Faculty of Electronics and Computer Technology and Engineering

Microfiber Sensor Development by Design Expert Software and Box Behnken Design (BBD) Optimization Parameters Approach the SME Automotive Industry

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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Supervisor Name : PUAN RAHAINI BINTI MOHD SAID

Date : 15 February 2024

DEDICATION

This project is dedicated to my mother Zuraya, father Abdul Manan and family members Oli and Atun, whose unceasing support and encouragement have been my anchor throughout the journey. Your belief in me fueled my determination and this achievement is a testament to the power of your love. Thank you for being my constant source of inspiration.

ABSTRACT

The demand for an effective Engine Oil detection system has prompted a focus on innovative solutions. Optical microfiber sensors are emerging as promising tools with significant potential. This study specifically targets the development of optical microfiber sensors for Small and Medium-sized Enterprises (SMEs) in the automotive sector, addressing challenges related to engine oil monitoring. SMEs play a crucial role in the engine oil sector, enhancing market competitiveness and product diversity. To overcome limitations faced by SMEs in costly and time-consuming oil assessment methods, wearable optical microfiber sensors are introduced as a practical solution. These sensors undergo optimization through a systematic Design of Experiment (DoE) approach, considering parameters like wavelength, microfiber diameter, engine oil concentration, and microfiber types. The proposed methodology integrates Design Expert Software and Box Behnken Design (BBD) optimization parameters to enhance sensor performance and sensitivity. This systematic approach tailors the development of optical microfiber sensors to meet the unique needs of SMEs in the automotive industry. The anticipated result is a significant improvement in the quality and efficiency of microfiber sensors, providing SMEs with a reliable tool for engine oil condition detection. This advancement is poised to boost the overall competitiveness of SMEs in the global automotive market, promoting innovation and ensuring efficient machinery operation across various sectors.

ABSTRAK

Permintaan untuk sistem pengesanan Minyak Enjin yang berkesan telah menarik perhatian kepada penyelesaian inovatif. Sensor mikrofiber optik muncul sebagai alat yang menjanjikan dengan potensi yang besar. Kajian ini secara khusus mengenai pembangunan sensor mikrofiber optik untuk Perusahaan Kecil dan Sederhana (PKS) dalam sektor automotif, menangani cabaran berkaitan pemantauan dan penyelenggaraan minyak enjin. PKS memainkan peranan penting dalam sektor minyak enjin, meningkatkan daya saing pasaran dan kepelbagaian produk. Untuk mengatasi had yang dihadapi oleh PKS dalam kaedah penilaian minyak yang mahal dan mengambil masa, sensor mikrofiber optik boleh dipakai diperkenalkan sebagai penyelesaian praktikal. Sensor ini dioptimumkan melalui pendekatan Sains Percubaan (DoE) yang sistematik, mempertimbangkan parameter seperti panjang gelombang, diameter mikrofiber, kepekatan minyak enjin, dan jenis mikrofiber. Metodologi yang dicadangkan menggabungkan Perisian Design Expert dan parameter optimisasi Box Behnken Design (BBD) untuk meningkatkan prestasi dan kepekaan sensor mikrofiber. Pendekatan sistematik ini menyesuaikan pembangunan sensor mikrofiber optik dengan keperluan unik PKS dalam industri automotif. Keputusan yang dijangkakan adalah peningkatan yang ketara dalam kualiti dan kecekapan sensor mikrofiber, menyediakan PKS dengan alat yang dapat dipercayai untuk pengesanan keadaan minyak enjin. Kemajuan ini dijangkakan untuk meningkatkan daya saing keseluruhan PKS dalam pasaran automotif global, merangsang inovasi dan memastikan operasi jentera yang efisien di pelbagai sektor.

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LIST OF ABBREVIATIONS

DOE	-	Design of Experiment
BBD	-	Box Behken Design
SME	-	Small and Medium Enterprise
MOF	-	Multimode Optical Fiber
TOFS	-	Tapered Optical Fiber Sensor
MSR	-	Micro-Sphere Resenator
RSM	-	Response Surface Methodology
OTDR	-	Optical Time Domain Reflectometer

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CHAPTER 1

INTRODUCTION

1.1 Background

Motor oil, also referred to as engine oil, serves as a versatile lubricant essential for reducing friction, preventing wear between moving parts, and offering simultaneous cooling and sealing properties. It plays a crucial role in ensuring optimal engine performance over an extended period. Engine oil is a sophisticated and engineered fluid that creates a hydrodynamic film between moving components, dissipates heat, suspends contaminants, neutralizes acid, and prevents wear and corrosion (Zhang, 2003). Previous research categorized engine oils into five types: Mineral-based oils, Synthetic oils, Mineral and synthetic-based oils (semi-synthetic), Oils from mineral base optimization (new generation base), and Refined base oils (mono-grid) (Hasan-Zadeh & Poshtiban, 2021).

Regular engine oil changes are essential to maintain automotive engine health and performance. The condition of the engine oil, indicative of its residual useful life, is crucial for sustaining engine functionality (Zhang, 2003). Vehicle maintenance, a key factor in road safety, involves routine measures and procedures to ensure the safety of vehicles (Mikulić et al., 2020).

Monitoring engine oil condition is vital for the longevity and health of automotive engines. Recent studies suggest various approaches, including sound signal analysis for motorcycle oil condition detection (Syafitri et al., 2019) and trend analysis using digital oil monitoring systems to analyze parameters like temperature, viscosity, pH, and water level (Mohan et al., 2020).

Inadequate engine maintenance in the SME automotive industry can lead to significant costs and negative consequences, accelerating engine wear and damage. Malaysian SMEs, competing globally, face challenges in creating high-quality products and services at reasonable prices (Rosni et al., 2013).

Maintaining oil viscosity during operation is crucial, requiring regular viscosity monitoring. The use of multi-mode optical fiber (MOF) with a tapered end has proven effective in measuring the refractive indices of fresh and expired oil in mechanical systems (Taheri Ghahrizjani et al., 2016). The optimization of microfiber parameters, such as fiber type, wavelength, concentration of engine oil, and fiber diameter, is necessary for producing optimal fibers.

To determine optimal parameters, the study employs the Design of Experiment (DoE) approach, specifically the Box Behnken Design (BBD), a response surface methodology. This statistical approach streamlines planning, conducting, analyzing, and interpreting experiments, offering efficiency in testing fewer variables. The BBD design is favored for its simplicity and feasibility (Razzaq et al., 2022). Integrating Design Expert Software and BBD optimization parameters provides a systematic and efficient means of advancing microfiber sensor development for SMEs in the automotive industry, enhancing sensor performance and functionality.

1.2 Problem Statement

Small and medium-sized enterprises in automative sectors often lack funding for maintaining automative engine oil. To achieve effective and efficient engine oil monitoring, SMEs need a method specifically tailored to their needs and constraints. In current methods, oil condition is assessed visually and through oil analysis, but these methods are often time-consuming, expensive, and not always reliable. If the engine oil is not changed at the right time or contaminants are not detected early enough, it can be damaged, leading to increase in repair costs. Engine oil is an important part of the vehicle, moving engine components such as pistons, connecting rods, and crankshafts. However, users cannot predict the concentration of engine oil will be. The engine oil will follow a predetermined distance provided by the car or motorcycle.SMEs need a tool that can determine the engine condition.A microfiber sensor can be applied to predict the concentration of engine oil , offering an alternative method for changing the engine oil without resorting conventional oil change method. The process of determining the optimal microfiber parameter is quite challenging in order to produce a sensor that provides the greatest detection accuracy possible. The design of experiment is then used to determine the optimal parameters of the sensor based on the data obtained from the experiment.

1.3 Project Objective

This project aims to develop a microfiber sensor using an optimization parameters approach for detect the condition of engine oil in the SME automotive industry. The goal is to provide a cost-effective and efficient solution for monitoring the condition of engine oil in this segment of the automotive industry. Specifically, the objectives are as follows:

a) To identify the significance effects of microfiber sensor parameter

b) To develop a mathematical regression model for microfiber sensor of engine oil detector

c) To develop microfiber sensor with optimum parameter to produce the sensor detector to detect engine oil conditions.

1.4 Scope of Project

The scope of this project are as follows:

a) Microfiber type is considered in the test study.

b) Single mode and multi-mode are used for the experiment.

c) The microfiber performance considered is power output.

d) The microfiber parameters considered are fiber type, diameter, wavelength, and concentration of engine oil.

e) Regression models that are related in this study.

f) Developing and testing prototype of the microfiber sensor using design of experiments software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter briefly discusses the fiber optic previous study. The purpose of this chapter is to give a brief overview of several topics related to the review of existing systems and the literature review, which are related to the project, briefly discussed. A literature review will be conducted to examine previous systems that have been created for similar purposes and analyze their strengths and weaknesses. The development of microfiber and design of experiment (DOE) is also briefly discussed in this chapter. This chapter provides a solid foundation and provides important information that will prove valuable to this project in the long run.

2.2 Fiber Optic Sensor

The fiber optic sensor is a device that uses fiber optic technology as a means of sensing or measuring changes in the surrounding environment, such as physical, chemical, or biological changes. It has been found that fiber optic sensors are widely used in various applications, including the oil and gas industry, aerospace, medicine, and structural health monitoring, among others. In terms of fiber optic sensors, they can be categorized into a single point sensor, a semi-distributed sensor, and a distributed sensor (Ashry et al., 2022). A fiber-optic sensor is a device that can monitor environmental parameters such as temperature and humidity at a single point along the fiber, at the outset. Fiber optic sensors, it is a type of sensor as well as a device that is used to convert light rays into electrical signals.

Exactly like a photoresistor, it measures the physical quantity of light and translates it into a form that can be read by any instrument that can read it. There are a variety of uses for fiber optic sensors. It can detect changes in the intensity, phase, or polarization of light transmitted through fiber optic cables. There are three components to the sensor a light source, an optical fiber, and a detector. There is a light source that emits light into a fiber optic cable, which transmits the light to the sensor location as it travels through the cable. It is the interaction of light with the target object or substance that leads to a change in the properties of the light. A detector detects these changes and converts them into an electrical signal.

There are three types of fiber optic sensors. intrinsic sensors, extrinsic sensors, and distributed sensors. An intrinsic sensor has the fiber itself as the sensing element since it is directly affected by the measurable parameter. Those sensors that use external materials to modify the properties of light, such as coatings or gratings, are called extrinsic sensors. In this type of sensor, the entire length of the fiber optic cable acts as the sensing element. This, in turn, allows continuous monitoring along the entire length of the cable. It is stated in the paper that fiber optic sensors have been developed to measure the oil film pressure under load without affecting tribological contact (Kapulainen et al., 2014). Fiber optic sensors have many advantages over traditional sensing methods, including high accuracy and reliability. Aside from this, they can withstand even harsh environments and are immune to electromagnetic interference. Since the advent of optical fiber sensors in the 1970s, there has been an explosion of research and development in this field (Castrellon-Uribe, 2012) .It is now clear that optical fiber sensors have a wide range of applications in a wide range of fields, and that their extension into sensors for optoelectronic systems has also contributed to a wide range of applications in diverse areas.

2.2.1 A Novel Method for On Line Monitoring Engine Oil Quality Based on Tapered Optical Fiber Sensor (TOFS)

In the previous study the purpose of this paper is to present an online method that uses a Tapered Optical Fiber Sensor (TOFS) for monitoring the quality of engine oil in real-time(Taheri Ghahrizjani et al., 2016). Using the TOFS, the authors propose that one can use the measurement of the oil's refractive index to determine the quality of the oil, which can serve as an indication of the engine oil's condition.

A TOFS sensor is a type of optical fiber sensor that is made up of a tapered section of optical fiber arranged in a "T" shape. During the transmission of light, some of it is reflected back at the tapered section of the fiber, creating an interference pattern that can be used to measure changes in the refractive index of the medium in which the light is being transmitted. In order to test the feasibility of their proposed method, the authors used both a TOFS and a sample of engine oil in their experiments. Using the TOFS, the researchers were able to detect changes in the refractive index of the oil, which was indicative of changes in the oil's quality, as well as changes in its refractive index. Using their method, the authors suggest that the engine oil quality may be able to be monitored online, with the engine oil quality being monitored in real-time with the help of this online monitoring system. It could also help to prevent engine damage, improve engine performance and reduce maintenance costs, thereby reducing downtime and maintenance costs associated with the engine (Taheri Ghahrizjani et al., 2016).

As a whole, the paper provides an innovative and interesting approach to engine oil monitoring, and the model-based engine oil monitoring method presented in the paper may have significant implications for engine tracking and maintenance in the future(Taheri Ghahrizjani et al., 2016).

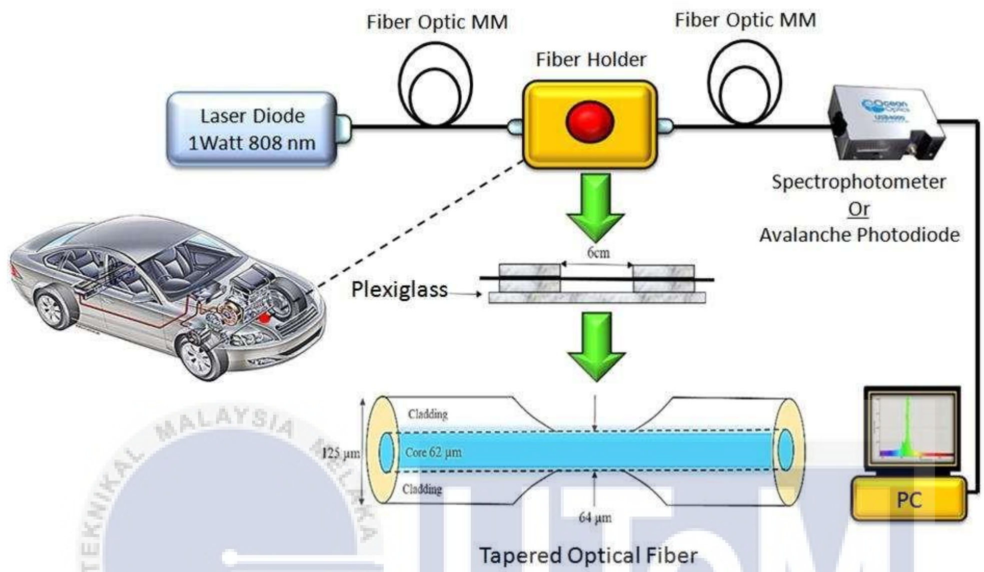


Figure 2.1 Block diagram of the experimental setup for the real-time monitoring of oil quality

2.2.2 Single Mode Fiber Optic Sensor For High Currents

It is the purpose of this article to present the development and application of a specialized sensor that uses single-mode fiber optics as a means to measure high electric currents (Veeser et al., n.d.). A single-mode optical fiber was integrated with components and materials that enable precise current sensing to be achieved in the design and fabrication of the sensor, which is described in the authors' discussion of the design and fabrication process. It is possible to detect high currents by measuring the changes in the optical properties of the fiber, such as variations in light intensity, phase, or polarization, which are caused by the interaction with high currents. There have been experimental results published in this article that demonstrate that the sensor is sensitive, linear, and responsive, establishing its accuracy in the measurement of high currents as a result of the experiments.

Using a single-mode fiber optic sensor for current sensing in this specific application has its advantages as well as its limitations, as the authors discuss the advantages and disadvantages of this method compared with other existing current sensing techniques(Veeser et al., n.d.). In addition, the article highlights the potential applications for the sensor in a variety of fields, such as electrical engineering, power systems, and industrial applications, highlighting the advantages of fiber optic sensors when used in challenging environments, for example their immunity to electromagnetic interference and their ability to operate in difficult environments. Overall, the article presents an overview of the process of developing, characterizing, and applying the single-mode fiber optic sensor developed specifically for accurate measurement of high currents, which provides valuable insights into the development, characterization, and potential applications of this device(Veeser et al., n.d.).

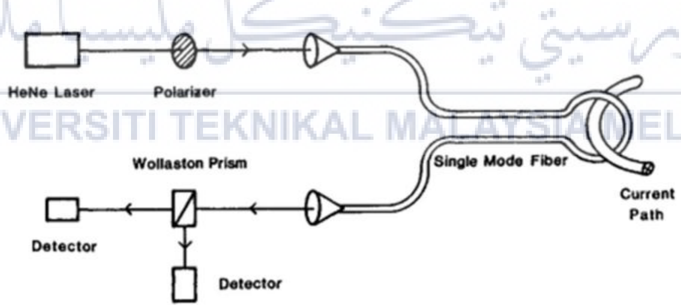


Figure 2.2 A schematic diagram of the fiber optic sensor.

2.3 Microfiber Sensor

The microfiber sensor is a type of sensing technology that has gained substantial attention in recent years due to its high sensitivity, low cost, and ease of fabrication, making it an interesting type of sensor technology. The typical design of these sensors uses fibers with small diameters, often less than ten microns in diameter, which have been coated with sensing materials such as polymers or nanoparticles that act as sensors. There are a variety of microfiber-based sensing structures available, such as biconical tapers, optical gratings, circular cavities, Mach-Zehnder interferometers, and functionally coated microfibers, as discussed in this paper(Lou et al., 2014) .These microfiber optical sensors measure refractive index, concentration, temperature, humidity, strain, and current in gas and liquid environments.

A literature review is an effort to summarize the recent developments in microfiber sensors and their potential applications in this paper. In this paper microfiber sensors are classified into three categories(Lou et al., 2014). Firstly, interference and resonance effects result in phase-based sensors. Second, loss-based microfiber sensors are enabled by optical absorption, leaky radiation, and elastic scattering. A third important component of frequency-based microfiber sensors is frequency spectral components generated by optical inelastic scatterings, parametric and nonlinear non-linear processes, and fluorescence. With their strong optical confinement and large evanescent fields, the sensors can measure a variety of physical, chemical, and biological parameters.(Lou et al., 2014)

2.3.1. Microfiber-based Sensor for Measuring Uric Acid Concentrations

For instance, this paper discusses the development of a microfiber-based sensor for detecting and quantifying the concentration of uric acid in tissues using a polymer solution (Saidin et al., 2018). Microfibers are functionalized with specific receptors or probes that can selectively bind to the uric acid molecules, resulting in a change in the optical, electrical, or mechanical properties of the microfiber because of the interaction. It is determined that the binding event has occurred and is quantified based on various transduction techniques(Saidin et al., 2018).

