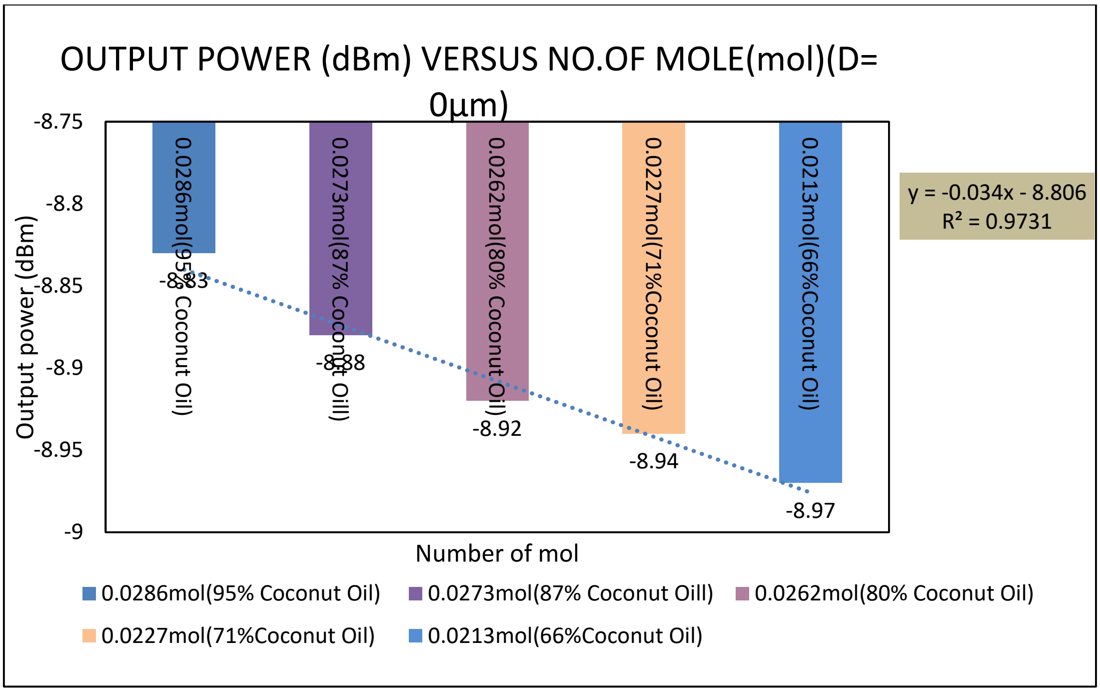


Figure 4.15: Graph Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil with Paraffin Oil for Distance 0µm using SMF-SMF

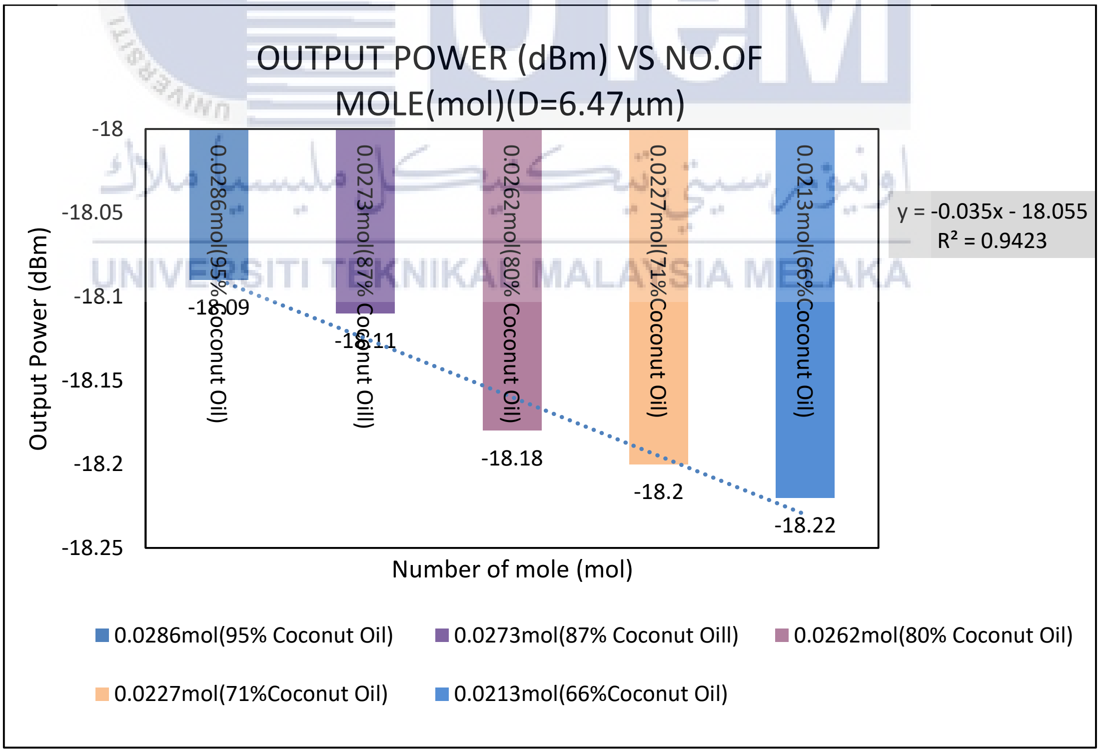


Figure 4.16: Graph Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil with Paraffin Oil for Distance 6.47µm using SMF-SMF

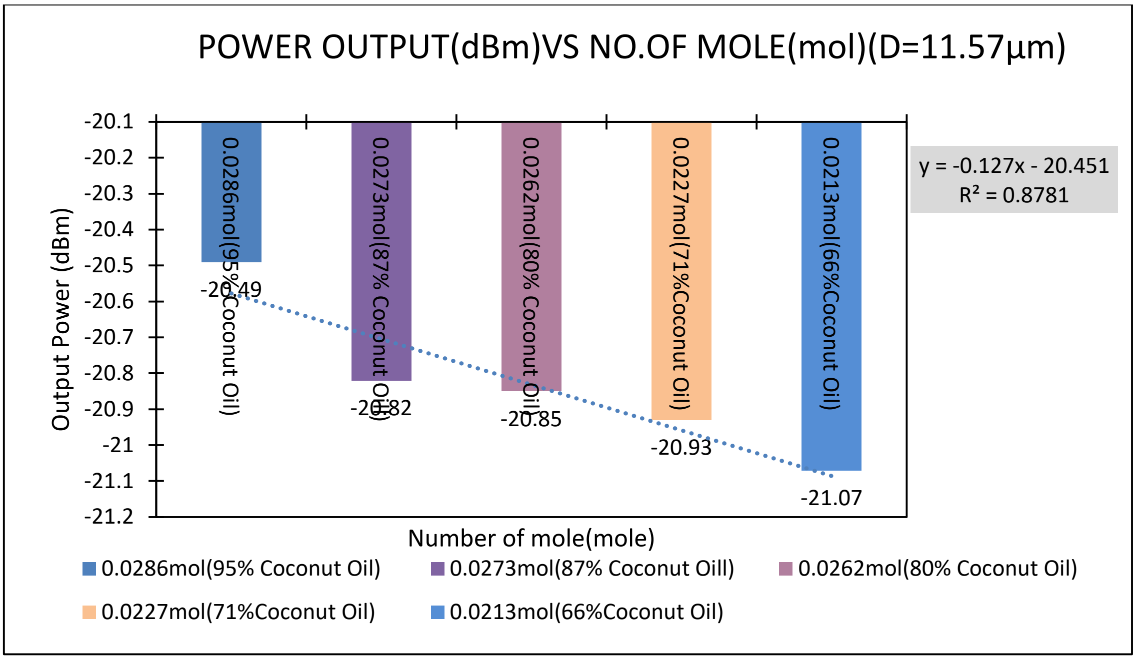


Figure 4.17: Graph Output Power (dBm) Versus Number Of Mole (mol) Coconut Oil with Paraffin Oil for Distance 11.57µm using SMF-SMF

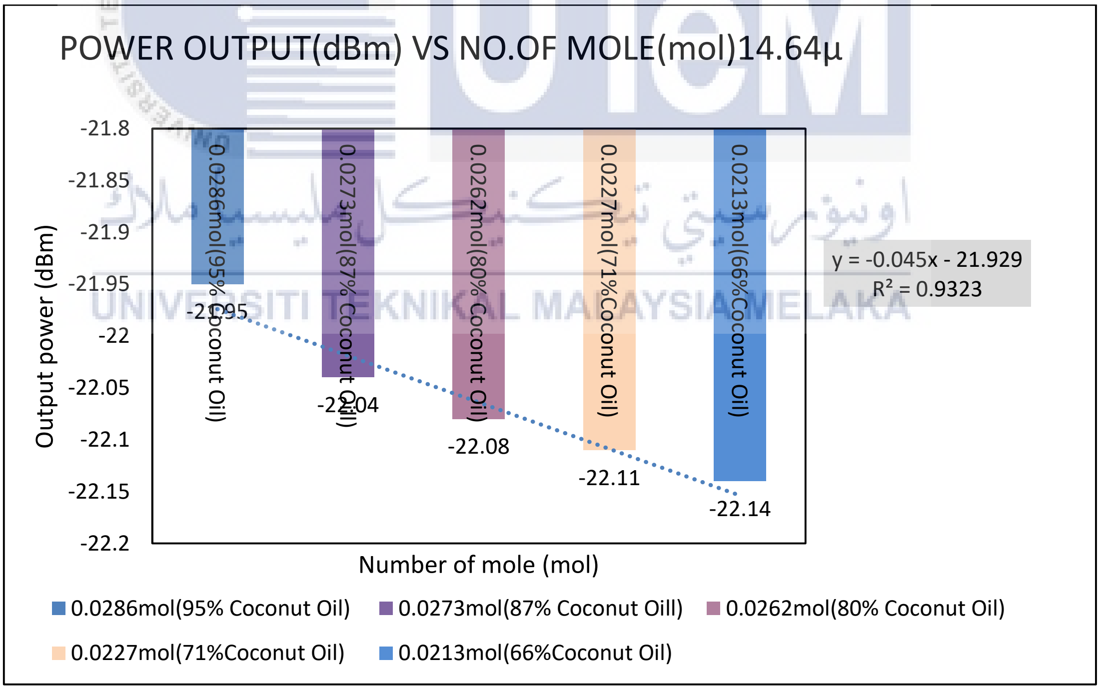


Figure 4.18: Graph Output Power (dBm) Versus Number of Mole(mol)Coconut Oil with Paraffin Oil for Distance 14.64µm using SMF-SMF

For figure 4.15 shows the graph for output power dBm versus the number of mole (mol) mixed solution which is coconut oil with paraffin oil with distance 0µm using normal splicing SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with the number of mole 0.0213 mol has a higher value which is -8.83 dBm compare to other mixed solutions.

