Faculty of Electronics and Computer Technology and Engineering

MODELING AND OPTIMIZATION OF MICROFIBER OPTIC SENSOR PARAMETERS USING DESIGN SOFTWARE AND BOX BEHNKEN DESIGN (BBD) APPROACH FOR THE SME FOOD INDUSTRY

NAJIHAH BINTI MUHAMAD ZARI

Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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A project report submitted
in partial fulfillment of the requirements for the degree of
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DEDICATION

This project is dedicated to my affectionate parents, Muhamad Zari and Hazlina, and my outstanding supervisor, Mrs. Rahaini Bt Mohd Said. Their persistent support, encouragement, and advice have played a crucial role in achieving the outcome of this last year. I express my gratitude for the support and encouragement provided by my cherished parents and excellent supervisor. This accomplishment serves as evidence of the combined impact that have had on my academic pursuits.

ABSTRACT

The development of a palm oil detection system for analyzing the condition of palm oil has garnered significant attention in recent years. Recently, optical microfibre sensors are growing as an achievable decision and there is considerable interest in applied for palm oil detection. Wearable optical microfibre sensors have been developed to fulfill the needs of small and medium-sized companies (SMEs) in the palm oil industry. These sensors have been optimized by microfiber input parameters including wavelength, microfiber diameter, palm oil content, and microfiber type to improve sensing performance and sensitivity. The optimization procedure was carried out using a Design of Experiment technique, with the objective of improving the overall quality of the optical microfibre sensor development for detecting palm oil conditions. The methodology is a systematic approach that utilises Design of Experiments (DOE) and statistical approaches to manipulate input parameters and assess their impact on the intended outcome. DOE enables the analysis of the interplay and impacts of many variables, hence promoting the development of microfibre technology for precise, efficient, and economical assessment of palm oil quality. The expected results of this research include a thorough comprehension of microfiber optic sensor characteristics, a mathematical model for palm oil detection, and optimised configurations for the microfiber sensor to precisely identify the condition of palm oil. This project aims to improve the capacity of small and medium-sized enterprises (SMEs) in guaranteeing the quality of palm oil by using new and easily available technologies.

ABSTRAK

Pembangunan sistem pengesanan minyak kelapa sawit untuk menganalisis keadaan minyak kelapa sawit telah menarik perhatian yang signifikan dalam beberapa tahun terakhir. Baru-baru ini, sensor mikrofiber optik sedang menjadi pilihan yang dapat dicapai, dan terdapat minat besar dalam penggunaannya untuk pengesanan minyak kelapa sawit. Sensor mikrofiber optik boleh dipakai telah dibangunkan untuk memenuhi keperluan syarikat kecil dan sederhana (SME) dalam industri minyak kelapa sawit. Sensor ini telah dioptimumkan oleh parameter input mikrofiber termasuk panjang gelombang, diameter mikrofiber, kandungan minyak kelapa sawit, dan jenis mikrofiber untuk meningkatkan prestasi pengesanan dan kepekaan. Prosedur pengoptimuman dilakukan dengan menggunakan teknik Reka Bentuk Eksperimen, dengan objektif meningkatkan keseluruhan kualiti pembangunan sensor mikrofiber optik untuk mengesan keadaan minyak kelapa sawit. Metodologi ini adalah pendekatan sistematik yang menggunakan Reka Bentuk Eksperimen (DOE) dan pendekatan statistik untuk memanipulasi parameter input dan menilai impaknya terhadap hasil yang diinginkan. DOE membolehkan analisis interaksi dan impak pelbagai pemboleh ubah, oleh itu mempromosikan perkembangan teknologi mikrofiber untuk penilaian yang tepat, efisien, dan ekonomi terhadap kualiti minyak kelapa sawit. Hasil yang dijangka dari kajian ini termasuk pemahaman menyeluruh mengenai ciri-ciri sensor mikrofiber optik, model matematik untuk pengesanan minyak kelapa sawit, dan konfigurasi yang dioptimumkan untuk sensor mikrofiber untuk mengenal pasti keadaan minyak kelapa sawit dengan tepat. Projek ini bertujuan untuk meningkatkan kapasiti syarikat kecil dan sederhana (SME) dalam menjamin kualiti minyak kelapa sawit dengan menggunakan teknologi baru yang mudah diperoleh.

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LIST OF ABBREVIATIONS

SMEs	-	Small and Medium Enterprise
DOE	-	Design of Experiments
TAG	-	triacylglycerols
MFOS	-	Microfiber Optic Sensor
RSM	-	Response Surface Methodology
FEMs	-	Finite Element Methods
FTIR	-	Fourier Transform Infrared Spectroscopy
BBD	-	Box Behnken Design
CNNs	-	Convolutional Neural Network
CFD	-	Computational Fluid Dynamics
PSO	-	Particle Swarm Optimization
GA	-	Genetic Algorithm
FA	-	Fatty Acids
UFA	-	Unsaturated Fatty Acids
SFA	-	Saturated Fatty Acids
SMF	-	Single Mode Fibre
MMF	-	Multimode Fibre
FTIR	-	Fourier Transform Infrared
TFC	-	Trans Fat Content
FFA	-	Free Fatty Acids
PV	-	Peroxide Value
IV	-	Iodine Value
SFC	-	Solid Fat Content

GC	-	Gas Chromatography
HPLC	-	High Performance Liquid Chromatography
MS	-	Mass Spectrometry
CNNs	-	Convolutional Neural Networks
AI	-	Artificial Inteligence
NH3	-	Ammonia Gas
CCD	-	Central Composite Design
ANOVA	-	Analysis of Variance
MPD	-	Modal Power Distribution
SI-MMFs	-	Step Index Multimode Fiber

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CHAPTER 1

INTRODUCTION

1.1 Background

The oil of palm trees finds wide application in various a food product such as baked goods, confectionery, and frying oil. The processing of palm tree fruits yield two distinct edible plant oils; Palm oil and palm kernel oil. (Imoisi et al., 2015) Palm oil is derived from the mesocarp of the palm fruit and palm kernel oil, a minor oil obtained from the seed of the palm fruit. (Y. H. Chong & Ng, 1991). Notably, palm oil is extensively used in culinary, hygiene, and chemical industries contributing to the significant surge in global vegetable oil demand, reaching 55.3 million tons in 2012 and 2013 (Villela et al., 2014)

The qualities of palm oil governed by various elements including its physical, chemical, and sensory aspects make it a unique edible oil. With a fatty acids (FA) balance of roughly 48% saturated fatty acids (SFA) and 52% unsaturated fatty acids (UFA), palm oil differs from other healthy oil like sunflower, olive or rapeseed. than other healthy oils like sunflower, olive, or rapeseed (Gesteiro et al., 2019) While palm kernel oil contains around 80% saturated fatty acids, palm oil has 50% saturated fatty acids. (Y. H. Chong & Ng, 1991) The nutritional quality of palm oil is also further influenced by the types of fatty acids present in palm oil. (Tagoe et al., 2012)

Palm oil undergoes changes during processing, making quality monitoring challenging for small and medium-sized enterprises (SMEs) in the food industry. Traditional methods like gas chromatography are impractical due to cost and expertise constraints. Modifications like hydrogenation, interesterification, and fractionation are employed to extend palm oil usage in fat-based foods, altering its physicochemical characteristics (Kellens et al., 2007).

Ensuring palm oil quality in storage requires regular cleaning, moisture prevention, and corrosion prevention measures. Neglecting maintenance can lead to increased expenses and equipment problems. Microfiber optic sensors (MFOS) offer a low-cost, portable solution for quality monitoring, detecting changes in acidity, peroxide value, and viscosity. Optimizing MFOS parameters enhances performance, providing high precision and real-time monitoring benefits in the food industry (C. L. Chong, 2012).

Ensuring palm oil quality with fiber optic sensors requires a systematic procedure for guaranteed product quality and lifespan. Proper selection, placement, and effective incorporation of fiber optic sensors into processing or storage systems are crucial for accurate measurements and direct communication with palm oil.

In process optimization, Design of Experiments (DOE) plays a vital role in identifying optimal values for input variables. Previous studies successfully used DOE to optimize significant reaction parameters in the palm oil cracking process (Ooi et al., 2004; Twaiq et al., 2001). DOE is essential for optimizing workflows, enhancing product quality, and achieving performance goals.

Response Surface Methodology (RSM), a statistical method, has been employed to examine and improve the transesterification process for biodiesel generation from palm oil (Kansedo et al., 2009). The Box-Behnken design, a valuable experimental design within response surface methods, is particularly useful for studying variables and responses in a quadratic or nonlinear situation. It efficiently estimates and optimizes parameters, enabling effective parameter space exploration with a minimal number of trials (Kansedo et al., 2009).

1.2 Problem Statement

Parameters of microfiber optic sensors are being modeled and fine-tuned to detect palm oil in applications within small and medium-sized enterprises (SMEs) in the food industry. This aims to facilitate the monitoring of palm oil quality throughout processing, transportation, and storage. Factors like light, heat, and air have the potential to degrade the quality of palm oil, causing changes in its chemical and physical properties. These modifications can impact the flavor, aroma, and nutritional value of palm oil, making it unfit for use in food.

Small and medium-sized enterprises (SMEs) frequently face challenges in effectively monitoring and guaranteeing the quality of palm oil due to limited resources and technical expertise. Microfiber optic sensors (MFOS) offer a cost-effective and straightforward solution for monitoring palm oil conditions. However, to attain optimal sensitivity and selectivity, it is crucial to model and optimize various MFOS parameters. These parameters encompass factors such as fiber diameter and length, core and cladding refractive index, and the sensing material. The optimization of these MFOS parameters has been conducted to assess the condition of palm oil within the food industry of SMEs.

To identify optimization parameters, including those for microfiber, a statistical technique known as Design of Experiments (DOE) is utilized. Design of Experiments (DOE) systematically alters input factors or variables and assesses their impact on the intended response. By examining the interactions and effects of different factors on the desired performance criteria, DOE aids in the enhancement of microfiber for precise, effective, and economically viable monitoring of palm oil quality.

1.3 Project Objective

In the project of modeling and optimizing microfiber optic sensor parameters for palm oil detection, SMEs will be able to monitor the quality of palm oil using MFOS technology in a low-cost, portable, and easy-to-use way. This project aims to accomplish the following:

a) To identify the significance effect of microfiber sensor parameter.

b) To develop a mathematical regression model for the microfiber sensor as a palm oil detector.

c) To optimize the microfiber sensor's settings to generate detector parameter capable of accurately detecting the state of palm oil.

1.4 Scope of Project

The scope of this project is as follows:

a) The test research considers the specific type of microfiber.

b) The experiment employs both single-mode and multimode fibers.

c) The power output of the microfiber is used to measure its performance.

d) A variety of microfiber factors, such as wavelength, microfibre diameter, microfiber types, and palm oil concentration, are taken into consideration.

e) Relevant models for this research are regenerated and assessed.

f) The microfiber sensor prototype is designed and tested using Design of Experiments (DOE) software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a brief overview of the prior fiber optic systems and related literature to the project with the objective of highlighting their applicability and quickly outlining both their advantages and disadvantages. The design of Experiments (DOE) and the invention of microfibre are also mentioned. In general, this chapter provides important information and a solid basis for the project's long-term success.

2.2 Fiber Optical Sensors

A fiber optic sensor is a device that can identify and measure a wide range of physical, chemical, or biological factors by using an optical fiber. The technology relies on the modulation and transmission of light across a fiber optic media to perform its functions. A coherent optical carrier such as a laser will carry more data (Arumugam, 2001). Fiber optic sensors have several potential uses, such as biological sensing, chemical analysis, vibration analysis, pressure monitoring, strain measurement, and vibration analysis.

There are several advantages to using fiber optic sensors, including their quick reaction times, high accuracy, small size, and resilience under extreme conditions. Fiber optic sensors are essential since they provide accurate and dependable monitoring of a wide range of parameters across a wide range of applications. They have become a standard instrument in several fields where collecting precise data in real-time is of paramount importance. The laser generates powerful, intensely monochromatic, and intensely directed light pulses that function as carrier waves for sending a considerable quantity of information, outperforming radio waves and microwaves while reducing divergence. (Arumugam, 2001)

The most important components of optical fiber networks are the core, cladding, buffer, and jacket. The core is made of high-purity glass or plastic and has a greater refractive index than the cladding. The buffer protects the fiber from abrasion and damage, while the jacket provides additional protection from exposure to chemicals, moisture, and abrasion. Figure 2.1 shows the basic component of optical fiber, the three main parts of an optical fiber are the core which moves the light, the cladding which holds the light around the core and has a lower refractive index, and the coating which covers the sensitive fiber inside. The way light moves through an optical fiber is shown in Figure 2.2. (Kaur et al., 2022)

The two main types of mode transmission in optical fiber are single mode and multimode. Single-mode fibers have a small core width and only let one mode of light travel along the fiber core. Multimode fibers have bigger core sizes and can carry more than one mode at the same time. There are different kinds of multimode fibers, such as step-index and graded-index fibers. Step-index fibers have a quick change in the index of refraction from the core to the coating, while graded-index fibers have a slow drop in their refractive index. In a single mode, light moves at a certain frequency to the center of the 8 to 10 µ. For multi-mode, the core size is either 50 or 62.5 µ. (Kaur et al., 2022)

Introduction of fiber optic sensor technology in the article titled "Fiber optic sensor technology: an overview." The paper covers the salient features, uses, and benefits of this technology. Fiber optic sensor technology provides a dependable and adaptable method for accurate and distant sensing, with applications in telecommunications, aircraft, medicine, and environmental monitoring. Sensor architectures such as Fabry-Perot interferometers and Bragg gratings improve sensitivity and precision. (Grattan & Sun, 2000)

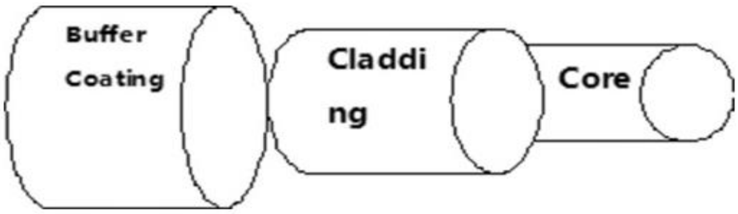


Figure 2.1 Basic Component of Optical Fiber

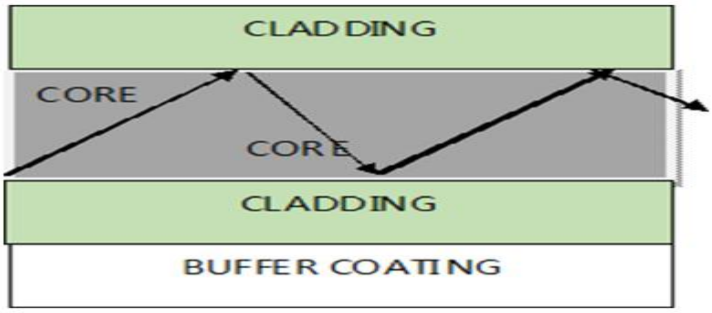


Figure 2.2 Light Propagation in Optical Fiber.

2.2.1 Microfiber Optical Sensors

Microfiber optical sensors are a particular kind of optical sensor used in sensing applications. These sensors are made to interact with many outside stimuli, including light, pressure, temperature, and chemical compounds, and they do so by transforming the measured changes into quantifiable visual signals. In comparison to conventional fiber optic sensors, they provide a number of benefits, including high sensitivity, small size, flexibility, and the ability to work in a variety of situations. The diameter of microfiber varies from tens of nanometers to micrometers when compared to ordinary optical fiber because a significant percentage of the evanescent field of subwavelength scale microfiber can reach the environment due to the light diffraction limit. (Tong et al., 2004) This allows microfiber to interact with its surroundings very strongly. (Tong et al., 2003)

Microfiber optical sensors and conventional fiber optic sensors vary primarily in their structure and mechanism of operation. The light signal is generally carried by a single optical cable in traditional fiber optic sensors. To detect changes in the surrounding environment, these sensors depend on the changing of light characteristics like intensity, phase, or polarization. They are extensively used for many different purposes, including telecommunication, industrial sensing, and structural health monitoring.