There are several features of the sensor that make it suitable for clinical, biomedical, and environmental monitoring of uric acid concentrations, including high sensitivity, selectivity, stability, and low detection limits. Throughout the paper, the author emphasizes the potential for microfiber-based sensors to be used for the detection of other biomolecules and analytes in a wide variety of fields(Saidin et al., 2018).

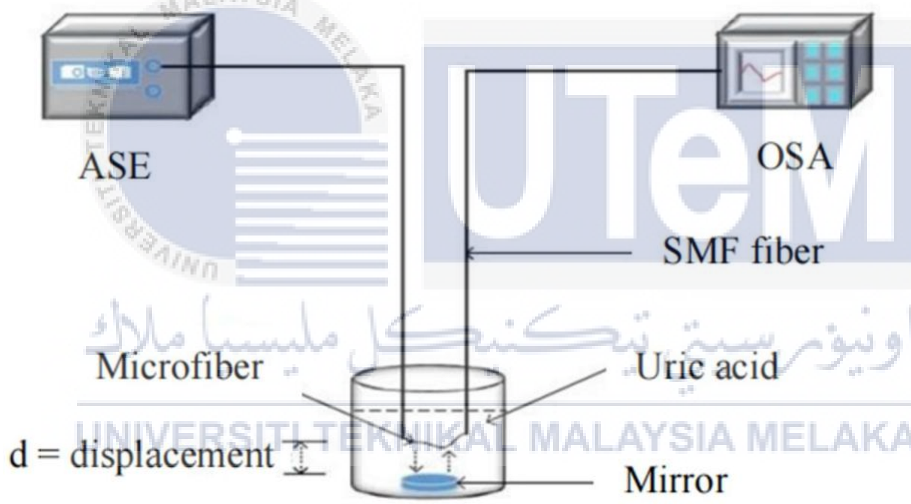


Figure 2.3 The experimental setup for measuring uric acid concentrations using microfiber FODS

2.3.2 Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor

This paper presents the performance of an micro-sphere resonator MSR-based humidity sensor that incorporates microfibers of different diameters to measure the humidity(Mohamad Ali et al., 2022). There is a method to soften and compress silica fiber used in this study, and the method is referred to as ‘soften-and-compressed’. This method creates a bulge at the end of the fiber, called the microsphere resonator (MSR), with a stem diameter of 125 mm, and a ball diameter of 200 mm. A laser source tuned to the IPI wavelength of the MSR via three microfibers with diameters of 5 mm, 8 mm, and 10 mm was used to generate the MSR (Mohamad Ali et al., 2022).

Afterwards, these structures were characterized by shifting the wavelength of the TLS from 1520 nm to 1525 nm with a delay of 0.001 nm between the two wavelengths. There was a comparison between three different diameters of the microfiber based on two parameters: linearity and sensitivity, which were used to compare the three different diameters (Mohamad Ali et al., 2022). It has been found that the microfibers with a diameter of 5 millimeters perform better than those with a diameter of 1 millimeter. Compared to the other microfibers tested, the microfiber with a diameter of 5 mm has the best performance. Due to the smallest diameter of the microfibers, the evanescent field can easily escape into the microsphere resonator through the microfiber, which then couples with the microsphere resonator since it has the smallest diameter(Mohamad Ali et al., 2022). In addition to the potential applications offered by this simple humidity sensor, it can also be used in greenhouse automatic control systems and in very humid environments.

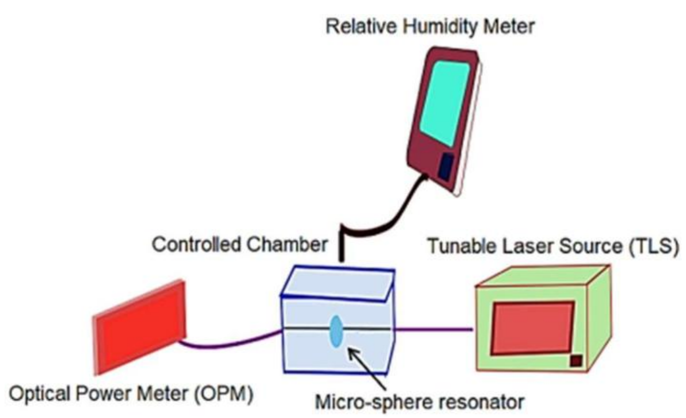


Figure 2.4 Experimental Setup for Humidity

2.3.3 Microfiber Optical Sensors: A Review

The optical microfibers, which have a diameter close to or below the wavelength of guided light and a high index contrast between their core and their surroundings, exhibit many fascinating waveguiding properties, such as customizable optical confinement, evanescent fields, and waveguide dispersion (Lou et al., 2014). Among various microfiber applications, optical sensing has been attracting increasing research interest due to the potential for developing miniaturized fiber optic sensors with high sensitivity, fast response, high flexibility and low optical power consumption, which makes it a promising field of research. The purpose of this paper is to summarize recent progress in the field of microfiber optical sensors in terms of their fabrication, waveguide properties, and applications(Lou et al., 2014). There have been several types of microfiber-based sensing structures described in this paper, including biconical tapers, optical gratings, circular cavities, Mach-Zehnder interferometers, and functionally coated/doped microfibers. Microfiber optical sensors are categorized by sensing structure, and they can be used for refractive index, concentration, temperature, humidity, strain, and current measurements in gas or liquid environments by using different sensing structures.

There have been many proposals or experimental demonstrations of microfiber optical sensors up to this point. Microfiber sensors have shown special advantages in comparison to conventional optical fiber sensors based on their short sizes and highly fractional evanescent fields (such as high sensitivity in measurements of refractive indices and fast response time at ambient temperatures and humidity levels) due to their small size and high fractional evanescent fields. Further, the tight confinement and surface enhancement provided by probing light waveguided through a microfiber are beneficial for achieving high-sensitivity with a very low optical power, which is highly desirable for many applications due to its high sensitivity and low optical power(Lou et al., 2014).

The future outlook for microfiber optical sensing presents both opportunities and challenges, such as higher sensitivity, a single molecule detection method for biochemical optical sensing, a detection limit of 10 ppb for gas sensing, and a detection limit of 10 −6 for refractive index sensing. Secondly, better selectivity can be achieved by properly functionalizing the microfiber structure so they can be used for selective detection of target samples. The third aspect is long-term stability: since it is a tiny structure that is highly sensitive to environmental changes, it is essential to obtain the highest degree of robustness for its long-term use. As a final point, a better package or protection would make a practical application easier(Lou et al., 2014).

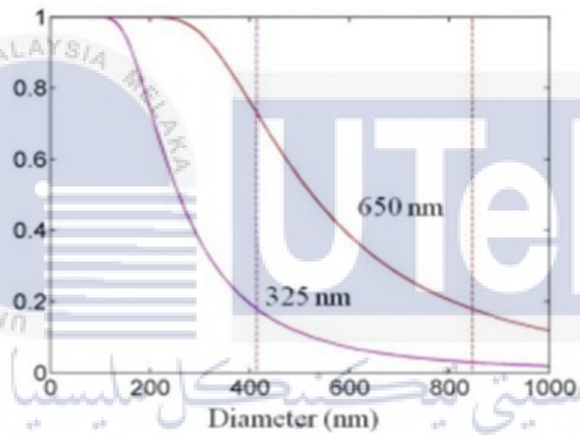


Figure 2.5 Power fractions of the fundamental mode outside the core of silica microfibers at 325 and 650

2.4 Wavelength 1310nm and 1550nm

The wavelengths 1310nm and 1550nm are crucial components in the field of optical fiber communication. The 1310nm wavelength occupies the initial window of the optical spectrum and is well-suited for medium to long-distance communication. It boasts lower attenuation in the fiber, making it historically prevalent in early single-mode fiber applications. On the other hand, the 1550nm wavelength, residing in the second window of the optical spectrum, is favored for its even lower attenuation, especially in long-haul applications. This wavelength is less susceptible to various optical losses in the fiber, allowing signals to traverse longer distances without significant degradation. In long-distance fiber optic communication, the 1550nm wavelength is often employed alongside Erbium-doped fiber amplifiers (EDFAs) to amplify optical signals effectively. The combined use of 1310nm and 1550nm wavelengths in optical fiber networks facilitates the construction of versatile and efficient communication systems catering to different distance requirements. The 1310 nm and 1550 nm are widely used to characterize an optical fiber (Nandhakumar & Kumar, 2021).

2.4.1 Backbone Optical Fiber Analysis at 1310nm and 1550nm

This journal focuses on a comprehensive examination of the central infrastructure, or backbone, of optical fiber networks. The backbone of these networks is crucial for the transmission of data, and the analysis delves into the characteristics and performance of optical fibers at two specific wavelengths 1310nm and 1550nm. The wavelengths used for the optical fibers are very small 1,550 nm and 1,310 nm are used mostly for long-distance communication because of the less attenuation(Nandhakumar & Kumar, 2021). These wavelengths hold significance in optical communication systems, with 1310nm historically being used for its lower attenuation in medium to long-distance applications, while 1550nm offers even lower attenuation and is often preferred for long-haul transmissions. The journal likely explores how optical fibers function and respond to these wavelengths, covering aspects such as signal transmission, dispersion, and other factors that contribute to the overall efficiency and reliability of optical communication systems. The insights from this analysis could provide valuable information for optimizing backbone optical fiber networks in terms of design, deployment, and maintenance.

2.5 Engine Oil Condition Detection

There is a technique known as engine oil condition detection that can be used to monitor the quality and health of engine oil in vehicles and other machinery. It is essential for the lubrication, cooling, and cleaning of engine components that engine oil is used for. Engine oil can become contaminated over time due to normal wear and tear, fuel dilution, water contamination, and oxidation, as well as other factors such as fuel dilution, water contamination, or engine contamination. Refer to this study, the engine oil needs to be changed at regular intervals as prescribed by the manufacturer, otherwise, dirt and sludge will accumulate inside the engine and this will lead to poor lubrication of the moving parts of the engine (Mohan et al., 2020). Various sensors and analytical techniques are used in engine oil condition detection systems to be able to measure key characteristics of the oil, including viscosity, acidity, and metal content, and to identify any changes or anomalies that may indicate a problem with the engine or the oil itself. In order to predict the degradation of lubricants, it has been decided to use two parameters, the viscosity, and the dielectric constant, as parameters. This is the same as the recommendation made by (Zhu et al., 2013) .Oil change intervals can be optimized, maintenance costs reduced, engine performance and longevity improved, and catastrophic engine failures prevented.In most research, oil degradation is monitored to provide early warning of machine failure and, most importantly, to extend lubrication oil's operational life, thus reducing maintenance costs and oil changes(Zhu et al., 2013).

2.5.1 Engine Oil Test Method Development

In this literature review the author focuses on developing a new method for testing the lubricating properties and ability to protect engines from wear and damage of engine oils as a way to gain a deeper understanding of the properties of engine oils (Zöldy, 2021). Using a combination of tribological techniques and chemical analysis techniques, the method was developed to simulate real-world engine conditions in a controlled laboratory environment, in which real-world engine conditions are simulated. The basic steps in this method, which can be applied to a variety of engine oils, involve selecting a set of oils for testing and then subjecting them to a series of tests designed to simulate various levels of wear and contamination as well as different levels of high temperatures and pressures. A range of tribological and chemical tests, including wear measurements, viscosity measurements, and spectroscopic analyses, are then used to analyze the oils. As a result of these tests, the results are used to evaluate the performance of each oil in different operating conditions, and in addition to that, they are used to identify any areas where improvements can be made in terms of lubricating properties and engine protection, in the future. The manufacturer and supplier of engine oil can use this information to develop new formulations that are better suited to the specific needs of the different types of engines and operating conditions to develop a more efficient engine and oil. In conclusion, the paper illustrates the importance of developing effective test methods for evaluating engine oils, as well as the potential benefits that can be achieved through more advanced testing techniques and the benefits derived from them. In order to better protect engines from wear and damage, we need to have a better understanding of how different oils behave under different conditions, to improve the overall performance and efficiency of engines.

	Sampling time	Oil conductivity index (-)
Oil A	16 h	18
	58 h	16
	100 h	14
Oil B	16 h	10
	58 h	9
	100 h	7
Oil C	16 h	8
	58 h	7
	100 h	6

Figure 2.6 Oil Conductivity index result

2.5.2 A Micro-acoustic Wave Sensor for Engine Oil Quality Monitoring

The purpose of this paper is to present and discuss the development and application of a micro-acoustic wave sensor that is designed to monitor the quality of engine oil in real-time.(Zhang, 2003). There are various parameters that are detected and analyzed by the sensor, such as viscosity, contaminants, and degradation products in the oil. The sensor is designed to provide continuous feedback on the condition of the oil in order to optimize engine performance and increase oil lifespan. This paper discusses the sensor's design principles, fabrication process, experimental validation, data analysis techniques, and possible applications in the context of its design.

Micro-acoustic wave sensors are being fabricated as miniaturized devices that are capable of interacting with oil samples as part of their function. The device detects and analyzes acoustic waves that are generated by oil's physical and chemical properties in order to determine whether the oil has been detected. During the experimental phase, a variety of engine oil samples with varying quality characteristics are used to validate the sensor's performance. The collected data is analyzed using algorithms and techniques to establish correlations between the sensor's output and oil quality parameters, based on the collected data(Zhang, 2003).

The sensor has a wide range of potential applications, including integrating into engine systems as a device capable of monitoring the engine continuously and providing continuous feedback for making timely maintenance decisions. This device is also suitable for portable oil analysis devices in workshops or remote locations because of its compact size and real-time monitoring capabilities(Zhang, 2003). It can be concluded, therefore, that this innovative micro-acoustic wave sensor is an effective solution for monitoring engine oil quality, optimizing performance, and extending the lifetime of engine oil.

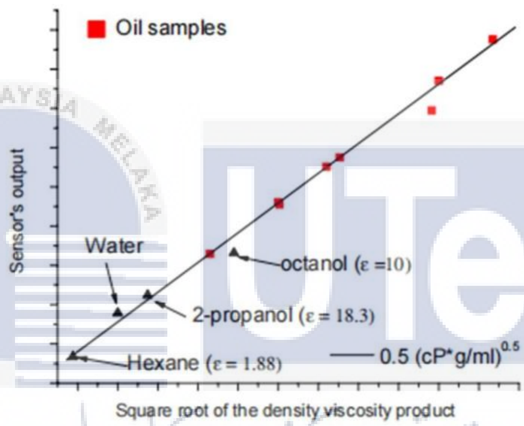


Figure 2.7 The response of the 2-sided sensor prototype to both oil and non oil samples

2.5.3 Viscosity Sensors for Engine Oil Condition Monitoring Application and Interpretation of Results

This paper focuses on the application and interpretation of the results derived from the use of viscosity sensors in monitoring the condition of engine oil(Agoston et al., 2005). A viscosity sensor is used to determine the quality and condition of engine oil using the information it provides about viscosity. The paper discusses the practical application of viscosity sensors, their integration into engine systems, as well as the interpretation of the sensor's output for making informed decisions regarding the maintenance of engine oil based on the sensor's output.

According to the paper, viscosity plays a crucial role in evaluating the oil condition and how it affects the performance of engines. This paper emphasizes the importance of a viscosity sensor's role in providing real-time measurements of the viscosity of oil, creating a means for continuous monitoring of the quality of oil in real time. Viscosity sensors are being used in practical applications in engine systems as a means of automating the process of monitoring and analyzing the trends in viscosity levels. Among the issues discussed in the paper are likely to be the interpretation of the sensor's output, including the determination of viscosity baselines, deviation thresholds and the identification of abnormal viscosity patterns that may indicate oil degradation or contamination. The information provided in this document allows informed decisions to be made regarding oil change intervals, maintenance schedules, and potential performance and durability issues that may arise during engine operation (Agoston et al., 2005). Overall, this article provides an insight into the practical application and interpretation of viscosity sensors to monitor engine oil conditions and highlight the importance of these sensors in maintaining an engine's optimal performance and extending its lifetime.

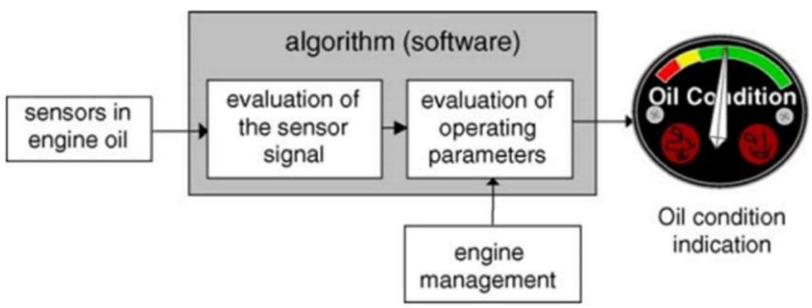


Figure 2.8 Structure of a sensor assisted algorithm for a lubrication-monitoring system

2.6 Design of Experiments (DoE)

The design of experiments (DOE) is a systematic statistical approach for organizing and carrying out tests in the areas of screening, advanced screening, and optimization(Kolekar, 2019). DOE are tools that are used to systematically examine a variety of problems that arise within, research and development and production, within the contexts of design and optimization of experiments(Badr, 2011). This method involves changing multiple variables simultaneously to identify the effect of each variable on a system, according to a predetermined experimental design, and analyzing the resulting outputs to identify what the effect of each variable is. During the process of systematically varying the input variables, the method allows for the identification of the optimal combination of input variables that are going to produce the desired output by systematically varying the input variables. DoE approach systematically varies controlled input factors to determine their effects on output responses, thus determining the most important input factors, identifying input factor settings that optimize output responses, and identifying input factor interaction.(Fukuda et al., 2018).A DoE can be used in engine calibration to optimize the engine performance by varying multiple variables at the same time and analyzing the results of the experiment. With the use of this approach, the optimal combination of input variables can be identified that will result in a desired output, such as increased fuel efficiency or a reduction in emissions, by identifying the optimal combination of input variables.