For figure 4.16 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with paraffin oil with a distance of 6.47µm by using method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.0213 mol has a higher value which is -18.22 dBm compare to other mixed solutions.

For figure 4.17 shows the graph for output power dBm versus number of mole (mol) mixed solution which is coconut oil with palm oil with distance 11.57µm by using method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with number of mole 0.0213 mol has higher value which is -21.07 dBm compare to other mixed of solution.

For figure 4.18 shows the graph for output power dBm versus number of mole (mol) mixed solution which is coconut oil with palm oil with distance 14.64 by using method lateral offset distance SMF-SMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with number of mol 0.0213 has higher value which is -22.14 dBm compare to other mixed of solution.

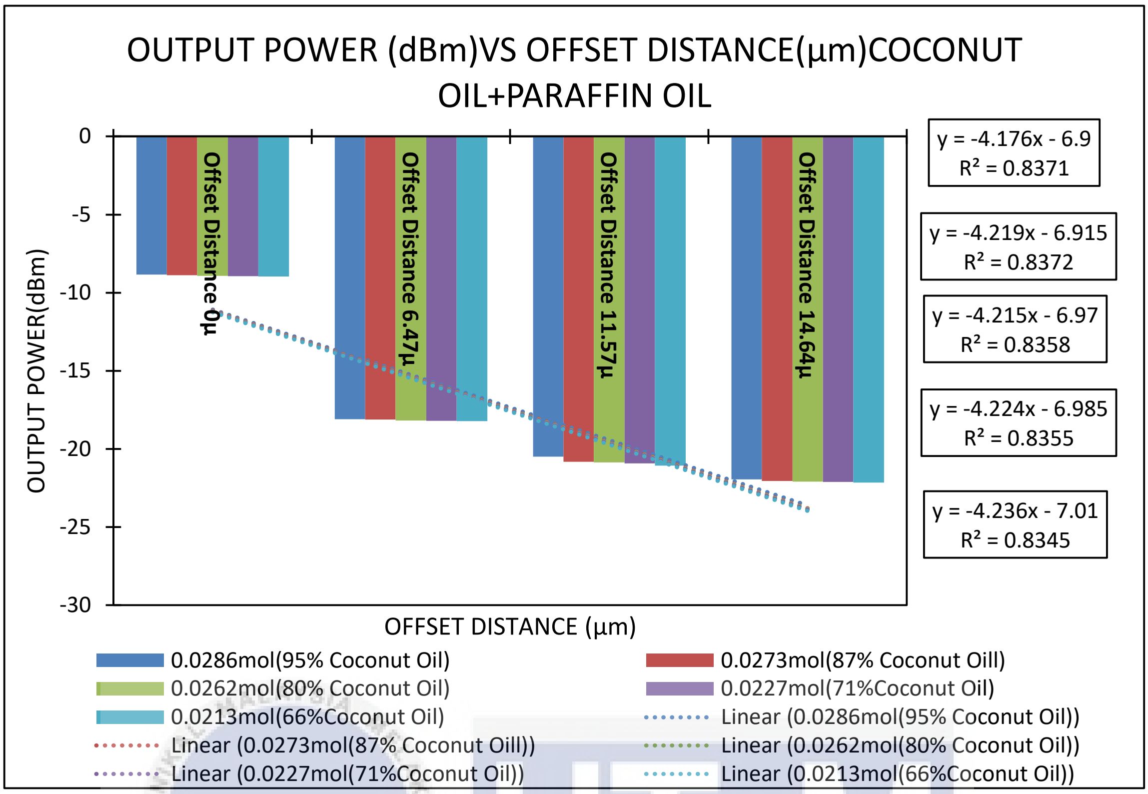


Figure 4.19: Graph Output Power (dBm) Versus Number Of Mole (mol) Coconut Oil with Paraffin Oil for All Distance (µm) using SMF-SMF

Figure 4.19 shows a graph of output power (dBm) versus distance (µm) of coconut oil mixed with paraffin oil in mole (mol) for all distance (µm) using SMF-SMF is a decrease in output intensity. The output power loss shows that the larger distance has a higher value output power loss compared to the other distance. The larger gap of distance, the higher output power loss will produce in the lateral offset method. The sensitivity for each of the solution coconut oil with palm oil has been shown in figure 4.19 for 95% of coconut oil mixed with 5% of paraffin oil the sensitivity is -4.176 dBm/mol and the R-value is 0.8371. Next for 87% of coconut oil mixed with 13% of paraffin oil the sensitivity is -4.219 dBm/mol and the R-value is 0. 8372. Next for 80% of coconut oil mixed with 20% of paraffin oil, the sensitivity is -4.215 dBm/mol and the R-value is 0.8358. Next for 71% of coconut oil mixed with 29% of paraffin oil the sensitivity is -4.224 dBm/mol and the R-value is 0.8355 and lastly, for 66% of coconut oil mixed with 34% of paraffin oil the sensitivity is -4.236 dBm/mol and the R-value is 0.8345.

4.3.2 Multimode Fiber Optic

For multimode fiber optic-based on lateral offset distance SMF-SMF, the distance used is 0µm,4.42µm, 7.49µm, and 7.83µm. Thirteen solutions have been tested which is pure coconut oil, pure palm oil, and pure paraffin oil, five mix solution which is pure coconut oil with palm oil, and another mix solution is pure coconut oil with paraffin oil. The number of mols that have been calculated for each solution, refractive index measurement, and the output power, have been recorded in Table 4.14, Table 4.15, Table 4.16, and Table 4.17.

Table 4.14: Normal Splicing Multimode Fiber

No	Solution	Concentration %	Refractive Index	No.of mol/g	Power (dBm)	Power (µW)
1.	Air	100%	1.0000	-	-29.37	1.156µ
2.	Distilled Water	100%	1.3333	1.0824	-29.15	1.216µ
3.	Coconut Oil	100%	1.4481	0.0329	-28.34	1.465
4.	Palm Oil	100%	1.4623	0.0214	-28.79	1.321
5.	Paraffin Oil	100%	1.4540	0.0484	-29.34	1.164
6.	Coconut with Palm Oil	95%	1.4533	0.0193	-28.42	1.4387
7.	Coconut with Palm Oil	87%	1.4539	0.0179	-28.64	1.3677
8.	Coconut with Palm Oil	80%	1.4549	0.0164	-28.77	1.3274
9.	Coconut with Palm Oil	71%	1.4551	0.0149	-28.79	1.3213
10.	Coconut with Palm Oil	66%	1.4560	0.0136	-28.82	1.3122
11.	Coconut with Paraffin Oil	95%	1.4533	0.0286	-28.15	1.5311
12.	Coconut with Paraffin Oil	87%	1.4535	0.0273	-28.24	1.4997
13.	Coconut with Paraffin Oil	80%	1.4538	0.0262	-28.35	1.4622
14.	Coconut with Paraffin Oil	77%	1.4541	0.0227	-28.46	1.4256
15.	Coconut with Paraffin Oil	66%	1.4551	0.0213	-28.64	1.3677

Table 4.15: Multimode Fiber Optic with Lateral Offset Displacement Sensor with Distance 4.42µm

No	Solution	Concentration %	Refractive Index	No.of mol/g	Power (dBm)	Power (µW)
1.	Air	100%	1.0003	-	-32.40	0.5754
2.	Distilled Water	100%	1.3333	1.0824	-32.56	0.5546
3.	Coconut Oil	100%	1.4481	0.0329	-34.25	0.3758
4.	Palm Oil	100%	1.4623	0.0214	-34.44	0.3597
5.	Paraffin Oil	100%	1.4540	0.0484	-35.31	0.2944
6.	Coconut with Palm Oil	95%	1.4533	0.0193	-35.3	0.2951
7.	Coconut with Palm Oil	87%	1.4539	0.0179	-35.46	0.2844
8.	Coconut with Palm Oil	80%	1.4549	0.0164	-35.52	0.2805
9.	Coconut with Palm Oil	71%	1.4551	0.0149	-35.89	0.2576
10.	Coconut with Palm Oil	66%	1.4560	0.0136	-36.05	0.2483
11.	Coconut with Paraffin Oil	95%	1.4533	0.0286	-32.04	0.6251
12.	Coconut with Paraffin Oil	87%	1.4535	0.0273	-33.5	0.4467
13.	Coconut with Paraffin Oil	80%	1.4538	0.0262	-34.86	0.3266
14.	Coconut with Paraffin Oil	71%	1.4541	0.0227	-35.72	0.2679
15.	Coconut with Paraffin Oil	66%	1.4551	0.0213	-36.24	0.2377

Table 4.16: Multimode Fiber Optic with Lateral Offset Displacement Sensor with Distance 7.49 µm

No	Solution	Concentration %	Refractive Index	No.of mol/g	Power (dBm)	Power (µW)
1.	Air	100%	1.0003	-	-35.85	0.2600
2.	Distilled Water	100%	1.3333	1.0824	-35.60	0.2754
3.	Coconut Oil	100%	1.4481	0.0329	-34.91	0.2564
4.	Palm Oil	100%	1.4623	0.0214	-35.60	0.2754
5.	Paraffin Oil	100%	1.4540	0.0484	-35.8	0.2630
6.	Coconut with Palm Oil	95%	1.4533	0.0193	-35.36	0.2911
7.	Coconut with Palm Oil	87%	1.4539	0.0179	-35.77	0.2649
8.	Coconut with Palm Oil	80%	1.4549	0.0164	-36.28	0.2355
9.	Coconut with Palm Oil	71%	1.4551	0.0149	-36.63	0.2173
10.	Coconut with Palm Oil	66%	1.4560	0.0136	-36.9	0.2042
11.	Coconut with Paraffin Oil	95%	1.4533	0.0286	-35.96	0.2535
12.	Coconut with Paraffin Oil	87%	1.4535	0.0273	-36.08	0.2466
13.	Coconut with Paraffin Oil	80%	1.4538	0.0262	-36.5	0.2239
14.	Coconut with Paraffin Oil	71%	1.4541	0.0227	-36.65	0.2163
15.	Coconut with Paraffin Oil	66%	1.4551	0.0213	-37.26	0.1879