A comprehensive review article on the current state of the art on microfiber optical sensors was published in the paper "Microfiber Optical Sensors: A Review". This paper is an in-depth review that discusses microfiber optical sensors from their design, fabrication, materials, sensing mechanisms, and applications from a comprehensive perspective. The authors start by introducing the field of microfiber sensors and the reasons for pursuing their development by providing an overview of what is involved in their development. The authors then go on to describe how microfibers are manufactured using a variety of fabrication methods, including tapering, stretching, and splicing as well as other techniques. Moreover, the authors suggest how microfibers can be coated with metals, polymers, and nanoparticles in order to modify the optical properties of the sensors, and how the materials used to do this can be incorporated into the coatings. (Lou et al., 2014)

The paper presents several different types of sensing mechanisms that are used in microfiber sensors, including reflective index sensing, surface plasmon resonance sensing, and fluorescence sensing. Each mechanism is described in detail in the book and its advantages and disadvantages are discussed in great detail. Microfiber sensors are one of the most widely used types of sensors and the researchers have described the various applications included in this chapter, including biomedical sensors, environmental sensors, and chemical sensors. Microfiber sensors have been used in many specific applications in a wide range of fields and have been shown to have some potential advantages over traditional sensing techniques in each area that they discuss. This paper provides an overview of microfiber optical sensors which may be of interest to researchers, students, and professionals in this field. This overview serves as a valuable resource for those researchers, students, and professionals interested in this topic. There is a comprehensive description of the current state of knowledge on microfiber sensors in the article, as well as potential directions for future research that are suggested. (Lou et al., 2014)

An important part of the research is the output power of the microfibre loop resonator in the context of formaldehyde liquid detection. This advances knowledge of and possible uses for microfiber-based sensors for formaldehyde liquid detection by enabling researchers to evaluate the functionality and sensitivity of the sensing device. (Jali et al., 2019)

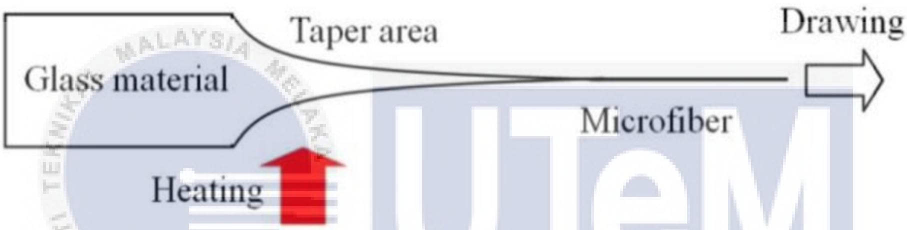


Figure 2.3 Schematic Of Tapering Technique

2.2.2 Wavelength

The concept of wavelength applies to the precise spectrum of light frequencies employed for data transmission via optical fibres within the domain of fibre optic communication. The near-infrared spectrum comprises a range of significant wavelengths, including 850, 1300, 1310, and 1550 nanometers and beyond. Unique applications are associated with each wavelength. A variety of wavelengths are utilised in single-mode fibre optics for longer-distance communications, such as telecommunications networks and 1550 nm; 1300 nm is compatible with both multimode and specific single-mode fibre systems and is commonly employed in shorter-distance multimode fibre optics; and 1550 nm is utilised in single-mode fibres for extensive transmissions, including those in undersea cables and long-haul systems. Opacity-level in the infrared spectrum, these wavelengths are selected according to equipment compatibility, transmission distance, and network requirements. Wavelength division multiplexing (WDM) is a technological advancement that permits the concurrent transmission of numerous signals across a solitary fibre. By utilising distinct wavelengths, fibre optic communication networks can achieve substantial improvements in data capacity and efficiency. Additionally, the fibre losses are wavelength dependent. The standard loss at 1,550 nanometers is 0.25 dB/km, while at 1,310 nanometers it is 0.4 dB/km. (P & Kumar, 2021)

2.2.3 Optimization Of Microfiber Optic Sensor

The paper titled "Optimizing Tapered Microfiber Sensor Design and Simulation". addresses the optimization of a tapered microfiber sensor design through the use of simulations. In recent years, the microfiber sensor has become increasingly popular as a type of fiber optic sensor because of its high sensitivity and small size compared to other types of fiber optic sensors. Microfiber sensors were designed to achieve the highest level of sensitivity and resolution possible, according to the authors. An overview of the theoretical background of tapered microfiber sensors is provided, along with its design principles and the mathematical model used to describe its behavior. As a result, the authors then describe their simulation methodology, which includes the use of finite element methods (FEMs) to simulate the behavior of the microfiber sensor under different design parameters, such as the taper length and waist diameter, which are both important parameters of the design. In order to optimize the design of the microfiber sensor, the authors conducted a series of simulations. By optimizing the taper length and waist diameter, they were able to increase the sensor's sensitivity and resolution. Besides the refractive index of the surrounding medium, other design parameters have been examined, such as the distance between the sensor and the light source. (Al-Askari et al., 2016)

A microfiber sensor design that has been optimized is also experimentally validated in the paper. In conjunction with a laser light source and a microfluidic system, the authors manufactured a microfiber sensor with the optimized parameters. According to the researchers, their design optimization method produces good agreement between experimental and simulation results. By analyzing the tapered microfiber sensor design through simulation, this paper provides an in-depth analysis of its optimization. Figure 2.4 shows how an optical fiber with a diameter of (D_O) is heated and stretched to make a microfiber with a diameter of (D_L). By using simulation techniques, the authors take advantage of microfiber sensors' high sensitivity and resolution. Simulated microfiber sensors provide new avenues for research and development and demonstrate the potential of simulation techniques for design and optimization. (Al-Askari et al., 2016)

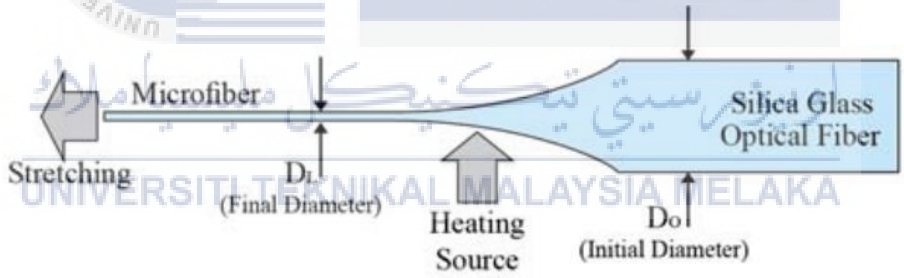


Figure 2.4 Microfiber Fabrication Technique

2.2.4 Optical Microfiber Based Temperature Sensors

The paper describes in depth the development and testing of a novel temperature sensor based on microfiber technology in a paper "Microfiber-Based Temperature Sensors". As a result of its low size and high sensitivity, microfiber technology has emerged as one of the most promising technology platforms in the world for sensing applications. These advantages have been exploited by the authors to develop a low-cost, reliable, and easy-to-integrate temperature sensor. Microfiber temperature sensors, including a microfiber sensor made from single-mode optical fibers, are described in detail in the paper, including the use of a tapering machine to reduce the diameter of the optical fibers. Based on the flame brushing method, a "multi-sweep" is shown in Figure 2.5. In order to facilitate sensing, a thin layer of metal is applied to the microfibers, such as nickel, gold, or platinum. The sensing material in this case is made of this metal. Microfibers' transmission spectrum shifts as the resistance of the metal layer change with temperature. Their microfiber temperature sensor has been tested at various temperatures by the authors. As small as 0.01 degrees Celsius can be detected by the sensor, which has been found to be highly sensitive. Moreover, their sensor has comparable sensitivity and response time to a commercial thermocouple, as was determined when they compared the performance of their sensor with a commercial thermocouple. (Talataisong et al., 2018)

Its small size makes it easy to integrate with existing optical systems, which makes the microfiber temperature sensor one of its biggest advantages. Multiple sensors or a small space can be used with this feature if you need a lot of sensors in one application. In addition to monitoring industrial processes, the authors suggest their sensors can be used in medical diagnostics and environmental monitoring. A novel microfiber-based temperature sensor is developed and tested in the paper. A low-cost and reliable sensor can be created by leveraging the advantages of microfiber technology. Research and development in this field are further facilitated by their work demonstrating the potential of microfibers for sensing applications. (Talataisong et al., 2018)

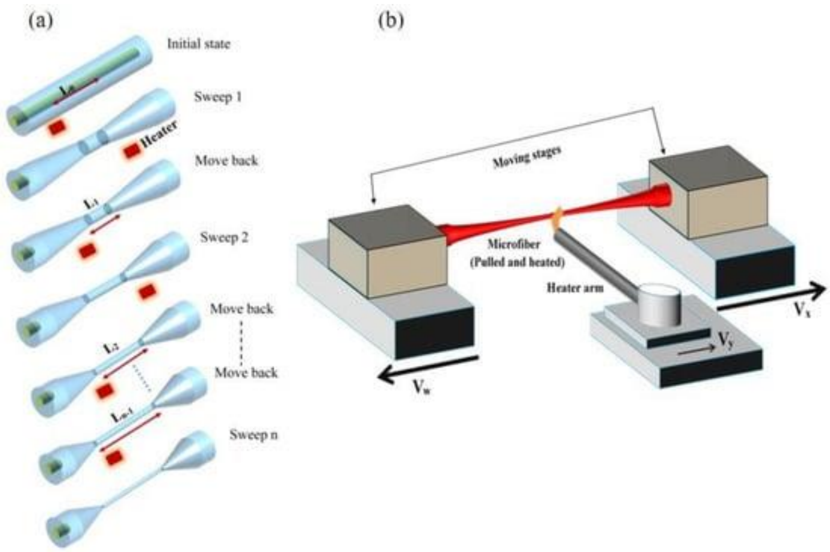


Figure 2.5 (A) Taper Profile Development Utilising The Multi-Sweep Tapering Approach and (B) Practical Development of The Single-Sweep Tapering Method.

2.3 Optical Fiber Cable

Light signals are used by optical fiber cables, a kind of high-speed data transmission medium, to transfer data. They are made of tiny glass or plastic fiber strands that are designed to transmit light pulses across great distances, carrying information. There are several kinds of optical fiber cables, and each is intended for use in a particular setting. Optical fiber cables utilize light signals for transmitting data and serve as a high-speed medium for communication. Comprising small strands of glass or plastic fibers, these cables are engineered to convey light pulses over extensive distances to transfer information. Various types of optical fiber cables exist, each tailored for specific applications or environments. (Baoping et al., 2021)

2.3.1 Single mode

Of all the optical fibre cables, single mode fibre (SMF) is unique in that it has a small core that can transmit just one mode of light. This core is usually 8 to 10 microns in diameter. Because of its single mode feature, SMF can transmit data across great distances with remarkable signal integrity. For applications needing continuous and dependable communication over long distances, it is the recommended option because to its adeptness in maintaining the purity and coherence of light signals. Because it acts as the internet's backbone and supports long-distance networking systems, SMF is essential to vital infrastructure such as telecommunications networks. It is an essential part of many vital communication systems because of its capacity to send data over great distances without encountering appreciable signal deterioration. This makes it invaluable in situations where reliable, high-quality transmission is critical. In data centres, single-mode connection is utilised at distances more than 100 metres as well as shorter ones, as MMF. Mega- and hyper-data centres often employ SM transmission because to its large system bandwidth and ability to reach further systems. (Chen et al., 2018)

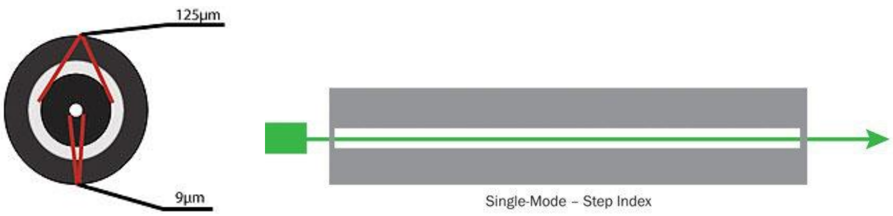


Figure 2.6 Single mode and Light Propagation Construction

2.3.2 Multimode

Multi-mode fiber (MMF) distinguishes itself in the realm of optical fiber cables by featuring a broader core, typically measuring around 50 or 62.5 microns in diameter, accommodating the propagation of multiple modes of light. This larger core size facilitates the transmission of various light signals but comes with certain limitations. MMF is better suited for shorter-distance communication due to modal dispersion, where multiple modes of light travel diverse paths within the core, leading to signal distortion over extended distances. Consequently, MMF finds its niche in applications demanding high bandwidth over limited spans, such as local area networks (LANs), data centers, and shorter-distance communication systems. These environments require substantial data transmission capacity within confined areas, where the broad core of MMF allows for the simultaneous transmission of multiple light signals. However, the dispersion resulting from these signals taking differing paths within the core restricts MMF's effectiveness over longer distances. Despite this limitation, MMF remains a vital component in scenarios where high-bandwidth communication within relatively restricted spaces takes precedence over extensive transmission ranges.

Multimode fiber (MMF) infrastructures have entrenched themselves firmly within the market, demonstrating a significant annual turnover that is projected to experience further growth. Despite a higher cost per kilometer in comparison to single-mode fiber, MMF's advantageous attributes, stemming from its wider core diameter and numerical aperture, directly yield broader coupling tolerances, thereby mitigating assembly costs. Principal domains where MMF systems find application encompass local and storage area networks, high-speed in-house networking, and interconnections among super computing systems. (Freund et al., 2010)

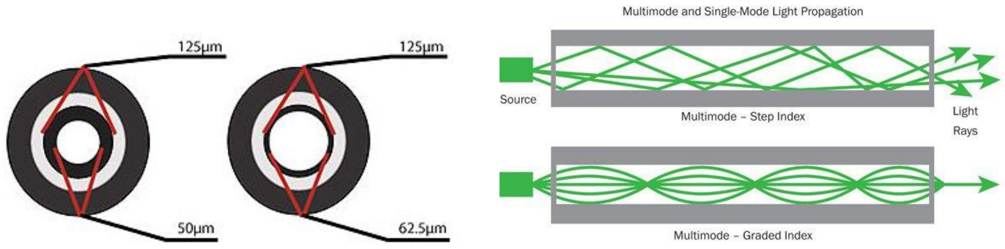


Figure 2.7 Multimode and Light Propagation Construction

2.3.2.1 Multimode Step Index

Multimode Step Index fibres consist of a core that maintains a consistent refractive index and size over its entire length, surrounded by a cladding layer with a reduced refractive index. Light signals propagate through this core by traversing different pathways, known as modes, as they continuously reflect off the border between the core and the cladding. However, the consistent refractive index of the fibre leads to the propagation of these modes across varying lengths, resulting in modal dispersion. This issue hampers the fiber's ability to transmit data effectively by causing signal distortion. However, due to scattering in the core and at the boundary with the cladding, as well as fibre bending and the insertion of passive components, the modal power distribution (MPD) in SI-MMFs changes gradually during propagation. Therefore, there is a need for an accurate measurement method and a way to represent the MPD. (Kagami et al., 2016)

2.3.2.2 Multimode Graded Index

Multimode Graded Index fibres use a core characterised by a refractive index that progressively diminishes from the centre towards the periphery. The gradient index design of the fibre causes light rays to follow curved trajectories, consistently driving them towards the centre of the core. This design mitigates modal dispersion by decreasing the temporal disparities across different modes. Graded Index fibres improve the bandwidth and transmission capacity of the fibre as compared to Step Index fibres. To reduce the impact of modal dispersion, current multimode fibers (MMFs) use cores with a refractive index profile that gradually changes. This profile minimizes the spread of group velocity and allows MMFs tailored for a wavelength of 850 nm to routinely achieve a modal bandwidth exceeding 5 GHz km. (Ryf et al., 2015)

2.4 Palm Oil

There is no doubt that palm oil is one of the most widely used vegetable oils in the food industry because of its low cost and versatility. In addition to enhancing the flavor and palatability of foods, edible oil is a rich source of fat-soluble vitamins and minerals. (Komaram et al., 2021) Despite this, the quality of palm oil can deteriorate over time due to factors such as oxidation, contamination, and even exposure to heat and light, which can cause the oil to lose its nutritional value. When it comes to ensuring the quality and safety of palm oil, it is essential to detect the condition of the oil before using it in food products. In order to ensure the edibility, safety, and quality of fats and oils, a quick and easy-to-use approach for quality parameter assessment and monitoring must be used. (Q. Li et al., 2019) The Fourier transform infrared (FTIR) approach paired with chemometry was used to determine the acid value, iodine value, peroxide value, moisture, and trans fat content (TFA) of oils and fats. (Komaram et al., 2021)

There are various physical and chemical properties of palm oil that can be assessed to determine its condition, such as its acidity, color, moisture content, viscosity, and impurity content, in order to determine the oil's condition. It is important to understand that these properties can have a considerable impact on the quality of palm oil as well as its shelf life, as well as its suitability for a range of different food applications. There are various factors that can contribute to the degradation of oil, such as high acid levels, impurities present, or excessive moisture content, all of which can lead to the loss of nutritional value and taste of the oil. There is a strong correlation between these properties and the quality and safety of palm oil used in food products, and monitoring these properties can be a valuable tool to protect the food industry from product recalls and complaints from its customers.

2.4.1 Analyzing The Condition of Palm Oil

In order to assess the quality and usability of palm oil for diverse uses, a variety of physical and chemical parameters must be evaluated. In this study, certain criteria are often taken into consideration. In order to avoid spoiling and microbiological development, the moisture level of palm oil is first analyzed to make sure it is within acceptable ranges. The amount of acidity, which may impact the flavor, odor, and stability of the oil, is assessed by looking at the free fatty acid (FFA) concentration. In order to determine the degree of oxidation or rancidity in the oil, the peroxide value (PV) is examined. In order to comprehend the oil's level of unsaturation and its susceptibility to oxidation, the iodine value (IV) is also measured. Analyzing the oil's color may provide information about its appearance, possible pollutants, or level of deterioration.

To assess the oil's consistency and melting qualities, the solid fat content, or SFC, is calculated. For in-depth investigation, including fatty acid profile, antioxidant evaluation, and contaminant detection, advanced methods like gas chromatography (GC), high-performance liquid chromatography (HPLC), or mass spectrometry (MS) may be utilized. The condition of palm oil may be precisely determined by performing a detailed analysis of these variables, assuring its quality and compliance with industry norms and laws.