2.6.1 Comparison of Engine Calibration Methods Based on Design of Experiments (DoE)

As in this literature review, the first step that the authors took was to identify a set of six variables that were expected to have a significant impact on the engine's performance(Castagné et al., 2008). The variables that were evaluated were the intake camshaft position, exhaust camshaft position, spark timing, fuel injection timing, fuel pressure, and exhaust gas recirculation (EGR) rate. A Latin Hypercube Sampling (LHS) approach, which is a form of DoE in terms of the sampling method, was used next by the authors to design a set of experiments. To minimize the number of experiments required, the LHS method is used to select subsets of input variable combinations that are equally distributed throughout the input space to minimize the number of experiments required while still providing a good representation of the input space in the output. As a result of using the LHS method, it was possible to reduce the number of experiments necessary from 729 (when using a full factorial design) to only 27 (when using an LHS method). During the experiment, different combinations of the six input variables were used, and the output of each experiment was recorded as engine torque, representing the result(Castagné et al., 2008). In conclusion, this study provides an overview of how DoE can be used to optimize the calibration process of an engine, and how this method can be used to attain optimal performance with fewer experiments than traditional approaches.

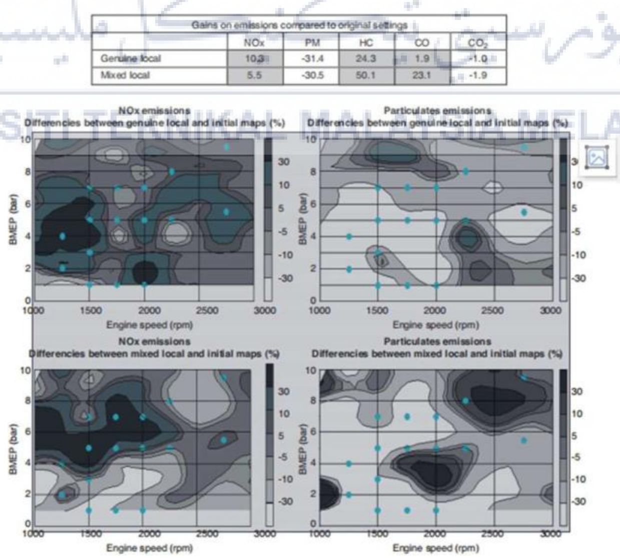


Figure 2.9 Comparison of emissions levels between initial and optimized settings.

2.7 Box Behken Design (BBD)

Box-Behnken Design (BBD) is a statistical experimental design method widely used in the field of design of experiments (DOE). It falls under the category of response surface methodology, which is employed to optimize and understand the effects of multiple variables on a response of interest. BBD is particularly useful when there are three or more independent variables, or factors, and each factor can take on three levels. The design creates a set of experimental runs at specified factor levels, allowing researchers to efficiently explore the factor space and model the response surface. BBD achieves this by selecting a set of points at the vertices of a cube (or hypercube in higher dimensions) and at the midpoints of the edges and faces, but avoiding the center. This balanced and fractional factorial design approach enables a thorough analysis of the relationships between factors and responses with a reduced number of experimental runs compared to a full factorial design. BBD is widely employed in various fields, including engineering, chemistry, and biotechnology, to optimize processes, improve product quality, and enhance understanding of complex systems.

2.7.1 Modeling and Optimization of Fiber Optic Chemical Vapor Sensor

This paper discusses the application of BoxBehnken Design (BBD) to get a mathematical model for

chemical vapor liquid detection with the objective of optimizing the optical fiber optic sensor probe.(Mulyanti et al., 1843)This paper focused on the journal is on the modeling and optimization of a fiber optic chemical vapor sensor. Fiber optic sensors are devices that utilize optical fibers to detect and measure physical or chemical properties. In this context, aim to develop mathematical models that accurately represent the behavior of the chemical vapor sensor and employ optimization techniques to enhance its performance.The interdisciplinary nature of the authors' affiliations, covering electrical engineering, informatics engineering, and electronic and system engineering, suggests a holistic approach to addressing challenges in chemical vapor sensing technology. This collaboration enables a synthesis of expertise, methodologies, and perspectives from different engineering disciplines, potentially leading to innovative solutions. Box–Behnken experimental design or BBD, which is a well known and most common multi-factorial design of response surface methodology (RSM) in various experiments has been applied in the optimization of probe sensing design (Mulyanti et al., 1843).While the specific details of the modeling and optimization strategies, as well as the outcomes of the study, are not provided in the provided excerpt, the comprehensive expertise and collaboration across diverse institutions imply a robust and multifaceted exploration of fiber optic chemical vapor sensing technology. The complete article would likely present in-depth analyses, methodologies, and findings related to the modeling and optimization of fiber.

2.8 Comparison of Project

Table 2.1 Comparison of project

	A Micro-acoustic Wave Sensor for Engine Oil Quality Monitoring (Zhang, 2003)	Engine Oil Test Method Development (Zöldy, 2021).	Viscosity sensors for engine oil condition monitoring (Agoston et al., 2005).	A Novel Method for On-Line Monitoring Engine Oil Quality (TOFS) (Taheri Ghahrizjani et al., 2016)
Sensor	Micro-acoustic wave sensor	Not specified	Viscosity sensor	Tapered Optical Fiber Sensor (TOFS)
Parameter	Oil quality, contaminants, viscosity	Oil performance, quality	Viscosity	Oil quality
Method	Design and implementation of micro-acoustic sensor	Development of a new test method	Practical application and analysis of viscosity	Design and implementation of TOFS sensor
Sensitivity	High sensitivity	Not specified	High sensitivity to viscosity	High sensitivity to oil quality
Measured	Quality, contaminants, viscosity	Oil performance, quality	Viscosity	Oil quality
Cost	Moderate	Not specified	Varies (depends on the sensor)	Not specified
Output	Real-time feedback on oil condition	Test results	Continuous viscosity monitoring	Real-time feedback on oil condition
Application	Monitoring engine oil quality, optimizing engine performance	Evaluating engine oil performance, potential applications	Continuous monitoring of engine oil viscosity for maintenance decisions	On-line monitoring of engine oil quality, potential for maintenance decisions

2.9 Summary

To be able to monitor and detect the condition of an engine's oil by using microfiber sensors, its accurate and reliable assessment is of great importance, given the fact that there would be numerous benefits available to SMEs involved in the automobile industry. However, it is vital to understand that the development of an optimized microfiber sensor design requires extensive testing and evaluation, which can be expensive and technically challenging. It should also be noted that at present there are no universally accepted methods for detecting engine oil conditions accurately using microfiber sensors, and determining the optimal combination of input parameters that produce the highest levels of sensitivity, accuracy, and durability remains a challenge. Thus, the objective of this project is to develop a method or system that is both effective and practical for assessing and detecting engine oil conditions using microfiber sensors, while minimizing the resources and technical expertise needed to implement the system. To ensure that the microfiber sensor is capable of reliably detecting changes in engine oil conditions under different conditions and environments, extensive testing and validation will be conducted during the project, as well as the resulting method is accessible and affordable to small and medium-sized businesses in the automotive industry.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed the methodology implemented in this study including the research flow that is required for the related implementation. The purpose of this chapter is to describe the method of construction of this project and how it is carried out. The step involved in developing microfiber and the optimization process of microfiber are also discussed. All the processes that are used in order to accomplish the project will be covered as well as ensuring that all the objectives are met as well. An important aspect of this methodology is that it discusses the project at an early stage in detail as well as explains the schematic diagram of the project at an early stage.

3.2 Methodology

This project proposes an innovative method for the development of a microfiber sensor that can be used to detect engine oil conditions in the SME automotive industry, as well as a systematic approach to the development of the microfiber sensor. Based on the proposed methodology, the microfiber sensor will be developed using the optimization parameters approach, which involves using the design of experiments software to identify the optimal combination of input parameters that are going to produce the highest levels of sensitivity, accuracy, and durability for the microfiber sensor. In order to determine the sensor's performance in detecting the condition of engine oil in SME automotive industries, an analytical model has been developed by which the sensor's performance is calculated and analyzed based on the performance of the analytical model. For this project, the method used is experimental, employing empirical modeling and statistical analysis to validate the sensor's performance on the basis of its performance as predicted by the empirical model. A schematic of the proposed research design can be found in Figure 3.1, which illustrates the steps involved in developing and validating a microfiber sensor.

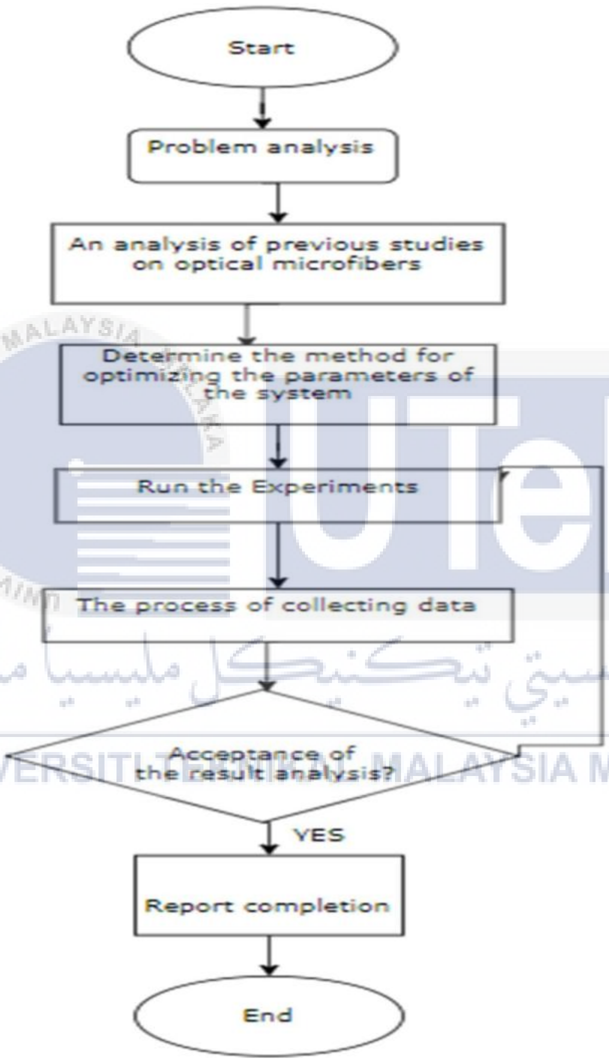


Figure 3.1 Project Flow

The first step in any research project is to precisely define the problem to be solved. This not only sharpens the focus of the research but also guides the collection of relevant data. The data collection process can then follow one of two paths, as shown in the flow chart: either conducting experiments or reviewing existing studies. For those who choose tests, the flowchart recommends careful planning and execution, emphasizing the importance of persistence until satisfactory results are achieved. On the other hand, those who rely on previous research should scour the literature for relevant information, but be careful to accept only high-quality information. After data collection, the next step involves detailed analysis, as highlighted in the flowchart, culminating in the presentation of the results in a comprehensive report. It should be noted that while the flowchart provides a comprehensive overview of the data collection process for optical microfiber research, the specific steps may vary based on the unique aspects of each project.

3.3 Experimental setup

There is an innovative and integrated approach proposed in this project that is designed with the objective of developing a microfiber sensor that can be used to detect engine oil conditions in the SMEs of the automotive industry. The approach focuses on the optimization of input parameters by using the design of experiments software in order to achieve the highest levels of sensitivity, accuracy, and durability. This project uses a quantitative methodology in order to develop an analytical model that will be used to calculate and analyze the sensor's performance on engine oil components, which is the objective of the research. An experimental approach is used, employing both statistical analysis and empirical modeling to test the hypothesis.

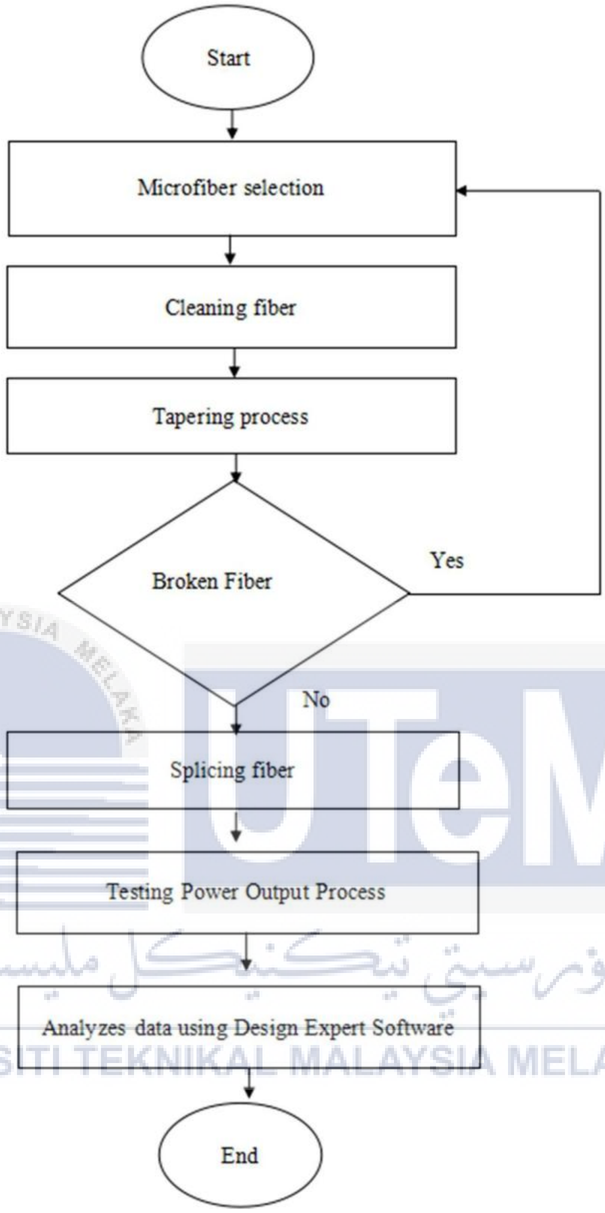


Figure 3.2 Flowchart Experimental Process

The flowchart in 3.2 detailing the power measurement process using a tapered fiber outlines a systematic procedure with distinct steps. The initial phase involves the selection of an appropriate microfiber, considering factors such as fiber type, diameter, and wavelength, all of which impact the power transmission capabilities. Subsequently, the chosen microfiber undergoes a crucial cleaning stage to eliminate any potential contaminants that might influence the accuracy of measurements.The pivotal element of the flowchart is the tapering process, wherein the fiber's diameter is systematically reduced through a combination of heating and stretching. This tapering results in a narrowed waist in the fiber, concentrating light within this region. A crucial checkpoint follows, inspecting whether the fiber is broken post-tapering. If so, the process restarts with a new microfiber; otherwise, the flow continues.The unbroken tapered fiber proceeds to the splicing phase, where it is connected to another fiber facilitating the transmission of light to the detector. The subsequent step involves testing the power output by directing light through the fiber and measuring the emerging light at the other end. Finally, the flowchart incorporates the use of Design Expert software for the comprehensive analysis of data, emphasizing the importance of sophisticated tools in interpreting the outcomes of the power measurement experiments.In essence, this flowchart encapsulates a multifaceted process, offering a detailed glimpse into the intricate steps involved in accurately gauging the power output of tapered fibers, ultimately contributing to advancements in optical measurements and research.

3.3.1 Parameters

Microfiber sensors are a potential technology in the automobile sector for measuring the state of engine oil. The state of engine oil can provide important information about an engine's health and performance. Temperature, oxidation, and contamination may all cause engine oil to deteriorate over time. This can have an effect on the lubricating characteristics of the oil and potentially cause engine damage. When a microfiber sensor comes into touch with engine oil, it detects changes in the optical characteristics of the microfiber. When light is transmitted through the microfiber, it interacts with the engine oil and can be scattered or absorbed differently depending on the condition of the oil. This change in light can be measured and used to determine the condition of the engine oil.

Optimizing the parameters of the microfiber sensor can improve its sensitivity and accuracy in detecting the condition of engine oil. The optimum wavelength can be determined through experimental testing to maximize the sensitivity and accuracy of the sensor. With probing light waveguided along a microfiber, it is possible to achieve high sensitivity with extremely low optical power, which is highly desirable for many applications, because of the tight confinement and surface enhancement of the probing light waveguided along the microfiber (Lou et al., 2014). In order to achieve the single mode operation and low loss requirements of their simulations, they adopted the following strategy, they chose the wavelength for operation to be 1.550 m, and the diameter of microfibers to be 0.3 m to 0.55 m, based on the wavelength used in (Shi et al., 2007).

The diameter of the microfiber is another important parameter to consider. Smaller diameter microfibers may have higher sensitivity due to their higher surface area-to-volume ratio. Microfiber is made by extending optical fibers until they reach a desired waist diameter while retaining the original fiber sizes at their inputs and outputs(Jali et al., 2021).However, they may also be more prone to bending and breaking. The optimum diameter of the microfiber can be determined by balancing sensitivity and robustness. Fiber diameter changes cause some light to pass through the core and cladding layers of the fiber, creating an evanescent field that decays exponentially into the external medium as a function of refractive index (Mustapha Kamil et al., 2023)]. As the diameter of the fiber decreases, the output intensity also decreases which is related to the level of sensitivity of the sensor as well (Taheri Ghahrizjani et al., 2016).

