UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# DEVELOPMENT A LIQUID SENSOR USING FIBER OPTIC FOR ENGINE LUBRICATION OIL AND OPTIMIZATION USING DESIGN OF EXPERIMENT (D.O.E) TECHNIQUE

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Electronic Engineering Technology

(Telecommunication) (Honours.)

By

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**BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA**

TAJUK: **Development A Liquid Sensor Using Fiber Optic for Engine Lubrication Oil and Optimization Using Design of Experiment (D.O.E) Technique**

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# APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering Technology (Telecommunication) (Hons). The member of the supervisory us as follow:

………………………….

(Aminah Binti Ahmad)

# ABSTRAK

Pada dasarnya, Reka bentuk eksperimen (DOE) adalah teknik statistik yang digunakan dalam kawalan kualiti untuk merancang, menganalisis dan mentafsirkan set eksperimen bertujuan untuk membuat keputusan yang bijak tanpa menanggung kos yang tinggi dan memakan banyak masa. Masalah-masalah yang berlaku boleh dianalisis dan tindakan penambahbaikan yang boleh dilakukan dengan serta-merta. Terdapat banyak kelebihan menggunakan teknik DOE dan untuk contoh bilangan ujikaji perlu dilakukan boleh menentukan dan dinyatakan dengan jelas mengikut kaedah-kaedah yang terlibat dalam teknik ini seperti Factorial penuh, kaedah Taguchi, Factorial pecahan dan lain-lain. Antara pelbagai jenis DOE, reka bentuk ekperimen Factorial adalah kaedah yang saya akan mengunakan dalam kajian saya ini. Rekan bentuk factorial dirancang untuk mengkaji fungsi-fungsi bebas-langsung dan sambungan antara faktor-faktor yang mempengaruhi tindak balas. Melalui kaedah Reka-bentuk faktoran, saya mampu untuk menentukan faktor yang optimum yang akan menyumbang kepada penderia gentian optic minyak mineral dan mengurangkan perubahan melibatkan, Akhirnya, kita boleh mendapatkan keputusan yang lebih tepat dan lebih baik dengan mengulangi menggunakan beberapa jenis factorial. Oleh itu, untuk melaksanakan experimen kaedah Reka bentuk faktoran, kita akan dibantu oleh beberapa parameter terpilih dalam menjana output berdasarkan perubahan kombinasi faktor-faktor yang berlainan. Pengesan gentian optic minyak mineral dilakukan didalam makmal gentian optic di Universiti. Selepas mengumpul data yang diperlukan, kita akan dapat untuk menjanakan graf dan memerhati keluaran supaya kita boleh mempunyai kefahaman yang lebih jelas tentang kepentingan setiap factor yang digunakan bagi mendapat keluaran yang optimum.

# ABSTRACT

Basically, Design of Experiment (DOE) is a statistical technique used in quality control for planning, analysing and interpreting sets of experiments aimed at making wise decisions without incurring a high cost and consuming much time. The problems occurred can be analysed and an improvement action can be done immediately. There are a lot of advantages of using DOE technique and for example the number of experiments need to be carried out can be define and stated clearly according to the methods that involved in this technique such as Full Factorial, Fractional Factorial, Taguchi Method and etc. Amongst the various types of DOE which is Factorial Design of Experiment is one of the methods in which my research design will be focusing on. Factorial design is planned to study non-direct functions and connections between factors influencing reaction. Through the factorial design method, I am able to determine the optimum factor which will contribute most to the fiber optic mineral oil sensor and reduce the variation involve. Ultimately, we could obtain a more precise and better result by repeating using several type of factorial. Thus, in order to perform the factorial design of experiment method, we will be assisted by tabulated parameters in generating outputs based on the variation of different combinations of factors. The optical fiber mineral oil sensor experiment is carried out within the university compound. After collecting the data needed, we are able to plot graphs and observe the output so that we could have a clearer understanding of the significance of each factor that we used in order to get an optimum output.

# DEDICATION

*Specially dedicated to,*

*My beloved parents, family members, and friends for supports, encouragements, understanding, guiding, and all the favour. May Allah bless all of you.*

# ACKNOWLEDGEMENT

First and foremost, I would like to express my greatest gratitude to my project supervisor, Associate Mrs. Aminah Binti Ahmad, for all the great supervision, supports, advises and guidance that help me lots with my final year project. His valuable advice is really useful for me.

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For my parents, you are the best "things" that I have. I don't know what is the best word to describe your patience, love and cares towards me. Thanks for your moral support and encouragement.

For all my friends, thank you very much for helping me to finish this project especially to Mohd Shaiful Azri bin Nus and Mohamad Assif Bin Ariffin@Mohd Saufi that always accompanied me to the laboratory early in the morning in order to finish the test.

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| | | |
|---|---|---|
| DOE | = | Design of Experiment |
| OFAT | = | One Factor at a Time Method |
| TQM | = | Total Quality Management |
| TPM | = | Target Performance Measure |
| NPM | = | Noise Performance Measure |
| LED | = | Light Emitting Diode |
| FFD | = | Full Factorial Design |
| DFSS | = | Design for Six-Sigma |
| IDDM | = | Insulin Dependent Diabetes Mellitus |
| NIDDM | = | Non-Insulin Dependent Diabetes Mellitus |
| MMF | = | Multi-Mode Strands |
| SMF | = | Single-Mode Strands |
| PCS | = | Plastic-Clad Silica |
| ASE | = | Amplified Spontaneous Emission |
| OSA | = | Optical Spectrum Analyzer |
| ANOVA | = | Analysis of Variance |
| LRIS | = | Liquid Refractive Index Sensor |
| SPR | = | Surface Plasmon Reverberation |
| dB | = | Decibel |
| nm | = | Nanometer |

# CHAPTER 1
# INTRODUCTION

## 1.1 Project Background

A lubrication is a substance that being used to reduce the friction between surfaces in a certain area, in other word it reduces the heat that being generated when a surface contact with each other. It might likewise have the capacity of transmitting powers, transporting remote particles, or warming and cooling the surfaces. This property to reduce the friction is well known as lubricity. In addition, big industrial application, use lubrication for many different purpose.

In a world of communication, fiber-optic is a form of transmitting data starting with one place then onto the next by sending beats of light through an optical fiber. The light structures form an electromagnetic carrier wave that is adjusted to convey data being sent. This project is to expend the use of fiber optic as a sensor not only sent data as we know today. The fiber optic sensor is used to detect the thickness of oil lubrication for a certain period of time, each time the lubrication being use by the engine it will get thick and this will damage the engine if it not changes. Therefore, fibre optic sensor will be develop to detect the suitable time for the lubrication oil to be change.

This project is also use design of experiment (D.O.E) technique which is a systematic method. This technique is a method to determine the relationship between factor affecting a process and the output of that process. In other word, it is used to find cause and effect relationships. This information is needed to manage process input in order to optimize the output

## 1.2 Problems Statement

Mineral oil is use for lubrication engine oil and importance to keep the engine in the best performance. They are many brand in market that have their advantages and disadvantages. Fiber optic sensor is develop to test the different of 2 brand in market that is mineral oil. Design of experiment will be use to analyses the optimum performance of each oil and determine the best among 2 brand.

In such many year fiber optic has a major impact in communication system but never much to know in becoming a sensor. By this project fiber optic sensor is develop to become a sensor for lubrication oil. This research is about to determine the must to know function and implement fiber optic to develop to becoming a liquid sensor for lubrication oil that is mineral oil.

## 1.3 Project Objectives

The main objectives in this research can be describe with three factor, which lead to project success. The objectives of the project are:

a) To study Fiber Optic Sensor (F.O.S)
b) To develop Fiber Optic Sensor to detect mineral oil
**c)** To analyse performance of FOS using Design of Experiment (DOE)

## 1.4 Project Scope

The scopes of this project involved the development of liquid sensor using fiber optic for engine lubrication oil and using design of experiment technique. In this project it is important to study on the compatibility of fiber optic as sensor to identify the concentration of lubrication oil. Analysing the system establishment for fiber optic as sensor. The data will be analysed by the power loss of fiber optic, where general hypothesis will be made.

Analysis will be conducted by varying the parameter that is time, source light, brand of oil and type of fiber optic. This parameter is use as the main point for this research on determine the variable for the fiber optic sensor that will be test. Lastly the result can be analysed and studied and implement to a good use in daily life.

## 1.5 Summary

For this chapter 1, it tells the introduction of the project that will be done. From the project background a small brief about lubrication oil, fiber optic and design of expert. The problem statement that being state is a point that need to be solve and know, by doing this research each of the problem give an impact for the research to complete. The project scope tells the scope that need to be done so it will not exceed the expectation to go beyond the limit of the research,

# CHAPTER 2
## LITERATURE REVIEW

### 2.1 Introduction

This chapter states all the studies and reviews from previous projects and other sources that help to successfully design, built and implement the entire task during this project. There are some previous projects that similar to this project and can be search across the internet and paper work done by the researcher who is inspired with the optical communication. For this project, the summation is all about to develop the fiber optic sensor.

### 2.2 Basic System of Communication

They have 2 type of communication that is analogue and digital

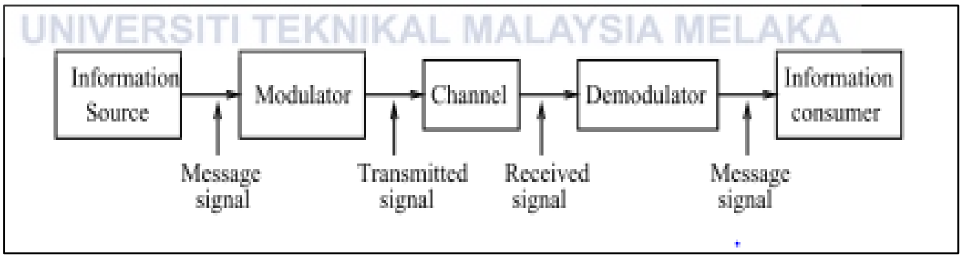


Figure 2.1:Analogue communication

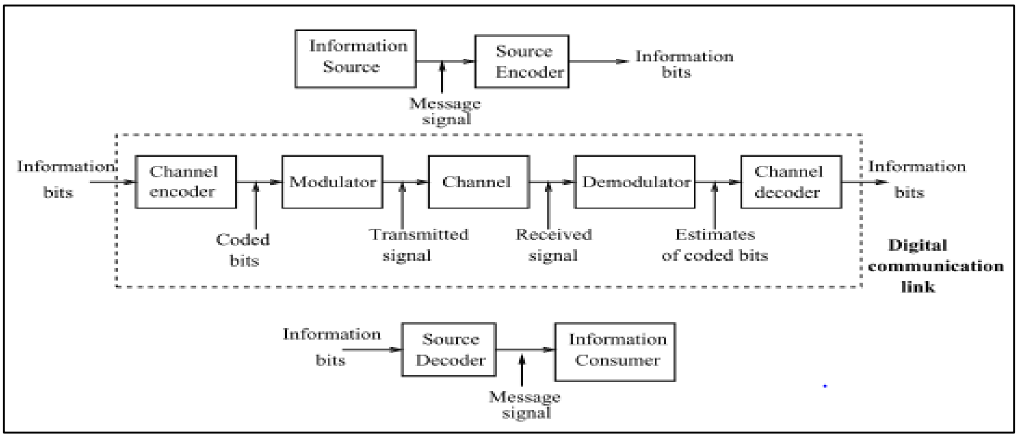


Figure 2.2:Digital communication

The figure above shows the basic of block diagram for communication system. Each of the block have they function. For each of the step to transmit the information to other side of the receive. As the figure about show two block diagram. Believe it or not by comparing the block diagram for analogue and digital communication respectively. The digital communication system involves far more processing. However, this is not an obstacle for modern transceiver design, due to the exponential increase in the computational power of low-cost silicon integrated circuit. By that digital communication has the advantages compare to analogue. In reality digital is more use than the analogue because the system will keep on improving. (Schiff, 2006)

There are three basic system of communication which is transmitter, channel for transmit the signal and receiver to receive the signal from transmitter. This is a summery to understanding the concept of communication for a fiber optic sensor for this project. (U.Madhow, 2008)

### 2.2.1 Transmitter

The transmitter modulates the information/data onto a carrier signal, amplifies the signal and broadcast it over the channel. It is a sub system that takes the input data and processes it.

### 2.2.2 Channel

Channel is the medium which transfer the modulated signal from the transmitter to the receiver section while on the same time air acts as the channel for broadcasting such as radio, television and Internet. Channel might also be a wiring system for example like a cable or fiber optic

### 2.2.3 Receiver

The receiver is a system which receives the transmitted signal from the channel and processes it to recover the message signal. The receiver has to be accomplished to distinguish the signals from others signal which that it might be use the same channel or tuning. Other than that, a receiver also should be able to amplify the signal for processing and demodulate to remove the carrier and then processes the input signal for reception and generate the output that being sent.

## 2.3 Fibre Optic



### 2.3.1 Basic Fiber Optic Communication System

Fiber optic is a medium that change the look of telecommunication field this day, it is an information carrier conveying data starting with one point to another as light. Compare to copper type of transmission, fiber optic is not electrical in nature. A fiber optic framework consists of a transmitting device that convert an electrical signal into a light signal, an optical fiber cable that carries the light, and a receiver that accepts the light signal and converts it back into an electrical signal. Unlike the copper the high data transfer (bandwidth) capacity abilities and low cost make it perfect for a fast and ideal for gigabit transmission and beyond. (Massa, 2008)

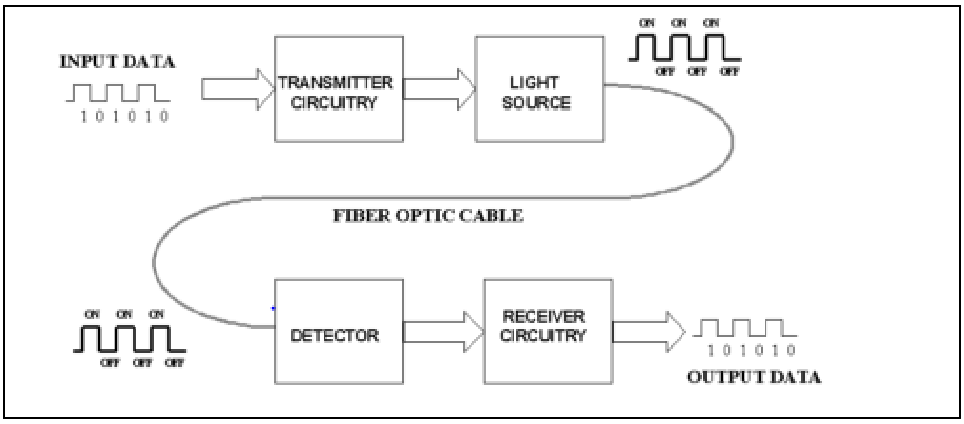


Figure 2.3::Basic fiber optic communication system

In order to comprehend the project of fiber optic sensor on fiber optic application work, it is important to understand the components of fiber optic link, with a specific end goal to grasp how fiber optic applications work, there are four primary segments in a fiber optic connection that is:

a) Optical Transmitter
b) Optical Fiber
c) Connectors
d) Optical Receive



### 2.3.2 How Does Fiber Optic Work?

Optical fiber is a very thin strand of pure glass, which goes about as a waveguide for light over long separation. Uses a primary known as "total internal reflection", when light tries to go between two different media. (Steenbergen, 2013), Lambert M. Surhone, Miriam T. Timpledon, Susan F. Marseken (2010).