2.4.1.1 Fiber Optic Sensors for Measuring Different Types of Palm Oil

A paper titled "Development of Fiber Optic Sensors Using Different Types of Palm Oil" has been published in the journal Sensors describes the development of a fiber optic sensor using different types of palm oil. A preliminary chapter provides an introduction to the field of fiber optic sensors, including the motivations for their development and their potential applications in fields such as the food industry and environmental monitoring in order to give the reader an idea of what fiber optic sensors are all about. This article provides an overview of the fabrication of the fiber optic sensor and the types of palm oil used in the manufacture of the sensor. In addition to the experimental setup, they describe the optical setup, the measurement procedure, and a detailed description of the experimental setting. As a result of the experiments carried out to evaluate the performance of the fiber optic sensor, the paper aims to present the results obtained from the experimentation. (Mohamad & Rosli, 2022)

As a result of their experiments conducted, the authors were able to test and measure the properties of palm oil, including the refractive index and the absorbance spectrum. The appropriate alcohol-soaked tissue was used to clean the tip of both pigtails' fiber heads before connecting the Optical power level and Optical power meters, as indicated in Figure 2.8. As well as discussing the potential uses of fiber optic sensors in the food industry, they discuss how they can be used to detect oil in foods, and how this can be done with a fiber optic sensor. In summary, the present paper presents a novel approach to the development of fiber optic sensors involving the use of various types of palm oil as a sensor material. An evaluation of the experimental setup and the results obtained by the authors is provided, as well as potential applications of the sensor in the food industry are described in detail by the authors. (Mohamad & Rosli, 2022)

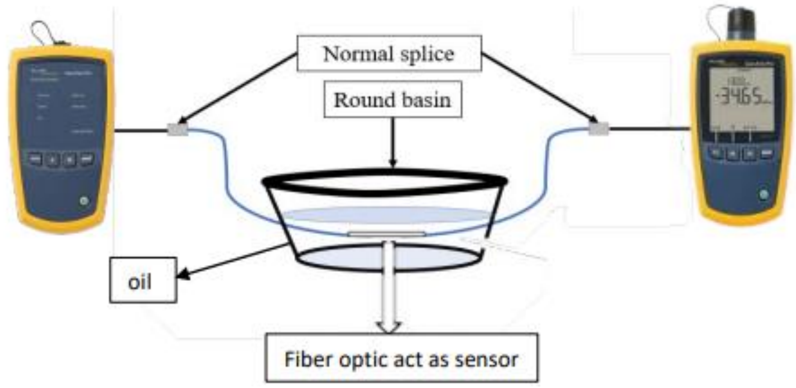


Figure 2.8 Fiber Optic Sensor Architecture

2.4.1.2 Detection for Food Industry Research Development

The paper "Corn Oil Concentrations Detection for Food Industry Research Development by Using Application of Fiber Optic Liquid Sensor Concept". This paper discusses the development of a fiber optic liquid sensor that can detect corn oil concentrations in different foods by using its fiber optics. According to the authors, the detection of oil concentration in food products is crucial to ensuring their quality and safety, as well as to meet the requirements of regulatory agencies. In order to test food samples for fiber optic liquid sensors, a fiber optic cable containing a multimode fiber optic cable was developed in this study, and the cable was immersed in the food sample to be tested. By acting as a waveguide for light, the cable acts as a means of transmitting light into the sample, where changes in the refractive index of the sample caused by the presence of corn oil cause changes in the intensity of the light transmitted through the cable. A light source, silicon detector, amplifier, and computer workstation are all part of the experiment's design shown in Figure 2.9. (Ashadi Md Johari et al., n.d.)

As a result of these changes in intensity, it is possible to detect them in the sample and use this information to determine the amount of corn oil there is. It is described in the article that the authors used a variety of food products with different concentrations of corn oil as part of their experiment to evaluate the performance of their sensor. As a result of the experiments, it was discovered that the sensor can be sensitive to different concentrations of corn oil and is capable of reliably detecting their presence in various food products regardless of the place in which they are found. There is a significant amount of material in this paper that gives a detailed description of the development and evaluation of a fiber optic liquid sensor that detects corn oil concentrations in food products by detecting the wavelength of light used. There are also some potential applications of the sensor in the food industry, with the sensors being utilized for quality assurance and regulatory compliance purposes as well. (Ashadi Md Johari et al., n.d.)

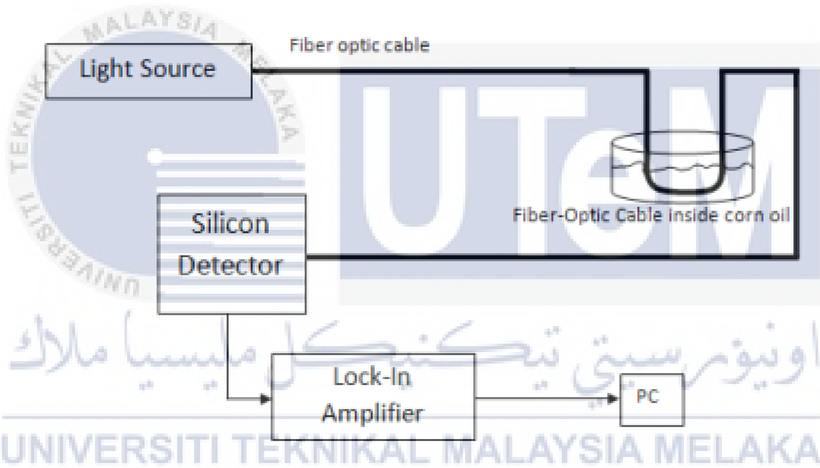


Figure 2.9 Fiber Optic Sensor Layout

2.4.1.3 Application of Fourier Transform Infrared Spectroscopy for The Quality and Safety Analysis of Fats and Oils

The study "Application of Fourier transform infrared spectroscopy for the quality and safety analysis of fats and oils" investigates the use of Fourier transform infrared spectroscopy (FTIR) to evaluate the quality and safety of fats and oils. FTIR spectroscopy measures how molecules in fats and oils absorb light at various wavelengths by shining infrared light onto the samples. The advantages of FTIR spectroscopy are highlighted in the research, including its non-destructive nature, which ensures that materials are neither changed or destroyed during examination. It is also a quick technology that can analyze several components in fats and oils at the same time, offering a thorough insight into their chemical makeup. (Q. Li et al., 2019)

The authors highlight how FTIR spectroscopy may be used in the food business to examine the quality, authenticity, and possible adulteration of fats and oils. FTIR spectroscopy may disclose vital information about the fatty acid content, oxidation levels, and presence of contaminants in materials by evaluating unique absorption patterns. Finally, the research emphasizes FTIR spectroscopy as a significant technique for fat and oil analysis. It provides a dependable and quick method of analyzing numerous quality and safety aspects. FTIR spectroscopy helps to maintain food safety requirements and ensure the overall quality of fats and oils in the industry by offering insights into the composition and properties of fats and oils. (Q. Li et al., 2019)

2.4.1.4 Deep Learning Applications for Oil Palm Tree Detection and Counting

The authors concentrate on the recognition and counting of oil palm trees in high-resolution remote sensing photos using deep learning approaches, notably convolutional neural networks (CNNs). Traditional techniques for detecting and counting oil palm trees often depend on physical labor, which is time-consuming and labor-intensive. To overcome this issue, the authors recommend using deep learning algorithms, which have shown amazing ability in picture identification and analysis tasks. Deep learning is used to train a CNN model utilizing a huge dataset of high-resolution remote sensing photos annotated with ground truth information identifying the presence and limits of oil palm plants. The CNN model learns to recognize the visual patterns and characteristics associated with oil palm trees by providing it with this labeled dataset. (Kipli et al., 2023)

The CNN model can count oil palm trees in remote-sensing photographs. The algorithm evaluates image data and finds regions that resemble oil palm trees, resulting in accurate identification. These data may be used to create count maps or density maps of a plantation's oil palm plants. Deep learning systems can recognize and count oil palm trees. First, it reduces manual labor and speeds up the process, improving plantation management. Second, the deep learning model can process massive datasets and react to environmental and plantation changes. Deep learning's accuracy is also higher than prior methods, yielding more reliable results. Deep learning's usage in oil palm tree counts and identification affects plantation management. It helps plantation owners and managers make decisions about resource allocation, harvesting planning, and plantation productivity by providing accurate and up-to-date oil palm tree distribution and density data. Finally, the study highlights CNNs' potential for recognizing and counting oil palm plants in high-resolution remote sensing data. Oil palm plantation management is more efficient with this system's accuracy, scalability, and efficiency. Figure 2.10 shows agricultural machine learning. (Kipli et al., 2023)

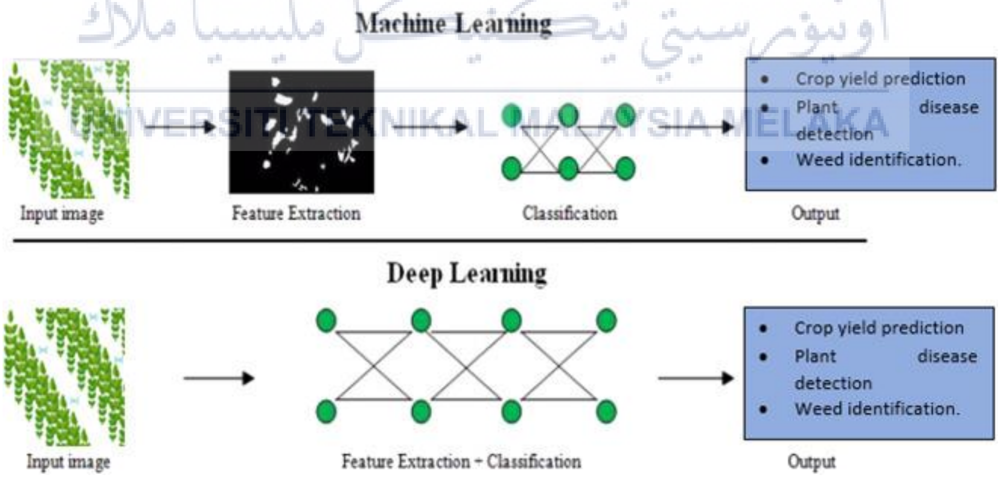


Figure 2.10 Machine Learning and Deep Learning Concept

2.4.1.5 Leveraging on Advanced Remote Sensing- and Artificial Intelligence-Based Technologies to Manage Palm Oil Plantation for Current Global Scenario

The research investigates the use of modern remote sensing and artificial intelligence (AI) technologies in palm oil plantation management in the present global setting. It emphasises the significance of sustainable palm oil production as well as the relevance of efficient and environmentally friendly management practises. The authors emphasise the use of remote sensing methods such as satellite images and aerial photography in providing significant information on many aspects of palm oil plantations such as land use, vegetation health, and crop yield. Furthermore, the study explores the use of AI-based technologies, namely machine learning and deep learning algorithms, to analyse and extract valuable insights from the gathered remote sensing data. These AI algorithms allow palm oil tree identification and classification, disease and pest detection, plantation condition monitoring, and crop yield prediction. (Akhtar et al., 2023)

Remote sensing and AI technologies can provide palm oil plantation managers with real-time, accurate data. This lets them make informed decisions regarding resource allocation, irrigation, fertilization, and pest control, enhancing productivity, decreasing environmental impact, and promoting palm oil sustainability. These tools may also address industrial challenges including deforestation monitoring, land use planning, and sustainability compliance. They stress the need for collaboration between academics, governments, and businesses to maximize the benefits of contemporary remote sensing and AI-based palm oil plantation management technology. Finally, advanced remote sensing and AI-based technologies are needed to manage palm oil plantations effectively. These technologies may help plantation managers make educated decisions, boost productivity, and promote sustainable palm oil production in the current global setting. Figure 2.11

illustrates the structure of the LeNet neural network, which consists of a fully connected layer, two convolutional layers, two pool layers, and two layers. (Akhtar et al., 2023)

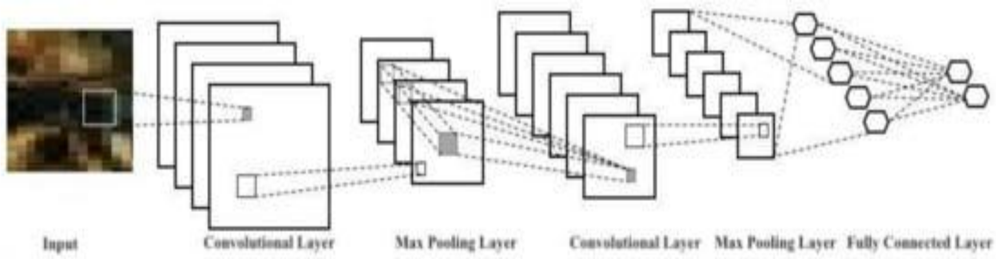


Figure 2.11 Illustration of a palm oil tree from the LeNet neural network.

2.5 DOE Software

For many years, design of experiments (DOE) techniques has been used to solve quality control issues in a variety of technical domains. (Kuhn & Reilly, 2003) A computer program known as DOE software, or Design of Experiments software, is made to help researchers and practitioners run experiments and analyze the data they gather. DoE approaches always need a significant number of experiments to be carried out and analyzed. (Mandenius & Brundin, 2008) Typically, one-factor-at-a-time techniques and statistical Design of Experiments (DOE) methodologies are used to design experiments for their development and optimization. (Moser et al., 2021) By maximizing the combinations of independent variables, DOE aims to optimize the quantity of information learned during an experiment. (Kuhn & Reilly, 2003) It provides a broad variety of features and tools that speed up the procedure for designing experiments, gathering data, doing statistical analyses, and deciphering the findings.

Users using DOE software may choose suitable experimental designs, add randomization and replication, and describe variables and their levels with ease. Effective data gathering is made possible by the software, which also automates statistical analysis using methods like ANOVA and regression and offers visualization tools so that data may be explored and understood visually using graphs and charts. Furthermore, optimization algorithms are often included in DOE software to assist users in determining the best combination of variables to get desired results. Researchers may save time, cut down on mistakes, and make wise judgments based on solid statistical analysis by using DOE software, thereby increasing the efficacy and efficiency of their experimental experiments.

Optimization of heat transfer in a grooved pipe model using stochastic algorithms and response surface methodology (RSM) is presented in the paper "Optimization of heat transfer in a grooved pipe model by stochastic algorithms and DOE based RSM". In this paper, stochastic algorithms and response surface methodology (RSM) are used to optimize heat transfer in a grooved pipe model. As a result of its enhanced heat transfer capabilities, grooved pipes are widely used in the refrigeration, air conditioning, and power generation industries. It is, however, difficult to optimize its geometric parameters to maximize the heat transfer rate. It was thus for this reason that the authors of the paper used the Design of Experiments (DOE) method to identify the parameters that are most significant in affecting the heat transfer rate through grooved pipes, to determine the most significant ones. (Güngör et al., 2021)

Three parameters have been chosen which are groove width, groove depth, and groove distance. In order to assess how the grooved pipe performs at different values of the parameters selected, the authors conducted Computational Fluid Dynamics (CFD) simulations. As a result of the results of the Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) algorithms, the authors have become able to optimize the selected parameters of a grooved pipe in a way that maximizes its heat transfer rate. The optimized grooved pipe is found to increase the heat transfer rate by 43% compared to the baseline case, validating the effectiveness of optimization. There is also evidence that the GA algorithm has a better convergence rate and greater accuracy than the PSO algorithm, which may indicate its potential application as an optimization tool when designing grooved pipes. Heat transfer optimization in grooved pipes can be improved by using stochastic algorithms and RSM. There are several engineering fields in which grooved pipes are frequently used, including refrigeration, air conditioning, and power generation. Furthermore, the study emphasizes the importance of utilizing optimization methods to improve efficiency and reduce the cost of engineering systems. (Güngör et al., 2021)

2.6 A Comparison of Products

Table 2.1 Comparison Previous Study

Comparison	Application of Fourier transform infrared spectroscopy for the quality and safety analysis of fats and oils	Deep learning applications for oil palm tree detection and counting	Leveraging on Advanced Remote Sensing and Artificial Intelligence-Based Technologies to Manage Palm Oil Plantation for Current Global Scenario
Method	Fourier transform infrared spectroscopy	Deep learning algorithms	Integration of remote sensing and AI techniques
Measured	Fats and oils	Palm trees	Palm oil plantations
Application	Quality and safety analysis of fats and oils	Oil palm tree detection and counting	advanced remote sensing and AI-based technologies
Parameter	Quality, safety	Palm tree detection, counting	Various aspects of palm oil plantations
Sensor	FTIR spectroscopy	Remote sensing	Remote sensing, AI-based technologies
Sensitivity	High	High	High
Cost	Moderate	Moderate	Varies
Output	Spectral data	Count or presence	Plantation management insights

2.7 Summary

The production of palm oil is an important part of the food industry, so the condition of palm oil must be monitored with accuracy, thus optimizing the microfiber optic sensor parameters can greatly improve the accuracy of the monitoring process. As a result, the optimization process is quite complex and extends over a wide range of data sources, and requires an intensive amount of calculations. The current state of the art is that no universally accepted method can be used to optimize microfiber optic sensor parameters to detect the condition of palm oil. Developing a method that is efficient and practical for the food industry is an important step towards reducing the number of resources required and producing results that are reasonably accurate at the same time. Thus, further research is needed to standardise Microfiber optic sensor optimisation for palm oil detection in SMEs.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology implemented in this study. The steps involved in the development mathematical model and the optimization process are also discussed. This chapter is also discussed the schematic design in this study.

3.2 Methodology

An innovative and integrated analytical approach, which employs a series of analytical techniques, is proposed in this study for optimizing the parameters of microfiber optic sensors used in the food industry for detecting the condition of palm oil in small and medium enterprises. There are a number of concepts associated with machine learning and statistical analysis that are fundamental to the proposed approach. It has been decided to use a quantitative approach, designed to develop a model that can be used to determine the quality of palm oil using microfiber optic sensors, which will be used to develop an analytical model. Statistical analysis and empirical modeling are employed in the analysis of the data, and the methodology used is experimental. According to Figure 3.1, the study was designed as a qualitative research study.