Table 4.17: Multi Mode Fiber Optic with Lateral Offset Displacement Sensor with Distance 7.83 µm

No	Solution	Concentration %	Refractive Index	No.of mol/g	Power (dBm)	Power (µW)
1.	Air	100%	1.0003	-	-39.59	0.109.9
2.	Distilled Water	100%	1.3333	1.0824	-38.14	0.155.4
3.	Coconut Oil	100%	1.4481	0.0329	-35.69	0.269
4.	Palm Oil	100%	1.4623	0.0214	-35.99	0.252
5.	Paraffin Oil	100%	1.4540	0.0484	-36.23	0.238
6.	Coconut with Palm Oil	95%	1.4533	0.0193	-35.51	0.2812
7.	Coconut with Palm Oil	87%	1.4539	0.0179	-36.27	0.2360
8.	Coconut with Palm Oil	80%	1.4549	0.0164	-36.53	0.2223
9.	Coconut with Palm Oil	71%	1.4551	0.0149	-36.77	0.2104
10.	Coconut with Palm Oil	66%	1.4560	0.0136	-37.29	0.1866
11.	Coconut with Paraffin Oil	95%	1.4533	0.0286	-38	0.1585
12.	Coconut with Paraffin Oil	87%	1.4535	0.0273	-38.17	0.1524
13.	Coconut with Paraffin Oil	80%	1.4538	0.0262	-38.34	0.1466
14.	Coconut with Paraffin Oil	71%	1.4541	0.0227	-38.98	0.1265
15.	Coconut with Paraffin Oil	66%	1.4551	0.0213	-39.78	0.1052

4.3.2.1 Solution Pure Coconut Oil, Paraffin Oil and Paraffin Oil

Table 4.18: List of Fiber Optic and Distance

Fiber Optic	Distance (D=µm)
Normal Splicing (NS)	0µ
Multi-Mode 1 (MM1)	4.42µm
Multi-Mode 2 (MM2)	7.49µm
Multi-Mode 3 (MM3)	7.83µm

Table 4.18 shows the list of MMF-MMF fiber optic and offset distance. Normal splicing(NS) the offset distance is 0µm, by using method lateral offset, multimode 1 (MM 1) the offset distance is 4.42µm, multimode 2 (MM 2) the offset distance is 7.49µm, and multimode 3 (MM 3), the offset distance is 7.83µm. Table 18 shows the output power in (dBm) for each solution which is pure coconut oil, pure palm oil, and pure paraffin oil-based on a number of mols. So based on the output power with the different offset distances, it will show which of the best length will detect the adulteration in coconut oil.

Table 4.19: Output Power in (dBm) Multimode Fiber Optic With Lateral Offset Displacement Sensor with Distance 0µm,4.42µm,7.49µm,7.83µm

	D= 0µm	D= 4.42µm	D= 7.49µm	D= 7.83µm
Number of mol/g	Output Power NS (dBm)	Output Power SM 1 (dBm)	Output Power SM 2 (dBm)	Output Power SM 3(dBm)
0.0329	-28.34	-34.25	-34.91	-35.69
0.0214	-28.79	-34.44	-35.60	-35.99
0.0484	-29.34	-35.31	-35.8	-36.23

Table 19 shows that each of the solutions has been tested according to the number of mols for each solution for pure coconut oil the number of mols is 0.0329 mol/g, pure palm oil is 0.0214 mol/g, and pure paraffin oil is 0.0484 mol/g.

The result for the output power in (dBm) based on Table 19 shows the longer distance will produce high power loss with method lateral offset distance for distance 7.83 µm the output power for pure coconut oil is -35.69 dBm, pure palm oil is -35.99 dBm and for pure paraffin oil is -36.23 dBm compared to the other shorter offset distance. For the output power with method lateral offset distance with distance which is 7.49 µm, the output power for each solution for pure coconut oil is -34.25 dBm, pure palm oil is -34.44 dBm and for pure paraffin oil is -35.31 dBm.

Lastly for output power with method lateral offset distance with the shorter distance which is 4.42µm, the output power for each solution for pure coconut oil is -34.25 dBm, pure palm oil is -34.44 dBm and for pure paraffin oil is -35.31 dBm.

For the normal splicing output power loss with a distance of 0µm, pure coconut oil is -28.34 dBm, pure palm oil is -28.79 dBm and pure paraffin oil is -29.34 dBm. Therefore, it can conclude that the longer the offset distance is, the higher the energy loss.

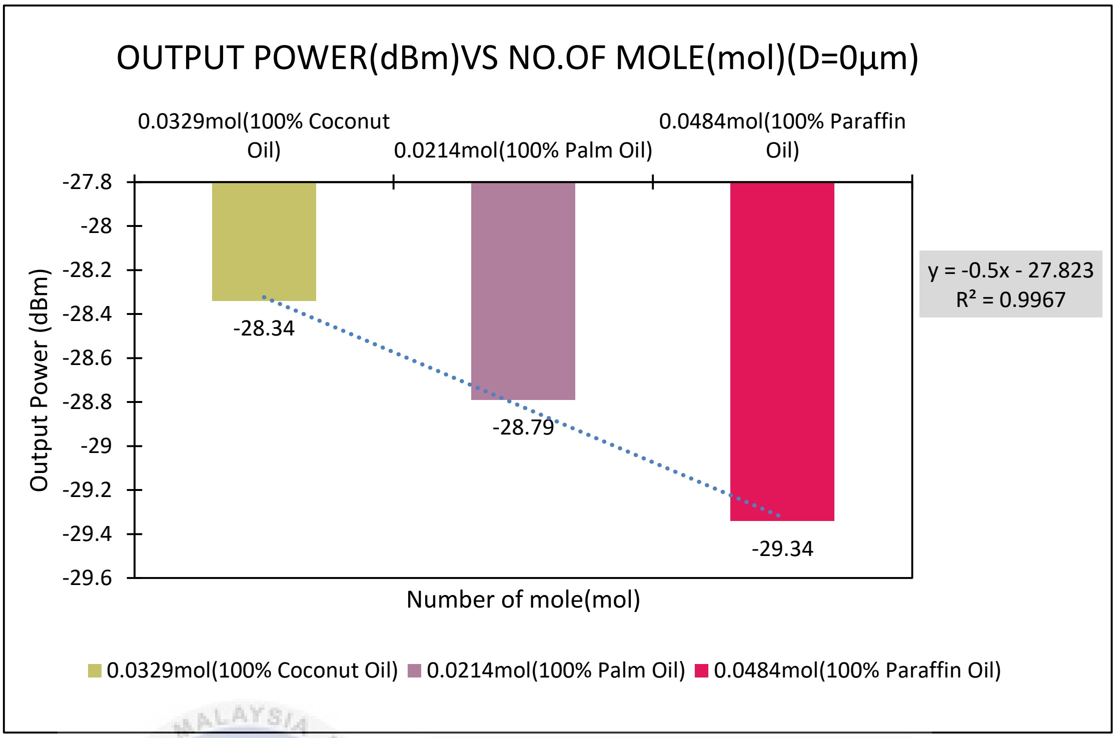


Figure 4.20: Graph Output Power (dBm) Versus The Number Of Mole (mol) Coconut Oil, Palm Oil, Paraffin Oil for Distance 0µm using MMF-MMF

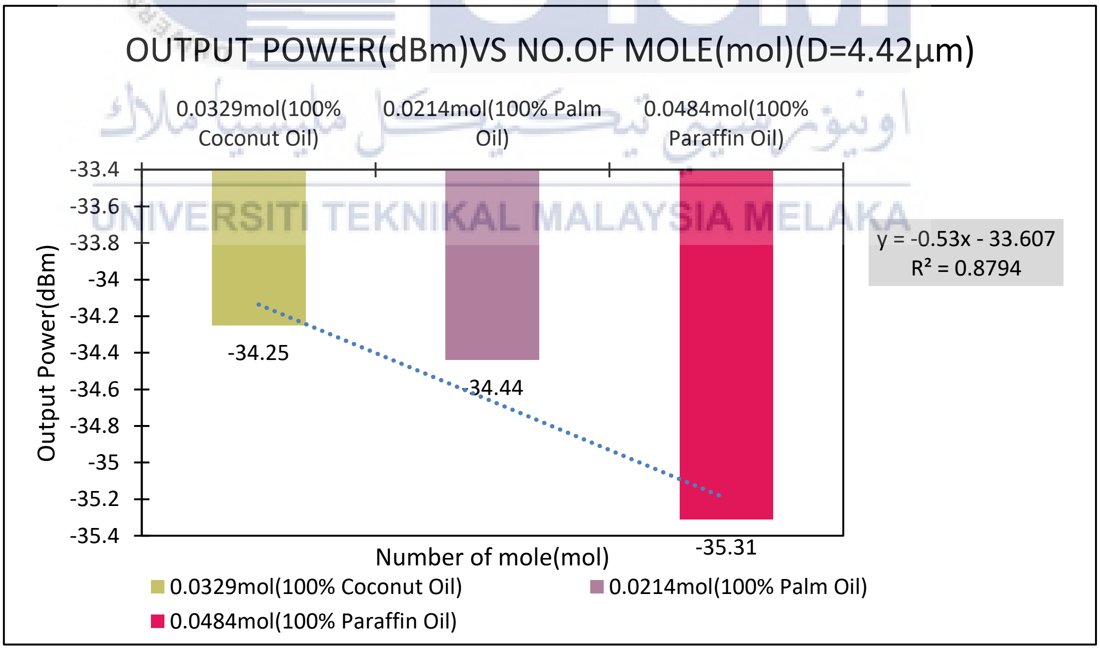


Figure 4.21: Graph Output Power (dBm) Versus The Number Of Mole (mol) Coconut Oil, Palm Oil, Paraffin Oil for Distance 4.42µm using MMF-MMF