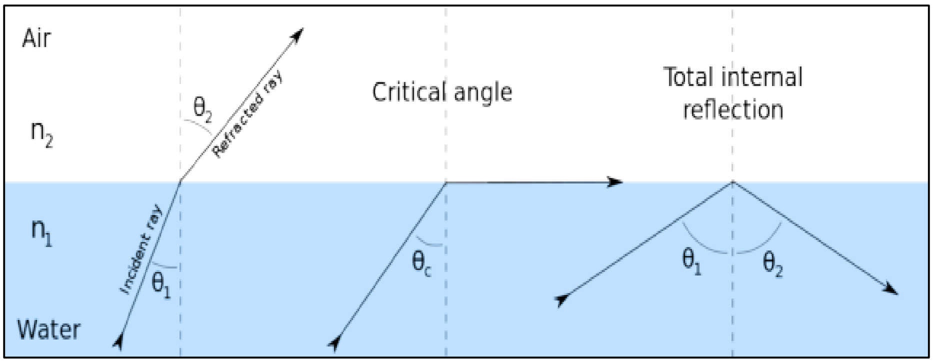


Figure 2.4: Ray of refraction

To discuss the speed of light, it normally discussing the speed in a vacuum (space), which is 3.00 x 108 m/s. when light go through something else, for example, glass or plastic, it travels at a different velocity. The velocity of light in a given material is identified as index of refraction, n, which is define as the pace of light in vacuum to the rate of the light in the medium;

Index of refraction: n = c / v

At the point when light goes starting with one medium then onto the next, the speed changes, as does the wavelength. The index of refraction can also be expressed as terms of wavelength

$$n = {}^{\lambda}/_{\lambda m}$$

Where $\lambda$ is the wavelength in vacuum and $\lambda m$ is the wavelength in the medium, in spite of the fact that the velocity changes and wavelength changes, the frequency of the light will be consistent. The frequency, wavelength, and velocity are connected by:$v = f\lambda$. The changing in light speed that happen when light through to one medium onto the next is in charge for the bending of the light, or refraction, that happens at an interface. If light from one medium into second medium, and angles are measured from the ordinary to the interface, the point of transmission of the light into the second medium is identified with the angle of incidence by Snell's law:

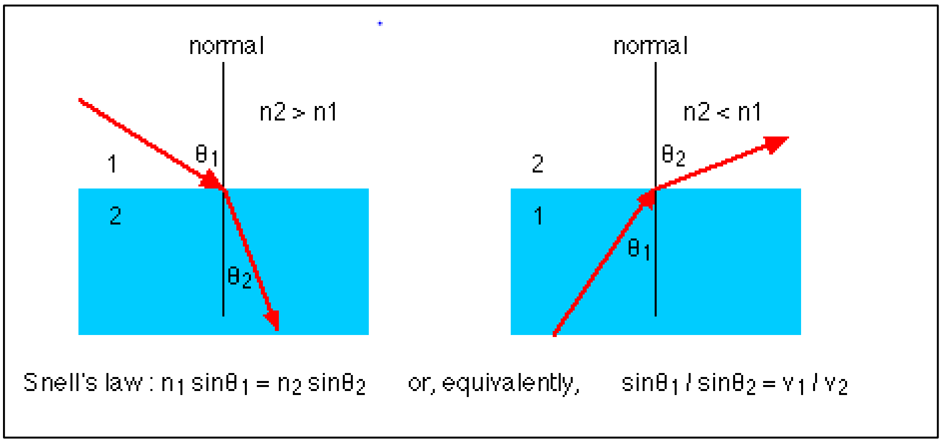


Figure 2.5: Snell's law

### 2.3.3 Critical Angle

This occur when light is bends at a non-normal state. When light travel at interface from point A to point B, from higher n to lower n it will bend at non normal way. This also call the effect of critical angle. The angle of refracted is at 90°.

In the event that the light hits the interface at any point bigger than this critical angle, it won't go through to the second medium by any means. Rather, all of it will be reflected back into the main medium, an effect that know as total internal reflection.



### 2.3.4 Total Internal Reflection

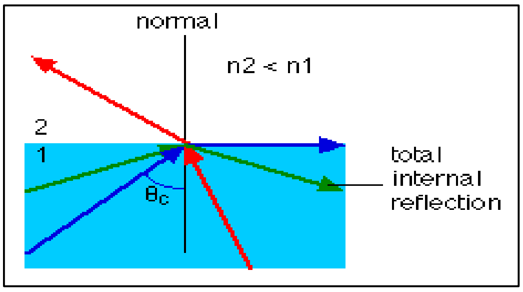


Figure 2.6:Total Internal Reflection

The critical angle can be found in the Snell's laws:

Critical angle $sin\theta c = {}^{n_2}/_{n_1}$ $\quad ( n_1 > n_2)$

As to remind that any angle of incidence larger than the critical angle, Snell's law cannot be solve for the angle of refraction. Because the refracted angle has a sine large than 1, which is not possible All things considered all the light is completely reflected off the interface, complying with the law of reflection.

## 2.4 Type of Fiber Optic

There are three type of fiber optic cable are used in communication systems, to identify the fiber optic the different we can see in the wider core that is single or multimode. And the thickness off the cable. For this project the detail will be more on single mode. (Shiva Kumar, M. Jamal Deen , 2014).

### 2.4.1 Multimode Step-Index (MMF)



Specifically intended for use with "less expensive" light sources. The wide core lets you use incoherent LED light sources. less expensive, less accurately pointed lasers, for example, vertical - cavity surface - emitting laser(VCSELs), and reduces tolerance requirement for alignment of connection. But this comes at the expense of long- distance reach. The wide centre core allow a multiple mode of light to enter it (propagate). (Awad, 2006), (Shiva Kumar, M. Jamal Deen , 2014).

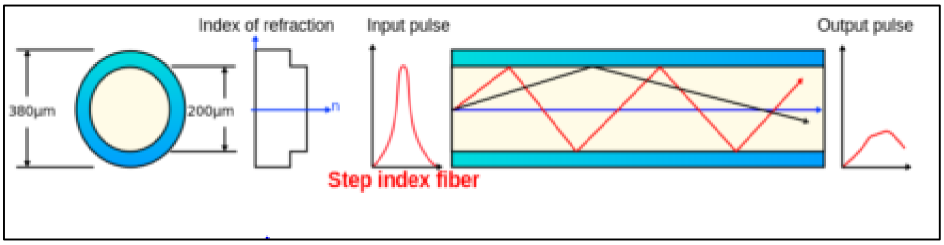


Figure 2.7:Multimode Step Index

This are the characteristic for multimode that is large Numerical Aperture (N.A), easy coupling, model dispersion, lower data rates, shorter distance.

### 2.4.2 Graded-Index

This is same as the multimode concepts but the different can see in the light. This cladding glass has a refractive index, a parameter related to the dielectric constant, which is slightly lower than the refractive index of the core glass. Large N.A easy coupling, less model dispersion, good multimode and single-mode fiber.

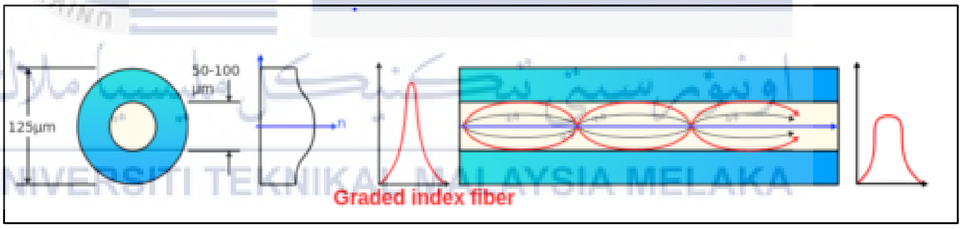


Figure 2.8:Graded Index

### 2.4.3 Single Mode Step- Index

This the fiber that will be used for this project, it is used in all long reach applications. The core is small that can only carry a single mode of light. This mode can support distance of to several thousand kilometre, with the right amplification and dispersion compensation. Small N.A, coupling more difficult, no modal dispersion, high data rates, long distance.

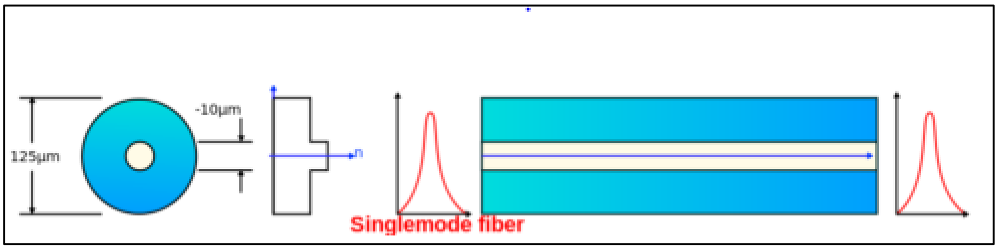


Figure 2.9:Single Mode Step Index

This project, will be use single mode fiber optic. It is more easy to get the data because only one light source will be use but at a different brightness source 850 and 1550 Nano meter (nm).

The specification of the optical fibres characteristic

a) Fibre attribute
b) Core characteristics
    i. Mode field characteristics
    ii. Effective area (Aeff )
    iii. Cladding characteristics
    iv. Cut-off wavelength
    v. Numerical aperture
    vi. Macro bending loss
    vii. Fibre and protective materials
    viii. Proof-stress level
    ix. Refractive index profile
    x. Modal bandwidth
    xi. Chromatic dispersion
        1. Chromatic dispersion definitions
        2. Chromatic dispersion coefficient
        3. Longitudinal uniformity of chromatic dispersion
c) Cables attributes Cable
    i. Attenuation
    ii. Polarization mode dispersion
d) Link attributes
    i. Attenuation

1. Attenuation of a link
2. Wavelength dependence of attenuation

e) Chromatic dispersion
f) Chromatic dispersion of a link The
g) Wavelength dependence of chromatic dispersion
    i. Differential group delay
    ii. Non-linear coefficient
h) Test methods of single-mode optical fibres and cables

## 2.5 Advantages of Fiber Optic

### 2.5.1 Long-distance signal transmission

The low attenuation and superior signal integrity found in optical systems allow much longer intervals of signal transmission than metallic-based systems. While single-line voice-grade copper systems longer than a couple of kilometers (1.2 miles) require in-line signal for satisfactory performance, it is not unusual for optical systems to go over 100 kilometers (km), or about 62 miles, with no active or passive processing. (Massa, 2008)



### 2.5.2 Large bandwidth, light weight, and small diameter

Today application required the use of ever-increasing amount of bandwidth. The installation of fiber optic is smaller plus the relatively small diameter and light weight of optical cable make such installation easy and safer, saving valuable space in the environments. (Massa, 2008)

### 2.5.3 Non conductivity

Another advantage of optical fibers is their dielectric nature. Since optical fiber has no metallic components, it can be installed in areas with electromagnetic interference (EMI), including radio frequency interference (RFI). Areas with high EMI include utility lines, power-carrying lines, and railroad tracks. All-dielectric cables are also ideal for areas of high lightning-strike incidence. (Massa, 2008)

### 2.5.4 Security

Unlike metallic-based systems, the dielectric nature of optical fiber makes it impossible to remotely detect the signal being transmitted within the cable. The only way to do so is by accessing the optical fiber. Accessing the fiber requires intervention that is easily detectable by security surveillance. These circumstances make fiber extremely attractive to governmental bodies, banks, and others with major security concerns. (Massa, 2008)



### 2.5.5 Designed for future application needs



Fiber optics is affordable today, as electronics prices fall and optical cable pricing remains low. In many cases, fiber solutions are less costly than copper. As bandwidth demands increase rapidly with technological advances, fiber will continue to play a vital role in the long-term success of telecommunication. (Massa, 2008)

## 2.6 Light Source

In fiber optic, light is the main of component that make the fiber to work, without light the fiber is just a fiber. There are many light source that we can use example is light-emitting diodes (LED) or Laser. This light source more use in fiber now day. In light source they divide in two part that is nonlinear and linear propagation. For this the concentration will take be at the nonlinear propagation effect. (luigi.l, Franco.P, Massimo.b, 2015)

Table 2.1:Characteristic between led and laser

| **Characteristic** | **Led** | **Laser** |
|---|---|---|
| Output power | Lower | Higher |
| Spectral width | Wider | Narrower |
| Numerical aperture | Larger | Smaller |
| Speed | Slower | Faster |
| Cost | Less | More |
| Ease of operation | Easier | More difficult |

### 2.6.1 Nonlinear Pulse Propagation.

The spread of an electromagnetic wave of pulse relies on the medium in which it propagates. In a vacuum a pulse can propagate unchanged, when spreading in a medium, in any case, an electromagnetic field cooperates with molecules, which for the most part implies that the beat encounters lost and dispersion. The last impact happens in light of the fact that the different wavelength components of the pulse travel at various speeds because of the wavelength dependence of the refractive index.

The effect of this will occur for this project the non-linear light will take effect as the source will give the output to the receive. (R.-J. Essiambre, G. Kramer , P. J. Winzer , G. J. Foschini and B. Goebel, 2010)

### 2.6.2 Linear Pulse Propagation.

It is the tolerance to which a reaction of a framework approximates a straight line in the measurement dynamic range.

## 2.7 Fiber Optic Sensor

Telecommunications have been revolutionized by fiber optic technology. The revolution began with limited system applications needing superior performance provided by fiber optics. Fiber optic sensor can categories at the figure below; (Udd, E., & Spillman Jr, W. B. ,2011)

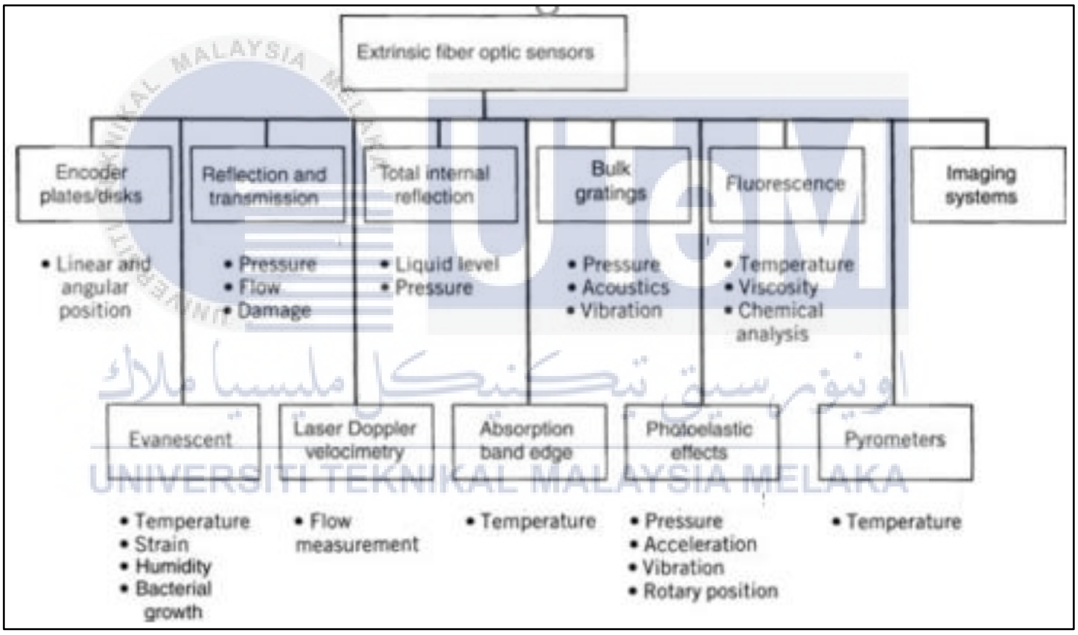


Figure 2.10:Extrinsic or Hybrid Fiber Optic Sensors: Light Transmits into and out of the Fiber to reach the Sensing Region.