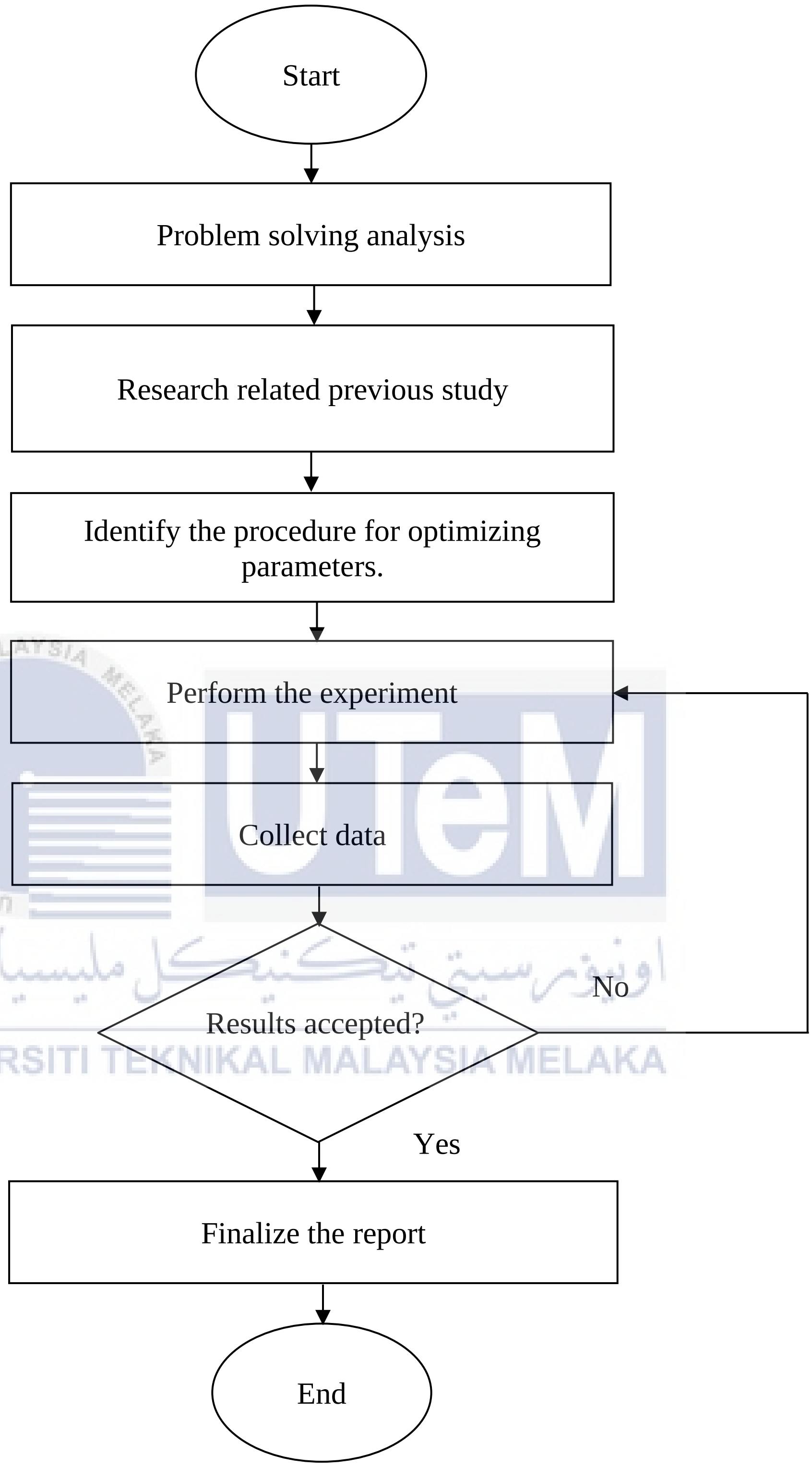


Figure 3.1 Experiment Process Flow

Based on Figure 3.1, every research attempt requires a first step of providing a comprehensive and precise characterization of the problem that requires attention. This aids in focusing the research and guiding the collection of relevant information. The flow chart demonstrates that the data collection process may start in two ways by conducting experiments or by assessing existing research. The flowchart recommends careful planning and implementation for those taking tests, highlighting the need of persisting until desired results are achieved. On the other hand, those who rely on previous research need to thoroughly analyse the literature for significant information, ensuring that they only consider material of superior quality. After the data collection process, as shown by the flowchart, the subsequent step involves doing a comprehensive analysis, and presenting the results in a detailed report. It is important to note that while the flowchart provides a comprehensive overview of the steps required in collecting data for optical microfiber research, the specific details may vary depending on the unique characteristics of each project.

3.3 Experimental Setup

This study proposes an innovative and thorough modelling technique to optimise microfibre optic sensors' palm oil detection characteristics in the SME food sector to increase their efficiency and efficacy. This work uses data-driven modelling and optimisation to construct the model and improve it. Quantitative methods are needed to construct a mathematical model that optimises sensor settings and establish an analytical modelling procedure to accurately assess palm oil quality.Experimental study using empirical modelling and statistical analysis will accomplish this research project's goal. The flow of the tapering process on microfibre is shown in Figure 3.2.

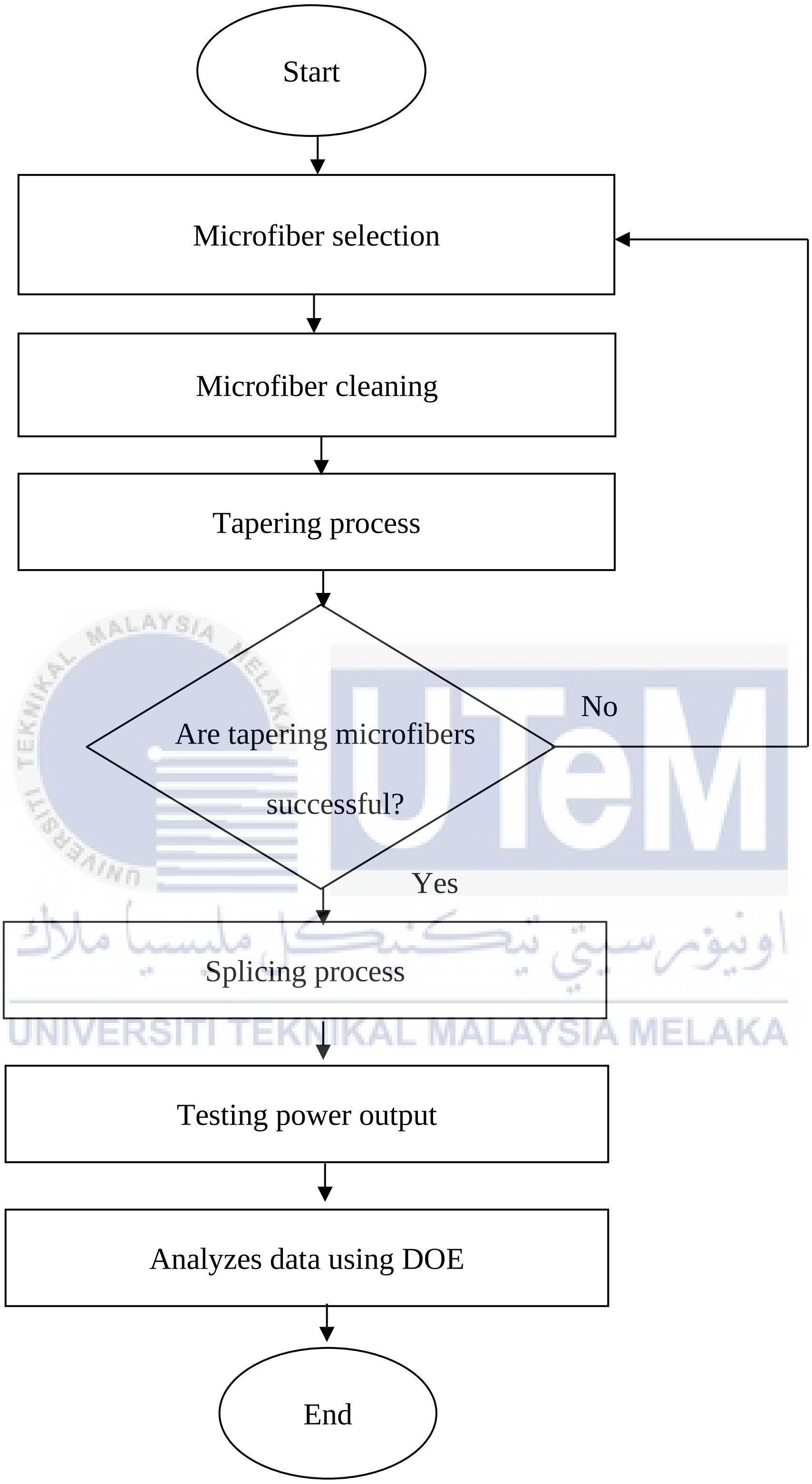


Figure 3.2 Flowchart Experimental Process

3.3.1 Parameters

The parameters involved in the modeling and optimization of microfiber optic sensors for detecting the condition of palm oil in the SME food industry include:

1. Wavelength:

   The wavelength of a microfiber optic sensor for detecting the condition of palm oil is the color of the light that is used to transmit through the microfiber. Different wavelengths of light interact with the palm oil in different ways, and the optimal wavelength depends on the specific chemical properties of the palm oil being measured. Short wavelengths such as in the visible or near-infrared range are more sensitive to changes in the palm oil, but may also be more susceptible to noise and interference. To determine the optimal wavelength, experiments should be conducted using different wavelengths and analyzing the resulting data to determine which wavelength range provides the most accurate and reliable detection. In another study, how a chemical responds to varied amounts of ammonia gas (NH3) at different light wavelengths. The wavelength range selected influences the sensor's sensitivity. Using various wavelengths will provide varied results depending on the amount of NH3 employed. (Girei et al., 2021)

2. Microfiber Diameter

   The diameter of the microfiber is an important parameter to consider when optimizing microfiber optic sensors for detecting the condition of palm oil. It affects the sensitivity of the sensor, as well as the amount of light that is transmitted through the fiber. Microfibers with smaller diameters are more sensitive to changes in the palm oil being measured, as they allow for more efficient light transmission and greater interaction between the light and the palm oil. Longer microfibers can allow for greater interaction, but may also be more susceptible to bending and other environmental factors that can affect the accuracy of the measurement. The minimum diameter at the waist of the microfiber taper is mostly influenced by the tapering length with a tapering speed of 0.3 mm/s and optimal flame size, and the geometric profile of the microfibers may be produced with high reproducibility. (W. Li et al., 2014) To optimize the diameter, it is important to find a balance between sensitivity and signal strength.

3. Types of Microfibers

   The type of microfiber used in a microfiber optic sensor can significantly impact its sensitivity, selectivity, and durability. Silica fibers are typically used for their high optical purity and low attenuation, polymers for their flexibility, and metals for their ability to support surface plasmon resonance. In the case of detecting the condition of palm oil, the microfiber material must be carefully selected to ensure that it can selectively interact with the specific chemical and physical properties of the palm oil. The choice of material should also consider factors such as cost, availability, and durability, as well as the operating conditions of the sensor, such as temperature and humidity.

4. Concentration of Palm Oil (First and Third Usage)

   The concentration of palm oil is an important parameter to monitor in the palm oil industry, particularly after the first and third usage. Several methods can be used to measure the concentration, such as titration, spectrophotometry, and gas chromatography. The acid-base titration technique is used to determine free fatty acids in palm oil by titrating the sample against potassium hydroxide in hot 2-propanol solution, using phenolphthalein as an indicator and the result is stated in mg KOH g^{-1} oil. (Azeman et al., 2015) The acids in the solution are neutralized throughout the titration, and the result obtained indicates the acid number of the sample, which is proportional to the free fatty acid amount. (da Silva Figueiredo et al., 2015) Despite this method is simple, it is slow, tedious, and inaccurate. (Raspe et al., 2013) Regarding convenience and analytical costs, gas chromatography is reasonably inexpensive. Before being detected by the detector, fatty acids are primarily separated by the interaction between a stationary phase and a mobile phase along the column. (Azeman et al., 2015) The choice of measurement method will depend on the specific properties of the palm oil being measured, as well as the accuracy and precision required for the intended application. It is important to establish a baseline measurement of the concentration after the first usage and to monitor changes in concentration over time. This can help identify potential quality issues or deterioration, and allow for timely corrective actions to ensure the quality and safety of the final product.

3.3.2 Equipment

Tapering optical fibers and fusion splicing can be performed with a variety of tools. Equipment commonly used includes:

1. Tapering machine: It is designed specifically to taper optical fibers. Generally, a pulley system consists of a motorized mechanism, a heat source, and a control system that regulates the speed and temperature.

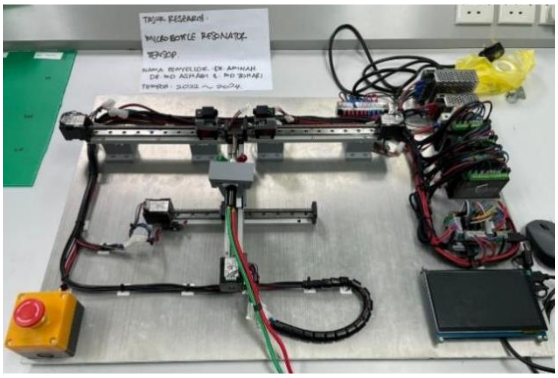


Figure 3.3 Tapering Machine

2. Fiber holder: During the tapering process, the fiber needs to be held tightly to avoid it moving or bending. Fiber holders include clamps and chuck that grip fibers without damaging them.

Figure 3.4 Fiber Holder

3. Heat source: To soften glass during the tapering process, a heat source is needed. This can be a flame, a laser, or an electric heater. The type of heat source depends on the application.

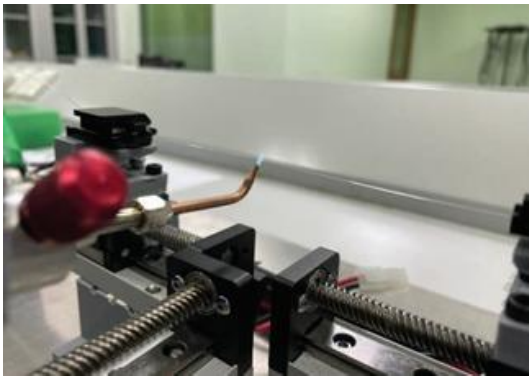


Figure 3.5 Heat Source

4. Pulling mechanism: Used to stretch fibers while heating. Manually pulling can be done, but usually, it is done with a motorized mechanism.

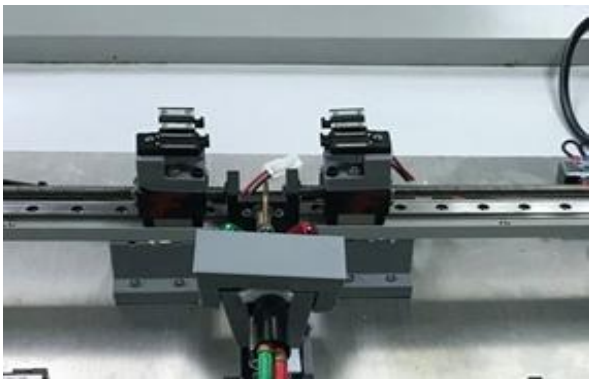


Figure 3.6 Pulling Mechanism

5. Fusion splicer: A fusion splicer joins two optical fibers for a continuous optical channel. Fusion splicers perfectly align fiber ends and fuse them together with an electric arc or laser. This fusion creates a low-loss, high-strength fiber splice that lets optical communications flow through.

Figure 3.7 Fusion Splicer

6. Fiber holders and alignment devices: To securely hold and align optical fibers throughout processes like fusion splicing, connectorization, or testing, fiber holders and alignment devices are crucial instruments used in fiber optic systems. In order to achieve minimal insertion loss and trustworthy optical connections, these devices are essential for maintaining precise and steady fiber alignment.

Figure 3.8 Fiber Holders and Alignment Devices

7. Light source device: By passing light pulses through the cables and measuring the quantity of light that emerges on the other end, optical light sources are used to assess the quality of these cables. It emits light in the 1310 nm and 1550 nm wavelength ranges.

Figure 3.9 Light Source Device

8. Fiber Cleaver: Fiber cleavers neatly cut optical fibers. For maximum optical performance, fiber splicing and termination need a clean, perpendicular end face. Fiber cleavers cut or scribe the fiber and provide controlled pressure to break it cleanly.

Figure 3.10 Fiber Cleaver

9. Fiber Stripper: This is a specialist instrument designed for removing the buffer layer or coating of protection from a fiber optic line. It is a crucial instrument for the installation, termination, and maintenance of fiber optic systems.

Figure 3.11 Fiber Stripper

10. Alcohol for fiber cleaning: Cleaning optical fibers with alcohol is a frequent practice. Its purpose is to remove any dirt, dust, oils, or pollutants from the fiber surface. To clean the fiber, alcohol, such as isopropyl alcohol (IPA), is put on a lint-free cloth or cleaning swab and gently rubbed over it.

Figure 3.12 Alcohol for Fiber Cleaning

11. Fiber optic cleaning wipe: A fiber optic cleaning wipe is a tool utilized for keeping the cleanliness of optical components by eliminating contaminants including grease, dust, dirt, and other impurities that might harm performance.

Figure 3.13 Fiber Optic Cleaning Wipe

12. OTDR: Important for diagnosing, locating, and maintaining fiber optic networks. This makes sure that they work well and reliably for industries that depend on sending and receiving data quickly, like cable TV companies, data centres, and telephones.

Figure 3.14 OTDR

13. Visual fault locator: tests fibre continuity and locates problem situations using visible spectrum laser light. Wherever there are fibre splits, faulty splices, or macrobends, the red-light source will be apparent through the coating.