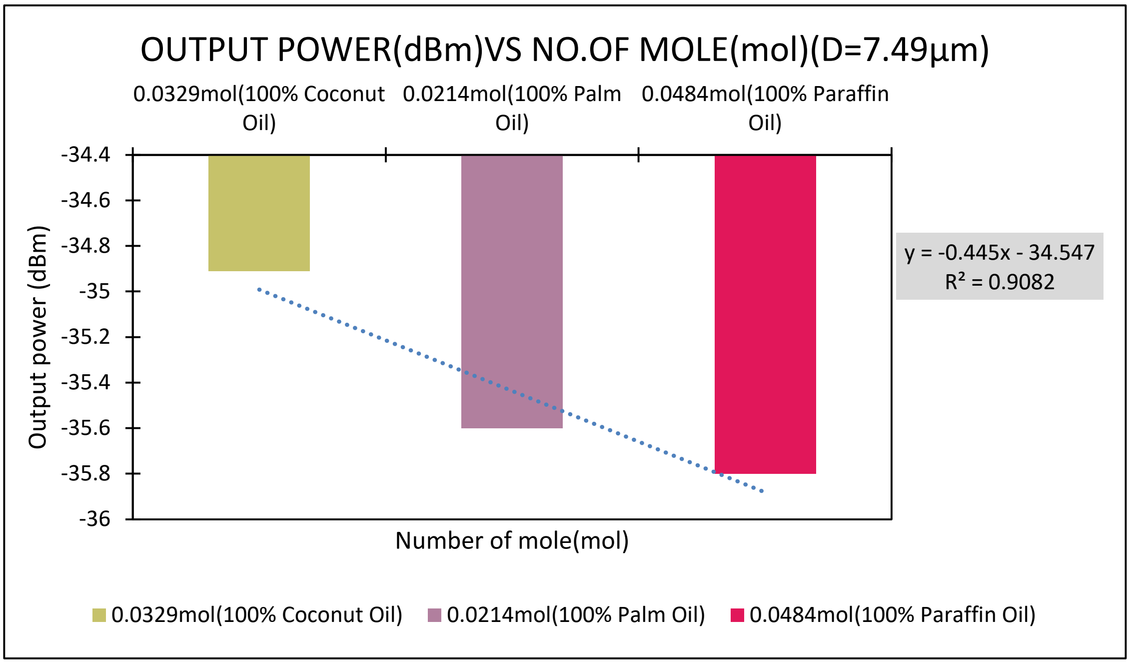


Figure 4.22: Graph Output Power (dBm) Versus The Number Of Mole (mol) For Coconut Oil, Palm Oil, Paraffin Oil Distance 7.49µm using MMF-MMF

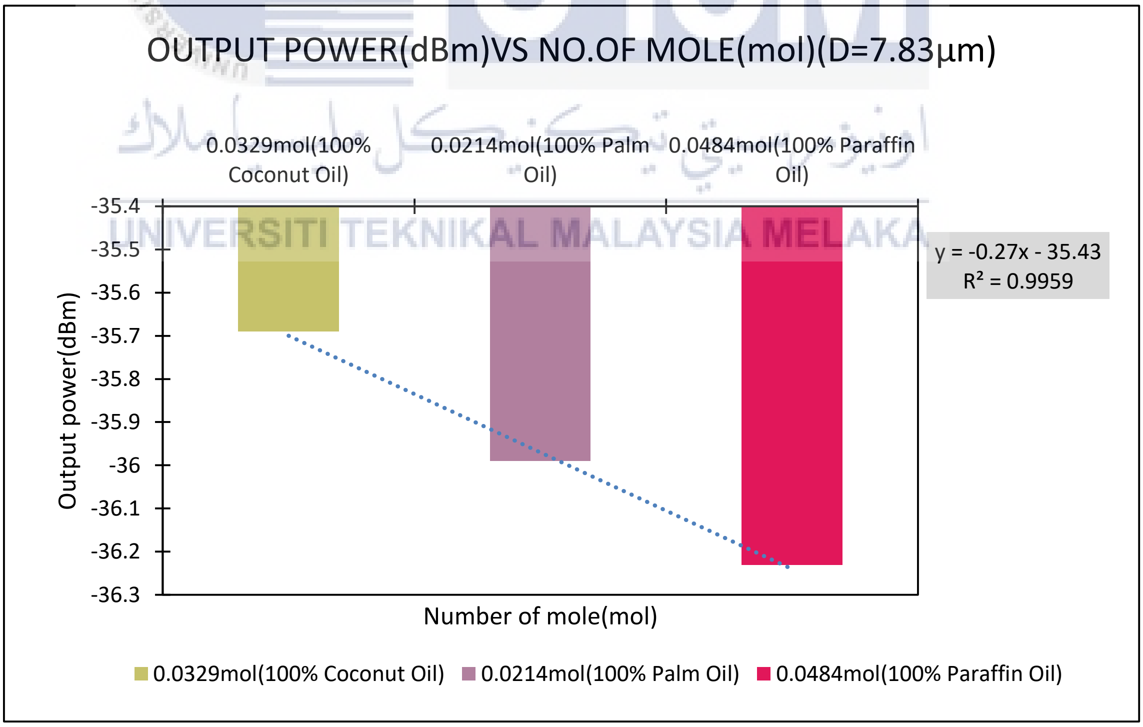


Figure 4.23: Graph Output Power (dBm) Versus The Number Of Mole (mol) Coconut Oil, Palm Oil, Paraffin Oil for Distance 7.83µm using MMF-MMF

For figure 4.20 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin oil for distance 0μm using normal splicing MMF-MMF is decreased in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -29.34 dBm compare to pure palm oil is only -28.79 dBm and pure coconut oil is -28.34dBm.

Next for Figure 4.21 shows the graph for output power versus a number of mole (mol) coconut oil, palm oil, paraffin for distance 4.42 μm using method lateral offset distance MMF-MMF is the decrease in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -35.31 dBm compare to pure palm oil is only -34.44 dBm and pure coconut oil is -34.25 dBm.

Next for Figure 4.22 shows the graph for output power versus a number of mole (mol) coconut oil, palm oil, paraffin for distance 7.49 μm using method lateral offset distance MMF-MMF is a decrease in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -35.8 dBm compare to pure palm oil is only -35.60 dBm and for pure coconut oil is -34.91 dBm

Next for Figure 4.23 shows the graph for output power versus the number of mole (mol) coconut oil, palm oil, paraffin for distance 7.83 μm using method lateral offset distance MMF-MMF is a decrease in output intensity. The output power loss shows that pure paraffin oil has a higher value which is -36.23 dBm compare to pure palm oil is only -35.99 dBm and pure coconut oil is -35.69 dBm.

Figure 4.21 until 4.23 shows the trend of the graph is decreasing towards the output in (dBm). Paraffin oil has a higher output loss compare to the other solution because the characteristics of paraffin oil are used to be colorless and low absorbance towards the sensing elements. Furthermore, paraffin oil also can be easily mixed with coconut oil and there will not be any notable difference in the smell or color of coconut oil

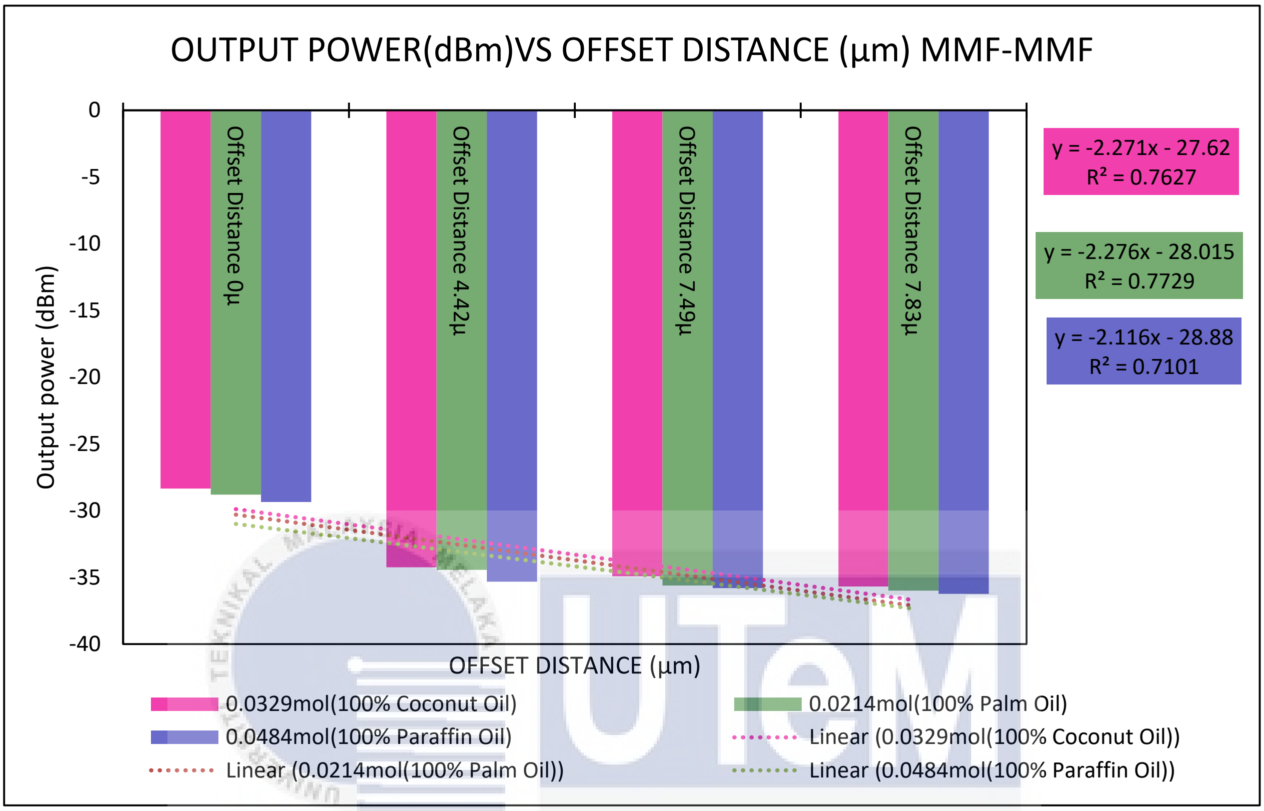


Figure 4.24: Graph Output Power (dBm) Versus The Number of Mole (mol) for All Distance Coconut Oil, Palm Oil, and Paraffin Oil in MMF-MMF

Figure 4.24 shows a graph of output power (dBm) versus distance (µm) of coconut oil, palm oil, paraffin oil in mole (mol) for all distances (µm) using MMF-MMF is the decrease in output intensity. The output power loss shows that pure paraffin oil has higher value output power loss in all tested distance compare to the other solution which is pure coconut oil and pure palm oil. The sensitivity for pure paraffin oil is -2.116 dBm/mol and R-value is 0.7101. Next for the sensitivity of pure palm oil is -2.276 dBm/mol and R-value is 0.7729 and lastly, pure coconut oil is -2.271 dBm/mol and R-value is 0.7627.