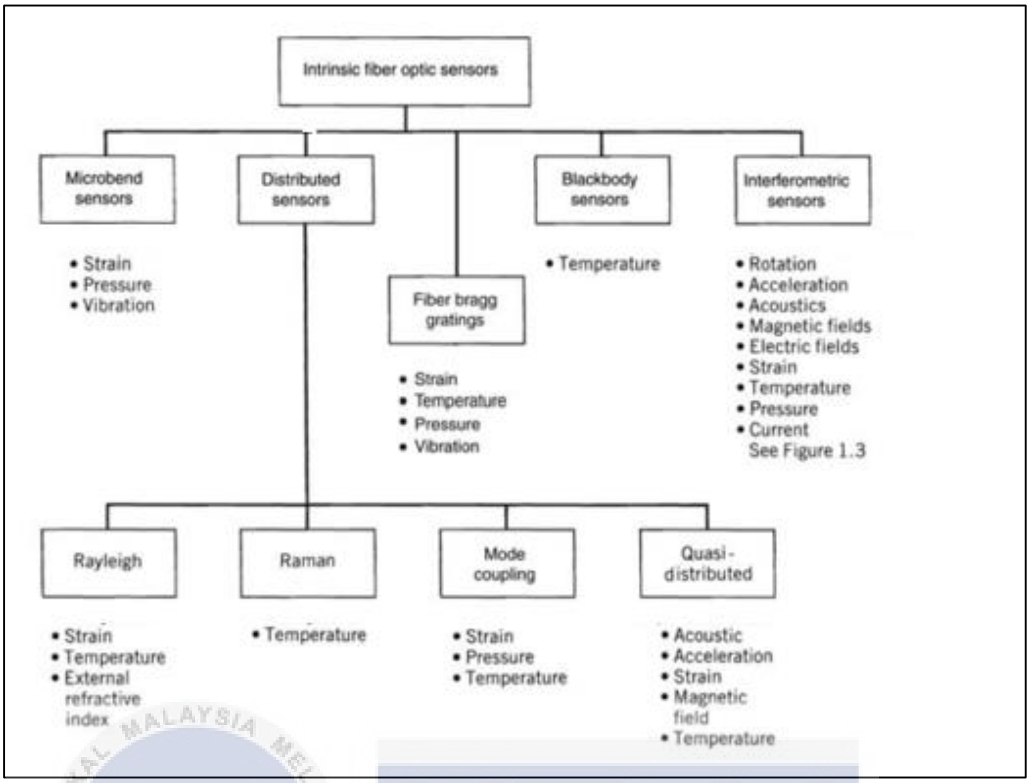


Figure 2.11: Intrinsic or All-Fiber Fiber Optic Sensors: the environmental Effect Is Converted to a Light Signal within the Fiber

### 2.7.1 Advantage of fiber optic sensors

a) Passive (all-dielectric)
b) Light weight
c) Small size Immunity to electromagnetic interference
d) High-temperature performance
e) Large bandwidth
f) Environmental ruggedness to vibration and shock
g) High sensitivity
h) Electrical and optical multiplexing
i) Component costs driven by large commercial telecommunication and optoelectronic market

### 2.7.2 Fiber Optic Sensor Principles

The general structure of an optical sensor system is show below, it consists of optical source, optical fiber, sensing or modulator element (which transduces the measuring to an optical signal), an optical detector and processing electronics (optical spectrum analyser etc.). (Address, K. , 2009)

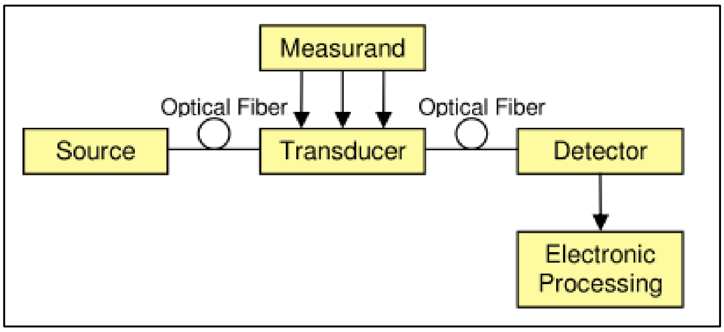


Figure 2.12:Basic Components of an Optical Fiber Sensor System.

Fiber optic sensors can be classified under three categories: the sensing location, the operating principle and the application.

Based on the sensing location, a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor, the fiber is simply used to carry light and from an external optical device where the sensing takes place. In this cases, the fiber just acts as a means of getting the light to the sensing location.



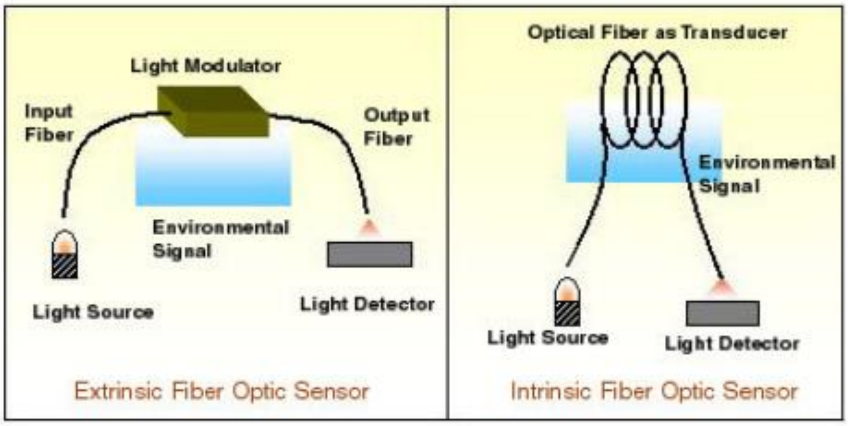


Figure 2.13:Extrinsic and Intrinsic Types of Fiber Optic Sensors.

For the development of this fiber optic sensor, using the intrinsic fiber optic sensor method. Then again, in an intrinsic fiber optic sensor, one or more of the physical properties of the fiber experience a change. Process or moving object or caused by an outside influence/interruption act on the fiber and the fiber in turn changes some characteristic of the light inside the fiber.

Based on the operating principle or modulation and demodulation process, a fiber optic sensor can be classified as an intensity, a phase, a frequency, or a polarization sensor. All these parameters may be subject to change due to external interference. Thus, by detecting these parameters and their changes, the external interference can be sensed.

### 2.7.3 Based on the application, a fiber optic sensor can be classified as follows:

a) Physical sensors: Used to measure physical properties like temperature, stress, etc.
b) Chemical sensors: Used for pH measurement, gas analysis, spectroscopic studies, etc.
c) Bio-medical sensors: Used in bio-medical applications like measurement of blood flow, glucose content etc.



### 2.7.4 Intensity based fiber optic sensors.

This type of method is relying on the signal that undergoing some loss. They are made by using an apparatus to convert what is being measured into a force that bend the fiber and causes attenuation of the signal is through absorption or scattering of a target.

One of this sensor is the micro bend sensor, which is based on the principle that mechanical periodic micro bends can cause the energy of the guided modes to be coupled to the radiation modes and consequently resulting in attenuation of the transmitted light. Can refer in figure below, the sensor is comprised of two grooved plates and between them an optical fiber passes. The upper plate can move in response to pressure. When the bend radius of the fiber exceeds the critical angle necessary to confine the light to the core area, light starts leaking into the cladding resulting in an intensity modulation.

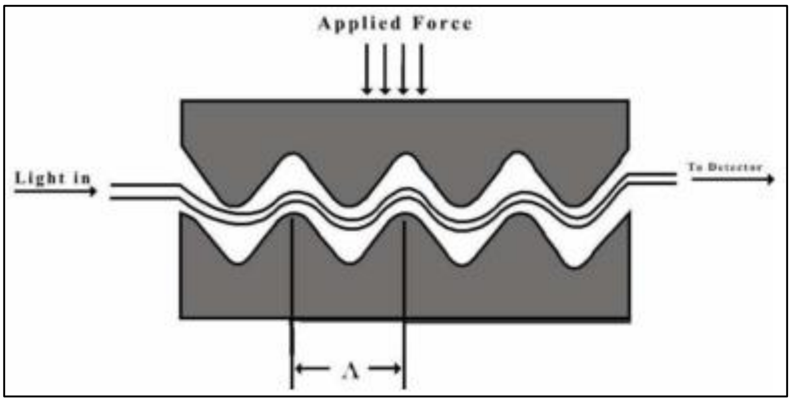


Figure 2.14:Intrinsic Fiber Optic Sensor

Some other FOS is the wavelength modulated fiber optic sensor, phase modulated fiber optic sensor, polarization modulation and etc. (Address, K. (2009)



## 2.8 Lubrication oil

### 2.8.1 Lubrication

A lubricant is a substance that is well known with a property to reduce friction between surface in a common contact, which eventually reduce the heat produced when the surface move. They are designed to perform many task in engines and other mechanical machines. These oil of moving parts, cooling, cleaning and corrosion control. Lube base produce by refineries and petrochemical manufacturers (synthetic lube base stocks) are used to produce a large number of products such as the following;

a) Gasoline and diesel engine oils

b) Agricultural engine oils
c) Marine engine oils
d) Aviation and turbine oils
e) Hydraulic and transmission oils
f) Gear oils
g) Automotive and industrial greases
h) Metal working oils
i) Electrical insulating oils
j) White mineral oils
k) Process oils

In industrial of automotive engine oils, transmission oils, and gear lubricants constitute roughly two-thirds of the total lube oil produced. A large portion of these items are set up by mixing a fitting rate added substances with lube base stock. For each application, the base stock and added substance mixing must be carefully choosing to meet the similarity and requirements of the proposed application. the use of this lubricant is in a great demand. Thus the research for this project will more concentrate on the lubrication oil for engine. (Surinder Parkash, 2010)



### 2.8.2 Classification of lubricating oils

Lubricating and greases can be arranged from numerous point of view; by their end use, by thickness grades, by their added substance bundle, or by their producer's brand names. The most popular arrangement of lubes is according to their usage:

a) Engine oils (petrol and diesel engines, aircraft, marine engines)
b) Turbine oils
c) Gear oils
d) Compressor (refrigeration, air) oils
e) Quench oils used in metalworking

f) Cutting oils (in metal cutting)

g) Insulating oils used in transformer and circuit breakers

h) Wire rope lubricants

i) Chain lubricants

j) Hydraulic oils

The type of base oil (naphthenic, paraffinic, or synthetic) and additives may vary to provide the qualities required for a given application. (Surinder Parkash, 2010)

## 2.9 Lubricant Selection

There are 3 type of lubricant oil specific for the use of engine oil that is mineral oil, semi synthetic and fully synthetic. Base on the research and develop for this fiber optic sensor the lubrication oil that will be use is mineral oil.

Why? Because mineral oil is the first of lubrication oil that being made after that come the semi and fully synthetic oil also the grease. This lubricant is well known among all the use with the low grade and cheap cost compare to the semi and fully synthetic. The develop of this fiber optic sensor will be more on to compare among two brand of mineral oil.



### 2.9.1 Term in lubrication oil

This are the term that maybe familiar in an area of lubrication that many use to describe a characteristic of lubrication and the understanding for it. Some of the term maybe use in this chapter and some of the term maybe not use in this research that will be done.

Table 2.2:Term of lubrication oil

| Properties | What it mean |
|---|---|
| High flash point | Improve fire resistance and thermal stability |
| Low pour point | Improve low-temperature pump-ability/lubrication |
| Fire resistance | Good for high-risk hydraulic application |
| Oxidation stability | Extended oil drain, resists severe conditions |
| Thermal stability | Oil doesn't degrade or thicken at high temperatures |
| High viscosity index | Function like a multi-grade oil |
| Lower friction | Reduce energy consumption costs |
| Natural detergency | Help keep surface clean of deposits |

### 2.9.2 Mineral oil

In automotive industry lubrication is important. As the gear of each rotation in the mechanism of the part is move at a great speed, it create friction. This friction can produce a lot of heat if there is no lubricant put on it.



### 2.9.3 Properties of mineral oil

Mineral oil is produced from both naphthenic and paraffinic feedstocks. By selecting careful feedstock (crude source), there are produce in a large scale of viscosity, specific gravity, volatility, pour point, and other properties to suit the different uses. (José André Cavalcanti da Silva, 2011)

### 2.9.4 Viscosity

There are many consistency, regularly going from 10 to 120 cSt or more at 104°F, as indicated by user industry standard. A plant may essentially create two consistency grade; most minimal and most astounding thickness grade. All other required evaluations are created by mixing these two grade in different proportions. However, very low viscosity oils also have low flash points, which cannot be used as quench oils.  (José André Cavalcanti da Silva, 2011)

Table 2.3:Properties of Commercial Mineral Oils

| Property | Units | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Color, Saybolt | | +30 | +30 | +30 | +30 | +30 | +30 | +30 | +30 | +30 |
| Density 68°F | kg/m$^3$ | 831 | 856 | 850 | 854 | 848 | 840 | 853 | 853 | 861 |
| Viscosity, 68°F | cSt | | | | 31–35 | 34–38 | | 60–66 | | |
| Viscosity, 68°F | SUS | | | | 146–164 | 160–178 | | 279–306 | | |
| Viscosity, 100°F | SUS | 53 | | | | | | | | 186 |
| Viscosity, 104°F | cSt | 7.8 | 9.2 | 11.5 | 12.5–15.5 | 15–18.5 | 15 | 23–26 | 29.7 | 36 |
| Viscosity, 104°F | SUS | | | | 68–79 | 77–92 | | 111–124 | | |
| Viscosity, 212°F | cSt | | | 3.14 | 3.1 | 3.5 | 3.38 | 4.5 | 5.25 | |
| | SUS | | | | 36 | 38 | | 41 | | |
| Flash point, COC, Min. | °F | 310 | 331 | 338 | 313 | 338 | 356 | 356 | 372 | 395 |
| Pour point, Max. | °F | 20 | −0.4 | −0.4 | 10 | 5 | −0.4 | 27 | 5 | 10 |
| Sulfur, Wt % | Wt % | | | | <0.001 | | | | | |
| Neutral number | | | | | 0 | 0 | | 0 | | |
| Carbon distribution | Wt % | | | | | | | | | |
| | Aromatics | | | | 0 | 0 | | 0 | | |
| | Naphthenes | | | | 37 | 35 | | 34 | | |
| | Paraffins | | | | 63 | 65 | | 66 | | |
| Initial boiling point | °F | | | | 536 | 626 | | 554 | | |
| Final boiling point | °F | | | | 860 | 806 | | 896 | | |
| Mol wt | | | | | | | | | | |

Mineral oil are excellent quench ants and are esteemed for their capacity to offer fast cooling over and extensive variety of temperatures. A standout amongst the greatest qualities of quenching oil is their capacity to thin when warmed, with high-warm exchange rates. They offer more uniform warmth exchange, bringing about a great deal less bending and braking in metals. The flash point of quenching oils is 270 to 550°F. For operation safety it is operated at 120 to 160°F below the flash point of the quenching oil.