Different types of microfibers can also be used in the sensor depending on the specific characteristics of the engine oil being monitored. Silica, polymer, and metal microfibers all have different optical properties that can affect the sensitivity and accuracy of the sensor. Then, the concentration of the engine oil being monitored can affect the signal detected by the sensor. The sensor should be calibrated to detect the specific concentration range of interest. Experimental testing can be used to determine the optimum concentration range for the sensor. While the calibration curves should be tailored to the individual oil life cycles of each oil-producing company, it should be noted that each oil-producing company uses its own chemical composition, which means that calibration curves should be designed for each oil life-cycle, as described by (Taheri Ghahrizjani et al., 2016). During the testing, one type of oil was tested on two different types of vehicles, one was a high-performance vehicle (HPV) and the other was a low performance vehicle (LPV)(Taheri Ghahrizjani et al., 2016).

Overall, optimizing these parameters can result in a microfiber sensor with high sensitivity and accuracy for detecting the condition of engine oil in the SME automotive industry. This can help improve engine performance, reduce maintenance costs, and increase the lifespan of the engine.

3.3.2 Equipment

It is important to emphasize that the tapering process is an important technique when it comes to the development of optical fibers, including the development of microfiber sensors for detecting the condition of engine oil in the automotive industry. In this process, the diameter of the fiber is gradually decreased along its length, resulting in the fiber forming a conical shape, which enhances the sensor's sensitivity and selectivity by increasing the conical shape along its length. It is common to use a variety of equipment during the tapering process, such as a tapering machine, a fiber holder, a heating source, a pulling mechanism, and an optical microscope to carry out the operation.

1. Tapering Machine : the tapering machine is composed of a motorized pulling mechanism. as well as a heat source, as well as a control system that can adjust parameters such as the speed of the pulling and the temperature of the heat source.

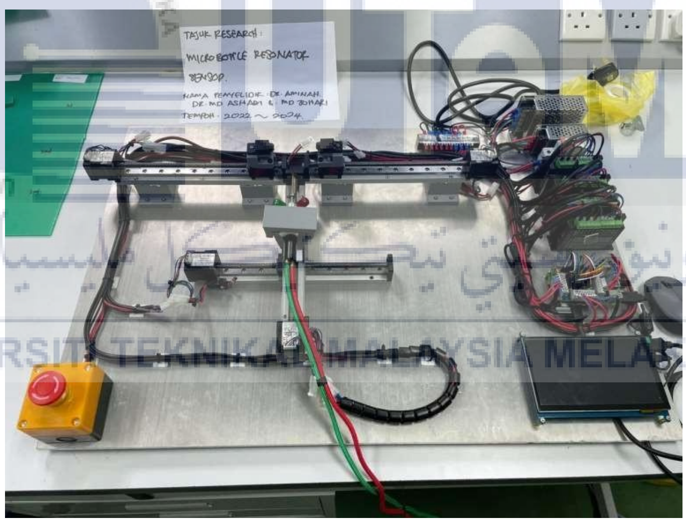


Figure 3.3 Tapering Machine

2. Heat Source: Heat sources are essential components of the process in which the process takes place. The source of heat is generally in the form of a high-temperature flame or an electric arc, depending on the situation. The purpose of this device is to apply controlled heat to the fiber optic cable during the process of tapering it.

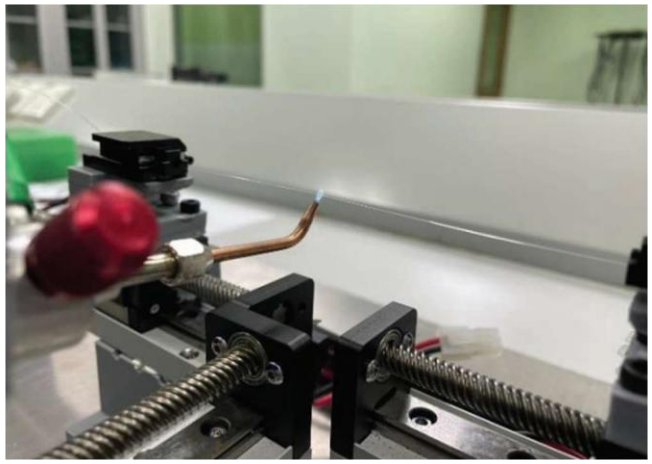


Figure 3.4 Heat source

3. Fiber Holder: In the process of tapering a fiber optic cable, the fiber holder is a very important component because it secures the fiber optic cable during the process. It is important to ensure proper alignment and stability of the fiber by using a fiber holder, so that precise and controlled tapering can be accomplished.

Figure 3.5 The Fiber Holder

4. Pulling Mechanism :A pulling mechanism is used to stretch the fiber while it is being heated, and an optical microscope is used to monitor the tapering process in order to determine if the desired shape is being obtained during the tapering process.In summary, it can be said that the

use of these pieces of equipment in the tapering process can ensure that accurate and reliable microfiber sensors can be developed for the automotive sector.

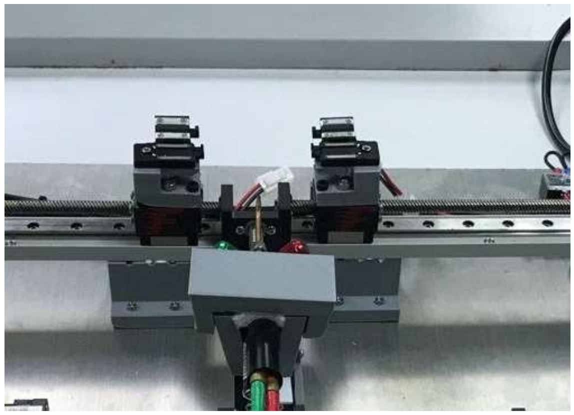


Figure 3.6 Pulling Mechanism

Next the fusion splicing technique is a means of permanently joining two fiber optic cables together using either an electric arc or a laser to create a low-loss connection between them. The technique is widely used in fiber optics for extending network reach, connecting cable segments, and repairing damaged fibers in a variety of applications.

1. Fiber Stripper: A fiber stripper is a tool that is used to remove the protective coatings on fiber optic cables before they are fusion spliced. It is possible to remove the coating precisely and control using these tools without causing any damage to the fiber. It is important to note that different strippers are available for different fiber sizes and coating materials.

Figure 3.7 Fiber Stripper

2. Fiber optic cleaning wipe: It is a specialist cleaning tool that is used for the maintenance and installation of fiber optic networks. The product is designed for the purpose of effectively cleaning and removing contaminants from fiber optic connectors and components on the surface of them.

Figure 3.8 Fiber Optic Cleaning Wipe

3. Fiber Cleaver: A fiber cleaver is used to cleave or cut the fiber accurately before it is spliced with the help of a fusion splicer. It provides a clean and flat surface at the end of the tube to ensure the best alignment. A cleaver can be distinguished into three types: one with a blade-based design, one with a score-and-break design, and one with a scribe-and-break design. To ensure reliable fusion splicing, high-quality cleavers are required to produce consistent and accurate cleaves.

Figure 3.9 Fiber Cleaver

4. Fiber Holders and Alignment Devices: During the fusion splicing process, fiber holders and alignment devices are used to hold and align the fibers securely. A fiber fusion device ensures that the fibers are properly aligned and stabilized, as well as ensuring that they are properly positioned and stabilized. A variety of fiber sizes and types can be accommodated by these devices.

Figure 3.10 Fiber Holders and Alignment Devices

5. Fusion Splicer: The fusion splicer is the primary piece of equipment that is used for aligning and fusing optical fibers together. An electro splicing chamber is comprised of an electrode assembly, a splicing chamber, and a high voltage source. Various types of fusion splicers are

available on the market, such as fixed V-groove splicers, cladding alignment splicers, and core alignment splicers. This type of equipment offers a variety of features, including automated alignment, real-time monitoring, and the opportunity to program splicing parameters.

Figure 3.11 Fusion Splicer

6. Splice Loss Tester: A splice loss tester is used to verify the quality of the splice by measuring the loss on the splice. This device measures the optical loss across the spliced joint to ensure that it meets all the specifications required. The performance of the splice can be assessed by performing this test and determining whether there are any potential problems at the splice site.

Figure 3.12 Splice Loss Tester

3.3.3 Fabrication of Microfiber

The tapering of a single-mode optical fiber is normally accomplished either by chemically etching the fiber cladding or by heating and pulling both ends of the fiber together to reduce the diameter of the fiber. In order to taper an optical fiber, a region of the fiber is produced that has a reduced diameter and a uniform shape (the waist) enclosed by conical sections whose diameter changes as soon as the tapered section merges with the unperturbed surrounding fiber(Korposh et al., 2019). Flame brushing, chemical etching, mechanical stretching, and flame brushing are the most common techniques for tapering optical fibers. The tapering process involves heating and stretching a single-mode optical fiber to reduce its diameter in a controlled manner. This process causes the fiber diameter to gradually decrease as the glass flows. During the heating process, the fiber is either heated by a flame or a high-voltage electric arc until it reaches the softening point, which is typically around 2000 degrees Celsius. Heating the fiber slowly reduces its diameter. As tapered fibers get smaller in diameter, the difficulty in handling them increases, because thinner tapered fibers have a very fragile and lossy structure (Harun et al., 2013).

A very important aspect to consider during the fiber optic preparation process before the tapering process is the cleanliness of the fiber surface that will be subject to the heat source. In the presence of dirt or acrylate on the fiber's surface while it is being heated, light intensity drops abruptly, causing non-uniformities in its profile and non-adiabatic tapers(Graf et al., 2009).Stretching is controlled at the right rate to ensure that the tapering process is uniform and that the diameter is reduced gradually as the tapering process develops. Depending on the length of the fiber, a long taper can be created or a short taper can be created. It was found from a quantitative analysis that by increasing the number of tapering sweeps and shortening the length of the hot zone formed by the heater, the mismatch error in this technique decreases(Talataisong et al., 2018).In addition, this technique also allows the fabrication of biconical tapered fibers where the tapered fiber is connected to a single-mode fiber (SMF) at both ends(Al-Askari et al., 2016).Fibers can be tapered to change their properties, such as their mode field diameters and numerical apertures, which may influence the properties of light propagation.

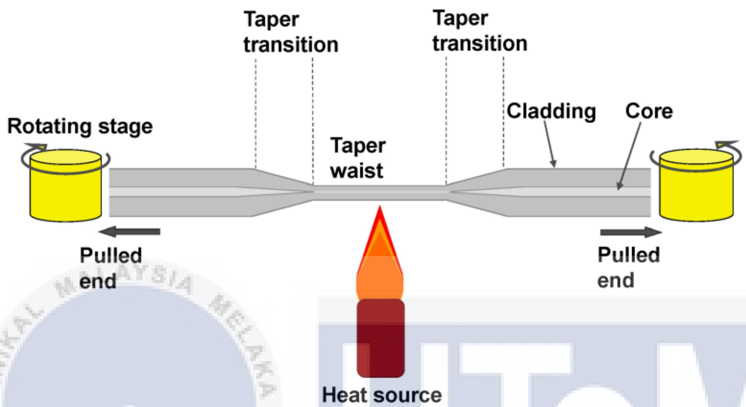


Figure 3.13 Tapering optical fiber sensor

3.3.4 Splicing of Fiber Optic

The fusion splicing process is one of the most used techniques in optical telecommunication networks in order to permanently connect the ends of fiber together (El-Diasty, 2004). Two fiber optic cables are joined to create a continuous optical path for light signals. After removing the outer layers, the fibers are cleaned and cleaved. Fusion or mechanical splicing techniques are then used to align and connect them. As opposed to mechanical splicing, which uses alignment devices and connectors, fusion splicing uses heat to melt and fuse fibers. Various methods are used to safeguard the fibers from the environment.

Splicing fiber optics plays a vital role in the expansion and maintenance of fiber optic networks. It allows the extension of the network reach, connecting different cable segments, and repairing damaged fibers to the network. A skilled technician with specialized tools and equipment performs the splicing procedures accurately. The quality and precision of the splicing directly impact the performance and efficiency of the telecommunications network. The fusion splices provide the highest quality connection with the lowest loss within the range of 0.01 dB to 0.10 dB compared to the mechanical splices which provide a loss in the range of 0.05 dB to 0.2 dB for SMF connections (Ahmad, 2017).

During splicing, the layers of the cable are carefully removed, the fibers are cleaned and cleaved, and fusion or mechanical splicing techniques are used to align and connect all the fibers together. As a result of the protection of the joint, long-lasting, and reliable connections can be achieved. According to experimental results, even though fiber pairs with 3% core eccentricity have been spliced with a loss of less than 0.05 dB in fiber pairs with 3% core eccentricity, splicing nonetheless is possible (Kawata et al., 1984).

Fiber optic splicing is essential to the growth and maintenance of telecommunication networks, the transmission of high-speed data, and the creation of efficient communication systems, so it is essential for telecommunications. For modern telecommunication infrastructure to function correctly and efficiently, skilled technicians are critical to performing accurate splicing, which directly impacts the performance and efficiency of the system.

Figure 3.14 Splicing Machine

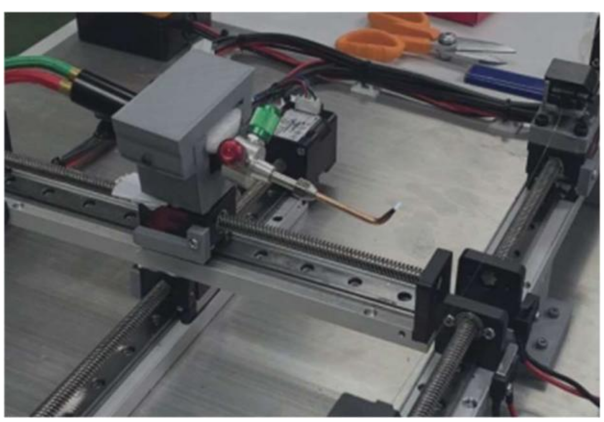
3.4 Experimental Process

3.4.1 Tapering Process

Table 3.1 Tapering Process

No	Procedure	Description
1.		Remove the protective coating from the fiber optic cable. This will expose the bare fibers that will be tapered upon removal of the protective coating.

2.		Clean the fiber using fiber alcohol wipe to remove the dust and other thing
3		Place the microfiber tails on both side carefully on the fiber holder.So the fiber cannot move.
4		Turn on the heat source and control the flow of air and gas to make a small flame of the perfect size

5		In order to perform this operation, a torch must move forward and heat the center of a fiber while in the same time pulling the fiber holder .
6		After the fiber has been stretched and the diameter at the center of the fiber has been reduced, stop the process
7		Turn off the heat source after moving back

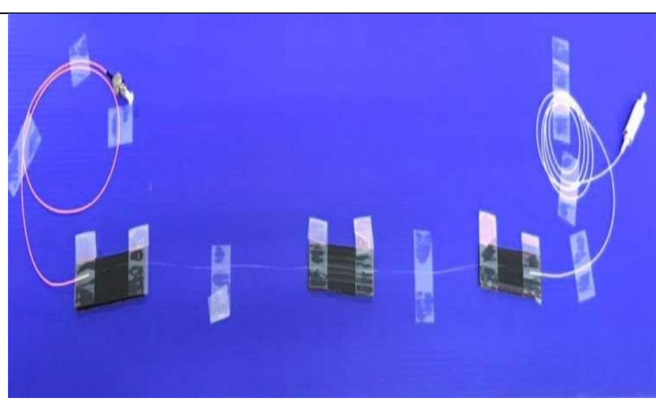
8		Remove the fiber from fiber holder carefully.The fiber may broken if not handle well .
9		Place the tapered fiber on the impra board

3.4.2 Splicing Process

Table 3.2 Splicing Process

No	Procedure	Description
1.		Remove the protective coating from the fiber optic cable

2.		Clean the fiber using fiber alcohol wipe to remove the dust and other thing
3.		The fiber ends should be cleaved with a fiber cleaver in order to create a clean and flat surface.
4.		Repeat step 1 untill 3 to the single mode or multimode connector

5.		Place the fiber and cable to the fiber holder carefully
6.		Press the ‘SET’ button and wait for the connection between fiber and cable
7.		The result of splicing will appear after the process finish
8.		Carefully placing the complete connection on the impra board will ensure that no mistakes are made

3.4.3 Data Collection

PARAMETER	LOW LEVEL (-)	HIGH LEVEL (+)
TYPE OF FIBER	Singlemode	Multimode
TYPE OF WAVELENGTH	1310nm	1550nm
TYPE OF DIAMETER	9u	11u

3.4.3.1 Type of Analysis

i. Half Normal Plot

The Half Normal Plot is a graphical tool used in DOE (Design of Experiments) to assess the significance of factors and identify possible outliers or influencing factors in a statistical model. In an experimental design, researchers often study the effect of various factors on the response variable. The Half Normal Plot is particularly useful in examining experiments where the main goal is to effectively identify the most influential factors. To form a half normal plot, the absolute values of the estimated effects of factors are plotted as a function of their respective factor combinations. These combinations are often ranked by effect size. The Half Normal Plot allows researchers to visually distinguish between significant and non-significant effects. Factors with a greater plot absolute value are considered more influential. If a point falls above a certain threshold line on the half-normal curve, it indicates that the corresponding factor has a significant effect on the response variable. Conversely, scores below the threshold indicate factors with less influence. This graphical representation helps researchers prioritize factors for further study or improvement in subsequent experiments. In conclusion, the Half Normal Plot is a valuable tool in the early stages of experimental design to help researchers effectively identify key factors and guide the optimization of experimental conditions.

ii. Normal Plot

In the context of DOE (Design of Experiments), a normal plot is a graphical tool used to assess the normality of the residuals of a statistical model. Residuals are the differences between observed and predicted values, and their normal distribution is an important assumption in many statistical analyses. The normal plot is particularly useful in confirming this assumption. To form a normal plot, ranked residuals are plotted based on the expected rank statistics of a standard normal distribution. If the residuals follow a straight line on the graph, this indicates that the assumption of normality is acceptable. Deviations from a straight line can be a sign of deviations from the normal, such as deflection or deviations. Researchers usually use a normal plot after fitting a statistical model to experimental data. If the curve shows an approximately straight line, this gives confidence in the assumption of normality, which supports the correctness of subsequent statistical inferences. On the other hand, if the graph shows significant deviations, it can prompt researchers to investigate the source of the deviation and consider alternative modeling methods. In summary, the standard DOE plot serves as a diagnostic tool to assess the normality of the residuals, helping researchers to ensure the appropriateness of the statistical model and the reliability of subsequent analyses.