4.3.2.2 Mixture Solution Coconut Oil with Palm Oil

Table 4.20: Output Power in (dBm) Multimode Fiber Optic with Lateral Offset Displacement Sensor (MMF-MMF) with Distance 0μ,4.42μ,7.49μ,7.83μ

	D= 0μ	D= 4.42μ	D= 7.49μ	D= 7.83μ
Number of mole(mol)	Output Power NS (dBm)	Output Power MM 1 (dBm)	Output Power MM 2 (dBm)	Output Power MM 3(dBm)
0.019	-28.42	-35.3	-35.36	-35.51
0.018	-28.64	-35.46	-35.77	-36.27
0.016	-28.77	-35.52	-36.28	-36.53
0.015	-28.79	-35.89	-36.63	-36.77
0.014	-28.82	-36.05	-36.9	-37.29

Table 4.20 above shows the solutions have been tested according to the number of mol for mix solution for pure coconut with palm oil. There are five solutions with a different volume percentage of concentration which is 95% of coconut oil with 5% of palm oil with the number of mols is 0.019 mol/g. Next is 87% of coconut oil with 13 % of palm oil with the number of mols is 0.018 mol/g. Next for 80% of coconut oil with 20 % of palm oil with the number of mols is 0.016 mol/g. Next for 71% of coconut oil with 29% of palm oil, the number of mols is 0.015 mol/g, and lastly, for 66% of coconut oil with 34% of palm oil, the number of mols is 0.014.

The result for the output power in (dBm) based on Table 20, shows the longer distance will produce high power loss with method lateral offset distance for distance 7.83 µm the output power for 66% of coconut oil mixed with 34% of palm oil with the number of mol 0.014 mol/g is -37.29 dBm, compare to the other of mixed solution and distance. For example, the distance offset 4.42µm with the same number of mol 0.014 mol/g, the output power loss is -36.05 dBm and for distance offset 7.49 µm the output power loss is -36.9dBm. The result showed an increasing the output power based on the volume of adulterant in the coconut oil. The higher the volume of adulterant oil in coconut oil, the higher the output loss will produce based on the sensing head with the method of lateral offset. All the measurements that have been tested have been tabulated in Table 4.20.

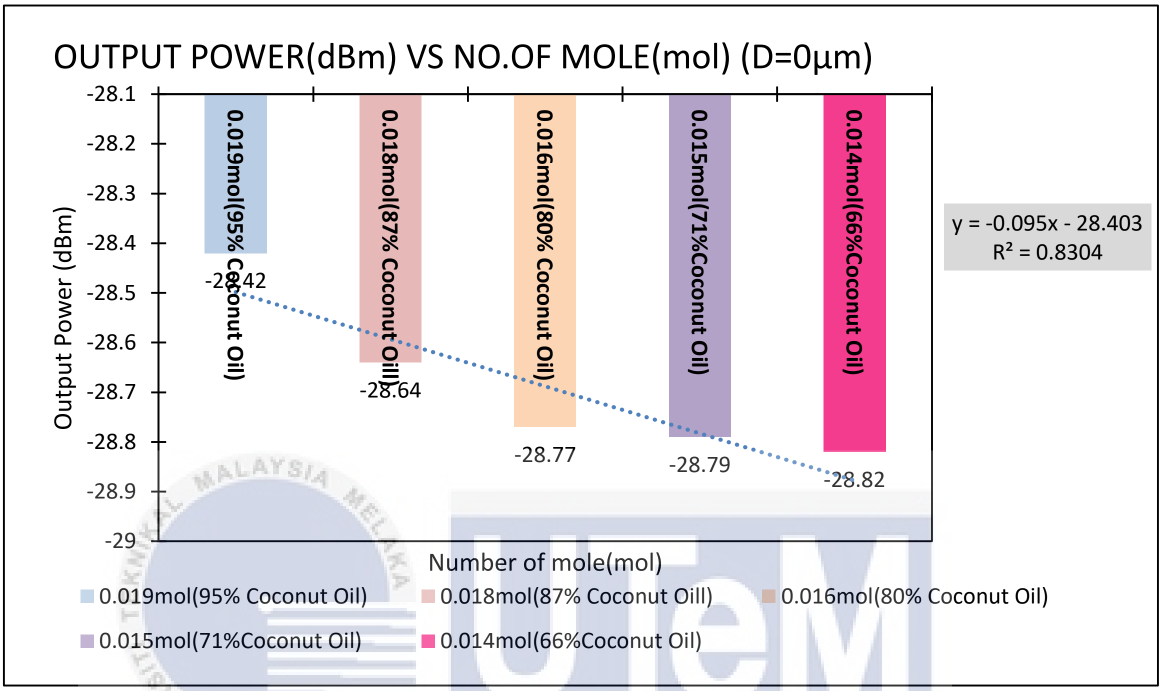


Figure 4.25: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil with Palm Oil with Distance 0µm by using MMF-MMF

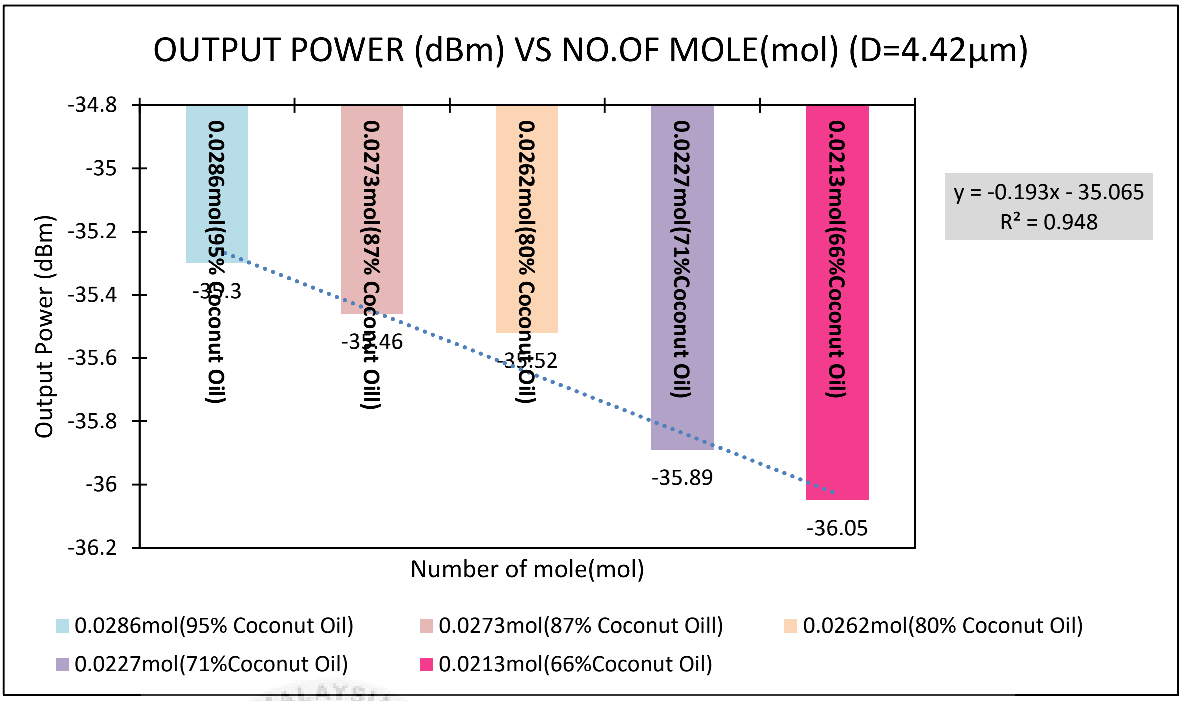


Figure 4.26: Graph of Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil with Palm Oil with Distance 4.42µm by using MMF-MMF

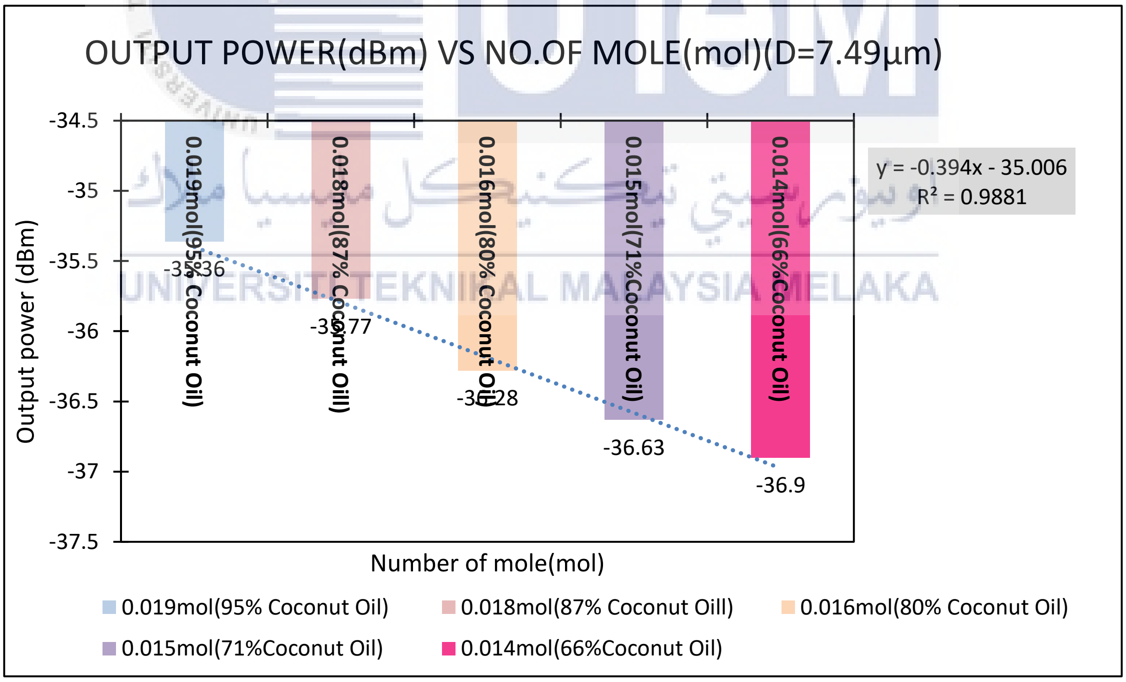


Figure 4.27: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil with Palm Oil with Distance 7.49 µm by using MMF-MMF