### 2.9.5 Boiling Point

The breaking point of quench oil is a vital basic element. The breaking point of quench oil influences the film boiling to nucleate boiling and to convective cooling.

### 2.9.6 Oxidation Stability

Oxidation of quenching oils occurs because of the chemical reaction of oil with atmospheric oxygen. The rate of oxidation increases greatly as the temperature of the oil rises. The presence of metallic contaminants acts as a catalyst for oxidation reactions. The products of oxidation are complex and may include acidic and insoluble components. These oxidation products can affect quench rates and may cause corrosion, metal staining, and sludge formation.

### 2.9.7 Quenching Speed

The behaviour of quenching oils may be modified by the incorporation of additives and is also affected by contaminants. However, it is physical properties that determine the cooling rates in successive stages of cooling. These properties are specific heat, thermal conductivity, heat of vaporization, and viscosity. Mineral oils vary in types. The selection of oils for quenching is basically based on their viscosity and volatility. An increase in viscous resistance to flow tends to hinder convective turbulence in the boiling or vapour transport stage. To a certain degree, this reduces the risk of cracking of oil, but the effect of the vapour transport stage is to reduce the quenching power of the oil. Oil quenchants can be classified into three groups:

a) Conventional
b) Fast
c) Mar tempering or hot,

Conventional oils are mineral oils that may contain antioxidants. They are characterized by a long vapour phase with relatively slow cooling, very fast cooling in their boiling range, and again very slow cooling during the convection stage. The use of these oils is limited to steels with medium to high hardenability.

Fast quenching oils are mineral oils that contain proprietary additives, antioxidants, and wetting agents. These are characterized by high initial quenching speeds that can approach than water, a fast cooling rate, and a cooling rate similar to that of conventional oils during the convection period. Mar tempering oils are paraffinic mineral oils that offer excellent thermal and oxidation stability. They are primarily used at high temperatures (200 to 450°F) for the mar tempering of ferrous metals. Many additives are added to modify cooling and quenching rates to suit various requirements. (Surinder Parkash, 2010)

## 2.10 Design of Experiment

Design of experiment (DOE) is a mathematical method characterizes an ideal arrangement of investigation in the outline space, so as to get the most relevant data conceivable with the most precision at the lower cost. This experimental investigation prepares, and is the speediest approach to get the most applicable data with least computational effort.

Many methods have created, for various type of applications. No attempt wil be made here to summarize all of these method. In any case, DOE techniques can be characterized into two classes: orthogonal and random design. (Ahmed Badr Eldin, 2011).

### 2.10.1 Random design

This method implies that the model parameter values for the investigations are assigned on the premise of an irregular procedure, which is another generally used DOE method. The most commonly method is called Latin Hypercube Design (LHD)

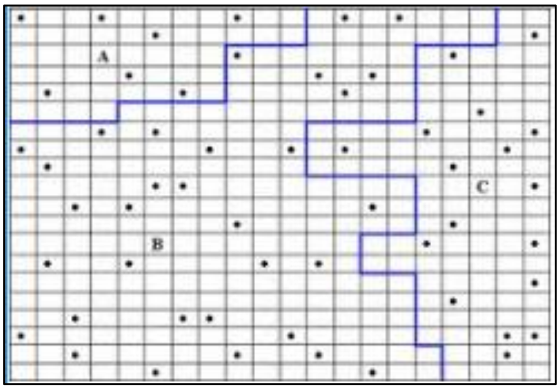


Figure 2.15:Random Design

The breakdown issue does not happen with LHDs. This is on the grounds that one or more elements show up not to be vital, each point in the configuration still gives some data in regards to the impact of alternate components on the reaction. Along these lines, none of the time-consuming computer experiments will be useless. (Ahmed Badr Eldin, 2011).

### 2.10.2 Orthogonal design

Orthogonality is a design implies that the model parameter is measurably. It implies that the elements in a test are uncorrelated and can varied independently. Many used are partial and full factorial designs, central composite design and box-Behnken design.



| | FACTORS | | | | | | |
|---|---|---|---|---|---|---|---|
| TRIAL NUMBER | A | B | C | D | E | F | G |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 3 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| 5 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| 6 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| 7 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 8 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |

Figure 2.16:Orthogonal Design

A factorial design has some disadvantages: at first it is normally misty which variable is critical and which is not. Since the basic capacity is deterministic. There is a probability that a portion of the initial design point collapse one or a greater amount of the time-consuming computer experiment become useless. This current issue’s known as the collapse issue. Most exemplary DOEs are just relevant to rectangular design regions. What more the quantity of test increments exponentially with expending number of lever.

As for the research that will be done using the factorial design is the more suit, because the each of the parameter will be test again each other parameter to gain the data in using fiber optic sensor as sensor. (Hsu, D., Kakade, S., & Zhang, T. 2011)

#### 2.10.2.1 Factorial design

As to understand more about DOE technique, this section focuses on the concept of the two-level full factorial designs only. In this type of design, all variables should have just two levels. Confining the levels to two and running a full factorial analysis lessens the quantity of treatments and it takes into consideration the examination of all the variables and every one of their connections. On the off chance that all factors are quantitative, the data from such experiments can be utilized for prescient purposes, thus it is suitable for modelling the response by providing a linear model

#### 2.10.2.2 $2^k$ Factorial Design

Full factorial design is probably the famous in system of experiment design. In the most fundamental structure of the two-level full factorial, there are K components and L = 2 levels for every variable. The sample are given by each possible combination of the variable values. Along these lines, the example size is N = $2^k$. the two levels are known as high (‘h’) and low (‘l’) or, "+1" and "−1". Starting from any example inside the full factorial plan, the example in which the elements are changed each one thus, are still part of the example space. This property considers the effect of each component over the response variable not to be mess with alternate factor. Now and again, in composing, it happens to Experience full factorial outline in which similarly the essential issue in the example wherein each of the parameter has worth which is the normal between the low and high level. In $2^k$ full factorial tables can be indicated with ‘m’ (mean quality) or ‘0’.

Basically, DOE enable in choosing the individual example and effects of various variable that could impact the yield result in any design simulation. Furthermore, it gives full information of participation between outline segments in this manner, changing any standard system into an outstanding system. Fundamentally, it eliminates the sensitive parts in design that realize issues in the yield. The figure below demonstrates the case of the $2^k$ full factorial outline.

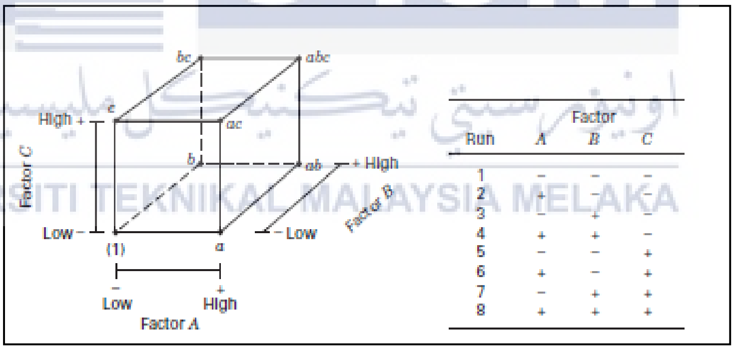


Figure 2.17:Example of Factorial Design

Table 2.4:The 23 design (Montgomery, 2013) Geometric view, design matrix and table.

| Run | A | B | C | Labels | A | B | C |
|---|---|---|---|---|---|---|---|
| 1 | − | − | − | (1) | 0 | 0 | 0 |
| 2 | + | − | − | *a* | 1 | 0 | 0 |
| 3 | − | + | − | *b* | 0 | 1 | 0 |
| 4 | + | + | − | *ab* | 1 | 1 | 0 |
| 5 | − | − | + | *c* | 0 | 0 | 1 |
| 6 | + | − | + | *ac* | 1 | 0 | 1 |
| 7 | − | + | + | *bc* | 0 | 1 | 1 |
| 8 | + | + | + | *abc* | 1 | 1 | 1 |

Table 2.5:The algebraic sign for calculating effects in the 23 design (Montgomery, 2013).

| Treatment Combination | Factorial Effect | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *I* | *A* | *B* | *AB* | *C* | *AC* | *BC* | *ABC* |
| (1) | + | − | − | + | − | + | + | − |
| *a* | + | + | − | − | − | − | + | + |
| *b* | + | − | + | − | − | + | − | + |
| *ab* | + | + | + | + | − | − | − | − |
| *c* | + | − | − | + | + | − | − | + |
| *ac* | + | + | − | − | + | + | − | − |
| *bc* | + | − | + | − | + | − | + | − |
| *abc* | + | + | + | + | + | + | + | + |



## 2.11 Design Expert

Design Expert is a piece of software designed to help with the design and interpretation of multi-factor experiments. In polymer processing, we might use the software to help us design an experiment to see how a property such as tensile strength varies with changes in the processing conditions - e.g. changes in rotor speed or ram pressure.

The software offers a wide range of designs, including factorials, fractional factorials and composite designs. It can handle both process variables, such as rotor speed, and also mixture variables, such as the proportion of resin in a plastic compound. Design Expert offers computer generated D-optimal designs for cases where standard designs are not applicable, or where we wish to augment an existing design - for example, to fit a more flexible model. (Stat-Ease, Inc. 2016)

## 2.12 Summary

This chapter tell about the literature review about the research that being done. base on it, this is the step to develop the fiber optic sensor. Each of the subtopic in this chapter is about the detail of the research that need to be known before moving to next step in develop this sensor of fiber. The development of communication system from the analog to digital system. The fiber optic structure and the concept of the reflection in fiber optic. Each of the fiber optic has it general specification. For the sensor in fiber optic have they own detail on how to develop it and lubrication oil have they own detail need to be known. In design of experiment using the factorial is the rightest choice to make the analyse. The data that being collect from the output is easy to understand and read by user.

# CHAPTER 3
# METHODOLOGY

## 3.1 Introduction

The methodology of a project is guidelines that will explain about the project path from beginning until it complete. Every action and testing must be done and every stages must be explained during implementing the project. This methodology is necessary to ensure the project development will have developed systematically, efficiently and successfully in order to gain the good results.

In addition, all steps must be planned and organized starting from data collection design, project simulation, project analysis and report writing of the thesis in order to avoid lack of time. These methods are used to find and also analysing data about the project.



## 3.2 Identify The Problem

Nowadays, there a many brand in lubrication oil. Many vehicle users don’t know the accurate time to change the lubrication oil that there use. User always depending on the kilometre show or advice form a mechanic. This research is to develop a fiber optic to use as a sensor to detect the lubrication oil in motor oil thus, can this sensor detect the condition for the lubrication oil that is good or not. The development of this project will basically to test the two brand oil with in market that is mineral oil in motor industry and using DOE to optimize the using for fiber optic sensor.

### 3.3 Project Planning

Before this project can be proceed, all flow or method must be planned before produce the expected result. This planning for the project can represent in a form of flow chart below:

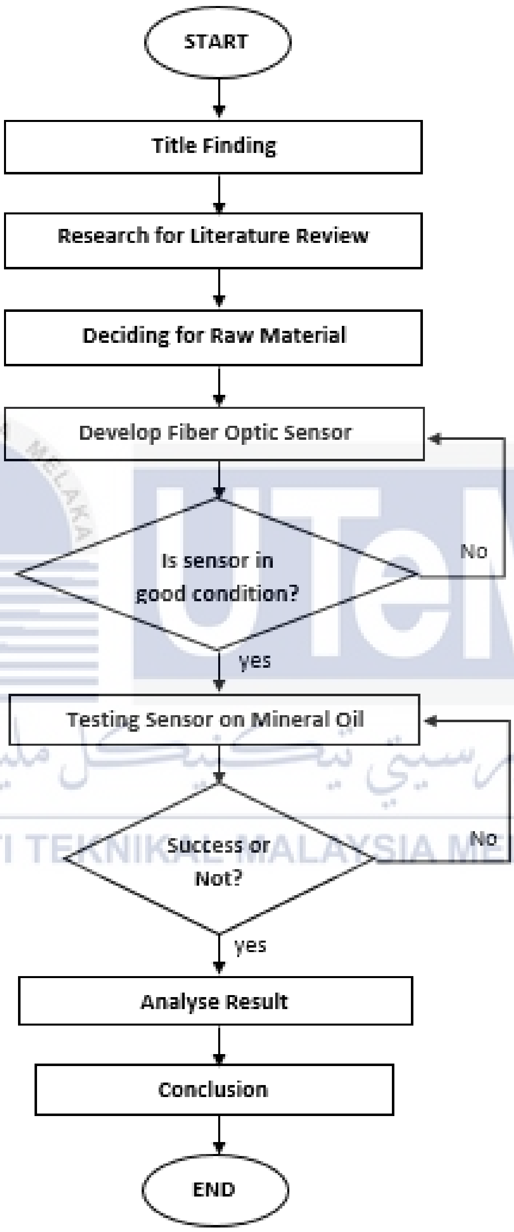


Figure 3.1:Flow Chart for This Project

### 3.3.1 Title Finding

The title finding is used to decide and identify the project title which is the journals and articles are being collected and analysed. Besides, in order to discover the project title, a discussion session have to be implemented with supervisor. Through this method, the suitable project title can be decided and be confirmed which are cover on the current issue in several aspects such as social development, economy and health. From discussion with supervisor and studies on journal and articles, the project title has been chosen. The title that are being chosen for this project is "***DEVELOPMENT A LIQUID SENSOR USING FIBER OPTIC FOR ENGINE LUBRICATION OIL AND OPTIMIZATION USING DESIGN OF EXPERIMENT (D.O.E) TECHNIQUE***".

### 3.3.2 Literature review

Literature review and technical research was conducted the project objectives and scope is understood as the result of discussion. From the journal and articles that being collected and analyse, many practical users have use the fiber optic as a sensor in many industry as example in detect a crack surface wall. Some of the article have strongly support this research in develop fiber optic sensor in lubrication oil.



### 3.3.3 Raw material

The hardware that will be used to analyse and develop the fiber optic sensor are listed below;

#### 3.3.3.1 Fiber Optic Cable

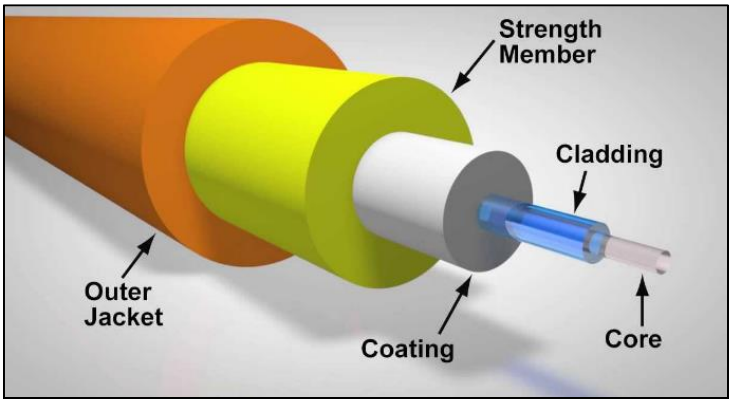


Figure 3.2:Fiber Optic Structure

Fiber optic cable are mode out of one or more transparent fiber encased in defensive cover and quality shell. For this project the type that will be use is single-mode and multi-mode fiber optic. In develop a sensor, this type is most suitable one that suit the characteristic for the project.