Figure 3.15 Visual Fault Locator

14. Palm oil: The concentration of palm oil in two condition which are first usage and third usage

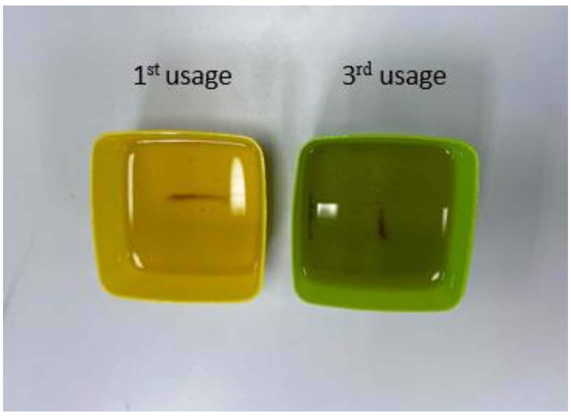


Figure 3.16 Palm Oil

3.3.3 Fabrication Technique of Microfiber

Microfiber manufacturing is shrinking the diameter of a structured fiber by heating and stretching a single mode fiber (SMF). The procedure starts with an SMF, which is a fiber optic cable with a consistent core diameter. The SMF is heated to generate a microfibre. This heating softens the fiber and makes it more flexible.

When an SMF is tapered, the diameter of the cladding along with the core is reduced by tugging the fiber's end while heating the fiber's waist. (Jali et al., 2021) As the power propagates along the taper, the tapered fiber meets adiabatic criteria if the majority of the power decouples from higher-order modes and remains in the fundamental mode. (Jali et al., 2021) In fact, adiabaticity is readily accomplished by drawing tapered fibers at a sufficiently slow diameter reduction rate, or by manufacturing tapered fibers with a sufficiently long taper transition length. (S. et al., 2012) Once the fiber has reached the correct temperature, it is gently stretched in a controlled way. Figure 3.17 represents the "heating and stretching" method of fabricating tapered optical fibers. The stretching process causes the fiber to extend while simultaneously decreasing its diameter. As a consequence, the core diameter of the fiber diminishes, and the fiber tapers towards a narrower waist area. The waist area has the lowest diameter of the microfibre. It is the most stretched area, resulting in a considerably decreased core diameter. Transition zones surround the waist area, where the diameter of both the core and the cladding decreases rapidly. The length of the transition areas is determined by the length of the stretching process. Chemically tapered fibers are usually distinguished by cladding removal while heat-pulling tapers retain the core and cladding dimensional ratio. (Corres et al., 2006)

The changing size of the core and cladding diameters in the transition areas affects the waveguide's field distribution during manufacturing. This change may result in energy transfer from the basic mode, which is the major mode of propagation, to a few higher-order modes that are closer in proximity. This energy transfer may cause system losses, lowering signal transmission efficiency. The propagating wave may suffer energy transfer from the basic mode to a few higher-order modes due to the rate of diameter change. (Razak et al., 2017) Overall, the manufacturing of microfiber comprises controlled heating and stretching of an SMF to shrink its core diameter and form a tapered structure. The resultant microfibre has unique qualities such as a reduced diameter, higher flexibility, and the possibility for better light transmission in optical applications.

Figure 3.18 is an example of a tapered fiber using a flame-heated source. Specifically for glass fibers, flame-heated taper drawing is used as a fabrication method. As the microfiber is generated in the Flame Brushing Technique by the tapering of standard optical fibers, both ends are pigtailed. (Miguel & Marques, n.d.) It entails the controlled heating and elongation of a glass preform using a flame source to create glass fibers with a smaller diameter. A flame of hydrogen is used to ignite the fiber. (Wu & Tong, 2013) Under a specific pulling force, the fiber is progressively stretched and elongated as its diameter decreases, until the desired length or diameter of the fiber taper is achieved. (Wu & Tong, 2013) Figure 3.19 shows a schematic of a tapered fiber. The tapered thread consists of three interconnected sections, a central waist of small and constant diameter, and two tapered transition zones of progressively variable diameter. (Tian et al., 2011) Non-tapered fibers are located at the end of the tapered transition zone. (Tian et al., 2011) The primary drawbacks of the Flame Brushing method are that the manufactured microfibers have a high OH content, as a consequence of the water vapor produced during gas combustion, and that the surface texture is significantly impacted by flame turbulence. (Miguel & Marques, n.d.) Due to their mingling after heating, the cladding material and fiber core material does not actually have distinct boundaries at the waist and transition zones. (Tian et al., 2011)

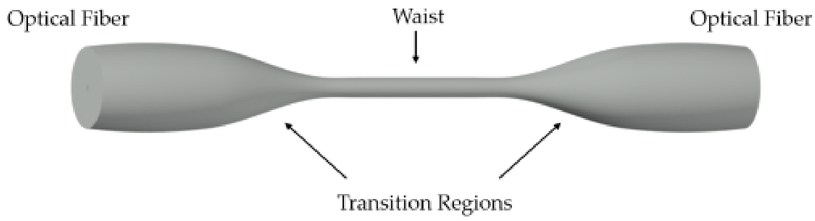


Figure 3.17 A Schematic Representation of A Standard Taper Profile, Illustrating The Untapered, Transition, and Waist Regions.

Figure 3.18 Microfiber Fabrication Technology with A Flame Heated Source

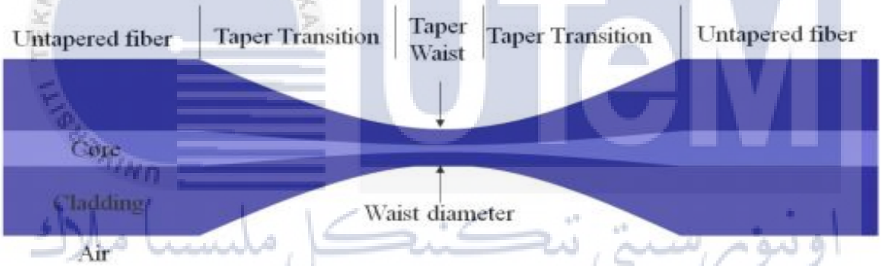


Figure 3.19 An Illustration of A Tapered Fiber

3.3.3.1 Fusion Splicing

Fusion splicing is a complex process that permanently joins two optical fibers together in the area of fiber optics. Optical fiber transmission systems are unable to be realized without low-loss splices between optical fibers. (Sakai & Kimura, 1978) It provides a continuous and efficient optical route for delivering light signals with minimum loss or disturbance. The primary goal of fusion splicing is to properly align the fiber ends and form a strong, permanent link between them. Light transmission losses of single-mode fiber splices are dependent on the respective alignment precision of the fiber endpoints. (Cook et al., 1973) Alignment is critical for obtaining perfect core-to-core alignment, which allows light signals to be effortlessly linked from one fiber to the next. Figure 3.20 shows the precise alignment for attaching two optical fibers. The splicing machine's fiber alignment mechanism is very important since single-mode and multimode fibers have different needs. (Inada et al., 1986) This fine alignment is often accomplished with the use of specialist fusion splicing machines that allow for micro-adjustments and sophisticated imaging methods for perfect alignment. Precision core alignment is often not required for multimode fiber splicing since aligning the fibers by the cladding is sufficient to achieve minimal loss. (Inada et al., 1986) On the other hand, splicing single-mode fibers requires very accurate core alignment to efficiently compensate core eccentricities and outer diameter disparities. (Inada et al., 1986)

Fusion splicing is a process in which fibers are aligned and heated to form a single continuous fiber with no air gaps or misalignments, resulting in effective light transmission. Misalignment of the core axis will arise if there is a little amount of dust between the fiber and the V-groove or if the diameter of the fiber varies. (Marcuse, n.d.) As multimode fiber's loss is not only sensitive to misalignment, it is important that the alignment mechanism be straightforward and small. (Inada et al., 1986) As the fibers cool and solidify, a strong and mechanically robust splice is formed that can tolerate external influences. One of the primary benefits of fusion splicing is its reduced insertion loss, which reduces signal attenuation and retains signal integrity. It also produces strong connections that can endure external forces and environmental conditions. The idea that a significant overlap may result in bend misalignment when arc discharge energy is modest is refuted by this information. (Xiao et al., 2007) A wide overlap distance indicates that the distance between the two fibers will assist to lower the size of the air gap or may even completely eliminate the air gap, hence reducing the coupling loss. (Tse et al., 2009) Additionally, it aids in the maintenance of high optical performance, decreasing back reflections and signal loss by eliminating air gaps and decreasing reflection at the splice site. This improves the overall performance and dependability of fiber optic systems in a variety of applications, such as telecommunications, data centers, and industrial networks.

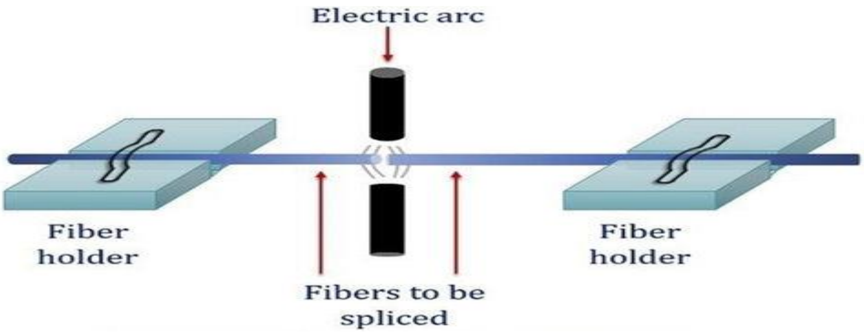


Figure 3.20 Fusion Splicing of Optical Fiber

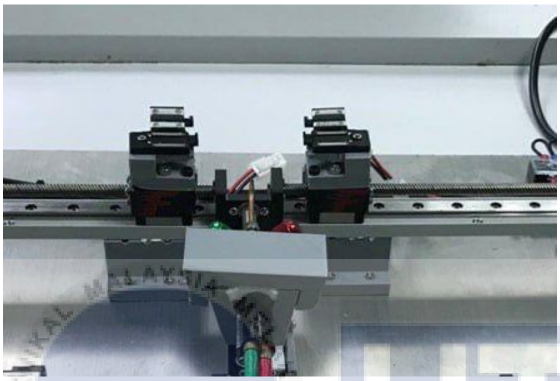
3.4 Experimental Process

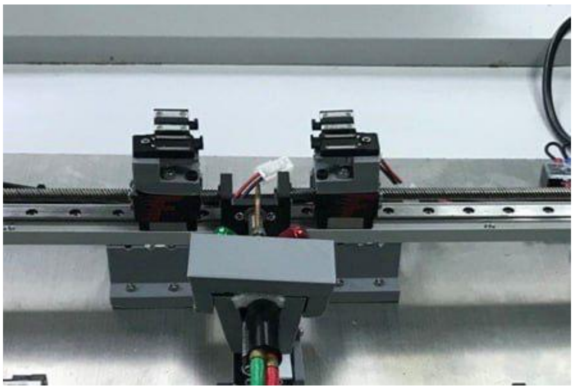
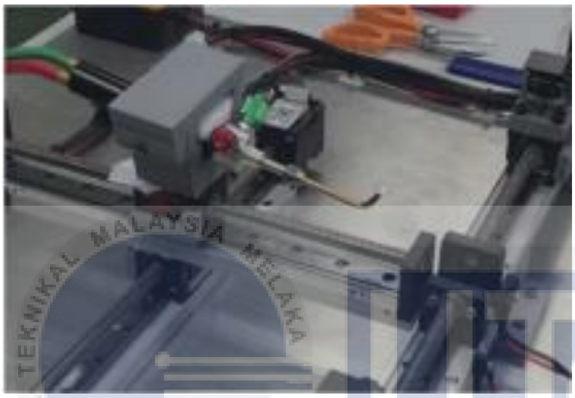
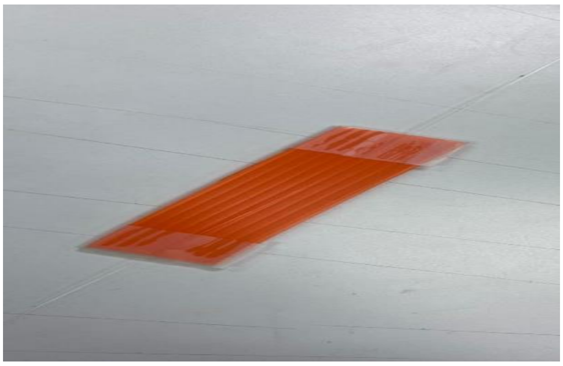
3.4.1 Tapering Process

In fiber optics, the tapering process refers to the steady decrease in diameter of an optical fiber or waveguide over a specified length. It entails delicately heating and stretching a segment of the fiber to form a tapered area with a smaller diameter.

Table 3.1 Tapering Process

No	Procedure	Description
1		Stripping off coatings or claddings that provide as protection, leaving the core uncovered. This guarantees that the fiber's core section will experience the tapering.

2		To remove dust and other contaminants from the fiber, use a fiber alcohol wipe.
3		Set up the microfiber tails on both sides of the fiber holder with care. As a result, the fiber cannot move.
4		Switch on the heat source and manage the flow of air and gas to create the appropriate size tiny flame.
5		To conduct this procedure, a torch must travel forward and heat the core of a fiber while dragging the fiber holder.

6		Stop the procedure after the fiber is fully stretched and the diameter at the core of the fiber has been lowered.
7		Extinguish the flame by moving the torch backward.
8		Carefully remove the fiber from the fiber holder.
9		Put the tapered microfiber optic on the impra board.

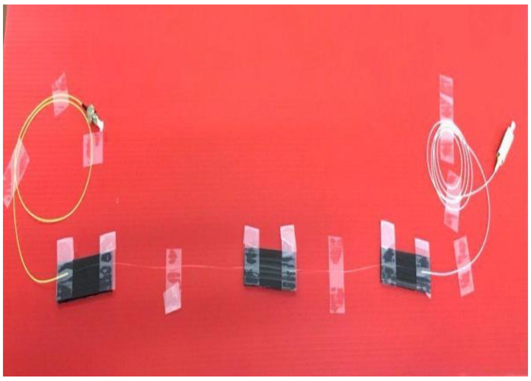
3.4.2 Splicing Process

A continuous and low-loss optical link is created by the splicing of two optical fibers in fiber optics. A fusion splicer, which applies heat to melt and fuse the fiber ends, is commonly used for this purpose.

Table 3.2 Splicing Process

No	**Procedure**	**Description**
1		Stripping off coatings or claddings that provide as protection, leaving the core uncovered.
2		To remove dust and other contaminants from the fiber, use a fiber alcohol wipe.
3		To get a smooth and level surface, the fiber ends should be split using a fiber cleaver.

		Follow the same procedures from 1 to 3 for either a single-mode or multi-mode connection.
5		Put the cable on the initial holder, with the optical fiber towards the middle.
6		Click the 'SET' button and wait for the fiber and cable to be attached.
7		After the operation is completed, the splicing result will be shown.

8		Placing the whole cable fibre optic connection on the impra board with care will guarantee that no errors occur.

3.5 Data Collection

Upon completion of the experiment, all the necessary data was acquired. Data will be presented as a table or graph, such as an ANOVA table. Throughout the duration of the experiment, all possible combinations of the parameters listed in table 3.3 were tested twice for each experiment. From each experiment, two sets of data were collected. These data were then computed and the resulting values were considered as the final results. Upon completion of the tests and measurements, pertinent results and data were acquired. Upon comparing the prediction value, it is evident that the result closely aligns with the predicted value, therefore rendering the results acceptable.

Table 3.3 Parameter of The Experiment

Variable Parameter	Low Level (-)	High Level (+)
Type of Fiber	Single mode	Multimode
Diameter	7 µm	11 µm
Wavelength	1310 nm	1550 nm

3.5.1 Type of Analysis

1. Half Normal Plot

   The half normal plot is a valuable tool in Design of Experiments for identifying the most significant factors or variables on the answer, especially when working with a large number of them. This plot facilitates the rapid identification of the most influential variables impacting the answer variable by organizing the absolute values of effects, such as regression coefficients or factor effects, in a descending order. Utilize this plot to select variables for additional inquiry or concentrate on those that have the most significant influence on the result.

2. Normal Plot

   The normal probability plot is used inside the Design of Experiments (DOE) to evaluate whether the residuals errors from the experimental model conform to a normal distribution. Ensuring the normality assumption of residuals is crucial in several statistical studies. A Normal distribution of residuals is essential for accurate statistical conclusions.

3. Effect List

   A Design of Experiments effect list provides a concise overview of the estimated effects or coefficients of different variables on the response variable. This succinct summary provides an estimate of the magnitudes of effects, making it easier to quickly identify elements that have large implications on the response. This list is used to prioritize important aspects, allowing for concentrated attention on those that significantly impact the result.

4. ANOVA Analysis

   ANOVA is a crucial technique used in DOE to determine whether the observed variations between different groups or treatments typically associated with different factor levels are statistically significant or just due to random variation. It helps assess the overall importance of various variables or their interactions in affecting the response variable, offering insights into the critical roles played by these components.

5. Normal of Residual Plot

   The Normal Probability Plot is a crucial tool in the Design of Experiments (DOE) framework for evaluating residuals from experimental models. It ensures normal distribution and validity of statistical studies. A straight line indicates strong normality, while curves or outliers indicate deviations. Deviations from normality can affect calculations and results. Addressing deviations requires investigating alternative methods to maintain accuracy and maintain the assumption of normality.