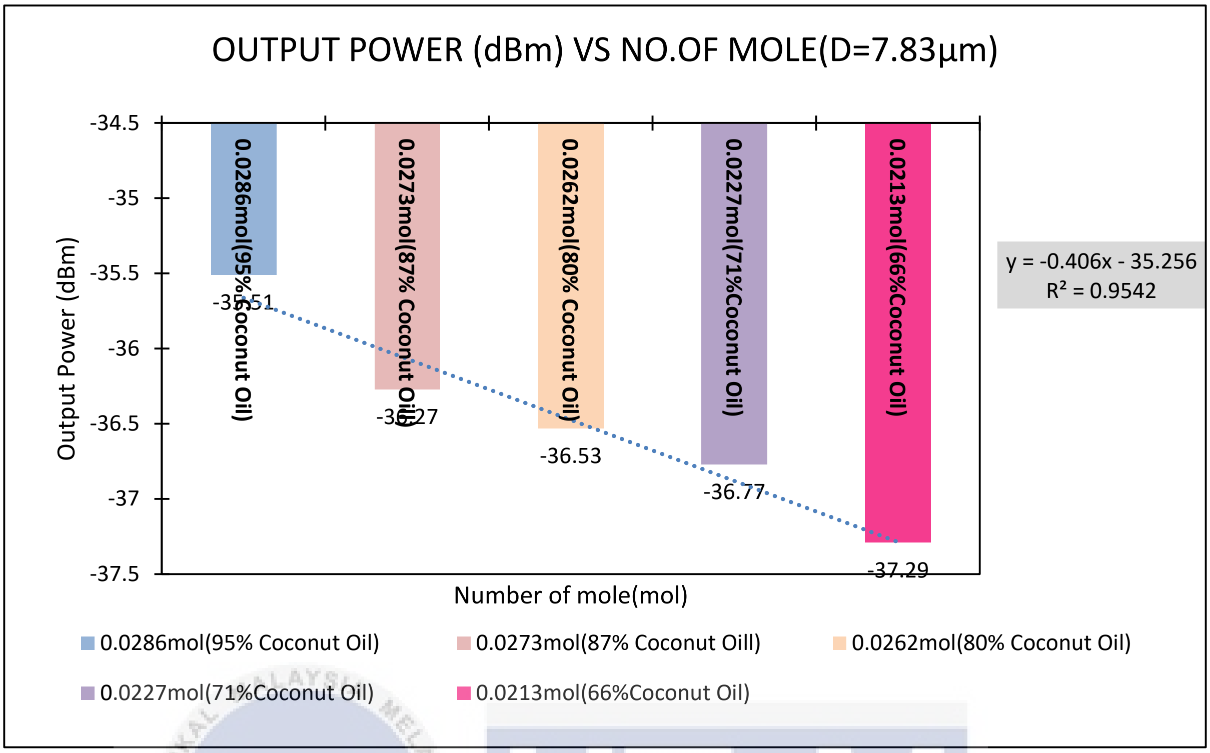


Figure 4.28: Graph of Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil with Palm Oil with Distance 7.83 µm by using MMF-MMF

For figure 4.25 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with palm oil with distance 0µm using normal splicing MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mole 0.014 mol has a higher value which is -28.82 dBm compare to other mixed solutions.

For figure 4.26 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with paraffin oil with distance 4.42µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with the number of mol 0.014 mol has a higher value which is -36.05 dBm compare to other mixed solutions.

For figure 4.27 shows the graph for output power dBm versus the number of mole (mol) mixed solution which is coconut oil with palm oil with distance 7.49µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mole 0.014 mol has a higher value which is -36.9 dBm compare to other mixed solutions.

For figure 4.28 shows the graph for output power dBm versus the number of moles (mol) mixed solution which is coconut oil with palm oil with a distance of 7.83 µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.014 mol has a higher value which is – 37.29 dBm compare to other mixed solutions.

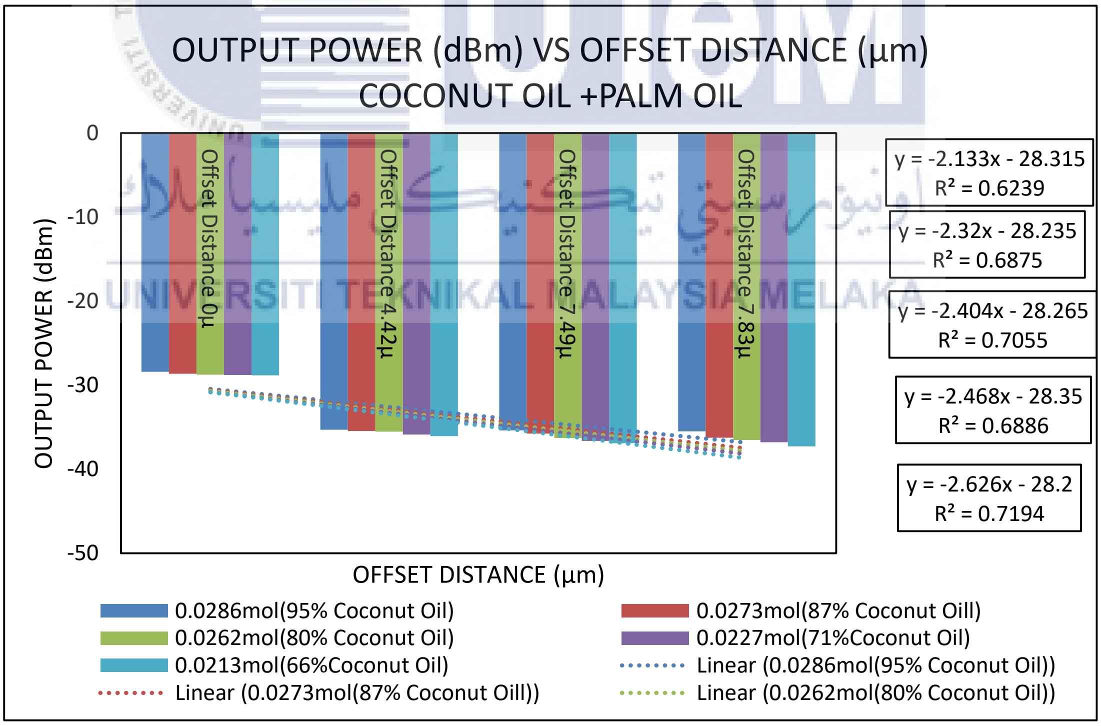


Figure 4.29: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil With Palm Oil with All Distance µm by using MMF-MMF

Figure 4.29 shows a graph of output power (dBm) versus distance (μm) of coconut oil mixed with palm oil in mole (mol) for all distance (μm) using MMF-MMF is a decrease in output intensity. The output power loss shows that the larger distance has a higher value output power loss compared to the other distance. The larger gap of distance, the higher output power loss will produce in the lateral offset method. The sensitivity for each of the solution coconut oil with palm oil has been shown in Figure 4.30 for 95% of coconut oil mixed with 5% of paraffin oil the sensitivity is -2.133dBm/mol and the R-value is 0.6239. Next for 87% of coconut oil mixed with 13% of paraffin oil the sensitivity is -2.32 dBm/mol and the R-value is 0. 6875. Next for 80% of coconut oil mixed with 20% of paraffin oil, the sensitivity is -2.404 dBm/mol and the R-value is 0.7055. Next for 71% of coconut oil mixed with 29% of paraffin oil the sensitivity is -2.468 dBm/mol and the R-value is 0.6886 and lastly, for 66% of coconut oil mixed with 34% of paraffin oil the sensitivity is -2.626 dBm/mol and the R-value is 0.7194.

4.3.2.3 Mixture Solution Coconut Oil with Paraffin Oil

Table 4.21: Output Power in (dBm) Multi-Mode Fiber Optic with Lateral Offset Displacement Sensor (MMF-MMF) with Distance 0µ,4.42µ,7.49µ,7.83µ

	D= 0µ	D= 4.42µ	D= 7.49µ	D= 7.83µ
Number of mole(mol)	Output Power NS (dBm)	Output Power MM 1 (dBm)	Output Power MM 2 (dBm)	Output Power MM 3(dBm)
0.0286	-28.15	-32.04	-35.96	-38
0.0273	-28.24	-33.5	-36.08	-38.17
0.0262	-28.35	-34.86	-36.5	-38.34
0.0227	-28.46	-35.72	-36.65	-38.98
0.0213	-28.64	-36.24	-37.26	-39.78

Table 4.21 above shows the solutions have been tested according to the number of mol for mix solution for pure coconut with paraffin oil. There are five solutions with a different volume percentage of concentration which is 95% of coconut oil with 5% of palm oil with the number of mols is 0.0286 mol/g. Next is 87% of coconut oil with 13 % of palm oil with the number of mols is 0.0273 mol/g. Next for 80% of coconut oil with 20 % of palm oil with the number of mols is 0.0262mol/g. Next for 71% of coconut oil with 29% of palm oil, the number of mols is 0.0227 mol/g, and lastly, for 66% of coconut oil with 34% of palm oil, the number of mols is 0.0213.

The result for the output power in (dBm) based on Table 4.21 it shows the longer distance will produce high power loss with method lateral offset distance for distance 7.83 µm the output power for 66% of coconut oil mixed with 34% of paraffin oil with the number of mol 0.0213 mol/g is -39.78 dBm, compare to the other of mixed solution and distance. For example, the distance offset 4.42µm with the same number of mol 0.0213mol/g, the output power loss is -36.24dBm and for distance offset 7.49 µm the output power loss is -37.26dBm. The result showed an increasing the output power based on the volume of adulterant in the coconut oil. The higher the volume of adulterant oil in coconut oil, the higher the output loss will produce based on the sensing head with the method of lateral offset. All the measurements that have been tested have been tabulated in Table 4.21.