#### 3.3.3.2 Fiber Optic Pigtail



Figure 3.3:Pigtail cable

The type that will use is the pigtail cable for fiber optic. Fiber optic pigtail cable have a connector only at one end where the other end gets spliced onto a fiber cable. Each fiber optic patch link 100% tried to protect all inside and outer models are met.

#### 3.3.3.3 Fiber Optic Fusion Splicer

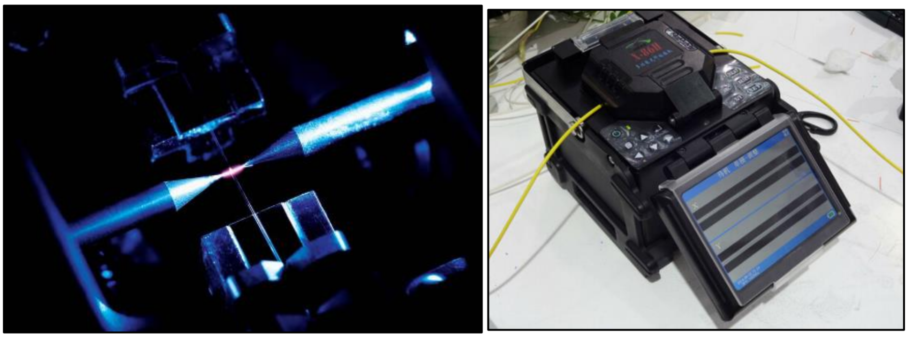

Figure 3.4: Fusion State and Splicer Equipment

As the information being collected from journal, articles and monitoring from the supervisor. By using appropriate equipment, the connection between fiber optic cable and pigtail cable can be made by using splicing process. The connection between two cable is connected without the cladding. This open area of the core will be as sensor to detect the loss of light that go through from the light source to the receive.



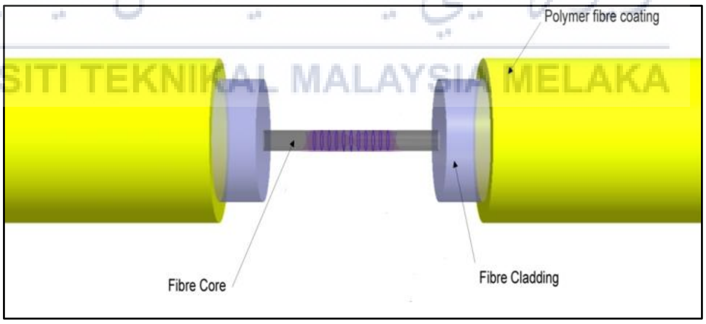


Figure 3.5:Fiber Optic Sensor Structure

#### 3.3.3.4 Optical Spectrum Analyser (OSA)

Figure 3.6:Optical Spectrum Analyser

An Optical Spectrum Analyser (or OSA) is a precision instrument designed to measure and display the distribution of power of an optical source over a specified wavelength span. An OSA trace displays power in the vertical scale and the wavelength in the horizontal scale.

#### 3.3.3.5 Amplified Spontaneous Emission (ASE)u



Figure 3.7:Amplified Spontaneous Emission

Amplified spontaneous emission (ASE) is light produced by spontaneous emission. It has been optically amplified by the process of stimulated emission in a gain medium. It is inherent in the field of random lasers. The light source mode used for testing are 1310nm and 1550nm. This will analyse the sensitivity of fiber optic as sensor to detect the loss in the core.

#### 3.3.3.6 Mineral Oil.

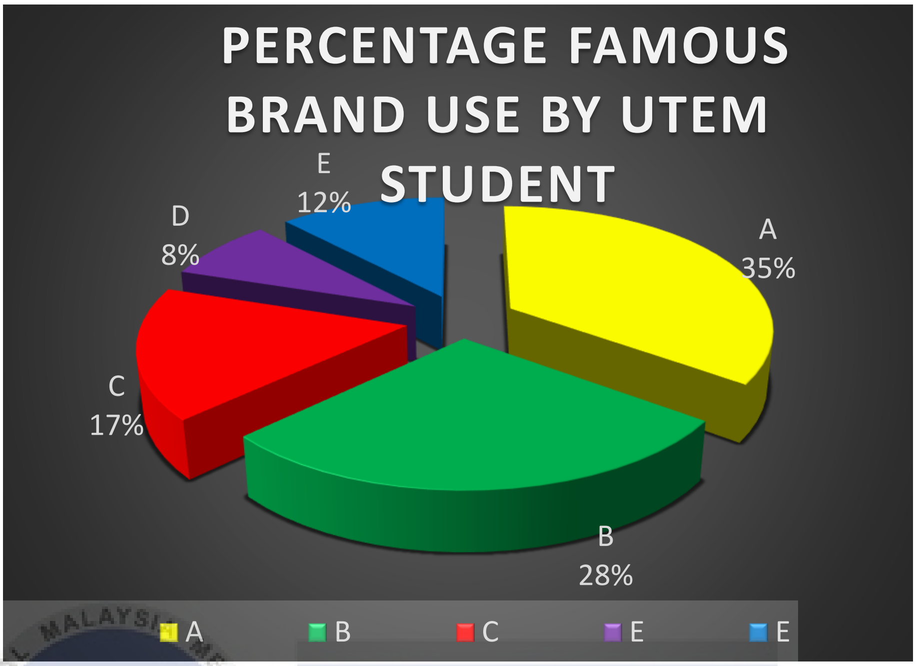


Figure 3.8:Chart for Determine Which Brand That Will Use

To determine the two brand that will use in this research a survey has been made. From all 30 students technical Malaysia Melaka in faculty of technology. The most commonly use and the second will be selected. Thus to declare this brand will be put as brand A and brand B.



#### 3.3.3.7 Tool That Use to Develop Fiber Optic Sensor


Figure 3.9:Tool box

This box of tool provides the equipment from cut the cable, clean the cable and the requirement to finish this project.

### 3.3.4 Development for fiber optic sensor

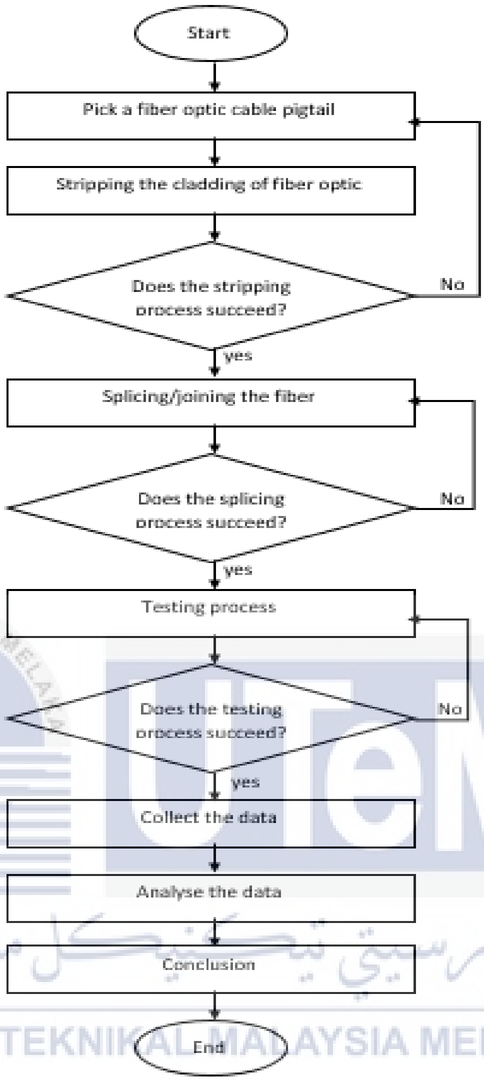


Figure 3.10:Development of Fiber Optic Sensor Flow Chart

This flow chart shows the development for fiber optic sensor from start to end. From the start the fiber itself need to be pick and stripping the cladding. If succeed move to joining the cable with one another to become a sensor. If all the procedure is proceeding with success, then no second attempt need to repeat until collecting data section and analyse it.

Figure 3.11:Stripping The Cladding of Fiber

Figure 3.12:Cleaving The Core of the Fiber

This picture show that is important to cut the core of the fiber to get the right angle in the next proses that is fusion the fiber core.




Figure 3.13:Fusion State Left Picture Show Before and Right Show After Fusion.

It is important to alert this state, because loss in the fiber will happen if the equipment show 0.0 dB loss that mean the fusion is correct and well done. But if the fusion show more than 1 dB loss it is better to make another connect until it get less than 1 dB

### 3.3.5 Testing the sensor

Figure 3.14:Left Picture Show That Mineral Oil is Tested to the Fiber and Left Picture Show the Full Scale of Testing the Sensor

When all the equipment and material use are known plus, the brand of lubrication oil that will be used to test the fiber optic as sensor. The next step is to test the fiber optic as sensor with the oil and different parameter that will be the variable for this research. This will analyse the sensitivity of fiber optic sensor with mineral oil in 30 minutes and 1-hour duration.

### 3.3.6 Analyse the result

This stage also will be implemented and the result that being obtain from testing process will be tabulated and be plotted using the DOE method software. Moreover, the study of relationship between the manipulated variable and responding variable of this project can be achieved.

### 3.3.7 Method of analyse the result

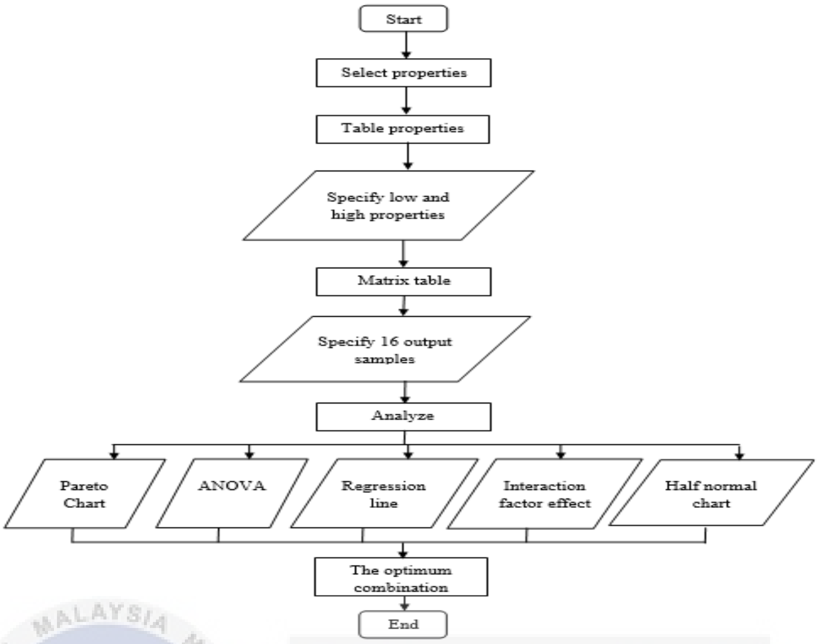


Figure 3.15:Flow Chart of DOE Using Factorial Design

The flow chart above shows the step to conduct an analyses using factorial design in DOE. This give move detail on the analyses will be done. In analyse section there will be many option to pick on but the testing will pick on the most suitable that meet with the research criteria.

### 3.3.8 Analyse using design of experiment

The data from the first stage of testing the fiber optic sensor with the parameter will be collected and the data will be analyses using a software of DOE to obtain the optimization for fiber optic. After the second stage where the data being analyse with the DOE method. This will show in the table, form where is more optimize in which condition for the fiber optic sensor. As mentions before the analyse will use a factorial design method. The outcome of the result will be show as below table.

Table 3.1:Variable of the experiment

| | Name | Units | Type | Low | High |
|---|---|---|---|---|---|
| A [Categoric] | Type of Fiber | Mode | Categoric | SIngle mode | Multimode |
| B [Numeric] | TIme | Minute | Numeric | 30 | 60 |
| C [Numeric] | Light Source | Nanometer | Numeric | 1310 | 1550 |
| D [Categoric] | Brand | Type of Brand | Categoric | B | A |

Table 3.2:Matrix Design of Experiment

| Select | Run | Factor 1 A:Type of Fiber Mode | Factor 2 B:TIme Minute | Factor 3 C:Light Source Nanometer | Factor 4 D:Brand Type of Brand | Response 1 Power dBm |
|---|---|---|---|---|---|---|
| | 1 | SIngle mode | 30 | 1310 | A | |
| | 2 | SIngle mode | 60 | 1310 | A | |
| | 3 | SIngle mode | 30 | 1310 | B | |
| | 4 | SIngle mode | 60 | 1310 | B | |
| | 5 | SIngle mode | 30 | 1550 | A | |
| | 6 | SIngle mode | 60 | 1550 | A | |
| | 7 | SIngle mode | 30 | 1550 | B | |
| | 8 | SIngle mode | 60 | 1550 | B | |
| | 9 | Multimode | 30 | 1310 | A | |
| | 10 | Multimode | 60 | 1310 | A | |
| | 11 | Multimode | 30 | 1310 | B | |
| | 12 | Multimode | 60 | 1310 | B | |
| | 13 | Multimode | 30 | 1550 | A | |
| | 14 | Multimode | 60 | 1550 | A | |
| | 15 | Multimode | 30 | 1550 | B | |
| | 16 | Multimode | 60 | 1550 | B | |



### 3.3.9 Conclusion from the result.

As the data that being obtain from this research, thus conclusion can be made from the result. which are the best optimization in what condition for the fiber optic will operate and the objective achieve or not.

### 3.3.10 Report writing

A full report will be write base on this research. This report will show on how the progress and all the research on the fiber optic sensor to detect lubrication oil that is mineral oil. The report format is based on the thesis format. Is consist of these criteria as listed below,

a. Introduction
b. Literature Review
c. Methodology
d. Expected Result
e. Discussion
f. Conclusion
g. Reference

## 3.4 Summary

This chapter tell about on how step should be taken to develop a fiber optic to become a sensor. The flow chart shows the flow of this research step. each step should be take carefully so that the progress of this research is not mistake and met with the objective. Each of the equipment that will be use and each of the parameter that will be test is detail in this chapter, so the research will not mistakenly misunderstand the propose of this research.

# CHAPTER 4

# RESULT & DISCUSSION

## 4.1 Project overview

For this chapter will focuses on the experiment result and how to develop the fiber sensor that been our main objective form the beginning of this project. The step from start to end, this will show how the experiment been done and the result been collected. Each testing will be in detail and the relationship between the manipulated variable and responding variable of this project can be achieved.

## 4.2 Optical Sensor Diagram

The diagram for the fiber to test the mineral oil is like below figure. The configuration for the light source is at 1310 and 1550. The type of fiber and brand of mineral oil is tested based on the table of variable that can be refer in previous chapter 3.