iii. Pareto Chart

A Pareto chart is a graphical tool used in design of experiments (DOE) and various quality improvement processes to identify and prioritize the most important factors influencing a given outcome. The table is named after the Italian economist Vilfredo Pareto. He found that most effects are usually explained by few causes. A Pareto chart is a visual representation of the 80/20 rule, where about 80% of the effects come from 20% of the causes. In the DOE context, a Pareto chart is often created after experiments have been conducted to determine the effect of various factors on a response variable. A graph usually shows the factors on the x-axis in descending order of their influence on the total variation or influence. Corresponding bars on the y-axis represent the effect size of each factor . A Pareto chart helps researchers and practitioners quickly identify the most critical factors to focus on for improvement or further research. This allows a clear distinction between the important few important factors that have a significant effect and the trivial many that have a smaller effect. The Pareto chart allows DOE practitioners to effectively prioritize their efforts and resources by focusing on impact factors first. This graphical representation facilitates decision making by providing a visual summary of the main drivers of observed variability in the response variable, helping to optimize processes and outcomes.

iv. Effect List

An Effect List in the context of Design of Experiments (DOE) is a condensed presentation summarizing the effects of different factors on the response variable in an experimental study. DOE involves systematically altering input factors to observe their influence on the response, and the Effect List serves as an organized way to convey this information. It includes estimated effects, quantifying the changes in the response variable with variations in each factor. These effects are classified as main effects and interaction effects. Main effects signify the average change in the response variable when altering one factor while keeping others constant, whereas interaction effects capture the joint impact of two or more factors, distinct from their individual effects. Typically structured as a table, the Effect List has columns for different factors and their levels, and rows indicating effect types. Analyzing this list is vital for DOE practitioners to discern significant factors and their magnitudes, aiding in the identification of key elements for optimizing processes or systems. In essence, the Effect List is a valuable tool in interpreting experimental outcomes, presenting a concise overview of how diverse factors affect the response variable in a designed experiment.

v. Anova Analysis

ANOVA, or analysis of variance, is a statistical technique widely used in design of experiments (DOE) to evaluate the significance of variations in the means of multiple groups or levels in an experimental study. In DOE, ANOVA is used to examine the variation of response variable of different factors and their interactions. The basic concept involves dividing the total observed variance of a response variable into separate components, such as variance due to main effects of individual factors and variance due to interactions between factors. ANOVA analysis compares the ratio of variance of different factors. groups within groups are produced by the F statistic. A higher F statistic indicates a more pronounced difference between group means. The researchers then use this statistic to test whether the observed differences are statistically significant or could be due to chance. A significant F statistic indicates that at least one factor or interaction has a significant effect on the response variable. ANOVA is a powerful DOE tool to help identify influential factors in test results. It also helps to understand the relative importance of different factors and their interaction. ANOVA results play a crucial role in guiding researchers to make informed decisions about process or system optimization by focusing their efforts on the most influential factors. In general, ANOVA is the main statistical technique in the analysis phase of DOE and provides valuable information about the sources of variation in experimental data.

vi. Normal of Residual

In the field of design of experiments (DOE), evaluation of the normality of residuals is a fundamental part of statistical analysis. Residuals are the differences between the observed and predicted values of the response variable. A normal probability plot of residuals is a graphical tool used to examine whether these residuals follow a normal distribution. The basic assumption is that the residuals should be normally distributed for statistical inferences drawn from experimental data to be valid. To create a normal probability plot of the residuals, the ordered residuals are plotted against the expected quantiles of the standard normal distribution. If the points on the graph form an approximate straight line, this indicates that the residuals follow a normal distribution. On the other hand, deviations or patterns in a chart can indicate deviations from the norm, such as trends or outliers. Analysis of the normal probability plot of the residuals is critical for DOE operators to ensure the assumption of normality and the accuracy of the statistical model. Non-normality of residuals can affect the reliability and confidence interval of hypothesis testing. Identifying and dealing with deviations from normality allows researchers to make more reliable statistical inferences and ensure the validity of conclusions drawn from experimental data. In conclusion, the normal probability plot of residuals is a valuable diagnostic tool in DOE to help researchers assess the normality of residuals and increase the confidence of statistical analyses.

vii. Residual vs Predicted Plot

A residual versus predicted plot is a graphical tool commonly used in statistical analysis, including design of experiments (DOE), to assess the fit of a regression or prediction model. In the DOE context, where the goal is often to understand the relationship between the input factors and the response variable, this plot helps evaluate the model and performance. Leftovers vs. in the predicted plot, the residuals (differences between the observed and predicted values of the response variable) are plotted as a function of the predicted values themselves. The horizontal axis represents the predicted values, while the vertical axis represents the corresponding residual values. A well-fitted model would have a random spread of scores around zero on the vertical axis, indicating that the residuals are uniformly distributed in the range of predicted values. Patterns or trends in the residual versus predicted curve can reveal important information about the model and performance. If the graph shows a systematic pattern (such as a curve, an increasing or decreasing trend), this indicates that the model may not adequately capture the underlying relationships in the data. Additionally, the plot can help identify outliers or influential observations that may disproportionately affect the model and performance. Analyzing the residuals and predicted plot analysis is necessary to confirm the assumptions of the regression model and ensure the adequacy of the model to make reliable predictions. If problems are discovered in the graph, researchers can revisit the model, consider transformations, or include other factors to improve its accuracy. In summary, residuals vs. The Predicted Plot is a valuable diagnostic tool for DOE that helps researchers assess the quality of their forecasting models.

viii. One Factor Effect Plot

A one factor effect plot is a graphical representation commonly used in design of experiments (DOE) to illustrate the effect of a one factor on a response variable. In DOE, researchers manipulate various factors to observe their effect on an outcome of interest. A one-factor effect plot is particularly useful for examining the effect of one particular factor while holding other factors constant. This curve shows the values of the response variable on the vertical axis and the levels or values of the individual factor being studied on the horizontal axis. Each point on the graph corresponds to the average response at a given level or value of the factor. By visually examining a one-factor effect plot, researchers can observe trends or patterns in how changes in the factor relate to changes in the response variable. A plot can reveal whether there is a linear relationship, a non-linear trend, or other significant patterns. A one-factor effect plot provides valuable information about the effect of a single factor on the outcome of an experiment. This helps researchers identify optimal levels of agent to achieve desired responses, guide decisions about process optimization or further testing. In general, the single-factor effect diagram is a practical tool for visualizing and interpreting the effects of individual factors in DOE studies.

ix. Interaction Effect Plot

An interaction effects diagram is a graphical representation often used in design of experiments (DOE) to illustrate the combined effect of two or more factors on a response variable. In experimental design, researchers often study not only the individual effects of factors, but also how these factors interact with each other. The interaction effect plot is particularly valuable for visualizing and understanding the interaction of factors on test results. In this graph, the values of the response variable are plotted on the vertical axis, while the levels or values of the two interacting factors are shown on the horizontal axis. Different lines or curves on the graph represent the response with different combinations of factor levels, allowing researchers to observe the interaction of the factors. Analyzing an interaction effect plot helps researchers identify whether the effect of one factor on a response variable depends on the level of another factor. The plot may show parallel lines indicating the absence of interaction, or lines that cross or diverge indicating the presence of interaction. Understanding interactive effects is critical to optimizing processes or systems because it provides insight into how the combined variety of factors affect the results of an experiment. Interaction effect plots help researchers make informed decisions about how factors interact and guide the adjustment of experimental conditions to improve performance.The Interaction Effect Plot is a valuable tool to visualize and interpret the interaction of interaction of factors in DOE studies, improving researchers and ability to optimize processes and achieve desired results.

3.5 Design of Experiment Process

The Design Expert software is employed for the analysis phase, following the method described earlier. A Box-Behnken design, which is a type of experimental design used in response surface methodology. Response surface methodology is a set of statistical techniques used to model and optimize the relationship between independent variables (also known as factors) and a response variable.

The Box-Behnken design is useful for modeling quadratic relationships between the independent variables and the response variable. It is a rotatable design, which means that the variance of the predicted response is the same at all points equidistant from the center of the design space. This makes it a good choice for experiments where the experimenter is not sure of the shape of the response surface.

Figure 3.15 Specifying name,units and type of factors

The figure 3.15 focus on enhancing expertise in solving data analysis problems, the provided table becomes a valuable resource. It encapsulates the responses of various fibers under distinct conditions, offering a comprehensive exploration of the interplay between fiber characteristics and response metrics. The table's key parameters include the fiber type (Singlemode or Multimode) is categoric and the wavelength (1310nm or 1550nm), the diameter (9.00um or 11.00um), and the concentration (1000 or 85) is all of which contribute to the measured response in POWER units. Given this dataset, a multitude of analyses becomes possible. One can discern trends by finding the average response for specific fiber types or wavelengths, identify optimal conditions by pinpointing the maximum response under different scenarios, explore variations by calculating response differences between two fibers, or visualize the relationships by plotting response against wavelength or diameter. The depth of insights achievable from this data ensures a robust foundation for informed decision-making and targeted improvements in the realm of data analysis and fiber characterization.

Std	Run	Factor 1 A:Type of fiber	Factor 2 B:Wavelength	Factor 3 C:Diameter	Factor 4 D:Concentrat...	Response 1 POWER
13	1	Singlemode	1310	9.00	1000	43
10	2	Singlemode	1550	9.00	1000	59.39
5	3	Singlemode	1310	11.00	1000	56.64
15	4	Singlemode	1550	11.00	1000	42.06
9	5	Multimode	1310	9.00	1000	41.23
2	6	Multimode	1550	9.00	1000	59.27
12	7	Multimode	1310	11.00	1000	42.53
14	8	Multimode	1550	11.00	1000	59.3
7	9	Singlemode	1310	9.00	85	75.09
16	10	Singlemode	1550	9.00	85	64.17
4	11	Singlemode	1310	11.00	85	73.48
1	12	Singlemode	1550	11.00	85	67.48
8	13	Multimode	1310	9.00	85	67.57
6	14	Multimode	1550	9.00	85	62.51
3	15	Multimode	1310	11.00	85	70.32
11	16	Multimode	1550	11.00	85	58.29

Figure 3.16 Matrix Design

As in figure 3.16 all of values representing factors and responses is conducted by accessing the "Analysis" section. Within this section, there are five tabs: Transform, Effects, ANOVA, Diagnostics, and Model Graphs. The Transform tab facilitates data transformation. The Effects tab offers valuable tools like the Half Normal Plot and Normal Plot, instrumental in discerning significant and insignificant effects. Moving on to the ANOVA tab, it furnishes an analysis of variance for all significant effects and establishes the mathematical model for the response. The analysis process proceeds to the Diagnostics tab, which contains several plots for standardized residuals and constant errors, aiming to identify influential values or outliers. Finally, in the Model Graphs tab, various graphical tools, including One Factor, Interaction, and Cube, are available to explore how each factor influences the response individually or in conjunction with other factors.

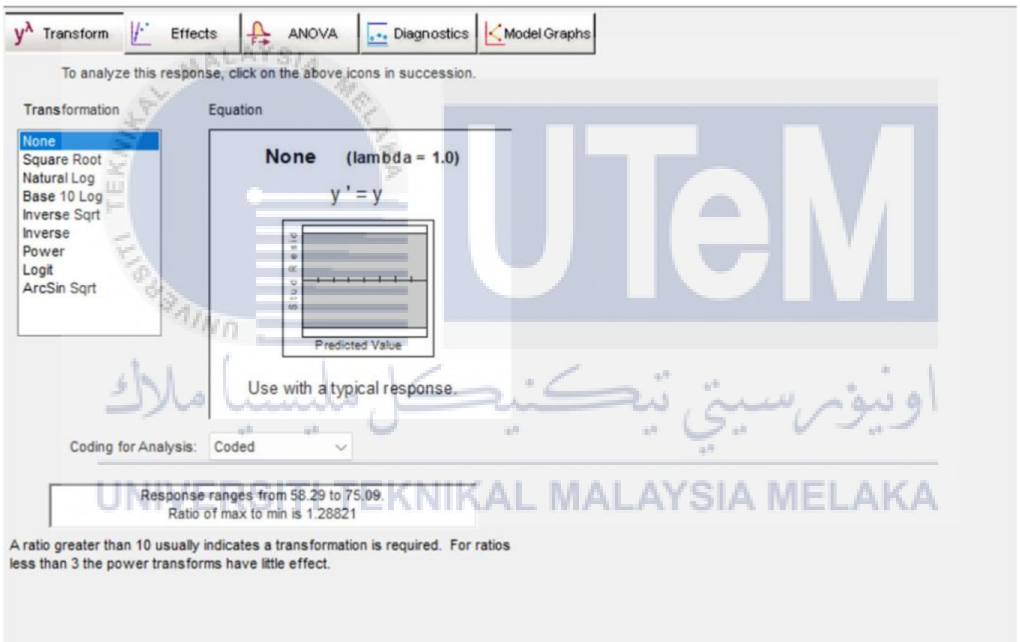


Figure 3.17 Analysis Section

To conclude the analysis stage and align with the research objectives, select "Numerical" in the Optimization section to generate optimal solutions. Within the Criteria tab, there are options to specify the goal for each response. For this research, the goal for all responses is configured to be "maximize," aiming to identify the optimal combination of parameters that enhance the optimization of fiber optics and achieve the maximum output power as in figure 3.17 . This step ensures that the research objectives, focused on optimizing the fiber optic system, are met by seeking the highest achievable output power through the designated parameters.

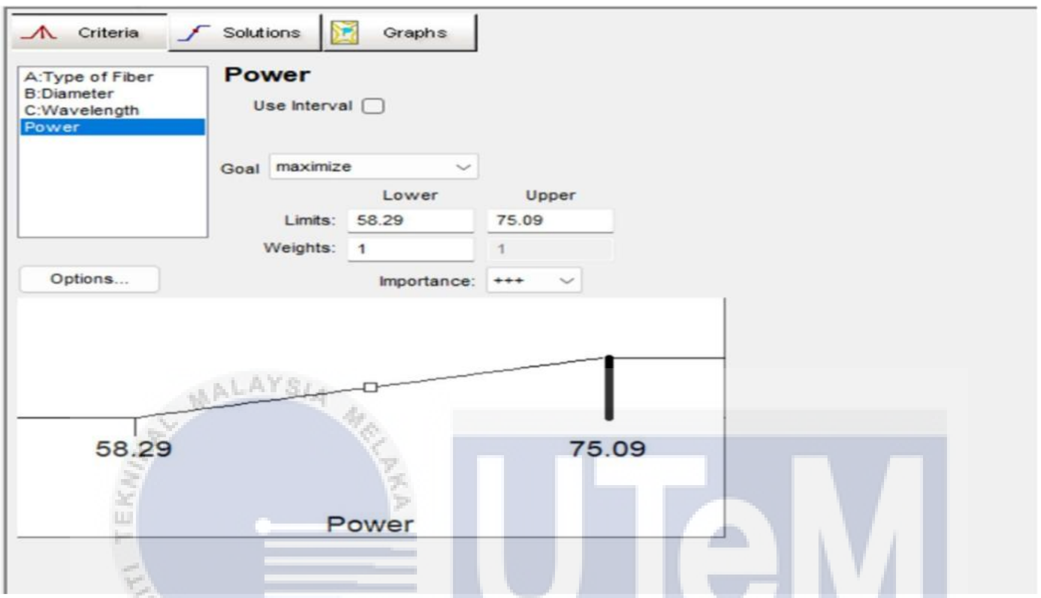


Figure 3.18 Optimization Section

3.6 Limitation of proposed methodology

In spite of the fact that the development of a microfiber sensor to detect the condition of engine oil has the potential to provide several benefits to the SME automotive industry, there may also be several limitations to consider. A major limitation of this type of investigation is the potential for the testing environment to be limited, which could affect the accuracy and reliability of the results as a result. Moreover, the development of microfiber sensors may prove to be a costly as well as technically complex process, requiring expertise in a variety of disciplines, which may limit their accessibility to smaller companies with limited resources. It may also be necessary to comply with specific regulations and standards, increasing complexity and costs. Additionally, there may be other similar technologies or sensors available on the market that are similar to the microfiber sensor and can achieve the same results, which could limit the demand for the microfiber sensor as well as its commercial viability. In order to minimize the impact of these limitations, it is crucial that careful planning and strategic development are undertaken to minimize their effects.

3.7 Summary

In summary, the methodology presented in this chapter serves as a systematic guide for the development of a microfiber sensor, placing a strong emphasis on optimizing parameters to achieve heightened accuracy and sensitivity. The detailed exploration of experimental processes, coupled with through insights into data analysis techniques and the pivotal role of the Design of Experiment process, enhances the clarity of the research approach. The acknowledgment of potential limitations reflects a pragmatic and thoughtful perspective, underlining the need for careful planning and strategic development to effectively address challenges. Ultimately, the outlined methodology provides a well-structured and strategic framework tailored for the creation of a microfiber sensor specifically designed for applications in the automotive industry.The performance of the sensor is validated and verified using samples from the automotive industry, and parameters are optimized for implementation. In this methodology, microfiber sensors will be developed to detect engine oil conditions with high accuracy and reliability for the SME automotive sector.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and analysis of microfiber sensors developed using Design Expert software and Box Behken Design (BBD) optimization parameters approach the SME automotive industry. The expected result will be planning in this phase.The input in this project will be considered to produce the required output.