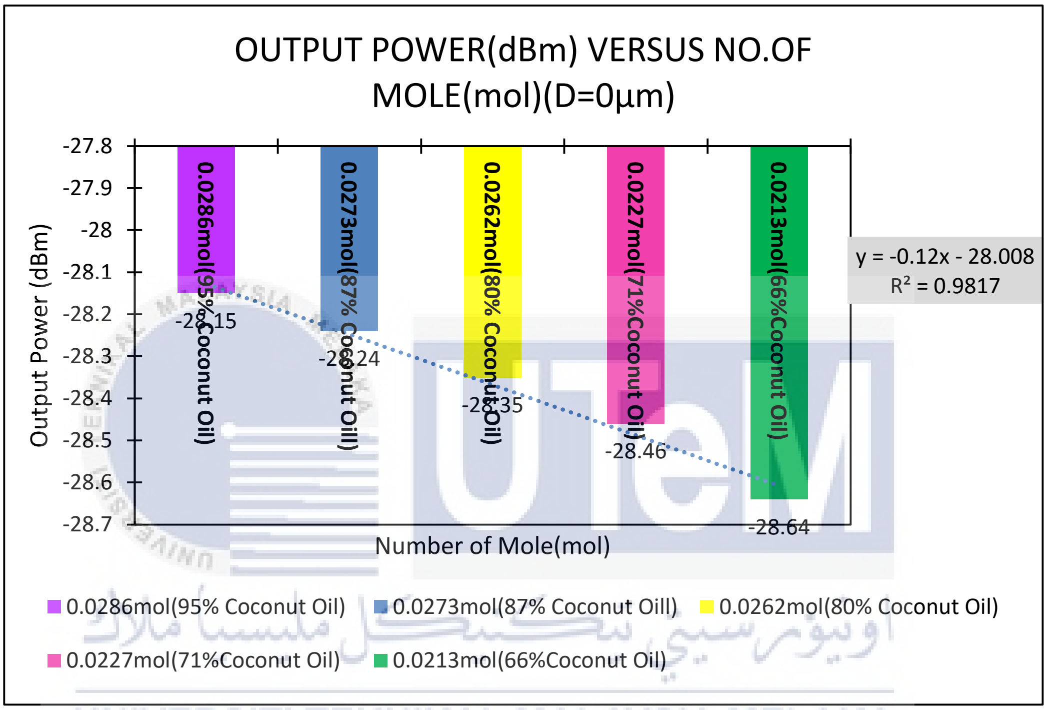


Figure 4.30: Graph of Output Power (dBm) Versus The Number of Moles (mol) Coconut Oil with Paraffin Oil With Distance 0µm by using MMF-MMF

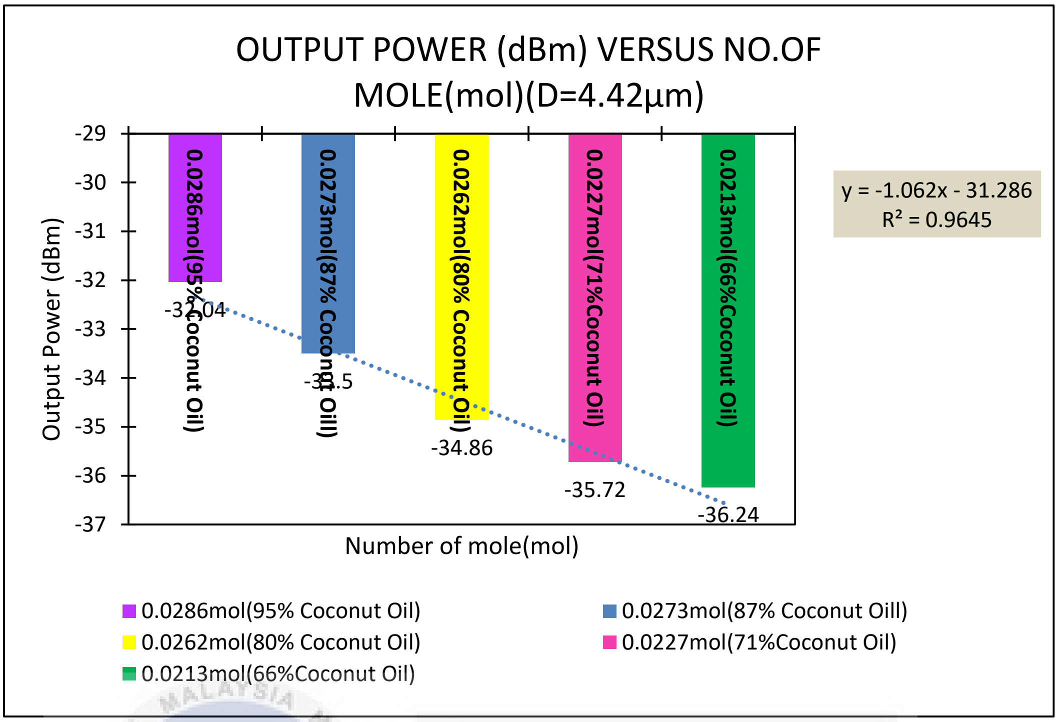


Figure 4.31: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil with Paraffin Oil with Distance 4.42µm by using MMF-MMF

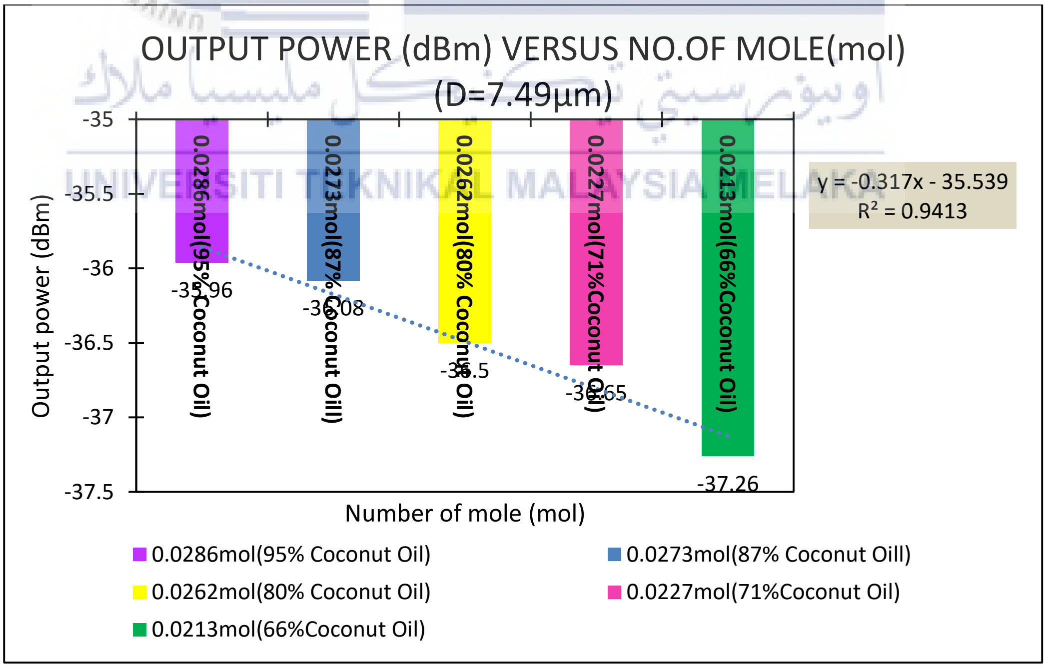


Figure 4.32: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil with Paraffin Oil with Distance 7.49 µm by using MMF-MMF

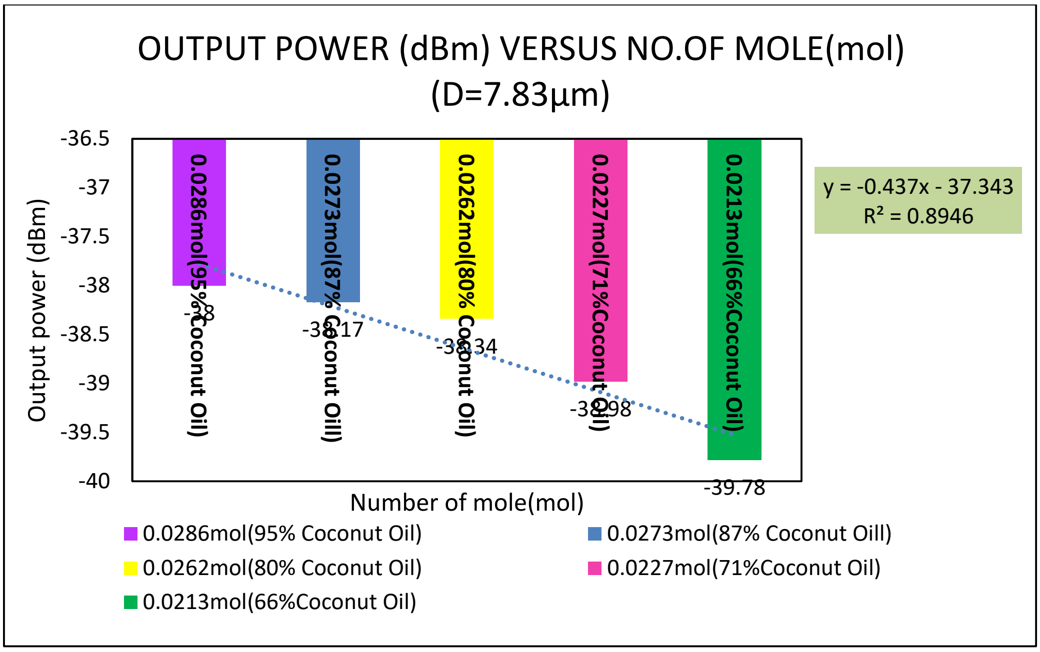


Figure 4.33: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil With Paraffin Oil with Distance 7.83 µm by using MMF-MMF

For figure 4.30 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with paraffin oil with distance 0µm using normal splicing MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mole 0.0213 mol has a higher value which is -28.64 dBm compare to other mixed solutions.

For figure 4.31 shows the graph for output power dBm versus a number of mole (mol) mixed solution which is coconut oil with paraffin oil with distance 4.42µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.0213 mol has a higher value which is -36.24 dBm compare to other mixed solutions.

For figure 4.32 shows the graph for output power dBm versus a number of moles (mol) mixed solution which is coconut oil with palm oil with a distance of 7.49 µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mole 0.0213 mol has a higher value which is -37.26 dBm compare to other mixed solutions.