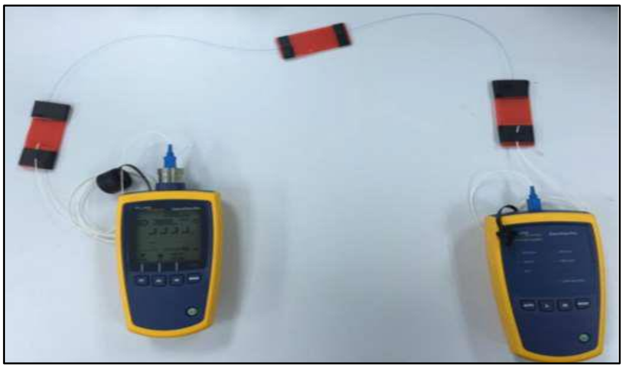

Figure 4.1:Single-Mode Optical Fiber Sensor

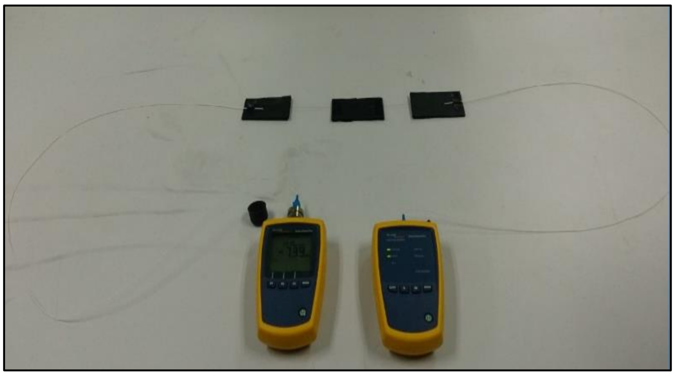

Figure 4.2:Multi-Mode Optical Fiber Sensor

## 4.3 Regular Two Level Factorial Design

Table 4.1:Table and The Signal to Noise from The Table of Variable

| | Name | Units | Type | Low | High |
|---|---|---|---|---|---|
| A [Categoric] | Type of Fiber | Mode | Categoric | Single mode | Multimode |
| B [Numeric] | Time | Minute | Numeric | 30 | 60 |
| C [Numeric] | Light Source | Nanometer | Numeric | 1310 | 1550 |
| D [Categoric] | Brand | Type of Brand | Categoric | B | A |

Power dBm

Signal (delta) = 2.00 Noise (sigma) = 1.00 Signal/Noise (delta/sigma) = 2.00

| A | B | C | D |
|---|---|---|---|
| 95.3 % | 95.3 % | 95.3 % | 95.3 % |

From this picture show that A, B, C and D is 95.3%. this show that the error that will get from the result that is 4.7% this significant number is the error that will be in out result. Signal to noise information was not changed from the default on one or more responses. The outcome from the result may not accurately reflect to the process.

### 4.4 Fiber Optic Mineral Oil Sensor Data Collection

The data that being collected is then put in the Design Expert software. It will calculate which will give more impact in given the output for the result. The result then auto resign by the software to show in a graph plot.

Table 4.2:Result of Mineral Oil Power Output Measurements

| Select | Run | Factor 1 A:Type of Fiber Mode | Factor 2 B:TIme Minute | Factor 3 C:Light Source Nanometer | Factor 4 D:Brand Type of Brand | Response 1 Power dBm |
|---|---|---|---|---|---|---|
| | 1 | SIngle mode | 30 | 1310 | A | -7.2 |
| | 2 | SIngle mode | 60 | 1310 | A | -7.21 |
| | 3 | SIngle mode | 30 | 1310 | B | -7.34 |
| | 4 | SIngle mode | 60 | 1310 | B | -7.32 |
| | 5 | SIngle mode | 30 | 1550 | A | -7.47 |
| | 6 | SIngle mode | 60 | 1550 | A | -7.5 |
| | 7 | SIngle mode | 30 | 1550 | B | -7.52 |
| | 8 | SIngle mode | 60 | 1550 | B | -7.5 |
| | 9 | Multimode | 30 | 1310 | A | -7.68 |
| | 10 | Multimode | 60 | 1310 | A | -7.7 |
| | 11 | Multimode | 30 | 1310 | B | -7.71 |
| | 12 | Multimode | 60 | 1310 | B | -7.73 |
| | 13 | Multimode | 30 | 1550 | A | -7.51 |
| | 14 | Multimode | 60 | 1550 | A | -7.5 |
| | 15 | Multimode | 30 | 1550 | B | -7.54 |
| | 16 | Multimode | 60 | 1550 | B | -7.56 |

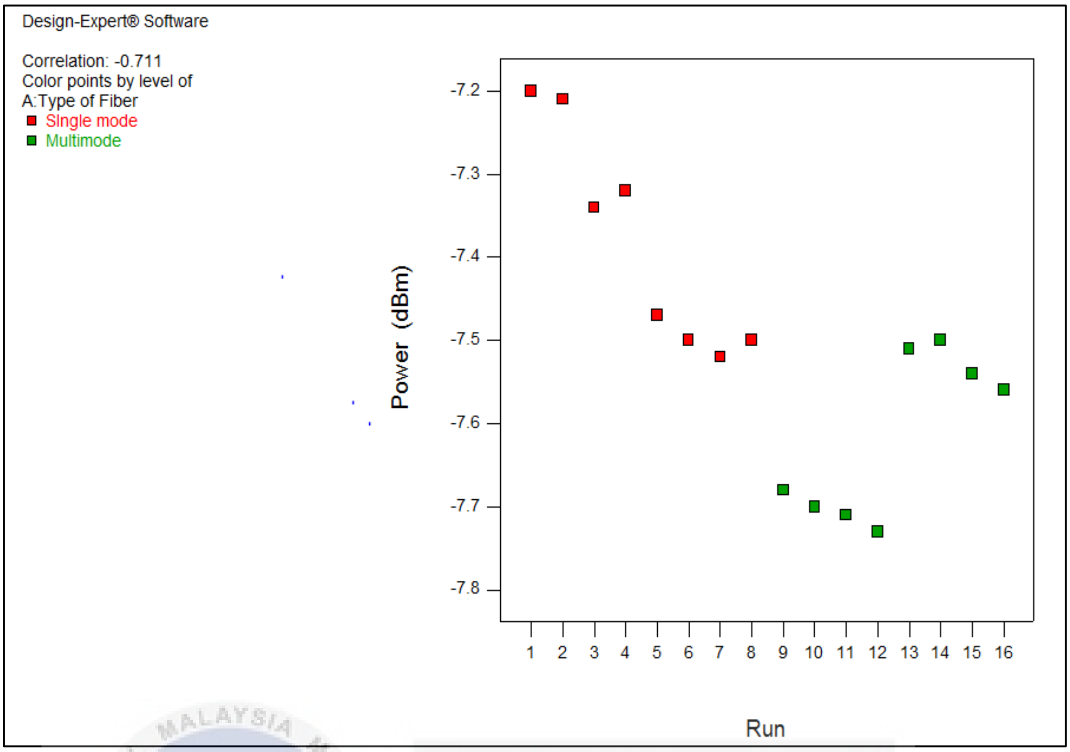


Figure 4.3:Graph of Run time versus Power

The figure shows the run for each parameter being taken and the colour show two parameters that is red single mode and green multi-mode. This is the graph for a first step to analyse the result. This show the parameters and the output for the graph is the same with the result that being taken.



## 4.5 Analysis of Design Expert Result

The main objective is to analysis which effect give the most influence in the fiber optic sensor. from the brand that being use, thought the sensor to detect the output power in the fiber optic sensor. characterize main effects and interaction between each other to get the optimize factor for this sensor.

## 4.6 Analysis of Half – Normal Plot

The half normal graph can be select from the Design Expert software. This plot of graph consists of the parameter that is A, B, C and D. Each of the term give a meaning as we can see in the figure below. The red line is the "error line" that represents the smallest 50% of the effects and the right side is the major effect that give the biggest outcome in the result. To get the best effect, we need to select and choose which the best parameter combination in the graph and that the P-value need to be less than 0.1 much better if the value is near to 0.05 for the P-value.

If The model for this value is not significant because of the p-value is high, the combination is not significant even do the combination of some parameter is significant. The overall result will show that is not significant because of one parameter will give effect to the overall result in ANOVA.

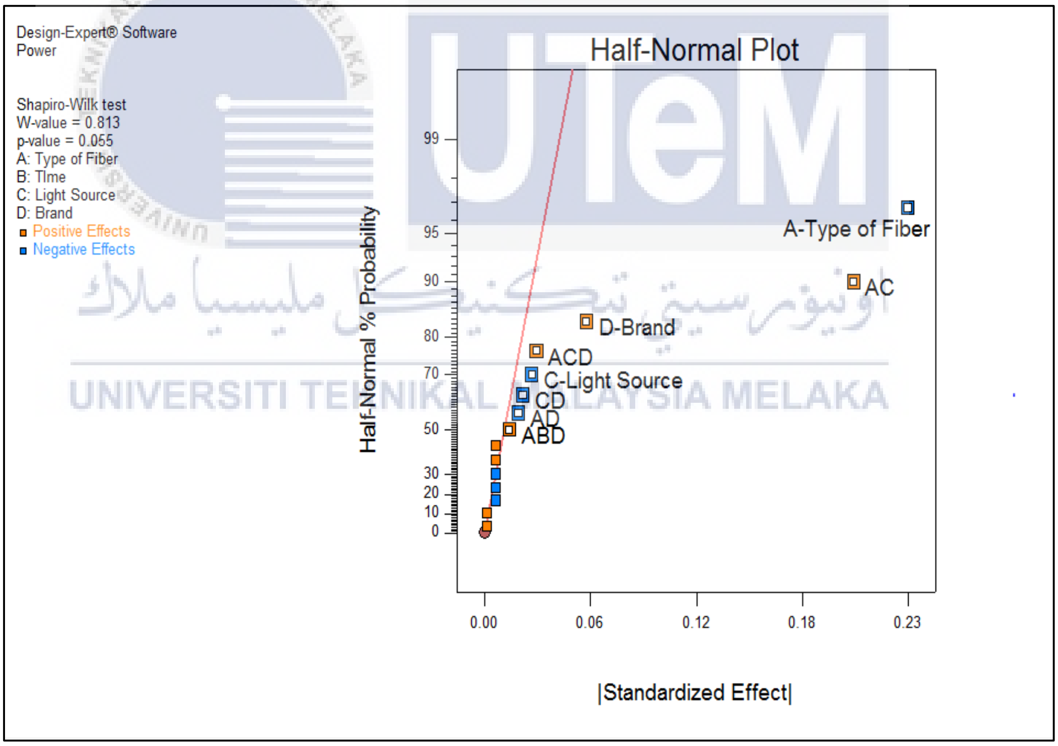


Figure 4.4:Graph is Significant

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

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 0.41 | 8 | 0.051 | 448.99 | < 0.0001 | significant |
| A-Type of Fit | 0.22 | 1 | 0.22 | 1927.43 | < 0.0001 | |
| C-Light Soun | 2.756E-003 | 1 | 2.756E-003 | 24.31 | 0.0017 | |
| D-Brand | 0.013 | 1 | 0.013 | 111.61 | < 0.0001 | |
| AC | 0.17 | 1 | 0.17 | 1464.43 | < 0.0001 | |
| AD | 1.406E-003 | 1 | 1.406E-003 | 12.40 | 0.0097 | |
| CD | 1.806E-003 | 1 | 1.806E-003 | 15.93 | 0.0052 | |
| ABD | 7.562E-004 | 1 | 7.562E-004 | 6.67 | 0.0363 | |
| ACD | 3.306E-003 | 1 | 3.306E-003 | 29.16 | 0.0010 | |

Figure 4.5:P-Value for The Graph

This plot of graph is significant because the P-value is less than 0.1 and in a range of 0.05. there is only 0.01% chance that an f-value this large could occur due to noise. In this case A, C, D, AC, AD, ABD, ACD are significant model terms. Values greater than 0.1 indicate the model term are not significant.



## 4.7 Analysis of Normal Plot

This is another tool that use to interpret the parameter. Compare half and normal plot graph it is much easier to analysis than normal graph but is totally the same in the outcome. Because of the half plot will likely to result in a correctly “picked”.

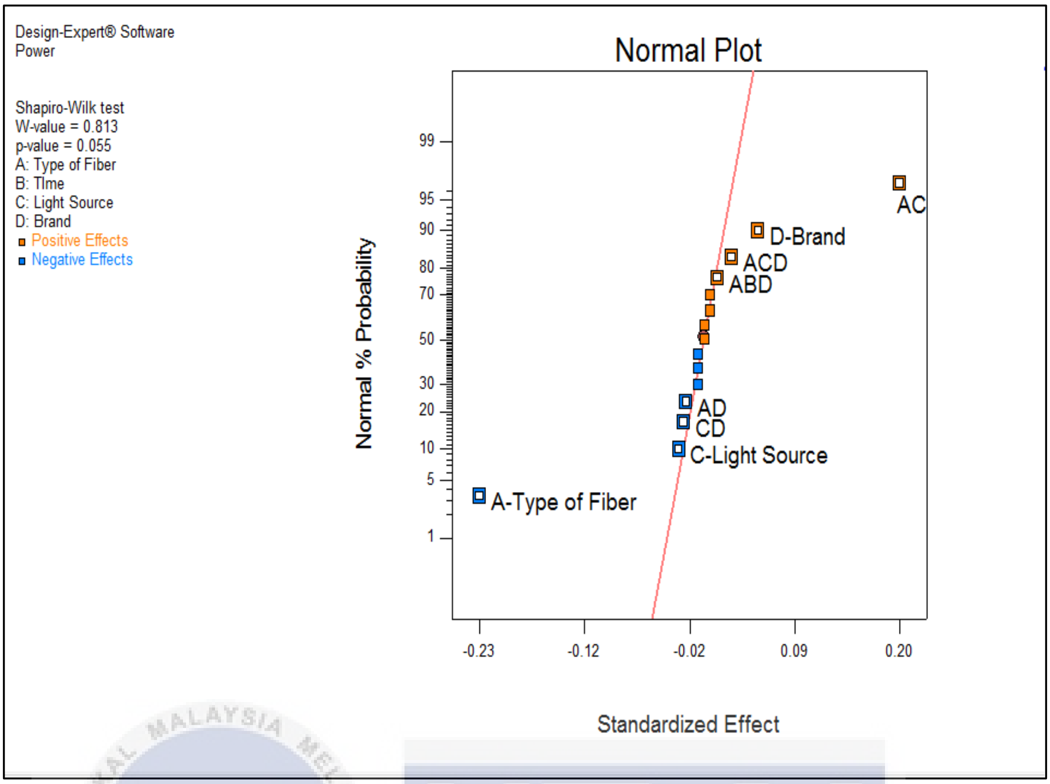


Figure 4.6:Graph is Significant

In term of compare the result is the same as the half plot. The compare for this graph is the data is scattered right and left and hard to pick which is the most given effect compare to the half graph. The P-value for normal plot graph is more than 0.05.