4.2 Experimental Setup

The experimental setup for this project is detailed in Figure 4.1, which illustrates the power measurement of an optical fiber sensor for an engine oil sensor. In this setup, the engine oil to be tested is fed to a fiber optic sensor, as shown in Figure 4.1. The process involves directing light from a selected light source through an excitation light, allowing the fiber optic cable to detect the concentration of the motor oil being tested. After that, the received data is transferred to the optical converter for further processing. The final results, as shown in figure 4.2, are then analyzed using Design Expert software. This software facilitates a comprehensive evaluation of the test results , providing valuable information about the sensor's effectiveness in detecting engine oil conditions.

Figure 4.1 Measure power outpur process

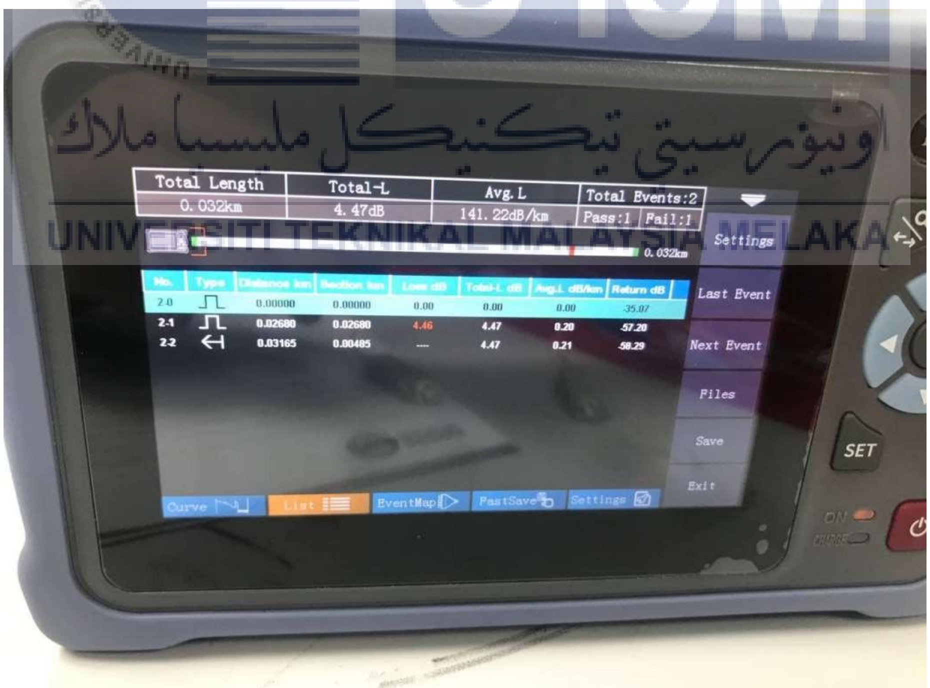


Figure 4.2 One of power output value that get in this experiment

In this study, various concentrations of engine oil were examined, emphasizing a critical investigation of the optimal wavelength for developing a fiber optic sensor. The research employed both single-mode and multi-mode fibers, focusing on two specific wavelengths, namely 1310nm and 1550nm. Following the experimental setup, data and results were systematically gathered. The concentrations of engine oil, derived from both new and used oil, were carefully considered. The experiment involved testing different concentrations of engine oil, and the recorded data included the output power in dB for each concentration.

4.3 Experimental Results and Analysis

Experimental data and results have been collected for two concentrations of engine oil. A total of 16 data points were gathered, with 8 data points for each application. The output powers, influenced by the concentration of engine oil, were analyzed across eight combinations of parameters, including the type of fiber, type of wavelength, and diameter of the fiber. All data and analyses have been documented for further reference.

4.3.1 Experimental Results

Test data and results for engine oil are summarized and presented in Table 4.1. The output of engine oil concentration outputs were analyzed for four parameter combinations of fiber type, wavelength type, and diameter of fiber.

Table 4.1 The experiment result output power

NO	WAVELENGTH	PARAMETER	TYPE	ENGINE OIL LEVEL	POWER OUTPUT(dBm)
1.	1550n	>10µ	Single Mode	1st level	42.06
2.	1550n	>10µ	Single Mode	2nd level	67.48

3.	1550n	>10µ	Multi-Mode	1st level	59.30
4.	1550n	>10µ	Multi-Mode	2nd level	58.29
5.	1550n	<10µ	Single Mode	1st level	59.39
6.	1550n	<10µ	Single Mode	2nd level	64.17
7.	1550n	<10µ	Multi-Mode	1st level	59.27
8.	1550n	<10µ	Multi-Mode	2nd level	67.57
9.	1310n	>10µ	Single Mode	1st level	56.64
10.	1310n	>10µ	Single Mode	2nd level	73.48
11.	1310n	>10µ	Multi-Mode	1st level	42.53
12.	1310n	>10µ	Multi-Mode	2nd level	70.32
13.	1310n	<10µ	Single Mode	1st level	43.00
14.	1310n	<10µ	Single Mode	2nd level	75.09
15.	1310n	<10µ	Multi-Mode	1st level	41.23
16.	1310n	<10µ	Multi-Mode	2nd level	62.51

Table 4.1 displays the experimental outcomes for engine oil concentration during the first and second usage. The output powers were assessed using an Optical Time Domain Reflectometer (OTDR). In each trial, the OTDR provided readings of the output powers corresponding to the concentration of engine oil, considering factors such as the type of fiber, wavelength type, and fiber diameter. The optimal output power was chosen from these readings for analysis.

4.3.2 Results Analysis

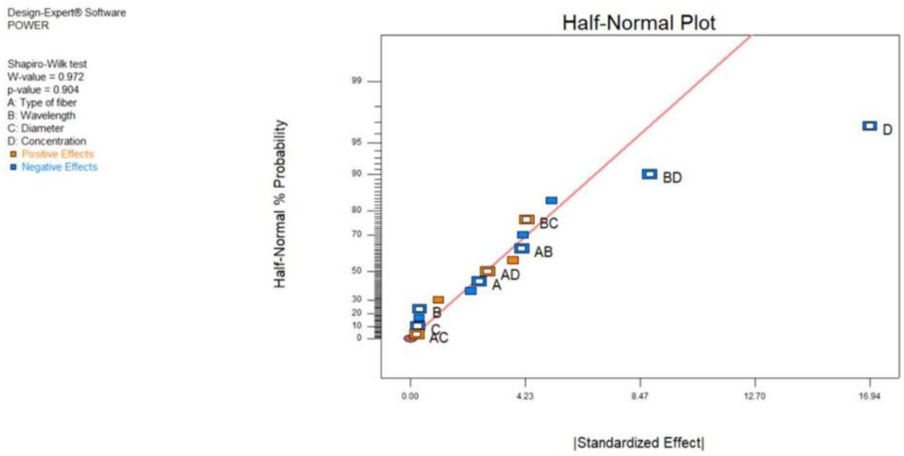


Figure 4.3 Half normal plot for engine oil concentration

The graph in figure 4.3 shown is a half-normal graph, a visual representation often used to assess the normality of data. In this graph, the data points are shown on the y-axis, while the expected values for a normally distributed data set are shown on the x-axis. The closeness of the data points to a straight line indicates the probability of a normal distribution. In this particular case, the data points deviate from the straight line, indicating that the data set is not normally distributed. This conclusion is supported by the Shapiro-Wilk test, which shows a test statistic of 0.972 and a p-value of 0.904, still indicating non-normality. The diagram also contains information about the experimental factors (A, B, C and D) and their levels are plotted on the axes. The positive and negative effects of each factor are described on the right side of the diagram. However, the diagram does not give an idea of the relationship between these factors. Further details explain that the half-normal plot is based on a normal distribution of standardized normal scores calculated with normative data points. The Shapiro-Wilk test serves as a statistical tool to assess normality, and the test statistic and p-value provide quantitative indicators. The identified factors and their levels probably represent the independent variables in the experiment that affect the dependent variable as indicated by the positive and negative effects.

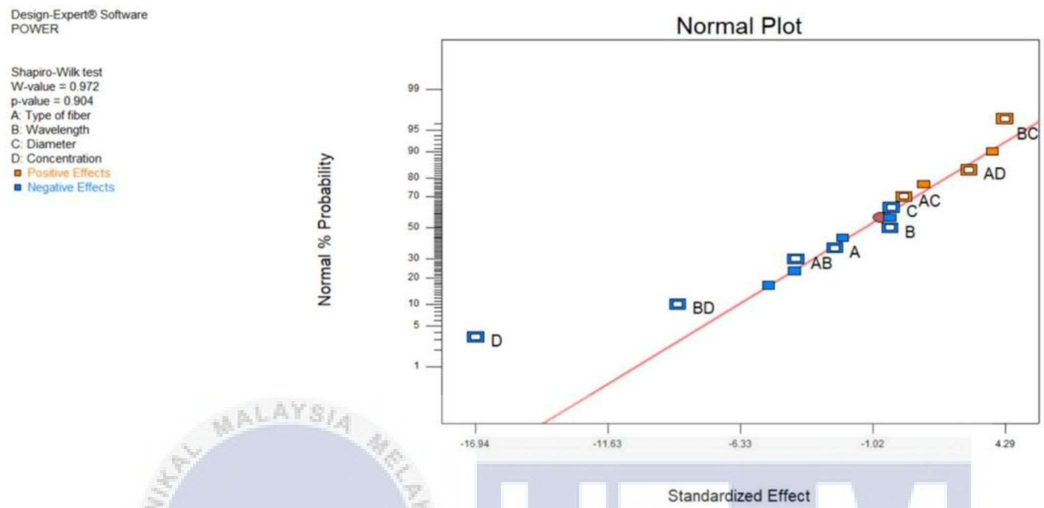


Figure 4.4 Normal plot for first usage engine oil concentration

In Design-Expert, normal plots play a crucial role in evaluating the normality of residuals, which are the differences between observed and predicted values of a statistical model. The purpose of these plots is to assess whether these residuals follow a normal distribution, a basic assumption of many Design Expert analyses. In the figure 4.4, the residual values are shown on the y-axis, while a line called the normal % probability line illustrates the expected values for data from a normal distribution. The results of the Shapiro-Wilk test, including the W-value and p-value, formally examine normality. A high W value approaching 1 and a non-significant p-value (usually >0.05) indicates normal activity. Interpretation involves observing whether the scores match closely, show normality, or differ significantly, indicate an outlier, and prompt further investigation into possible causes such as outliers or model errors. In addition, the graph contains information about the factors (A, B, C, D) and their standardized effects, which indicate a factorial model. The plot is probably a semi-normal plot, focusing on the magnitude of the effects rather than their signs.

This integrated approach provides a comprehensive assessment of both normality and factor influence in the Design-Expert model.

Table 4.2 Analysis of Anova Table for engine 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	1659.04	9	184.34	4.28	0.0453	significant
A-Type of fiber	*25.73*	*1*	*25.73*	*0.60*	*0.4688*	
B-Wavelength	*0.43*	*1*	*0.43*	*9.891E-003*	*0.9240*	
C-Diameter	*0.28*	*1*	*0.28*	*6.587E-003*	*0.9380*	
D-Concentration	*1147.35*	*1*	*1147.35*	*26.65*	*0.0021*	
AB	*67.36*	*1*	*67.36*	*1.56*	*0.2575*	
AC	*0.21*	*1*	*0.21*	*4.969E-003*	*0.9461*	
AD	*32.40*	*1*	*32.40*	*0.75*	*0.4189*	
BC	*73.49*	*1*	*73.49*	*1.71*	*0.2392*	
BD	*311.79*	*1*	*311.79*	*7.24*	*0.0360*	
Residual	258.27	6	43.05			
Cor Total	1917.32	15				

Std. Dev.	6.56	R-Squared	0.8653
Mean	58.90	Adj R-Squared	0.6632
C.V. %	11.14	Pred R-Square	0.0421
PRESS	1836.62	Adeq Precisior	7.023

The accompanying ANOVA (analysis of variance) table 4.2 is a comprehensive tool for evaluating the significance of various factors and their interactions in a multivariate study. The table breaks down sources of variation and provides key statistics for interpretation. Each factor labeled with letters (A, B, C, D) is evaluated based on its p-value, which indicates the probability of obtaining the observed results in the absence of a true effect. The overall model is considered statistically significant with a p-value of 0.0453, indicating that at least one factor or interaction has a significant effect on the response variable. Analyzing individual factors, fiber type (A), wavelength (B) and diameter (C) do not show statistically significant effects because their respective p-values exceed 0.05. However, concentration (D) stands out with a low p-value of 0.0021, indicating a significant effect on the response variable. Interaction terms (AB, AC, AD, BC, BD) do not show statistical significance. In short, the ANOVA table emphasizes that the concentration factor has a significant effect on the response variable, while other main factors and interactions do not play a significant role in the observed variations. This analysis provides valuable information about the main factors that contribute to research variability.

Table 4.3 Output Power Equation for first usage engine oil concentration

$$\text{Output Power} = +\,58.90 - 1.27 * A - 0.16 * B - 0.13 * C - 8.47 * D - 2.05 * A * B + 0.12 * A * C + 1.42 * A * D + 2.14 * B * C - 4.41 * B * D$$

Creating a final equation in table 4.3 with both coded and real factors is a key result of the ANOVA statistical analysis. This equation is necessary to predict the response variable based on the levels of different factors. In the coded equation, the high and low factor levels are standardized to +1 and -1. This coding facilitates the comparison of factor coefficients, which allows an examination of their relative influence on the response variable. The coded equation proves useful in evaluating the size and direction of each factor and its influence, helping to identify the most influential factors.The term of A,B,C and D state for A is type of fiber B is type of wavelength C is diameter of fiber and D is concentration of engine oil. In addition, it is a practical tool for making predictions and optimizing the response variable by manipulating factor levels. Overall, the coded equation improves the interpretability and usability of the statistical model, providing valuable information for decision making and practical applications.

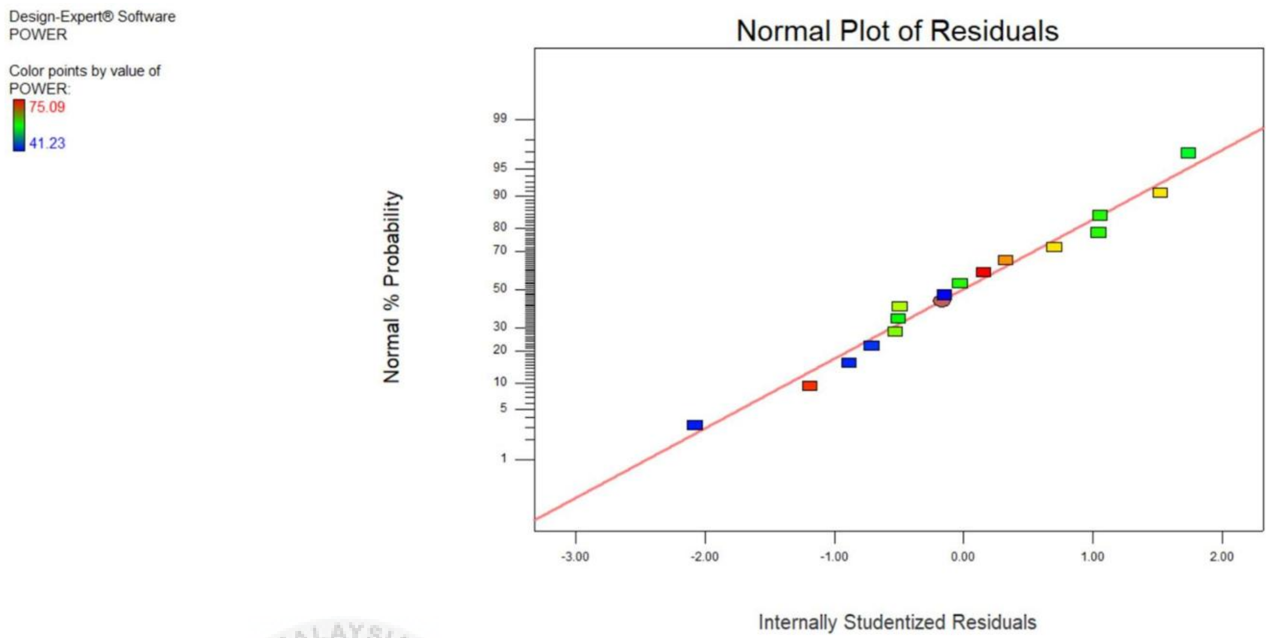


Figure 4.5 Normal Plot of Residuals for Output Power

The plot in figure 4.5 provides is a normal probability plot of residuals, serving as a tool to evaluate the normal distribution of errors within a statistical model. Residuals, representing the differences between predicted and actual values, are depicted on the x-axis as internally studentized residuals, a standardized version. Meanwhile, the y-axis displays normal probability. A normal distribution would be indicated by points clustering around a straight line on the graph. However, in this instance, the points deviate from a straight line, indicating that the residuals are not normally distributed. While this isn't inherently problematic, it's crucial to acknowledge when interpreting model results. Departures from normal distribution may impact the reliability of the model, and specific features of the graph, such as scattered points, outliers, and a non-straight line, further highlight the deviation from normality in the residuals. Understanding these aspects is essential for a more accurate interpretation of the statistical model's outcomes..