6. Residual vs Predicted Plot

   The purpose of this plot in Design of Experiments (DOE) is to verify the accuracy of the experimental model by comparing the residuals to the expected values generated by the model. Any deviations from constant variance or linearity in the residuals of this plot suggest possible problems that might affect the validity of the model, therefore requiring additional examination.

7. One Factor Effect Plot

   The one-factor effect plot in DOE provides a visual representation of the connection between a single factor or variable and the response, considering varying levels or categories of that component. It facilitates the visualization and comprehension of how changes in a singular component affect the response variable, hence assisting in the interpretation of its effect.

8. Interaction Effect Plot

   A Design of Experiments (DOE) interaction effect plot visually demonstrates the varying impact of one variable as it relates to various degrees of another variable. This plot effectively showcases the collective influence of numerous variables on the response. The narrative plays a vital role in discerning and comprehending the interplay of elements, revealing if the impact of one factor fluctuates depending on the levels of another.

3.6 Design Expert Software

The Figure in 3.21 depicts a Design-Expert software program for a fiber optic optimization problem, focusing on a central composite design (CCD) with four factors. The factors are A (Numeric), B (Numeric), and C (Numeric), which are numeric and can take on a continuous range of values. The response surface indicates the study's goal is to maximize the output power. The numerical factors are numeric, while the horizontal and vertical factors are categoric. Each factor has no specified units and can range from -1 to 1. The Miscellaneous section provides additional options or settings for the design, but the current view only shows "Optimal" The experiment may be divided into groups or blocks for better analysis and control of potential variability. The center points per block specifies the number of replicates for the center point combination of factors in each block. The specific meanings of the factors and the optimal configuration depend on the experiment's context.

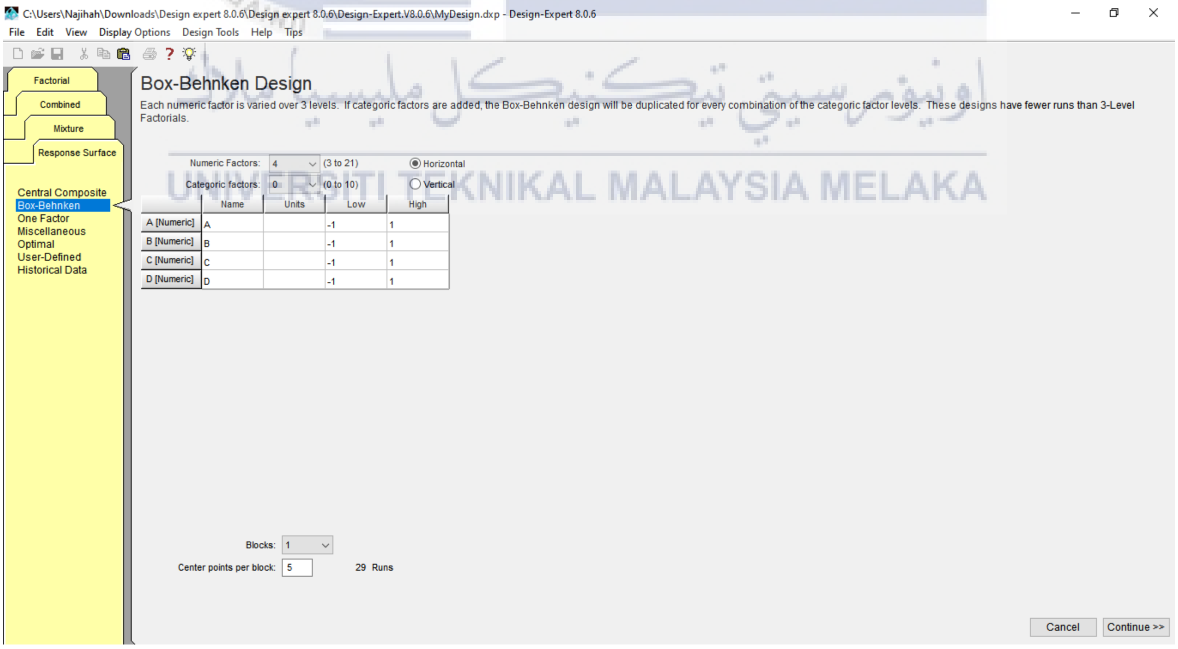


Figure 3.21 Specifying Name, Units and Type of All The Factor

Based on figure 3.22, the Design-Expert software is used to analyze four factors influencing the output power of a fiber optic system. The factors are A type of fiber (numerical), B diameter (numerical), C wavelength (numerical), and D concentration (numerical). The Box-Behnken design allows for efficient exploration of interactions between all four factors within 16 experimental runs. The response variable, R1, measures the power output of the fiber optic system for each experimental run. The goal is to find the combination of factors (A, B, C, and D) that maximizes this output power. The analysis and optimization of the factors reveal individual effects, interaction effects, and the optimal factor combination. Additional details for deeper understanding include the specific range of values used for each factor, units associated with each factor, and any additional constraints or goals for the experiment. The factors are numeric, meaning they can take on a continuous range of values. The design may be divided into groups or blocks for better analysis and control of potential variability. The center points per block specifies the number of replicates for the center point combination of factors in each block.

Figure 3.22 Specifying Name and Units for response

Figure 3.23 emphasises the improvement of skills in resolving data analysis issues, making the offered table a useful asset. This study examines how different fibres respond under certain settings, providing a thorough analysis of how fibre qualities affect response measurements. The important factors of the table are the categorical fibre type (Single mode or Multimode), the wavelength (1310 nm or 1550 nm), the diameter (7 µm or 11 µm), and the concentration (1st and 3rd usage). All of these parameters contribute to the observed response in Power units. With this dataset, several analysis may be conducted. Trends can be identified by calculating the average response for specific fibre types or wavelengths. Optimal conditions can be determined by finding the maximum response under different scenarios. Variations can be explored by calculating the differences in response between two fibres. The relationships can be visualised by plotting the response against wavelength or diameter. The profound level of understanding attainable from this data guarantees a strong basis for making well-informed decisions and implementing specific enhancements in the field of data analysis and fibre characterisation.

Select	Std	Run	Factor 1 A:Type of Fiber	Factor 2 B:Diameter	Factor 3 C:Wavelength	Factor 4 D:Concentration	Response 1 Output Power
	6	1	Single mode	7.00	1310	1.00	63.31
	16	2	Single mode	7.00	1550	1.00	70.13
	10	3	Single mode	11.00	1310	1.00	41.9
	9	4	Single mode	11.00	1550	1.00	67.81
	2	5	Multimode	7.00	1310	1.00	39.48
	5	6	Multimode	7.00	1550	1.00	58.61
	15	7	Multimode	11.00	1310	1.00	41.61
	3	8	Multimode	11.00	1550	1.00	67.5
	7	9	Single mode	7.00	1310	3.00	64.08
	13	10	Single mode	7.00	1550	3.00	42.29
	1	11	Single mode	11.00	1310	3.00	39.99
	4	12	Single mode	11.00	1550	3.00	59.35
	12	13	Multimode	7.00	1310	3.00	64.68
	8	14	Multimode	7.00	1550	3.00	58.03
	14	15	Multimode	11.00	1310	3.00	46.68
	11	16	Multimode	11.00	1550	3.00	47.58

Figure 3.23 Matrix Design

All values representing factors and responses are obtained by accessing the "Analysis" section, as illustrated in figure 3.24. Five categories comprise this particular section: Model Graphs, Effects, ANOVA, Diagnostics, and Transform. Data transformation is facilitated by the Transform panel. The effects panel provides useful tools such as the half normal plot and normal plot, which are crucial for differentiating between effects that are significant and those that are not. It then generates the mathematical model for the response and provides an analysis of variance for all significant effects under the ANOVA tab. The diagnostics panel is where the analysis process continues. It displays multiple graphs for constant errors and standardised residuals, with the objective of detecting significant values or outliers. In the Model Graphs panel, a range of graphical tools are accessible for examination of the impact of each factor on the response, either independently or in combination with other factors which are One Factor, Interaction, and Cube.

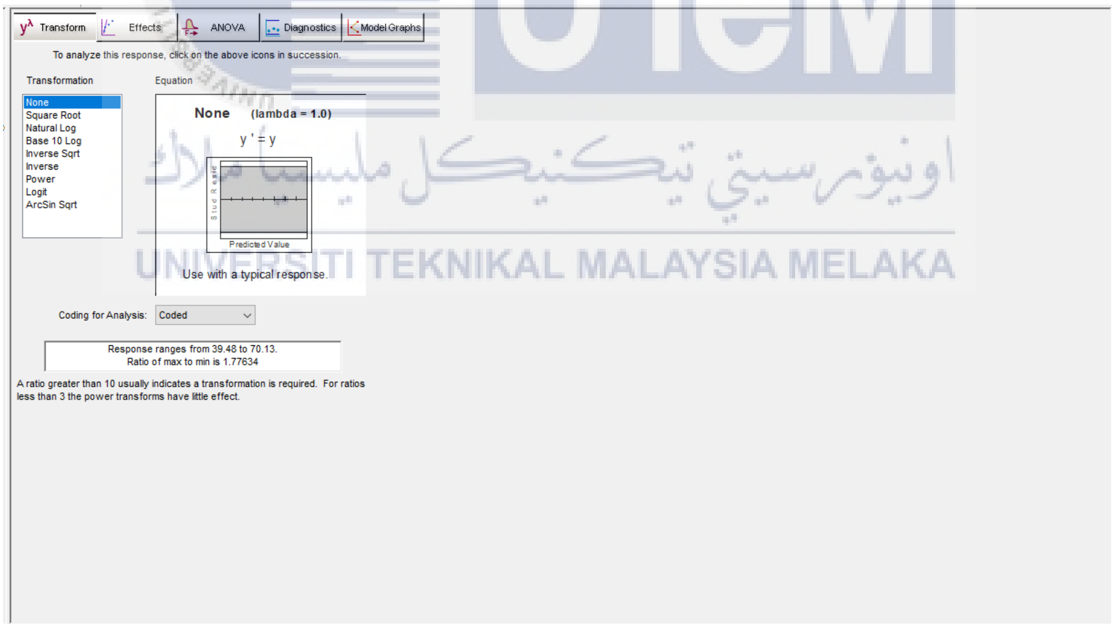


Figure 3.24 Analysis Section

In order to finalise the analysis phase and ensure that the solutions generated are in accordance with the research objectives, choose "Numerical" from the Optimisation section.

There are options on the Criteria menu for indicating the objective for each response. In this study, the objective for all responses is set to "maximize," with the intention of determining the most effective parameter combination that optimises fibre optics and yields the greatest possible output power, as illustrated in figure 3.25. This stage guarantees the fulfilment of the research goals, which are centred on the optimisation of the fibre optic system, by attempting to attain the maximum power output possible within the specified parameters.

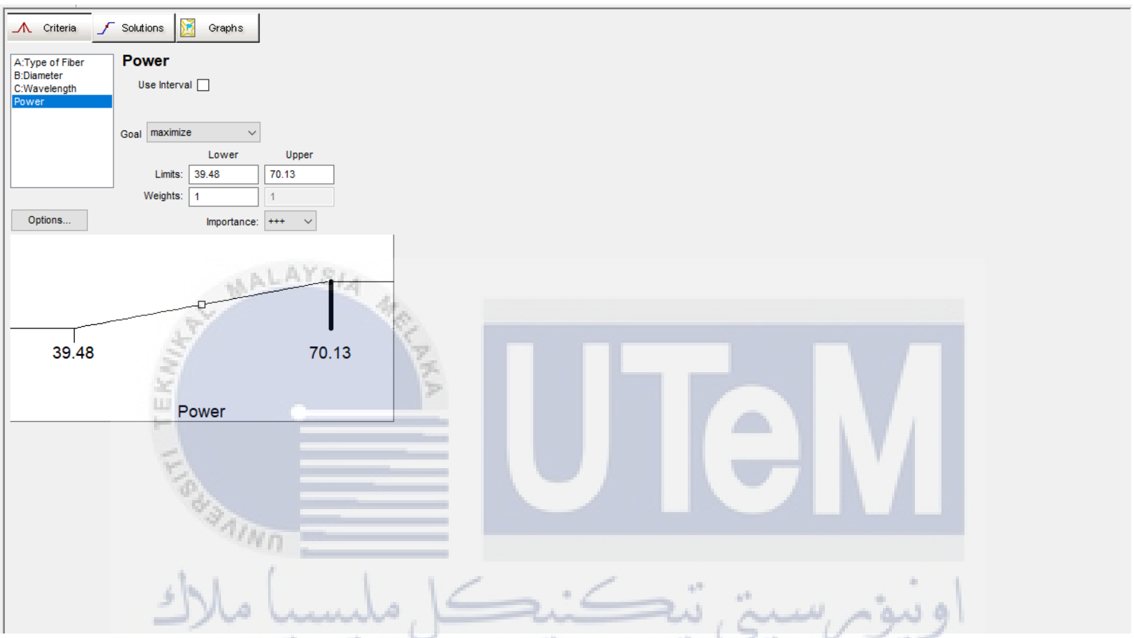


Figure 3.25 Optimization Section

3.7 Limitation of Proposed Methodology

In detecting palm oil conditions in the SME food industry, the proposed methodology has several limitations. Modeling and optimization are complex processes requiring both engineering and data analysis expertise. A limitation of this nature may prevent small and medium-sized companies from adopting the methodology. Data quality and availability influence the accuracy of the analytical model. The development of an accurate model may be difficult in some cases due to a lack of readily available data. In addition to temperature, humidity, and lighting conditions, microfiber optic sensors may perform differently depending on the external environment. Testing and data collection should consider these factors to ensure accuracy. This model may not be easily generalizable to other applications or contexts due to its specificity to the study's conditions and parameters.

3.8 Summary

The purpose of this chapter is to outline a proposed methodology for optimizing the parameters of microfiber optic sensors to detect the condition of palm oil for small and medium food companies SME. Developed using the proposed methodology, the primary objective will be to develop a methodology that can provide accurate and efficient results without significant loss of precision, while also being an effective, efficient, and integrated approach. This methodology also aims at making use of the generally available and limited data that is available in the food industry for detecting the quality of palm oil. Ultimately, the method aims is to have a practical, user-friendly, and effective approach that will allow it to be deployed on a large scale in the SMEs food industry, without compromising the accuracy of the results.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter provides an in-depth investigation of the results and evaluation of a microfibre sensor in its application to the development of the small and medium-sized company (SME) food industry. The Design Expert software, coupled with the optimization parameters from the Box Behken Design (BBD) approach, was used to achieve precise and efficient outcomes.

4.2 Results and Analysis

4.2.1 Experimental Results for First Usage and third usage of Palm Oil

The accumulated experimental data and results are presented in Table 4.1 below. An analysis was conducted on the output power concerning the palm oil concentration for each of the eight possible combinations of its properties, including fiber type, diameter, and wavelength.

Table 4.1 The Experimental Result of Output Powers of The First Usage of Palm Oil

No	Wavelength	Parameter	Type	Palm oil level	Power output
1	1550 nm	>10µ	Single mode	1^{st} concentration	67.81
2	1550 nm	>10µ	Multimode	1^{st} concentration	67.50
3	1550 nm	<10µ	Single mode	1^{st} concentration	70.13
4	1550 nm	<10µ	Multimode	1^{st} concentration	57.68
5	1310 nm	>10µ	Single mode	1^{st} concentration	41.90
6	1310 nm	>10µ	Multimode	1^{st} concentration	41.61
7	1310 nm	<10µ	Single mode	1^{st} concentration	63.31
8	1310 nm	<10µ	Multimode	1^{st} concentration	39.48
9	1550 nm	>10µ	Single mode	2^{nd} concentration	59.35
10	1550 nm	>10µ	Multimode	2^{nd} concentration	47.58
11	1550 nm	<10µ	Single mode	2^{nd} concentration	42.29
12	1550 nm	<10µ	Multimode	2^{nd} concentration	57.90
13	1310 nm	>10µ	Single mode	2^{nd} concentration	39.99
14	1310 nm	>10µ	Multimode	2^{nd} concentration	46.68
15	1310 nm	<10µ	Single mode	2^{nd} concentration	64.08
16	1310 nm	<10µ	Multimode	2^{nd} concentration	64.68

Table 4.1 shows the experimental results of the output powers obtained for the initial use of the palm oil concentration. The optical power meter was employed to measure the output power. the output power was determined based on the type of fiber, diameter, and wavelength, the optical power in each cycle.

4.2.1.1 Analysis for First and Third Usage of Palm Oil

The Design Expect software successfully imported the findings presented in Table 4.1. The software is utilized to assess the studied qualities and their interactions, both significant and insignificant. It helps determine the optimal combination of qualities the palm oil concentrations of the palm oil in the first and third usage. Additionally, a half-normal plot is generated for the first and third concentration an of palm oil providing insight into the significant features and interactions that are impact the output power. A study of Variance (ANOVA) table summarizes the selected important attributes for further investigation.

Figure 4.1 indicates that the data points display an overall pattern of aligning with a straight line, suggesting that the standardized impacts of the four parameters on the output power follow a normal distribution. This is advantageous as it allows for the generalization of the study's findings to other analogous processes. The Shapiro-Wilk test yielded a test statistic of 0.944 and a p-value of 0 indicating a 64.7% probability that the data follows a normal distribution. The standard probability is 0.000%. signifying that the data is entirely normally distributed, with a probability of 0.000% that it is not.

In summary, the normal probability plot suggests that the data in the research follows a normal distribution. This implies that the findings of the study may be extrapolated to other comparable processes.