## 4.8 Analysis of Normal Plot Residuals

Step by step in using Design Expert. After analysis the effect and analysis of variance (ANOVA), therefore the residuals plot can be analysis. From the graph if the points are normal probability plot indicates whether the residuals follow a normal distribution, in which case the point will follow a straight line. Excepts some moderate scatter even with normal data. For this result the normal plot residuals was plotted and the plot indicated that the residuals are normally distributed because the data is close to the red line and not scatter far from the red line and in range with it.

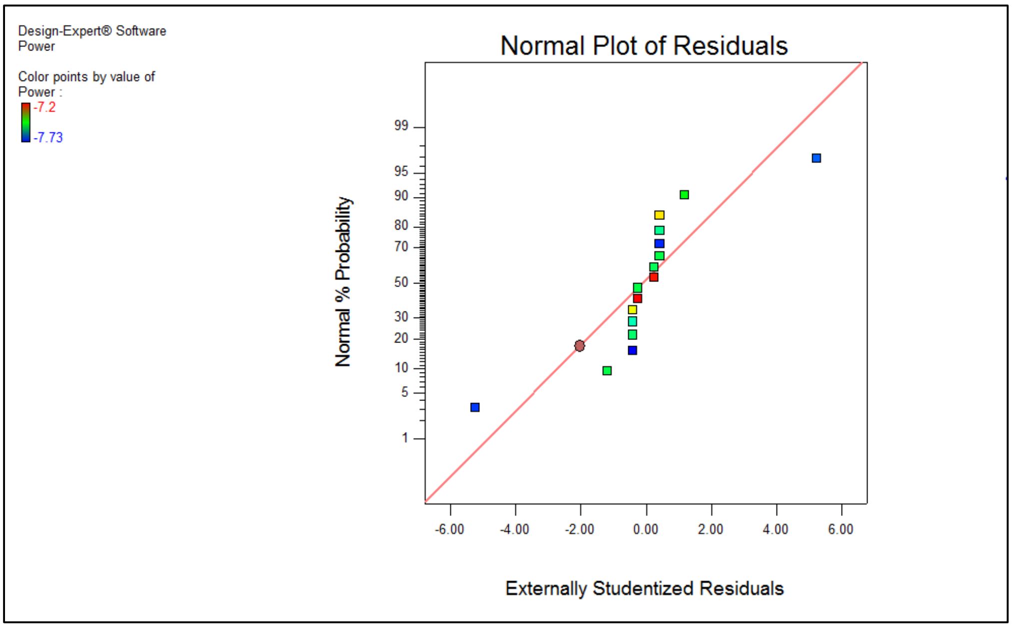


Figure 4.7:Normal Plot of Residuals Graph

## 4.9 Analysis of Residual Vs Predicted

The graph that show the residual versus the ascending predicted response values. Residual is the error for this graph. Is a predicted plot of graph between residuals value from the graph, the graph should be a random scatter consistent up and down range of residual across the predicted line. For this graph that been generate it show it is consistent and ideal that consist of all the data. The scattered data that near to the middle line is the error factor. If the data far from the middle line it show that the error is high. The graph shows an obvious pattern.

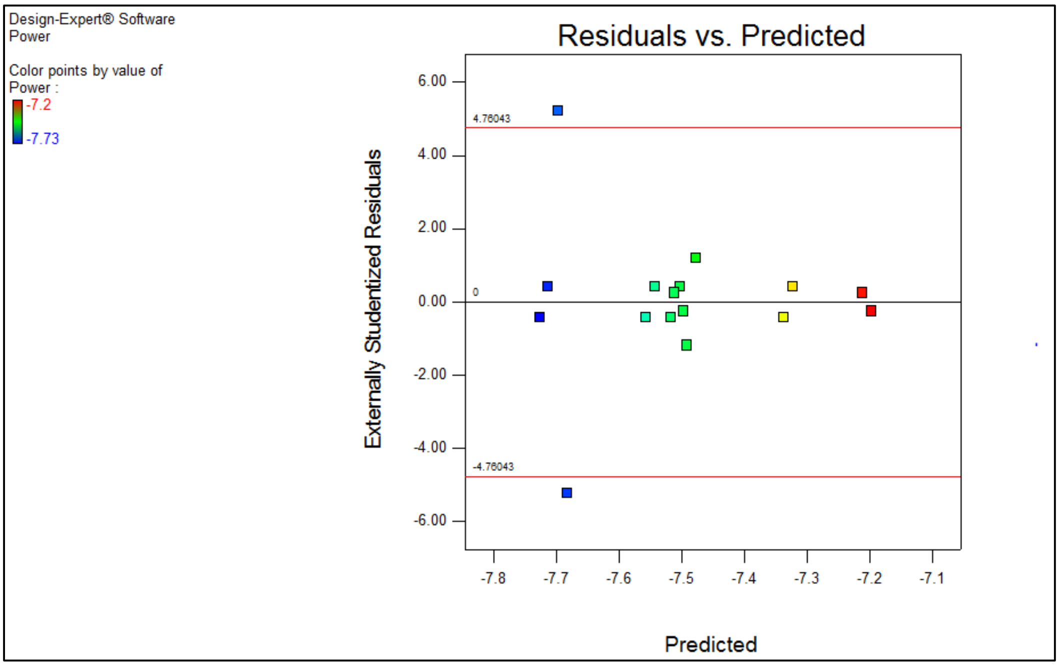


Figure 4.8:Residuals versus predicted ideal graph

## 4.10 Analysis of Residual Vs Run

For this graph analysis it shows the residual versus run time for each parameter. It shows some of outlier variable that may influenced the response during the experiment. The plot should show the random scattered as the plot the right respond. There are two intersection of the parameter that are out of the red line and this can say that both the point that are out the line is the outlier variable response for this graph. Can say that the graph is an ideal graph even do of the outlier variable, it still has the ideal look and the pattern of scattered that we need.

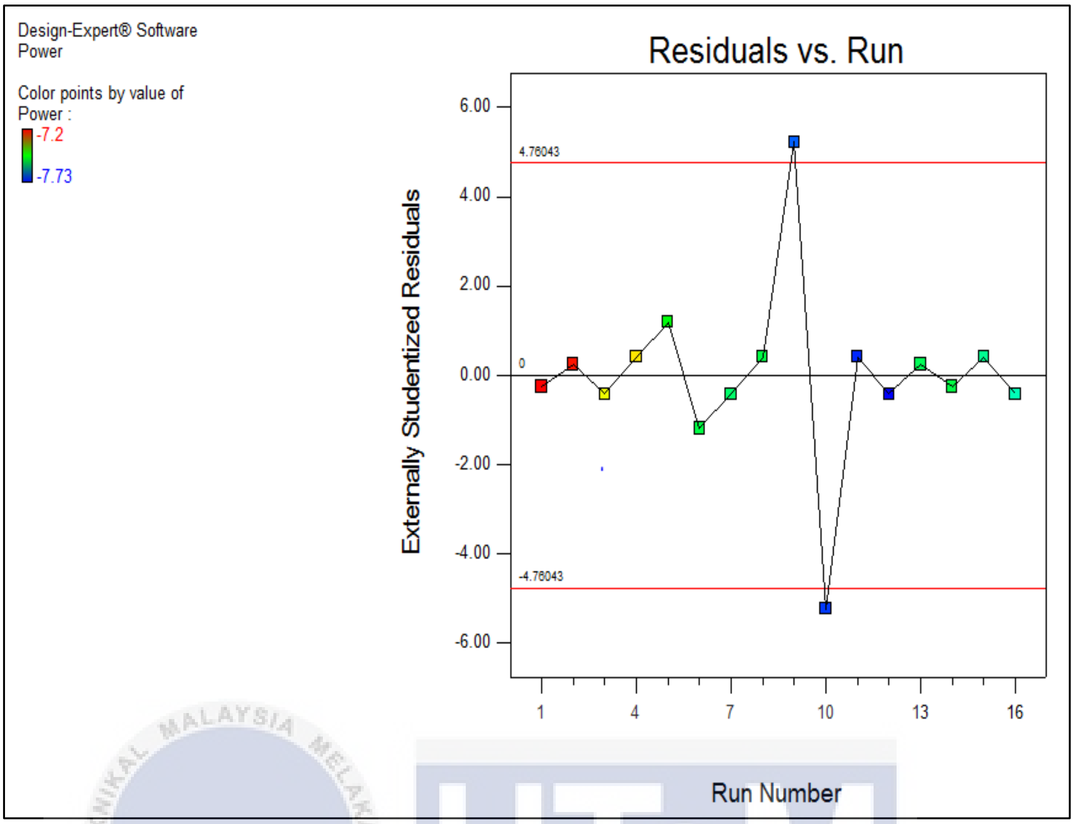


Figure 4.9:Residuals versus Run Time graph

## 4.11 Analysis of Factor Interaction of Type of Fiber

In one factor graph, show the one factor that been selected. That is the type of fiber, there are many factor can be choose but the most give effect for this experiment is the Type of fiber. This show that the reading is high and slowly decrease when it comes to multimode fiber. From the theory is true that single mode is better and faster data transferring compare to multimode. As a type of fiber from single mode to multimode will decrease in term of power.

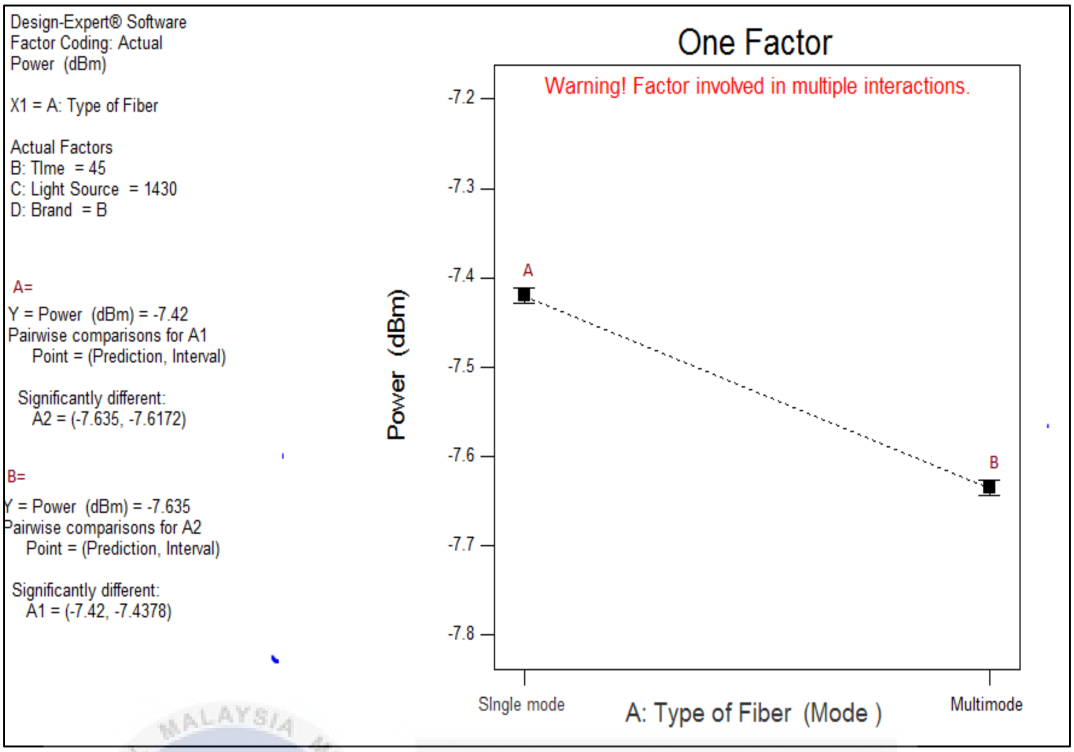


Figure 4.10:One Factor Graph for Type of Fiber.

**Percentage Calculation in Power.**

$$\frac{A-B}{A}\ x\ 100\% =$$

$$\frac{-7.42-(-7.635)}{-7.42}\ x\ 100\% = 2.8\%$$

The percentage different from single mode to multimode in term of power is 2.8%

## 4.12 Analysis of Factor interaction of Light Sources

Another one factor that most important is the light source. Without the light source there is no power to calculated and no data can be collect. The graph shows the decrease from 1310 to 1550 in reading. This show the light source also give a big effect in getting the result for this experiment

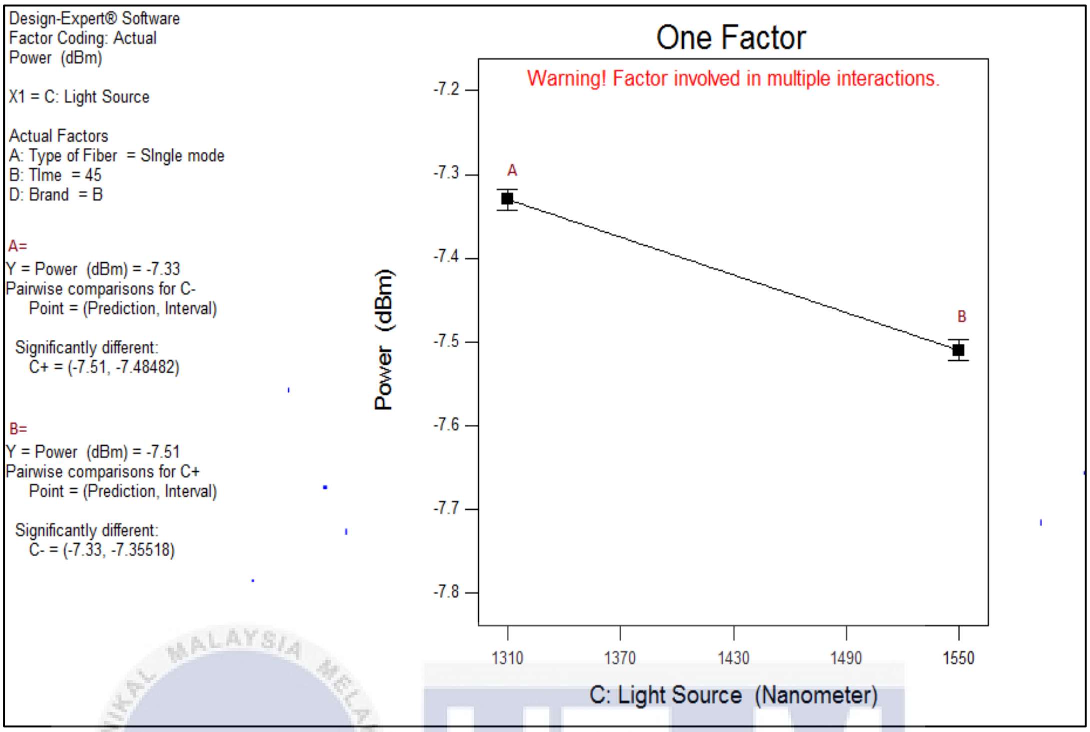


Figure 4.11:One Factor Graph for Light Source.

**Percentage Calculation in Power.**

$$\frac{A-B}{A}\ x\ 100\% =$$



$$\frac{-7.33-(-7.51)}{-7.33}\ x\ 100\% = 2.4\%$$

The percentage different from light source 1310 to 1550 in term of power is 2.4%

## 4.13 Analysis of Factor Interaction of Type of Fiber and Light source

For both factor that is Type of Fiber and Light Source is the most important in this experiment. Both have the interaction between them. This factor need each other so there can interact and give the most impact. From the graph show the interaction between one another.