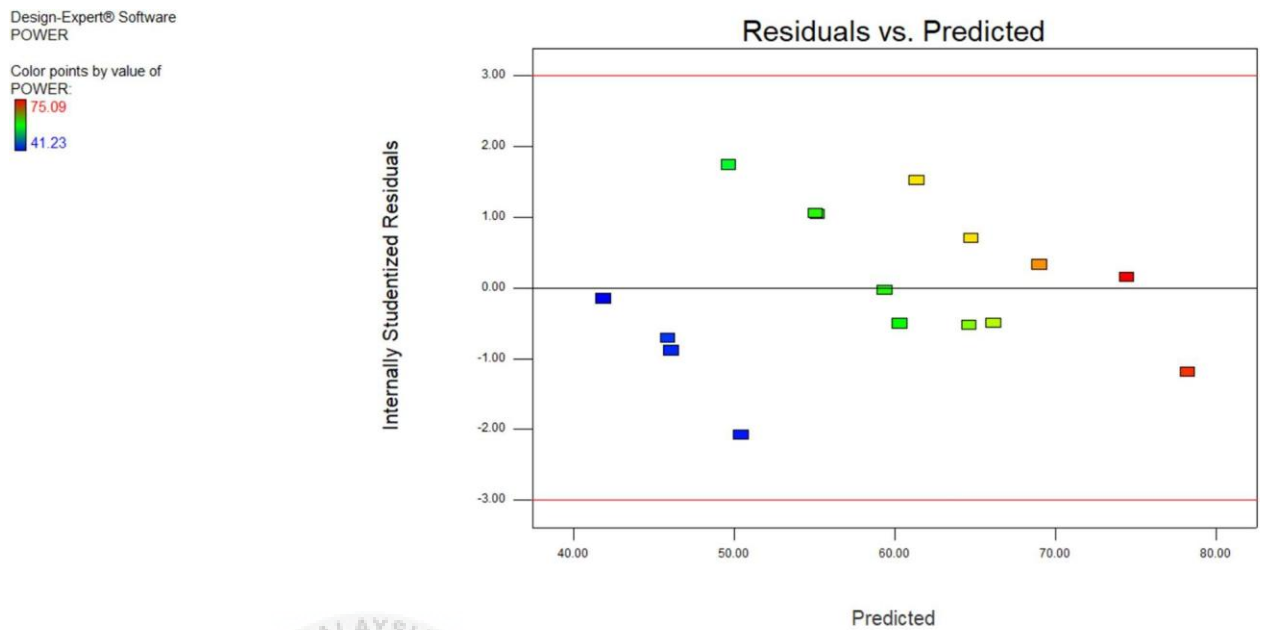


Figure 4.6 Residuals vs.Predicted for Output Power

The plot provided in figure 4.6 is a residuals vs. predicted plot, commonly employed to visually assess the disparities between actual and predicted values in statistical models, likely stemming from a regression analysis. On the x-axis, the predicted values are depicted, while the y-axis illustrates the residuals, indicating the deviations between actual and predicted values. The absence of a discernible pattern in the distribution of points on the graph implies that the model's assumptions, such as linearity and homoscedasticity, may be reasonably satisfied.Notably, the graph was generated using Design-Expert® Software and includes three distinct sets of colored points: blue, green, and yellow/red. Each color corresponds to different power levels, with blue points representing power levels below 41.23, green points indicating power levels between 41.23 and 75.09, and yellow/red points signifying power levels above 75.09. The legend on the left provides a key to these color-coded power levels. Additionally, a horizontal line at y=0 serves as a reference point, indicating where residuals would be zero. This information enhances the interpretation of the graph by providing insights into the relationship between power levels and the associated residuals, contributing to a more comprehensive understanding of the model's performance.Residuals tend to be higher than expected for low predicted values and lower than expected for high predicted values, indicating that the model might not perfectly capture the relationship between variables but is still reasonably fitting the data. In summary, this graph provides a valuable visualization for assessing the relationship between residuals and predicted values in a statistical model. It aids in identifying potential issues like non-normality of residuals or lack of fit, enhancing the overall understanding of the model's performance.

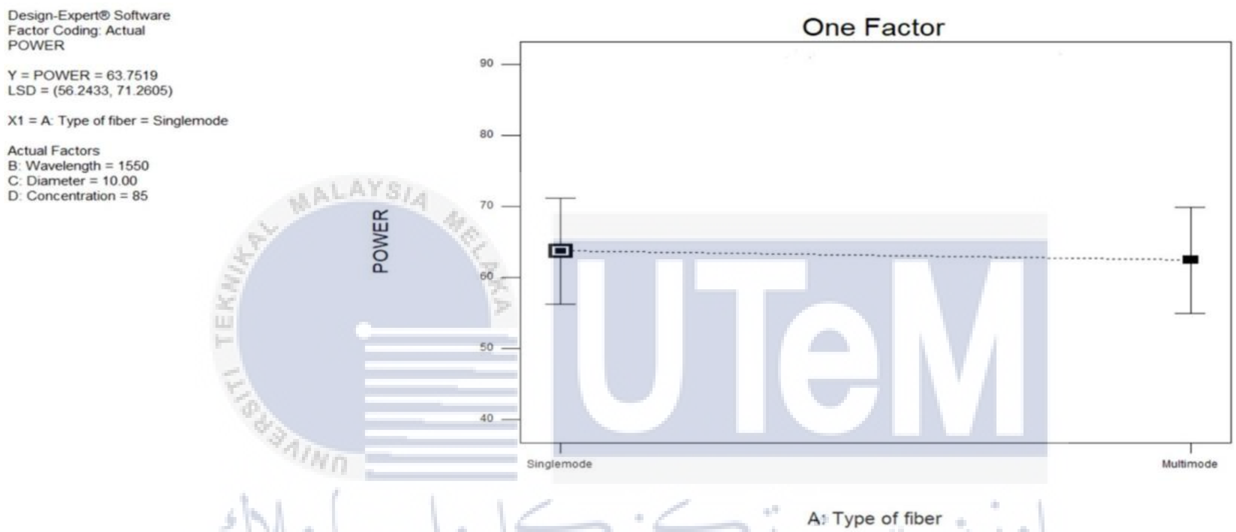


Figure 4.7 One Factor Effect Plot Output Power (Type of Fiber)

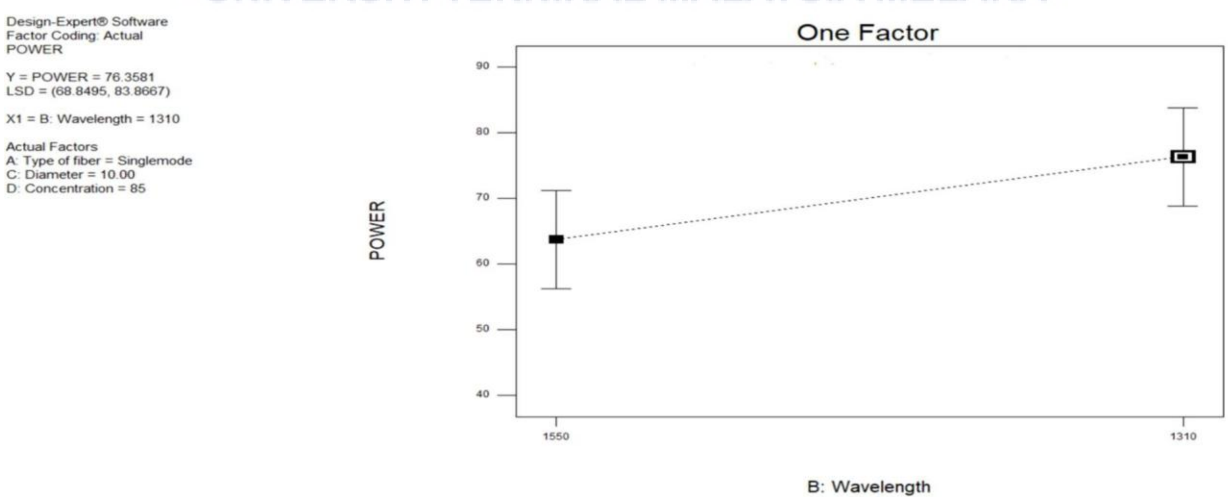


Figure 4.8 One Factor Effect Plot Output Power (Type of Wavelength)

Figures 4.7 and 4.8 show detailed information on the effect of certain factors on output power in a series of tests. Figure 4.7 focuses on the fiber type factor and the results show a significant effect on output power. The single-mode fiber type shows excellent performance and produces a higher output power of 63.75 dBm, while the multi-mode fiber type lags behind with a lower output power of 62.47 dBm. This means that the choice of fiber type significantly affects the total capacity in the tested scenarios.Figure 4.8 shifts the focus to the wavelength type. The data show that the wavelength of 1310 nm corresponds to a higher output power response, registering 76.36 dBm. In contrast, the 1550 nm wavelength is associated with a lower output power response of 63.75 dBm. These findings highlight the influence of wavelength selection on output power and clearly difference between the two wavelengths tested. Overall, these figures provide valuable information about the effect of fiber type and wavelength on output power, helping to understand and optimize the system or experiment under consideration.

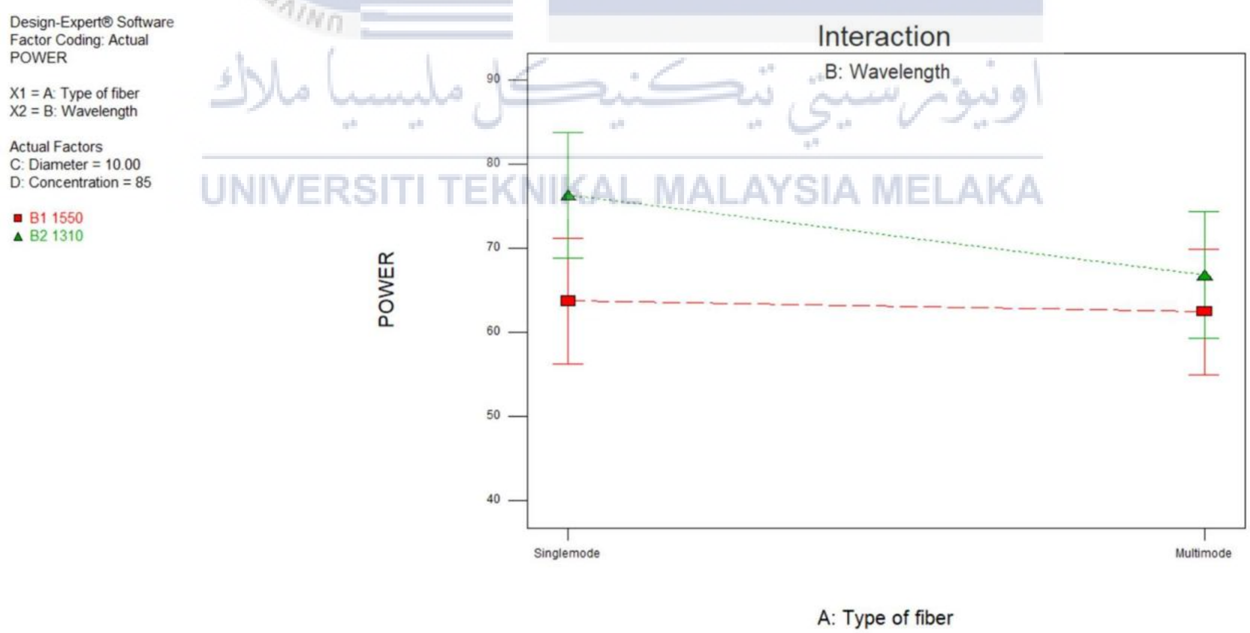


Figure 4.9 Interaction of Output Power

The figure 4.9 effectively describes the complex interaction between wavelength and fiber type in light signal attenuation in optical fibers. The attenuation trends, represented by the green and red lines at 1310 nm and 1550 nm, show a decrease in power with increasing distance, indicating the inherent attenuation of light signals during transmission. In particular, 1550 nm has consistently less attenuation than its 1310 nm counterpart in both single-mode and multi-mode fibers. This observation is consistent with the established understanding that longer wavelengths generally have less attenuation in optical fibers. Additionally, the graph highlights the effect of fiber type, showing that single-mode fibers have lower attenuation than multi-mode fibers at both wavelengths. This difference is due to the fact that single-mode fibers allow light to travel in only one path, minimizing interactions and scattering that affect attenuation. Interaction analysis further emphasizes the nuances of the slope of the attenuation curves, highlighting the complex interaction between wavelength and fiber type.

Finally, the chart provides valuable information on optimizing optical signal transmission in optical fibers and highlights the importance of careful consideration of both wavelength and fiber type based on specific application requirements and transmission distances..

4.4 Optimization Results

Design Expert can be used to experiment and achieve an optimal solution. Numerical optimization is chosen to determine target objectives for each asset and response, ensuring that optimal conditions are created. The tables 4.7 below show the criteria to optimize the responses based on the variables studied in the experiment for the first and second application of engine oil. In short, experiment and goal achievement can be accomplished with Design Expert using numerical optimization to set function and response goals and ensure optimal conditions.

Table 4.4 Optimization Criteria Setting

Constraints						
Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Type of fiber	is in range	Singlemode	Multimode	1	1	3
B:Wavelength	is in range	1550	1310	1	1	3
C:Diameter	is in range	9	11	1	1	3
D:Concentration	is in range	85	1000	1	1	3
POWER	maximize	41.23	75.09	1	1	3

The table 4.4 shows the limitations of a fiber optic connection and information about each limitation's name, lens, lower and upper limits , lower and upper weight, and overall weight. Each row corresponds to specific parameters such as fiber type, diameter, wavelength and power. For example, a type constraint specifies that a fiber must be either SingleMode or MultiMode. The weights given to the lower and upper barriers help calculate the overall importance of the constraint. If both weights are equal, the limit is considered equally important. However, different weights indicate different importance between lower and upper bounds. The importance value helps prioritize constraints during fiber optic connection decisions. For example, if a wavelength limit is the most important, it will take priority in decision making and guide the selection of fiber that meets that limit, even if it does not fully satisfy other limits. The structure and weighting of the table allows a systematic approach to evaluating and prioritizing the constraints associated with fiber optic connections.

Table 4.5 Optimization Solution (the first 10 over 36 solutions displayed)

Solutions for 8 combinations of categoric factor levels

Number	Type of fiber	Wavelength	Diameter	Concentratio	POWER	Desirability	
1	Singlemode	1310	11.00	85	78.2525	1.000	Selected
2	Singlemode	1310	9.40	85	75.2215	1.000	
3	Singlemode	1310	9.36	85	75.1445	1.000	
4	Singlemode	1310	9.67	85	75.7347	1.000	
5	Singlemode	1310	10.47	85	77.2557	1.000	
6	Singlemode	1310	9.51	85	75.4216	1.000	
7	Singlemode	1310	10.70	85	77.6789	1.000	
8	Singlemode	1310	10.02	85	76.4023	1.000	
9	Singlemode	1310	10.04	85	76.4274	1.000	
10	Singlemode	1310	10.98	85	78.2163	1.000	

The detailed breakdown in Table 4.5 provides a comprehensive overview of the key elements, providing general interpretation based on understanding of the factors influencing the choice of optical configurations. A careful comparison of the four configurations, cosidering differences in fiber type, diameter, wavelength and power, presents a thorough evaluation of the possible configurations. Assigning desirability scores, which range from 0 to 1, quantifies the overall suitability of each configuration for a specific application, adding a quantitative dimension to the analysis.

The identification of a single-mode fiber with a diameter of 11 microns, a wavelength of 1310 nm, and a power of 78.2525 mW as the optimal configuration highlights the importance of achieving a delicate balance between performance and efficiency. This configuration is the most desirable and represents a thoughtful choice that meets the application's requirements with an optimal compromise Further explaining the factors contributing to the lower desirablity score strengthens the narrative. Recognizing that larger diameter single-mode fibers may be less desirable due to cost sheds light on the economic considerations influencing the decision-making process. Simulteneously, the finding that multimode fibers are considered less efficient than their single-mode counterparts complicates the trade-offs involved in choosing a fiber-optic configuration

Moreover, , accurately observing the application's dependence on factors such as cost and performance greatly enriches the context. Noting that multimode fiber is preferred in cost-sensitive applications and single-mode fiber is preferred in performance-based scenarios adds a practical dimension to the analysis and emphasizes the importance of tailoring choices based on the specific needs of the application.In conclusion, this detailed review moves through the complexities of figures and tables to provide a complete and understandable interpretation of fiber optic assemblies and their desirable points.

4.5 Discussion

The experimental setup detailed in Figure 4.1 outlines the process of measuring the power output of an optical fiber sensor for an engine oil sensor. The engine oil under test is directed to a fiber optic sensor, where light from a chosen source passes through an excitation light, enabling the fiber optic cable to detect the motor oil's concentration. The collected data is then transmitted to the optical converter for further processing. The final results, as depicted in Figure 4.2, are analyzed using Design Expert software, offering a comprehensive evaluation of the test outcomes and valuable insights into the sensor's effectiveness in detecting engine oil conditions.

The study focuses on examining various concentrations of engine oil, emphasizing the critical exploration of the optimal wavelength for developing a fiber optic sensor. Both single-mode and multi-mode fibers are employed, concentrating on two specific wavelengths, 1310nm and 1550nm. The experimental data is systematically collected, considering factors such as the type of fiber, wavelength, and diameter, while the concentrations of engine oil, from both new and used oil, are meticulously studied. The recorded data includes the output power in dB for each concentration.

The experimental results, summarized in Table 4.1, provide insights into the output power for different combinations of fiber type, wavelength, and diameter, across various concentrations of engine oil. The subsequent analysis, including the Half-Normal Plot in Figure 4.3 and the Normal Plot in Figure 4.4, evaluates the normality of the data and the influence of factors (A, B, C, and D) on the output power. The ANOVA table (Table 4.2) further dissects the significance of different factors and their interactions. Concentration (D) stands out as statistically significant, emphasizing its effect on the response variable.The Output Power Equation in Table 4.3 represents the culmination of the ANOVA statistical analysis, offering a predictive model based on factor levels. The subsequent diagnostic plots, such as the Normal Plot of Residuals in Figure 4.5 and the Residuals vs. Predicted Plot in Figure 4.6, provide insights into the model's performance and assumptions. While indicating some potential issues like non-linearity and slight non-normality, these plots don't necessarily invalidate the model but suggest areas for consideration and further diagnostics.