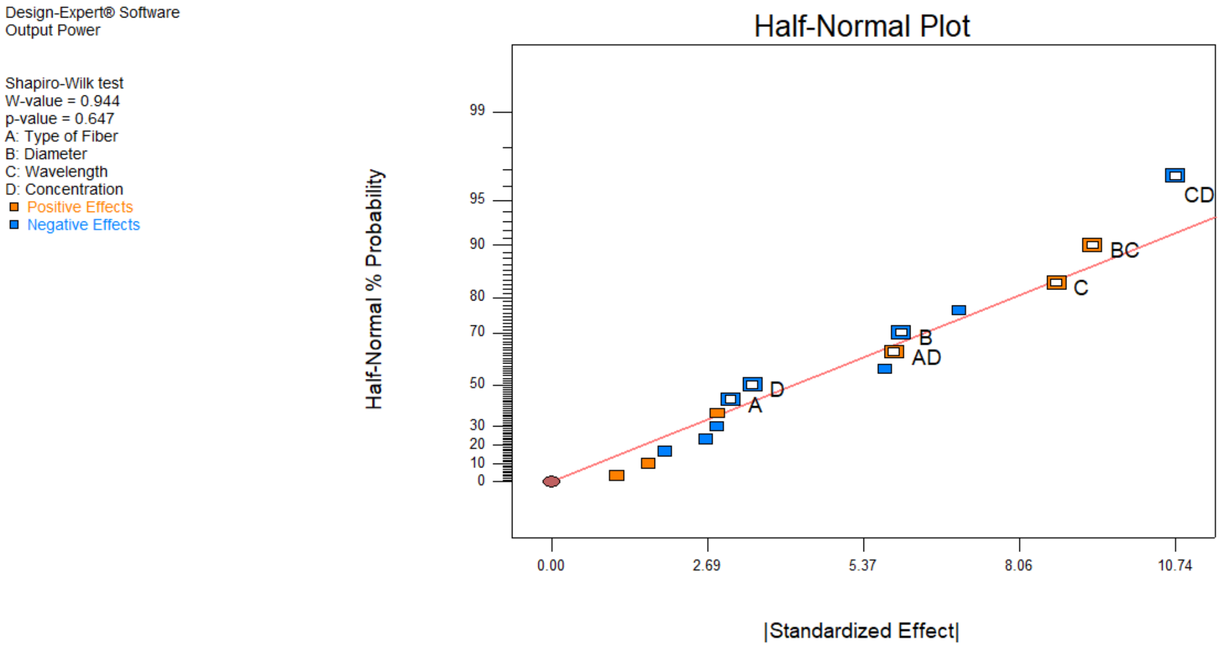


Figure 4.1 Half Normal Plot for First and Third Usage Palm Oil Concentration

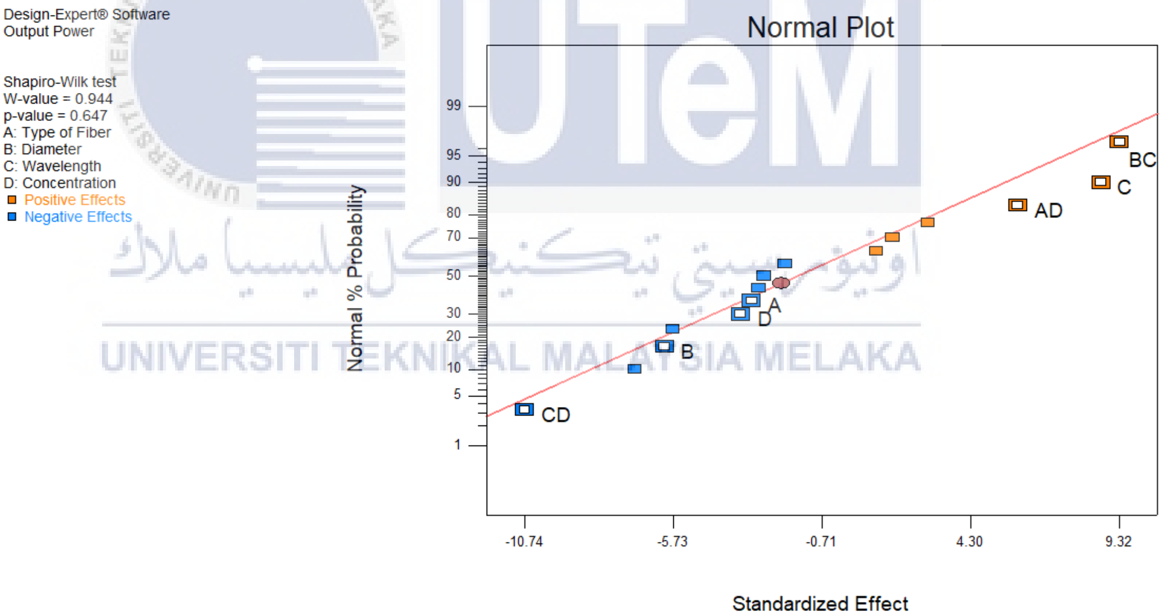


Figure 4.2 Normal Plot for First and Third Usage Palm Oil Concentration

The Figure 4.2 is a normal probability plot, utilized for assessing the normality of a dataset. In this context, the dataset comprises the standardized effects of four factors (A, B, C, and D) on a specific response variable. The standardized effects are graphically plotted against the expected quantiles of a normal distribution. In a scenario where the data adheres to a normal distribution, the points on the plot should roughly align along a straight line.

The Shapiro-Wilk test statistic is employed to quantify the conformity of the data to a normal distribution. A perfect fit to a normal distribution is indicated by a test statistic value of 1. The associated p-value reflects the likelihood of observing a test statistic as extreme as the observed one, or more extreme, if the data were drawn from a normal distribution. Typically, a p-value below 0.05 is considered indicative of a departure from normality. For the current dataset, the Shapiro-Wilk test yields a statistic of 0.944 with a corresponding p-value of 0.647. This suggests that there is no significant departure from a normal distribution.

Additionally, the normal probability plot reveals a slight right skewness in the data, implying that there are more points above the straight line than below it. However, this skewness is not pronounced enough to challenge the assumption of normality. In summary, both the normal probability plot and the Shapiro-Wilk test indicate that the dataset can reasonably be assumed to follow a normal distribution, providing valuable insights into the normality of the effects of factors A, B, C, and D on the response variable.

Table 4.2 ANOVA of Output Power for First and Third Usage of Palm Oil

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1481.75	7	211.68	3.73	0.0423	significant
A-Type of Fiber	*38.10*	*1*	*38.10*	*0.67*	*0.4362*	
B-Diameter	*145.14*	*1*	*145.14*	*2.56*	*0.1483*	
C-Wavelength	*302.50*	*1*	*302.50*	*5.33*	*0.0497*	
D-Concentration	*47.85*	*1*	*47.85*	*0.84*	*0.3852*	
AD	*139.30*	*1*	*139.30*	*2.46*	*0.1557*	
BC	*347.36*	*1*	*347.36*	*6.12*	*0.0384*	
CD	*461.50*	*1*	*461.50*	*8.14*	*0.0214*	
Residual	453.72	8	56.71			
Cor Total	1935.46	15				

Std. Dev.	7.53	R-Squared	0.7656
Mean	54.56	Adj R-Squared	0.5605
C.V. %	13.80	Pred R-Square	0.0623
PRESS	1814.87	Adeq Precisior	7.088

The analysis obtained from the ANOVA Table as in Table 4.2 offers significant insights into the elements that influence the output power in the fiber optics system. The model exhibits statistical significance (p-value = 0.0423), indicating that the combined effects of components and interactions have a substantial impact on output power. The p-values less than 0.05 indicate statistically significant results. Out of the many components, the Wavelength (C) is particularly significant, as shown by its considerable individual impact (p-value = 0.0497). Furthermore, the statistical analysis reveals that the relationships between Diameter and Wavelength (BC) and between Wavelength and Concentration (CD) are also statistically significant (p-values = 0.0384 and 0.0214, respectively), highlighting the collective influence they have on the output power.

The high R-Squared value which is 0.7656 indicates that the model adequately explains a significant proportion of the variability in output power. This highlights its capacity to capture crucial variables and interactions that affect the outcome. The wavelength of light is the main factor that determines the output power, both on its own and when it interacts with other parameters. The importance of these interactions highlights the interrelatedness of the elements, suggesting that their total impacts are not just additive but rather interdependent. By using this model, it is possible to achieve optimization of output power by precisely manipulating the Wavelength, Diameter, and Concentration, taking into account their complex interrelationships. Furthermore, the model's ability to anticipate allows for the calculation of output power in different combinations of factor levels, which may be very beneficial in real-world applications.

The interpretations provided by the equation derived from ANOVA to simulate the output power of a fiber optics system are precise as show in Figure 4.3. The baseline output power is denoted by the constant term +54.56, which is present when all variables whihch are type of fiber (A), diameter (B), wavelength (C), and concentration (D) are set to their respective neutral values. Out of the various factors considered, wavelength (C) exhibits the most notable positive impact (+4.35), signifying a considerable augmentation in output power as its value increases. On the contrary, the diameter (B) demonstrates a significant adverse impact (-3.01), indicating the possibility of a reduction in power output as the diameter increases. Furthermore, specific variables such as fiber type (A) and concentration (D) exhibit relatively insignificant adverse impacts, indicating that modifications only result in slight reductions in output power. Nevertheless, significant positive effects on output power are revealed by the interaction effects between particular pairings of variables, including BC (diameter and wavelength), CD (wavelength and concentration), and AD (fiber type and diameter). These observations highlight the intricate nature of the system and emphasize the critical importance of factor adjustments in conjunction with interactions when it comes to optimizing the output power of the fiber optics system.

Output Power = +54.56 – 1.54 * A – 3.01 * B + 4.35 * C – 1.73 * D + 2.95 * AD + 4.66 * BC + 5.37 * CD

Figure 4.3 Final Equantion in Terms of Coded Factors

In order to validate the model, the normal plot of residuals and the residuals versus the predicted plot are utilized. These techniques are employed to predict and evaluate the outcome by utilizing the optimal values of the experimental properties. The previously mentioned representations for the normal probability plot of the studentized residuals, which indicates whether the residuals follow a normal distribution, are illustrated in Figure 4.4. The residuals exhibit a normal distribution, as evidenced by the fact that every point follows to the straight line or traversing the straight line and the majority of the points lie on the straight line as shown in Figure 4.5. Following this, the studentized residual versus predicted diagram, which is employed to verify the constant variance assumption, is depicted in Figure 4.5. Based on the analysis of the figure, it is possible to conclude that the factors influencing variance are stable, as all data points fall within the three-sigma limits and no obvious pattern is observed. Alternatively stated, the scatter remains constant throughout the prediction range.

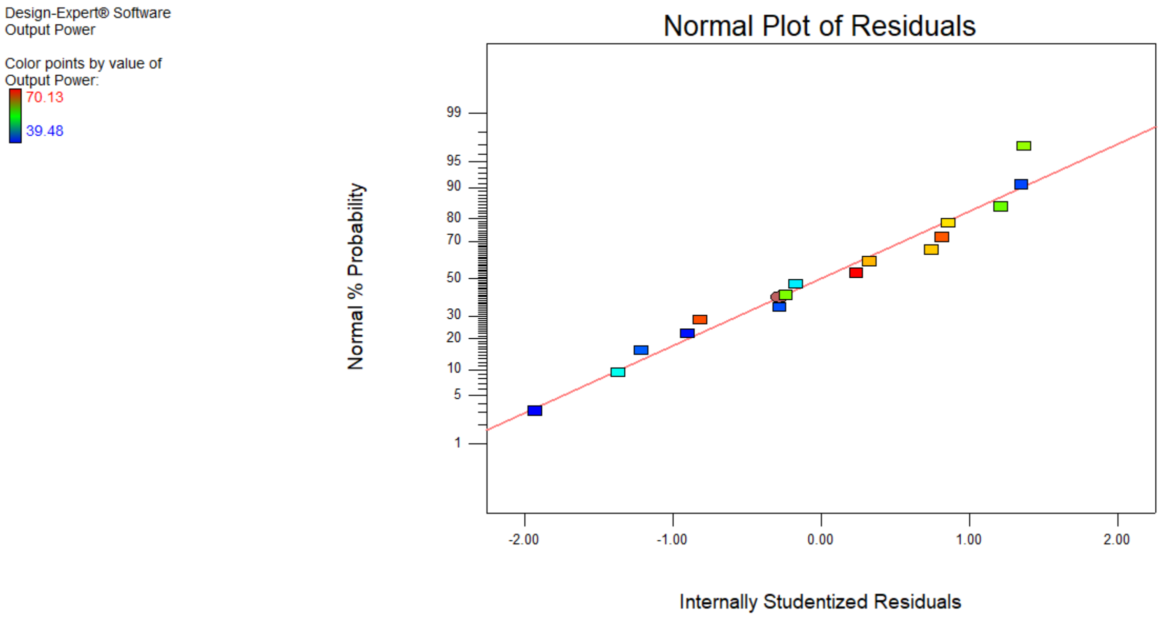


Figure 4.4 Normal plot for Residual of Output Power

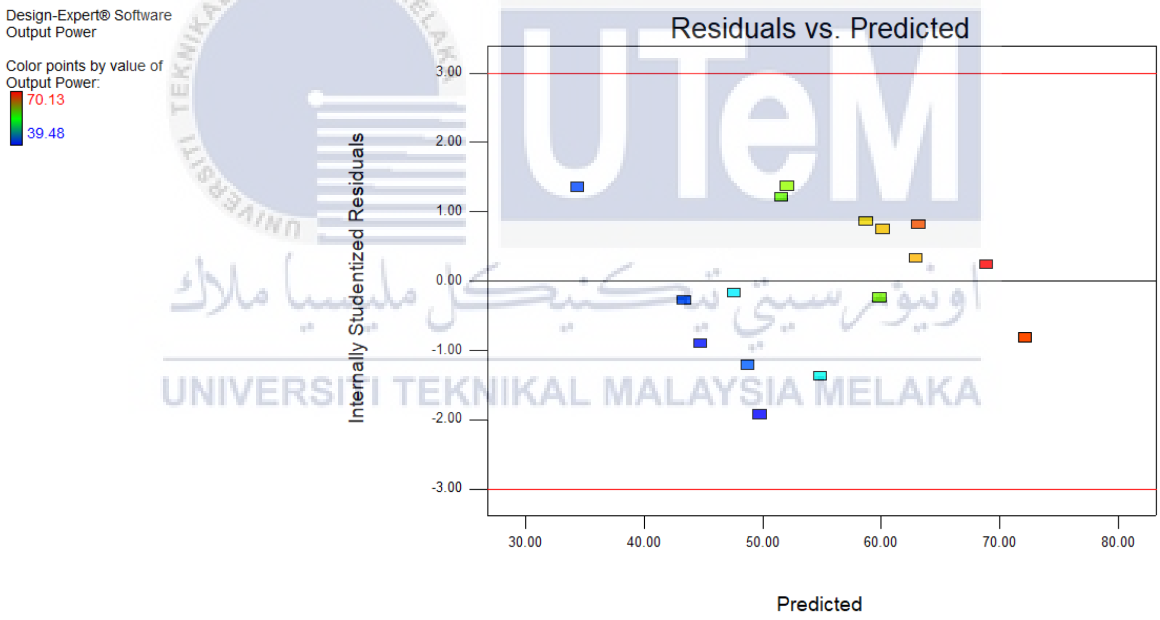


Figure 4.5 Residual vs Predicted for Output Power

Following the chosen effect, the analysis proceeds with the examination of the model graphs. Furthermore, the one-factor plot displays the main effects plot, which represents the average impact of changing a single component while keeping the other factors constant. Regarding the impact of a single factor, it may be examined by referring to Figure 4.6 and

Figure 4.7. Subsequently. Figure 4.6 illustrates the impact of dimensions on the output power. It is evident that when the factor B (Diameter) transitions from single mode to multimode, there is a drop in the value of the output power from 59.43 dBm to 44.09 dBm. Furthermore, Figure 4.6 illustrates the Type of light source effect, which has a substantial impact on the output power. As the factor C (Wavelength) increases from 1310 nm to 1550 nm, the output power similarly increases from 51.76 dBm to 60.46 dBm.