For figure 4.33 shows the graph for output power dBm versus a number of moles (mol) mixed solution which is coconut oil with palm oil with a distance of 7.83 µm using lateral offset distance MMF-MMF is decreasing in output intensity. The output power loss shows that 66% of coconut oil mixed with 34% of palm oil with a number of mol 0.0213 has a higher value which is -39.78 dBm compare to other mixed solutions.

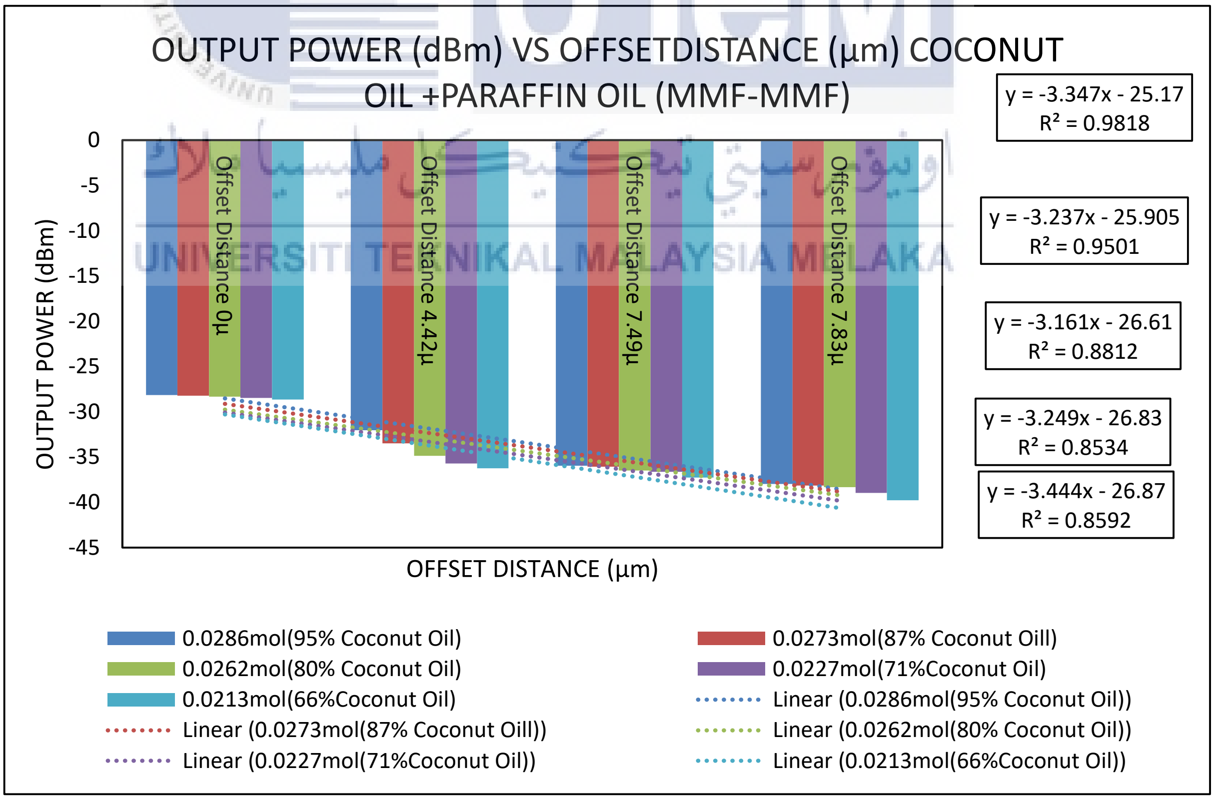


Figure 4.34: Graph of Output Power (dBm) Versus The Number Of Moles (mol) Coconut Oil with Paraffin Oil with All Distance (µm) by using MMF-MMF

Figure 4.34 shows the graph of output power (dBm) versus distance (μm) of coconut oil mixed with paraffin oil in mole (mol) for all distance (μm) using MMF-MMF is a decrease in output intensity. The output power loss shows that the larger distance has a higher value output power loss compared to the other distance. The larger gap of distance, the higher output power loss will produce in the lateral offset method. The sensitivity for each of the solution coconut oil with palm oil has been shown in Figure 4.35 for 95% of coconut oil mixed with 5% of paraffin oil the sensitivity is -3.347 dBm/mol and the R-value is 0.9818. Next for 87% of coconut oil mixed with 13% of paraffin oil the sensitivity is 3.237 dBm/mol and the R-value is 0. 9501. Next for 80% of coconut oil mixed with 20% of paraffin oil, the sensitivity is -3.161 dBm/mol and the R-value is 0.8812. Next for 71% of coconut oil mixed with 29% of paraffin oil the sensitivity is -3.249 dBm/mol and the R-value is 0.8534 and lastly, for 66% of coconut oil mixed with 34% of paraffin oil the sensitivity is -3.444 dBm/mol and the R-value is 0.8592.

4.4 Conclusion

Throughout this project, the sensitivity of sensors can be varied by changing the offset distance by using the method of lateral offset. Shishi Xu et.al [15] studied sensor structure when the offset distance is 0 μm, a small amount of light enters the outer of the core, so when the offset distance increasing, the light entering the cladding gradually increases. The longer the offset distance, the higher the energy loss. In this project, the MMF sensor has better sensitivity than the SMF sensor due to its different structure.

In this project, the highest offset which is at 14.64 μm has produced the highest output power (dBm) compared to the others offset distance SM-SM fiber sensor. The solutions that have been tested with solution coconut oil with palm oil with sensitivity -0.286dBm/mol and for solution coconut oil with paraffin oil with sensitivity -0.045 dBm/mol. Next for MMF-MMF, the highest offset distance which is at 7.83 µm also produce the highest output power (dBm) with all the solution that has been tested. The solutions that have been tested with solution coconut oil with palm oil with sensitivity -0.406 dBm/mol and for solution coconut oil with paraffin oil with sensitivity -0.437 dBm/mol. It has proved that the larger the offset distance, the higher the sensitivity of the fiber sensor.

Next for solution testing, M. Sheeba et.al [14] studied the oil mixture of different mix ratios are introduced into the sensing region and we observed a sharp decrease in the output intensity. As the concentration of adulterants oil increases in the edible oils, the refractive index of the medium surrounding the sensor head increases, which results in a reduction of output power. Based on this project, it can be compared that the results of this project are similar to M.Sheeba et.al [12]. according to the output power with the number of adulterants based on the refractive index. For the type of solution, it shows that sensors of SMF-SMF and MMF-MMF detect the sensitivity of paraffin oil better than palm oil. This is because palm oil has the similarity characteristics to coconut oil and it easily blends. Hence, adulteration detection becomes rather difficult, especially when the adulterant has similar chemical characteristics to that of the original oil [13].

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter concludes the overall project, including a discussion on the achievement of the objectives and the overall working of the project. At the end of this chapter, a future recommendation is given to further improve on this project.

5.1 Conclusion

In this project, the optical characterizations of different liquid concentrations have been made. This project uses three types of solution: pure coconut oil, pure palm oil, and pure paraffin oil. All this solution will be mix to detect the contaminants in coconut oil. The sample was divided into two types adulterated pure coconut oil with palm oil, and the second type is adulterated pure coconut oil with paraffin oil.

There are two types of fiber optic that have been used for the development of SMF-SMF and MMF-MMF sensors which are single-mode and multimode fiber optic cable.

The structure of the SMF sensor is done by splicing both single-mode fibers in the method of lateral offset displacement sensor. Meanwhile, the design of MMF –MMF is done by splicing both ends of multimode fiber with multimode fibers. Both structures are elementary to be constructed and implemented in the industries. Furthermore, an environmentally friendly project has been successfully designed by using optical fiber optic without any chemical substances.

For this project, two objectives have been successfully achieved. SMF-SMF and MMF-MMF's first objective has been successfully designed and fabricated by using the lateral offset displacement sensor method. A variety of distance offsets have been made as to the sensor area.

Next, the second objective is also successfully achieved as this project can analyze the sensing response of SMF-SMF and MMF-MMF towards the adulterants concentration in coconut oil based on lateral offset displacement sensor. The sensitivity of both sensors is observed by changing the two main parameters: the length of offset distance in fiber and the volume of adulterants concentration in solution. From the experiment result, the output optical power is decreased when the concentration of adulterants solution is increased. Besides that, if the concentration of solutions increases, the refractive index value will also increase. The highest offset, at 14.64 µm of SMF-SMF, and for MMF-MMF highest offset distance at 7.83 µm has produced the highest output power (dBm) the solutions that have been tested. It has proved that the larger the offset distance, the higher the sensitivity of the fiber sensor.

The project's sustainability and impact are divided into three categories which are economic, social, and environmental. First, it does not require daily maintenance in terms of economy and has a longer lifespan than a conventional electronic sensor. As a result, the cost of maintenance will be significantly reduced. In terms of social, the optical fiber sensor is entirely safe for any living being because it does not require a large amount of energy to operate, which could be harmful. Lastly, optical fiber is environmentally friendly because it does not emit chemical or hazardous substances and uses less power to operate than a conventional electronic sensor.

5.2 Future Work

The fiber optic sensor can be used in various industries, including the chemical, biomedical, oil and gas, and food industries. This project is proved that how the sensors can use as a sensing device in liquid testing. However, it is not limited to liquid testing, and it can also be used to test other parameters such as temperature, pressure, and humidity. Because the main structure of both sensors is glass, they are impervious to harmful interference and can withstand extreme conditions such as high temperatures and pressure.

To help enhance, fiber optic sensors can be combined with any microcontroller, such as connect with the IoT, to make it more convenient and easier to monitor sensor output. The user can monitor from afar using IoT because an authorized person has global access to the system. Furthermore, increasing the length of the sensing region can improve sensor sensitivity. This allows the sensors to produce higher resonant output when the optical signal passes through it.

In the future, this sensor also can be applied in oil and food companies such as Delima Oil Product Sdn Bhd to monitor any substances chemical or adulterant oil in the tank. Due to the sensors' features and size, they are the most suitable for these industries because they only need simple and cost-effective techniques to check the adulterants in oil-based or food products compared to the other expensive instrument, requiring manpower expertise and arduous interpretation skills.

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APPENDICES

Appendix A: Periodic table of the element