Figures 4.7 and 4.8 delve into the effect of fiber type and wavelength on output power, highlighting significant differences between single-mode and multi-mode fibers and the impact of specific wavelengths. Figure 4.9 illustrates the complex interaction between wavelength and fiber type in light signal attenuation in optical fibers.The optimization results in Table 4.4 showcase the criteria set for numerical optimization, aiding in achieving optimal conditions for fiber optic connections. Finally, Table 4.5 provides a comprehensive overview of key configurations, their desirability scores, and the importance of factors in decision-making.In conclusion, this comprehensive analysis navigates through the intricate details of the experimental setup, results, and optimization, providing a thorough understanding of the factors influencing the choice of optical configurations for engine oil detection.

4.6 Summary

This chapter presents the development of microfiber sensors in the SME automotive industry using Design Expert Software and Box-Behnken Design (BBD) optimization parameters approach, significant results have been obtained through the use od Design expert software , a tool employed by the researchers to designing and analyze experiments systematically.This approach enhanced their understanding of variable response relationship , aiming to improve the sensitivity, accuracy, and reliability of complex microfiber sensors. The BBD approach was utilized to optimize the the key parameters of the sensor technology resulting in an improved product quality and enhanced sensor technology.

The findings of the study have practical implications of the industry, providing a systematic and efficient pathway for sensor development, and strengthening the competitive position of the industries involved in sensor research and development. The approach demonstrated its effectiveness and provided valuable insights for industry professionals, paving the way for future advancements in sensor technology.

In conclusion, the test results, statistical analysis and optimization criteria, explore the impact of engine oil content on the performance of the fiber system by considering a set of parameters.. The results provide essential information for selecting the best fiber filters based on factors such as fiber type, diameter, wavelength, and power. The techniques employed,, including modeling and statistical optimization, provide a robust framework for understanding and optimizing the complex interactions of optical fibers concerning oil concentration.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this project, the focus is on addressing the challenges faced by small and medium-sized enterprises (SMEs) in the automotive sector, particularly related to engine oil maintenance. A lack of funding often prevents effective monitoring of engine oil conditions, leading to potential damages and increased repair costs. Conventional method such as visually examining oil condition or the using oil analysis, are time-consuming, expensive, and not always a reliable in assessing oil quality. The project aims to develop a microfiber sensor as an alternative method for detecting engine oil conditions consideration the importance of engine oil in vehicle functionality and the unpredictability of engine oil concentration.

To accomplish this goal, this studies aims to provide SMEs in the automotive industry with a cost-effective and efficient solution that can be tailored to their specific needs and constraints. The project's objectives include identifying the significant effects of microfiber sensor parameters, developing a mathematical regression model for the sensor, and creating a microfiber sensor with optimum parameters for detecting engine oil conditions. o The proposed microfiber sensor will investigated a wide range of microfiber types, single and multi-mode configurations, power output performance, and key parameters such as fiber type, diameter, wavelength, and engine oil concentration. It is designed to offer SMEs a reliable and accessible solution for monitoring and detecting engine oil conditions a regularly, , ultimately reducing business costs and improving efficiency in the automotive industry.

The methodology outlined in this chapter provides a systematic approach to developing a microfiber sensor, emphasizing the need for parameter optimization to achieve greater accuracy and sensitivity. Despite the difficulty and technical complexity associated with designing and constructing an optimized microfiber sensor, the project aims to develop a practical and effective system for assessing and detecting engine oil conditions, Extensive testing and validation processes underline the commitment to ensuring sensor reliability in various conditions and environments. The methodology provides a well-structured framework adapted to create a microfiber sensor specifically for the automotive industry.

The chapter conclude with a detailed summary of the test results and statistical analyses related to the first and second use of the engine oil. This highlights the importance of factors such as fiber type, wavelength and their interaction on power. The presented predictive models and optimization criteria provide valuable information to decide on the optimal fiber configuration. Extensive research contributes to the understanding and optimization of a robust framework for fiber-optic interfaces affected by motor oil concentration. Overall, the project aims to deliver a microfiber sensor that meets the unique needs of automotive SMEs and provides a reliable and cost-effective solution for engine oil monitoring.

5.2 Potential for Commercialization

The commercial potential of microfiber sensors developed for monitoring engine oils in the small and medium-sized automotive industry is significant given the challenges faced by SMEs in engine oil maintenance. The project and focus on providing a cost-effective and efficient solution to meets the urgent needs of these companies, which often struggle with financial constraints. Current methods of visual assessment or analysis of engine oil condition are not only time-consuming and expensive, but also unreliable. In this context, the proposed microfiber sensor emerges as an alternative method that addresses the limitations of existing approaches and revolutionize how SMEs manage motor oil in the automotive industry.

The importance of this commercial potential become evident when considering the advantages of the microfiber sensor. By accurately identifying engine oil conditions, SMEs can avoid the pitfalls of premature oil changes or early detection of contaminants, both of which can increase repair costs. The ability to predict engine oil concentration and condition with a microfiber sensor gives SMEs a predictive tool for maintenance, improving engine performance and longevity.

However, the road to commercialization is considered challenging, as highlighted in the chapter. Testing and optimizing the design of microfiber sensors is a resource-intensive endeavor, and there are no universally accepted methods for accurately detecting engine oil conditions using such sensors. The chapter emphasizes the need for careful planning, strategic development, and extensive testing to overcome these challenges. Despite these hurdles, the systematic methodology presented in the chapter provides a strong foundation for potential business success. An optimization parameter approach, supported by experimental design processes and statistical analyses, ensures that microfiber sensors are developed with greater accuracy and sensitivity. Focusing on identifying key parameters and building regression models increases the reliability of sensor technology, which is critical to achieving market acceptance.

In summary, the business potential lies in providing automotive SMEs with a reliable, cost-effective and efficient solution for engine oil inspection. The developed microfiber sensors, when optimized and validated, can not only simplify the maintenance processes of these companies, but also contribute to significant cost savings and improved work efficiency. The methodology outlined in the chapter serves as a road map for turning research and development into a practical and marketable solution that will make microfiber sensor technology a valuable asset for automotive SMEs.

5.3 Future Works

However, certain aspects can be highlighted that are necessary to obtaining more accurate and improve result in future work, even if the optimization of the fiber experiment is successful. The Suggested improvement can be listed as follows:

i. Focus on further refining of the optimization parameters for microfiber sensors. This involve considering of additional factors that may impact sensor performance, such as environmental conditions or variations in engine types, to improve the adaptability and robustness of the technology.

ii. Investigate the compatibility of microfiber sensor materials with different engine oil formulations. Different vehicles and manufacturers may use varying oil formulations, and understanding the sensor performance of these variations is essential for widespread application.

iii. Evaluation and optimization of energy consumption of microfiber sensors. Low power consumption not only helps improve energy efficiency, but also extends the life of the associated battery, thus reducing overall maintenance requirements.

REFFERENCES

[1].Agoston, A., Ötsch, C., & Jakoby, B. (2005). Viscosity sensors for engine oil condition monitoring - Application and interpretation of results. *Sensors and Actuators, A: Physical*, *121*(2), 327–332. https://doi.org/10.1016/j.sna.2005.02.024

[2].Ahmad, N. (2017). *The Analysis of Fusion Splice Technique on Single Mode Fiber Optic*. *October*.

[3].Al-Askari, S., Hamida, B. A., Khan, S., & Harun, S. W. (2016). Optimizing tapered microfiber sensor design and simulation. *ARPN Journal of Engineering and Applied Sciences*, *11*(1), 449–452.

[4].Ashry, I., Mao, Y., Wang, B., Hveding, F., Bukhamsin, A., Ng, T. K., & Ooi, B. S. (2022). A Review of Distributed Fiber-Optic Sensing in the Oil and Gas Industry. In *Journal of Lightwave Technology* (Vol. 40, Issue 5, pp. 1407–1431). https://doi.org/10.1109/JLT.2021.3135653

[5].Badr, A. (2011). General Introduction to Design of Experiments (DOE). *Wide Spectra of Quality Control*. https://doi.org/10.5772/23878

[6].Castagné, M., Bentolila, Y., Chaudoye, F., Hallé, A., Nicolas, F., & Sinoquet, D. (2008). Comparison of engine calibration methods based on design of experiments (DoE). *Oil and Gas Science and Technology*, *63*(4), 563–582. https://doi.org/10.2516/ogst:2008029

[7].Castrellon-Uribe, J. (2012). Optical Fiber Sensors: An Overview. *Fiber Optic Sensors*. https://doi.org/10.5772/28529

[8].El-Diasty, F. (2004). Laser-scattering-based method for investigation of ultra-low-loss arc fusion-spliced single-mode optical fibers. *Journal of Lightwave Technology*, *22*(6), 1539–1542. https://doi.org/10.1109/JLT.2004.829232

[9].Fukuda, I. M., Pinto, C. F. F., Moreira, C. D. S., Saviano, A. M., & Lourenço, F. R. (2018). Design of experiments (DoE) applied to pharmaceutical and analytical quality by design (QbD). *Brazilian Journal of Pharmaceutical Sciences*, *54*(Special Issue), 1–16. https://doi.org/10.1590/s2175-97902018000001006

[10]. Graf, J. C., Teston, S. A., De Barba, P. V., Dallmann, J., Lima, J. A. S., Kalinowski, H. J., & Paterno, A. S. (2009). Fiber taper rig using a simplified heat source and the flame-brush technique. *SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference Proceedings*, 621–624. https://doi.org/10.1109/IMOC.2009.5427507

[11]. Harun, S. W., Lim, K. S., Tio, C. K., Dimyati, K., & Ahmad, H. (2013). Theoretical analysis and fabrication of tapered fiber. *Optik*, *124*(6), 538–543. https://doi.org/10.1016/j.ijleo.2011.12.054

[12]. Hasan-Zadeh, A., & Poshtiban, M. (2021). Car Engine Oil: Investigation of Function and Related Challenges, and Provision of Environmental Solutions. In *Asian Journal of Applied Sciences* (Vol. 9, Issue 1). https://doi.org/10.24203/ajas.v9i1.6486

[13]. Jali, M. H., Rahim, H. R. A., Md Johari, M. A., Baharom, M. F., Ahmad, A., Yusof, H. H. M., & Harun, S. W. (2021). Optical Microfiber Sensor: A Review. *Journal of Physics: Conference Series*, *2075*(1). https://doi.org/10.1088/1742-6596/2075/1/012021

[14]. Kapulainen, M., Ronkainen, H., Hokkanen, A., Stuns, I., Varjus, S., Nyyssönen, S., Turunen, R., & Halme, J. (2014). Fibre Optic Sensors for Long-Term Monitoring of

Oil Film Pressure in Diesel Engine Main Bearing. *Tribology Letters*, *56*(1), 47–54. https://doi.org/10.1007/s11249-014-0373-5

[15]. Kawata, O., Hoshino, K., & Ishihara, K. (1984). Core-axis-alignment method to achieve ultra-low-loss fusion splicing for single-mode optical fibers. *Optics Letters*, *9*(6), 255. https://doi.org/10.1364/ol.9.000255

[16]. Kolekar, Y. M. (2019). Understanding of DoE and its advantages in Pharmaceutical development as per QbD Approach. In *Asian Journal of Pharmacy and Technology* (Vol. 9, Issue 4, p. 271). https://doi.org/10.5958/2231-5713.2019.00045.x

[17]. Korposh, S., James, S. W., Lee, S. W., & Tatam, R. P. (2019). Tapered Optical Fibre Sensors: Current Trends and Future Perspectives. *Sensors (Basel, Switzerland)*, *19*(10). https://doi.org/10.3390/s19102294

[18]. Lou, J., Wang, Y., & Tong, L. (2014). Microfiber optical sensors: A review. *Sensors (Switzerland)*, *14*(4), 5823–5844. https://doi.org/10.3390/s140405823

[19]. Markova, L. V., Makarenko, V. M., Semenyuk, M. S., & Zozulya, A. P. (2010). On-line monitoring of the viscosity of lubricating oils. *Journal of Friction and Wear*, *31*(6), 433–442. https://doi.org/10.3103/S106836661006005X

[20]. Mikulić, I., Bošković, I., & Zovak, G. (2020). Effects of driving style and vehicle maintenance on vehicle roadworthiness. *Promet - Traffic - Traffico*, *32*(5), 667–677. https://doi.org/10.7307/ptt.v32i5.3443

[21]. Mohamad Ali, U. U., Jusoh, Z., Md Johari, M. A., Abdul Rahman, H., Adnan Zain, H., Zulkipli, N. F., & Wadi Harun, S. (2022). Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor. *Journal of Electrical & Electronic Systems Research*, *20*(APR2022), 66–69. https://doi.org/10.24191/jeesr.v20i1.009

[22]. Mohan, M. K. M., Abinaya, S., Kaviya, P., Sandhya, S. M., & Lavanya, P. (2020). *JOURNAL OF CRITICAL REVIEWS Engine Oil Condition Monitoring using IoT and Predictive Analysis*. *7*(04), 1196–1204.

[23]. Mustapha Kamil, Y., Abu Bakar, M. H., Zainuddin, N. H., Yaacob, M. H., & Mahdi, M. A. (2023). Progress and Trends of Optical Microfiber-Based Biosensors. *Biosensors*, *13*(2). https://doi.org/10.3390/bios13020270

[24]. Razzaq, L., Abbas, M. M., Miran, S., Asghar, S., Nawaz, S., Soudagar, M. E. M., Shaukat, N., Veza, I., Khalil, S., Abdelrahman, A., & Kalam, M. A. (2022). Response Surface Methodology and Artificial Neural Networks-Based Yield Optimization of Biodiesel Sourced from Mixture of Palm and Cotton Seed Oil. *Sustainability (Switzerland)*, *14*(10). https://doi.org/10.3390/su14106130

[25]. Rosni, M., Hussin, A., Alias, R. A., Ismail, K., & Hussin, M. R. A. (2013). Cost management skills among the owners of Malaysian small and medium enterprises (SMEs) in the era of globalisation. In *Int. J. Entrepreneurship and Small Business* (Vol. 20, Issue 2).

[26]. Saidin, N., Idris, N. F., Amaluddin, M. N., Irawati, N., Ralib, A. A. M., & Harun, S. W. (2018). Microfiber-based sensor for measuring uric acid concentrations. *Journal of Telecommunication, Electronic and Computer Engineering*, *10*(2–7), 49–52.

[27]. Shi, L., Xu, Y., Tan, W., & Chen, X. (2007). Simulation of optical microfiber loop resonators for ambient refractive index sensing. *Sensors*, *7*(5), 689–696. https://doi.org/10.3390/s7050689

[28]. Syafitri, F., Darojah, Z., & Ningrum, E. S. (2019). Detection of oil condition on motorcycle based on sound signal analysis. *International Electronics Symposium on*

Knowledge Creation and Intelligent Computing, IES-KCIC 2018 - Proceedings, 332–336. https://doi.org/10.1109/KCIC.2018.8628485

[29]. Taheri Ghahrizjani, R., Sadeghi, H., & Mazaheri, A. (2016). A Novel Method for onLine Monitoring Engine Oil Quality Based on Tapered Optical Fiber Sensor. *IEEE Sensors Journal*, *16*(10), 3551–3555. https://doi.org/10.1109/JSEN.2016.2523805

[30]. Talataisong, W., Ismaeel, R., & Brambilla, G. (2018). A review of microfiber-based temperature sensors. *Sensors (Switzerland)*, *18*(2). https://doi.org/10.3390/s18020461

[31]. Tekindal, M. A., Bayrak, H., Ozkaya, B., & Genc, Y. (2012). Box- behnken experimental design in factorial experiments: The importance of bread for nutrition and health. *Turkish Journal of Field Crops*, *17*(2), 115–123.

[32]. Veeser, L., Veeser, L. R., Caird, R. S., Freeman, B. L., Kania, D. R., Kruse, P. J., Trainor, R. J., & Zimmermann, E. L. (n.d.). *Single-mode fiber-optic sensor for high currents Plasma Focus neutron scaling View project Explosive Pulsed Power View project SINGLE MODE FIBER OPTIC SENSOR FOR HIGH CURRENTS.* https://www.researchgate.net/publication/253082457

[33]. Zhang, C. (2003). A Micro-acoustic Wave Sensor for Engine Oil Quality Monitoring. *Proceedings of the Annual IEEE International Frequency Control Symposium*, 971–977. https://doi.org/10.1109/freq.2003.1275222

[34]. Zhu, J., Yoon, J., He, D., Qiu, B., & Bechhoefer, E. (2013). Online Condition monitoring and remaining useful life prediction of particle contaminated lubrication Oil. *PHM 2013 - 2013 IEEE International Conference on Prognostics and Health Management, Conference Proceedings*, *2008*, 1–15. https://doi.org/10.1109/ICPHM.2013.6621415

[35]. Zöldy, M. (2021). Engine oil test method development. *Tehnicki Vjesnik*, *28*(3), 1012–1016. https://doi.org/10.17559/TV-20200122150623

[36].Mulyanti, B., Ramza, H., Pawinanto, R. E., Abdurrahman, F., & Supian, L. S. (1843). *Modeling and Optimization of Fiber Optic Chemical Vapor Sensor*. *9*(2), 73–79.

[37] Nandhakumar, P., & Kumar, A. (2021). Backbone Optical Fiber Analysis at 1310 nm and 1550 nm. *Journal of Optical Communications*, *42*(1), 79–84. https://doi.org/10.1515/joc-2018-0042

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 Turnitin Report

psm2 Balqhis

ORIGINALITY REPORT

10%	6%	6%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.ncbi.nlm.nih.gov Internet Source	1%
2	www.science.gov Internet Source	1%
3	Reza Taheri Ghahrizjani, Hossein Sadeghi, Azardokht Mazaheri. "A Novel Method for onLine Monitoring Engine Oil Quality Based on Tapered Optical Fiber Sensor", IEEE Sensors Journal, 2016 Publication	1%
4	journal.utem.edu.my Internet Source	<1%
5	Ummu Umairah Mohamad Ali, Zulzilawati Jusoh, Md Ashadi Md Johari, Husna Abdul Rahman et al. "Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor", Journal of Electrical & Electronic Systems Research, 2022 Publication	<1%

Appendix C 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 D Single Mode and Multi Mode 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...