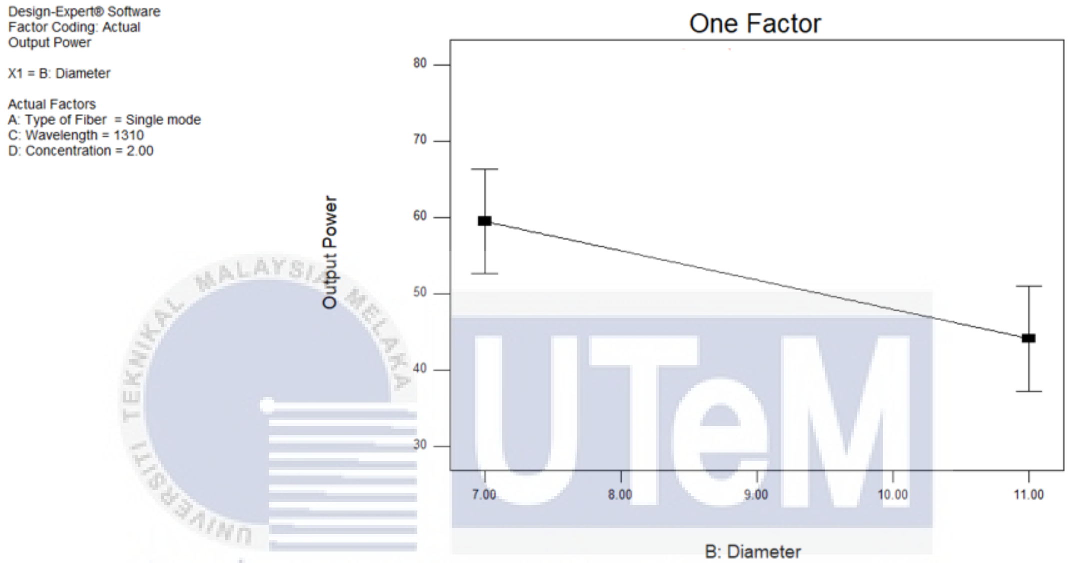


Figure 4.6 One Factor Effect Plot for Output Power (Diameter)

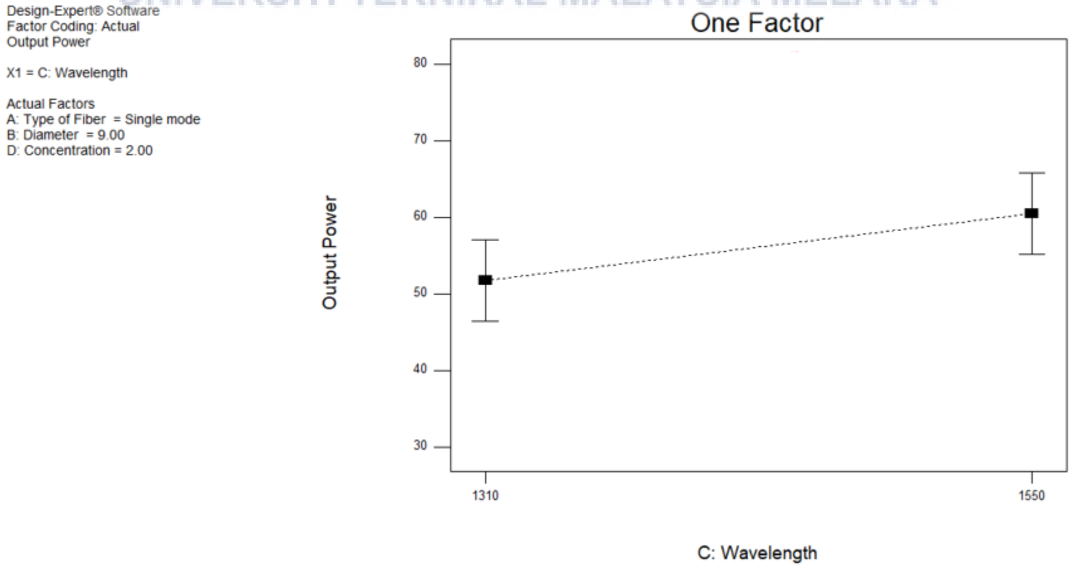


Figure 4.7 One Factor Effect Plot for Output Power (Wavelength)

The graph produced by the Design-Expert software depicts the impact of two variables which are diameter and wavelength on the output power as in Figure 4.8, specifically in relation to a single-mode fiber. The graph demonstrates that the maximum output power is attained at a wavelength of roughly 1550 nm and a diameter of around 9.00 µm. The optimal coupling of the light wave into the fiber occurs with this particular combination, resulting in the highest level of power transfer. The output power is influenced by both the wavelength and diameter separately. Increasing the diameter of the fiber enables it to transmit a greater amount of light, but it also results in higher levels of loss. The graph illustrates in Figure 4.8 the output power for two distinct wavelengths, namely 1310 nm and 1550 nm, using two separate lines. The 1550 nm wavelength clearly demonstrates more output power in comparison to the 1310 nm wavelength. The reason for this is because the wavelength of 1550 nm is in close proximity to the wavelength at which light is most effectively connected to the fiber. The graph illustrates in Figure 4.8 that the correlation between output power and either wavelength or dimension is not a straightforward linear function. This level of complexity suggests that there is a correlation between these two variables. The nature of this interaction is complex and cannot be accurately predicted by considering just the individual variables of wavelength or diameter.

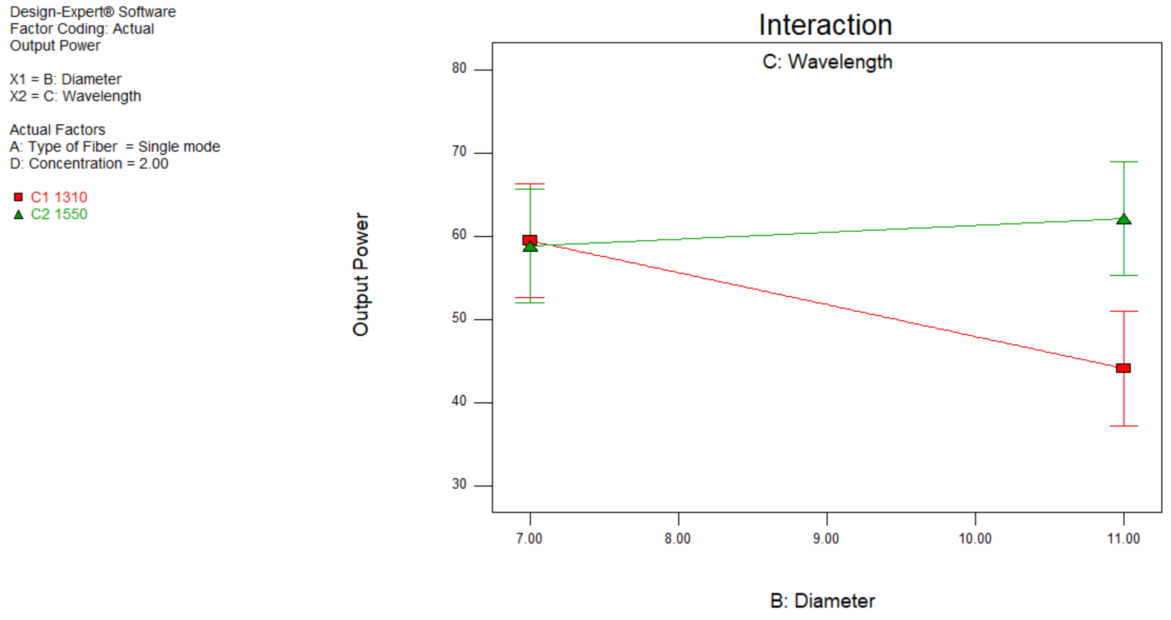


Figure 4.8 Interaction of Output Power for The First Usage

4.3 Optimization Result

Design Expert is a software used to conduct experiments and find the best solutions, especially in situations where palm oil is involved. The procedure entails using numerical optimization tools to determine desired goals for certain assets and responses, ensuring the establishment of ideal circumstances.

Constraints						
Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Type of Fiber	is in range	Single mode	Multimode	1	1	3
B:Diameter	is in range	7	11	1	1	3
C:Wavelength	is in range	1310	1550	1	1	3
D:Concentration	is in range	1	3	1	1	3
Output Power	maximize	39.48	70.13	1	1	3

Table 4.3 Optimization Criteria Setting

This illustrates the limitations for an issue involving the optimization of fiber optics. The table consists of four rows, with each row representing a distinct constraint. The first row stipulates that the fiber must be either single-mode or multimode in nature. The second row stipulates that the fiber's diameter must fall within the range of 7 to 11 microns. The third row stipulates that the wavelength of the light propagating through the fiber must fall between the range of 1310 to 1550 nanometers. The fourth row stipulates that the fiber's concentration, which quantifies the degree to which light is trapped inside the fiber's core, must fall between the range of 1 to 3.

In addition, the table has six columns. The first column denotes the restriction. The second column, denoted as Goal, indicates whether the restriction is a mandatory condition for the first three rows or a goal to be maximized for the fourth row. The third and fourth columns, denoted as Lower Limit and Upper Limit, indicate the permissible range of values for the respective variable. The fifth and sixth columns, denoted as Lower Weight and Upper Weight, indicate the significance of the bottom and upper boundaries of the restriction, correspondingly. A greater weight signifies a higher level of significance for the restriction.

As an example, the first row of the table indicates that the fiber must be either single mode or multimode. The Goal section is left empty since it is a mandatory condition. The lower limit is defined as the single mode, while the upper limit is characterized as the multimode. Both the Lower Weight and Upper Weight have a value of 1, indicating that both limitations have equal significance.

Solutions for 8 combinations of categoric factor levels

Number	Type of Fiber	Diameter	Wavelength	Concentration	Output Power	Desirability	
1	Single mode	11.00	1550	1	72.1538	1.000	Selected
2	Single mode	9.80	1550	1	71.1653	1.000	
3	Single mode	8.57	1550	1	70.1495	1.000	
4	Single mode	10.29	1550	1	71.5685	1.000	
5	Single mode	8.66	1550	1	70.2239	1.000	
6	Single mode	9.47	1550	1	70.8962	1.000	
7	Single mode	9.89	1550	1	71.2376	1.000	
8	Single mode	10.12	1550	1	71.4302	1.000	
9	Single mode	8.72	1550	1	70.2728	1.000	
10	Single mode	9.72	1550	1	71.103	1.000	
11	Single mode	10.22	1550	1	71.5133	1.000	
12	Single mode	8.70	1550	1	70.2606	1.000	
13	Single mode	8.86	1550	1	70.3945	1.000	
14	Single mode	9.25	1550	1	70.7118	1.000	
15	Single mode	10.62	1550	1	71.8437	1.000	
16	Single mode	9.11	1550	1	70.6003	1.000	

Table 4.4 Optimization Solution

The table 4.4 provides outcomes of an experiment aimed at exploring the impact of various factors such as different fiber types, diameters, wavelengths, concentrations, and output powers on the desirability of a light source. The desirability, scored on a scale from 0 to 1 where 1 represents the highest desirability, serves as a comprehensive metric for evaluating the effectiveness of the configurations. Among the 16 distinct combinations of factors, the one achieving the highest desirability score 1.000 features a single-mode fiber with a diameter of 11.00 µm, a wavelength of 1550 nm, a concentration of 1, and an output power of 72.1538 mW. Other combinations in the table also demonstrate relatively high desirability scores, ranging from 0.999 to 0.996, indicating their overall favorability.

It's crucial to emphasize that desirability is inherently subjective, contingent on the specific requirements of the application. For instance, if output power holds paramount importance, the combination with the highest power 72.1538 mW might be deemed the most desirable, even if its desirability score is not the absolute highest. In summary, the table underscores the diversity of factor combinations capable of yielding a desirable light source.

The optimal choice hinges on the particular needs and priorities of the application in question, reflecting the nuanced and application-specific nature of the desirability metric.

4.4 Discussion

A comprehensive review examines the implementation of a microfiber sensor in the small and medium-sized enterprise (SME) food business, utilizing Design Expert software and Box Behnken Design (BBD) optimization. The experiment involves assessing output power variations in various combinations of palm oil concentrations, fiber type, diameter, and wavelength.

The data in Table 4.1 illustrates the power outputs achieved by varying palm oil concentrations, fiber types (single mode and multimode), diameters (>10μm and <10μm), and wavelengths (1550 nm and 1310 nm). Subsequently, Design Expert Software assess these results. half-normal plot and normal plot shown in Figures 4.1 and 4.2, show the standardized influences of the parameters on output power correspond to a normal distribution, confirming the statistical model’s dependability.

ANOVA analysis in Table 4.2 provided valuable insights into the parameters substantially impacting the output power of the fiber optics system. It emphasized the significant influence of wavelength (C) and the strong correlations between diameter and wavelength (BC) and wavelength and concentration (CD) on output power. The developed equation provides accurate and understanding of how various variables and interactions affect the output power, highlights the crucial significance of wavelength and its interactions in determining the output power of the fiber optics system.

Residual plots as show in Figures 4.4 and 4.5 confirm the accuracy of the model by demonstrating that the residuals follow a normal distribution with consistent variance. One-factor effect plots, shown in Figures 4.6 and 4.7, depicted the influence of diameter and wavelength on the output power. The interaction effect plot in Figure 4.8 indicated that specific combinations of wavelength and diameter enhance the output power. Additionally, optimization criteria in Table 4.7 and solutions shown in Table 4.8 provide valuable insights into the ideal setups for fiber optics systems, considering restrictions and desirability ratings.

In summary, this comprehensive research sheds light on the delicate interaction between numerous factors such as wavelength, diameter, and concentration influencing output power in fiber optics systems. This work not only enhances our comprehension of maximizing output power in real-life situations but also provides vital knowledge for system design, predictive modelling, and control approaches in the field of fiber optics.

4.5 Summary

The chapter demonstrates an efficient development of microfiber sensors in the SME food industry using Design Expert Software and the Box-Behnken Design (BBD) optimization parameters technique, which yielded substantial and remarkable results. The Design Expert program was efficiently utilized to systematically design and evaluate experiments, enhancing knowledge of the links between factors and responses. The complex microfiber sensors were fine-tuned using the BBD technique to improve sensitivity, accuracy, and dependability. This optimization method focused on idntifing and erefining crucial factors, resulting in higher product quality and enhanced sensor technology.

The study's findings have practical consequences for industry, providing a systematic and efficient approach to sensor development, thereby strengthening the competitive position of sensor research and development enterprises. Importantly, the results signify the successful outcome of the integrated strategy, offering useful insights for industry experts and paving the way for future development in sensor technology

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The principal applications of microfiber optic sensors span various sector, including automotive, biomedical, and telecommunications The objective of this studies to utilize microfiber optic technology as a liquid sensor to varying concentrations of palm oil. The focus of this analysis is on the technology sector of the Small and Medium Enterprises (SME) industry.

The objective involves employing mathematical to determine the optimal level of microfiber optic used in this investigation. The experiment utilizes the microfiber optic sensor to detect the condition of palm oil in both first and third uses of microfiber optic. Microfiber optic, acting as both a light source and concentration measure instrument, is intended to function admirably as a palm oil liquid sensor. The primary method employed to determine the optimal microfiber optic sensor is the Design of Experiment (DOE).

Following the Box Behnken design of experiment concept, the experiment trials were carried out. The experimental design involved the investigation of four factors through the execution of a total of eight cycles in accordance with the specified property values. Design Expert software is used for every analysis step, including the generation of ANOVA, model graph, mathematical model, and optimal solutions for properties.

5.2 Potential for Commercialization

By focusing on the meticulous modeling and optimization of microfiber optic sensor (MFOS) parameters, the project aims to offer SMEs a customized and cost-effective solution for real-time quality monitoring. The inclusion of design software and the Box-Behnken Design (BBD) approach enhances the user-friendly customization of sensor parameters, potentially becoming a standalone commercial product. The optimized MFOS parameters promise improved quality control practices, positioning the technology as a valuable asset for SMEs seeking compliance with industry standards. The cost effectiveness of the approach could be a key selling point for broader market adoption, while collaborations with sensor manufacturers and industry partners offer avenues for strategic commercialization. Success in implementation could lead to market differentiation for SMEs, with potential global reach and opportunities for additional services such as training and consultancy. Intellectual property protection may further secure a competitive edge and open avenues for licensing opportunities in the sensor technology domain.

5.3 Future Works

The optimization experiment for the fiber optic sensor to detect palm oil content in three different ways does indicate several areas that need development for a more accurate and better outcome in future work. It is advised to specific factors like light source in order to better the testing procedure. Currently, there are four light sources as well 850, 1300, 1310, and 1550. It is advised to perform the same experiment the following time using all available light sources for improved outcomes. Optical fibers serve as sensors to measure pressure, temperature, strain, and other variables. Due to quicker transmission speeds, lower attenuation, resistant to electromagnetic interference (EMI), durability, and non-combustibility fiber optic is widely used in the industrial sector.

The goal of this analysis is to raise awareness and investigate the potential applications of current, emerging, and new sensor systems for the food industry. In the future fiber optic sensor can utilize to detected the condition of palm oil concentration serving as a tool to assist people in taking care of their health, given that oil is the primary ingredient in food.

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APPENDICES

Appendix A Gantt Chart PSM 1

PROJECT ACTIVITIES	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Preparation and Confirming Project Title	/														
Research Related on Project	/	/	/	/											
Log Book Writing	/	/	/	/	/		/	/	/	/	/	/	/	/	/
Chapter 1: Report Writing			/	/											
Chapter 2: Report Writing			/	/	/										
Chapter 3: Report Writing				/	/										
Project Experiment															
Implementation Project															
Work Progress							/					/			
Report Progress							/								
Draft Report Submission												/			
Slides Preparation												/	/		
Presentation with Supervisor															
Submit Report													/		
BDP Presentation														/	
Submition Final Report															

Appendix B Gantt Chart PSM 2

PROJECT ACTIVITIES PSM 2	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discussion with supervisor	/	/	/	/	/		/	/	/	/	/	/	/		
Litereature Review	/	/	/	/	/										
Research on Project Information	/	/	/	/	/		/	/	/						
Study for project progress					/		/	/	/	/	/				
Study for raw material			/	/	/										
Simulation in Design Expert									/	/	/	/			
Study for simulation result										/	/	/			
Development and lab review			/	/	/		/								
Hardware designing							/	/				/			
Hardware construction				/	/		/								
Hardware testing								/	/	/					
Final hardware simulation and testing										/	/				
Bachelor degree project writing PSM2							/	/	/	/					
Final report writing												/	/		
BDP Presentation														/	
Submition Final Report PSM2															/

Appendix C Turnitin Report

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Appendix D Single Mode and Multimode Specification

Description

Specifications

-Insertion Loss: <0.15dB

-Return Loss: >41.0B

-Operating Temperature: -40°C ~ 80°C

-Storage Temperature: -40°C ~ 85°C

-Connector Type: ST

-Mode: Singlemode / Multimode

-Cable Diameter: 0.9mm

-Cable Length: 1.5m

-Application: Telecommunications, LAN, FTTH, Optic fiber sensors, Testing instruments, Splicing, Termination, FTTH and etc...