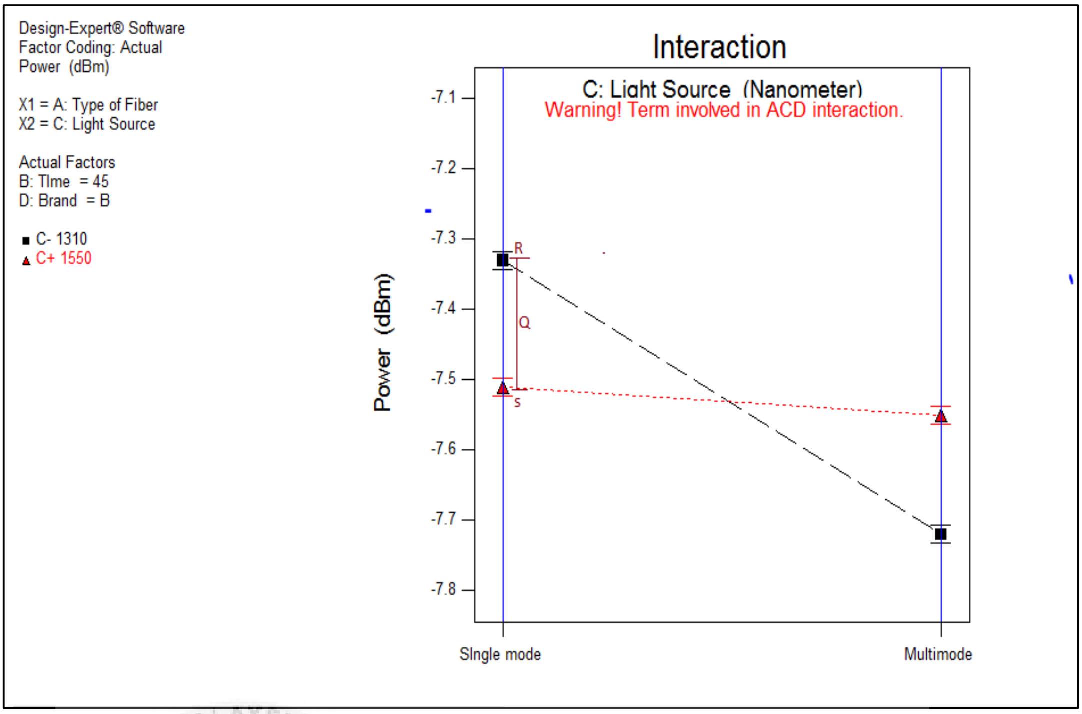


Figure 4.12:Interaction Graph of Factor A (Type of Fiber) Versus C (Light Source).

From the graph have the blue line. The blue line show that the interaction of light source 1310 and 1550 thus, the interaction is high. Because the distance of intercept between two point that is R and S is far and the distance between this two is Q. The light source effect at 1310 is high when the type of fiber is single mode. For multimode the effect is small when the light source is 1310. For 1550 the line is slightly decrease from single to multimode. The power from single to multi-mode show the loses in fiber this can be accepted based on the theory for fiber optic.

## 4.14 Optimization Design

This experiment is indeed to get the optimization with a specific parameter for the sensor to work. Each test being done have given another step to understand the parameter and the analysis important to get the best result for the sensor to work with the mineral oil. The final result obtained by respond optimization in Design Expert below:

## 4.15 Regression Model

From the data to the plot of graph and interpreted it. Next is Regression model is a model of equation that give the output result that can be used to make prediction about the response for given level of each factor. It is the final proses in the ANOVA analysis. Below is the equation that generate by the Design Expert:

### 4.15.1 Final Equation Terms of Coded Factors:

$$\begin{aligned} Output\ Power(mW) &= -7.50 - 0.12 * \mathrm{A} - 0.013 * \mathrm{C} + 0.028 * \mathrm{D} + 0.10 * \mathrm{AC} \\ &- 9.375\mathrm{E} - 003 * \mathrm{AD} - 0.011 * \mathrm{CD} + 6.875\mathrm{E} - 003 * \mathrm{ABD} \\ &+ 0.014 * \mathrm{AC} \end{aligned}$$

This equation is a condition equivalently as coded segments can be used to make assumption about the response for given level of each term as A, B, C, D, AC, ABD or etc. From the beginning in using this software, Design Expert have a table of parameter that is divide between a low and high condition. -1 as (low) and +1 as (high) for each condition of parameter. The coded condition is helpful for identifying the relative effect of the elements by looking at the element coefficients



## 4.16 Final selected Factors:

Table 4.3:Fiber Optic Optimization Combination

**Solution:**

| Number | Type of Fiber | Time | Light Source | Brand | Power | Desirability |
|---|---|---|---|---|---|---|
| 1 | Single mode | 47.068 | 1499.654 | A | -7.427 | 1.0 |

| Number | Type of Fiber | Time | Light Source | Brand | Power | Desirability |
|---|---|---|---|---|---|---|
| 1 | Multimode | 56.713 | 1322.379 | A | -7.675 | 1.000 |

To finalize the analysis is to determine which is the best optimization combination of all the parameter. This result show that the combination of the type of fiber is single mode, time taken 47.068 minutes, light source is 1499.654 and brand A. This show that the result meet with the theory as fiber optic in single mode with the high light source that is approximately with 1550 is the best combination. For multimode the combination like in the table show in Table 4.3. The combination that give the optimize output in power.

This show the similarity in brand A for multi-mode and single mode. To compare with brand A and B is the concentration between them this can say that concentration A is more thick compare to the concentration B. The core of fiber that being coated with brand A is high concentration compare to brand B, thus give the light to reflected and less loss occur in the transmit the power in fiber core.

## 4.17 Summary

This chapter has shown the result and analysis that being done. Each of the data being collected has been analysis in full detail. The Design Expert is a software or tool to interpret a factor of situation in given parameter. Each analysis is connected with each other, if one analysis is not correct all the data will be wrong and the interpretation of the data will be mistaken.

# CHAPTER 5
## CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

This project was successfully done and the fiber optic sensor was develop to detect the different concentration of mineral oil. The result has been optimized. The development of this sensor using a two type of fiber optic that is multi-mode and single mode with the light source of 1310nm and 1550nm using optical spectrum analyser (OSA) and amplified spontaneous Emission (ASE). An Optical Spectrum Analyser (or OSA) is a precision instrument designed to measure and display the distribution of power of an optical source over a specified wavelength span. An OSA trace displays power in the vertical scale and the wavelength in the horizontal scale. For Amplified spontaneous emission (ASE) is light produced by spontaneous emission. It has been optically amplified by the process of stimulated emission in a gain medium. It is inherent in the field of random lasers. The light source mode used for testing are 1310nm and 1550nm. This will analyse the sensitivity of fiber optic as sensor to detect the loss in the core. The analysis using a tool of Design Expert.

The analysis for Half-normal plot show that the red line is the "error line" that represents the smallest 50% of the effects and the right left side is the major effect that give the biggest outcome in the result.  To get the best effect, we need to select and choose which the best parameter combination in the graph and that the P-value need to be less than 0.1 much better if the value is near to 0.05 for the P-value. But for normal plot is better more than 0.05 for the P-value. This both graph plot need to be check using analysis of ANOVA, the plot of graph is significant because the P-value is less than 0.1 and in a range of 0.05. there is only 0.01% chance that an f-value this large could occur due to noise. In this case A, C, D, AC, AD, ABD are significant model terms. Values greater than 0.1 indicate the model term are not significant.

In the parameter that been choose that is type of fiber, time, light source and brand of mineral oil. From all the factor that been analysis, Time not give any effect to the performance of mineral oil. In a fiber optic core, mineral oil is a lubrication that coted material with a fast time. This core of fiber is small thus, time take for the lubrication to coted is fast. The core of the sensor will immediately detect the concentration that contact with it in a second.

In a develop a sensor, time is important as to detect the changes in a substance that need to test. This give a good effect for the develop of the fiber optic sensor because time will not give effect in this research.

Overall the fiber optic sensor in a mineral oil is a first step that need further research. Even do this is the first stage of the research in many years the fiber optic will give a big major in a world that is not only we know as a cable that give connection between people but as an item that can give changes in a daily life for people.

## 5.2 Recommendation

Based on the research that been done. There are several recommendations that can be implemented to improve the fiber optic sensor in detect the mineral oil. For this concentration that been done is the mineral oil that still new for further research is to test after use of the mineral oil and get the changes in the power, plus compare other type of lubrication oil that is semi synthetic and fully synthetic. Also time can be a factor that can be an important role in the sensor.

Besides using the Design of Experiment technique. The two-level factorial it should be use in a design to give which parameter that can give the accurate and optimum condition in mineral oil detection. Even do this is a first stage of the research the data is important for the next generation research to use as a guide in improving the sensor and the implementation for this mineral oil sensor for real use in daily life.

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# APPENDICES

Appendix A – GUI user Guide

Appendix B- Table of all the combination

Appendix C- Software Guide (Design Expert 10)

In this section provided all the information relevant to the data that collected and it is being analyse. Most of the information is form the “Design of Expert” package although it also used normal calculation in a few occasions. Note that factor A= type of fiber, B= time, C= light source, D= brand.

Appendix A – GUI user Guide

**Final Equation in Terms of Actual Factors:**

Type of Fiber = SIngle mode

Brand = B

Power = -6.36813 +4.58333E-004 * Time -7.50000E-004 * Light Source

---

Type of Fiber = SIngle mode

Brand = A

Power = -5.65604 -4.58333E-004 * Time -1.16667E-003 * Light Source

---

Type of Fiber = Multimode

Brand = B

Power = -8.62729 -4.58333E-004 * Time + 7.08333E-004 * Light Source

---

Type of Fiber = Multimode

Brand = A

Power = -8.72042 +4.58333E-004 * Time +7.70833E-004 * Light Source

Using this non-hierarchical polynomial regression model (it excludes hierarchically inferior terms) is not recommended. Measures of goodness of fit and the predicted response values may be not be the same as those from the coded equation. All analysis within the software is based on the coded equation.

## Appendix B- Table of all the combination

### Single mode optimize combination for each parameter

| Number | Type of Fiber | TIme | Light Source | Brand | Power | Desirability |
|---|---|---|---|---|---|---|
| 1 | SIngle mode | 47.068 | 1499.654 | A | -7.427 | 1 |
| 2 | SIngle mode | 60 | 1310 | A | -7.212 | 1 |
| 3 | SIngle mode | 60 | 1310 | B | -7.323 | 1 |
| 4 | SIngle mode | 60 | 1550 | A | -7.492 | 1 |
| 5 | SIngle mode | 33 | 1334 | A | -7.228 | 1 |
| 6 | SIngle mode | 30 | 1310 | B | -7.337 | 1 |
| 7 | SIngle mode | 60 | 1550 | B | -7.503 | 1 |
| 8 | SIngle mode | 30 | 1550 | B | -7.517 | 1 |
| 9 | SIngle mode | 43.967 | 1402.948 | B | -7.4 | 1 |
| 10 | SIngle mode | 42.836 | 1356.98 | B | -7.366 | 1 |
| 11 | SIngle mode | 56.343 | 1346.906 | B | -7.352 | 1 |
| 12 | SIngle mode | 45.342 | 1322.922 | B | -7.34 | 1 |
| 13 | SIngle mode | 59.856 | 1392.327 | B | -7.385 | 1 |
| 14 | SIngle mode | 35.723 | 1446.757 | B | -7.437 | 1 |
| 15 | SIngle mode | 46.467 | 1508.146 | B | -7.478 | 1 |
| 16 | SIngle mode | 57.899 | 1416.542 | B | -7.404 | 1 |
| 17 | SIngle mode | 46.329 | 1538.383 | B | -7.501 | 1 |
| 18 | SIngle mode | 31.276 | 1493.437 | B | -7.474 | 1 |
| 19 | SIngle mode | 53.562 | 1331.228 | B | -7.342 | 1 |
| 20 | SIngle mode | 50.716 | 1407.304 | B | -7.4 | 1 |
| 21 | SIngle mode | 42.79 | 1318.557 | B | -7.337 | 1 |
| 22 | SIngle mode | 48.766 | 1380.836 | B | -7.381 | 1 |
| 23 | SIngle mode | 32.196 | 1337.816 | B | -7.357 | 1 |
| 24 | SIngle mode | 35.049 | 1470.044 | B | -7.455 | 1 |
| 25 | SIngle mode | 37.729 | 1437.073 | B | -7.429 | 1 |
| 26 | SIngle mode | 32.945 | 1509.475 | B | -7.485 | 1 |
| 27 | SIngle mode | 34.326 | 1421.495 | B | -7.419 | 1 |
| 28 | SIngle mode | 46.759 | 1338.209 | B | -7.35 | 1 |
| 29 | SIngle mode | 49.677 | 1441.753 | B | -7.427 | 1 |
| 30 | SIngle mode | 39.109 | 1358.222 | B | -7.369 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 31 | SIngle mode | 30.021 | 1399.903 | B | -7.404 | 1 |
| 32 | SIngle mode | 47.28 | 1498.614 | B | -7.47 | 1 |
| 33 | SIngle mode | 35.609 | 1516.077 | B | -7.489 | 1 |
| 34 | SIngle mode | 31.48 | 1371.362 | B | -7.382 | 1 |
| 35 | SIngle mode | 56.148 | 1394.13 | B | -7.388 | 1 |
| 36 | SIngle mode | 48.623 | 1342.901 | B | -7.353 | 1 |
| 37 | SIngle mode | 39.823 | 1483.417 | B | -7.462 | 1 |
| 38 | SIngle mode | 58.636 | 1375.164 | B | -7.373 | 1 |
| 39 | SIngle mode | 44.335 | 1480.232 | B | -7.458 | 1 |
| 40 | SIngle mode | 37.015 | 1540.021 | B | -7.506 | 1 |
| 41 | SIngle mode | 50.896 | 1316.663 | B | -7.332 | 1 |
| 42 | SIngle mode | 45.039 | 1452.365 | B | -7.437 | 1 |
| 43 | SIngle mode | 58.772 | 1379.862 | B | -7.376 | 1 |
| 44 | SIngle mode | 42.848 | 1444.978 | B | -7.432 | 1 |
| 45 | SIngle mode | 45.044 | 1377.811 | B | -7.381 | 1 |
| 46 | SIngle mode | 38.998 | 1504.663 | B | -7.479 | 1 |
| 47 | SIngle mode | 50.133 | 1544.031 | B | -7.503 | 1 |
| 48 | SIngle mode | 50.941 | 1372.355 | B | -7.374 | 1 |
| 49 | SIngle mode | 32.694 | 1328.101 | B | -7.349 | 1 |
| 50 | SIngle mode | 48.556 | 1462.511 | B | -7.443 | 1 |
| 51 | SIngle mode | 50.196 | 1410.298 | B | -7.403 | 1 |
| 52 | SIngle mode | 53.708 | 1365.503 | B | -7.368 | 1 |
| 53 | SIngle mode | 45.48 | 1514.11 | B | -7.483 | 1 |
| 54 | SIngle mode | 33.177 | 1502.275 | B | -7.48 | 1 |
| 55 | SIngle mode | 39.817 | 1368.563 | B | -7.376 | 1 |
| 56 | SIngle mode | 48.789 | 1537.703 | B | -7.499 | 1 |
| 57 | SIngle mode | 47.968 | 1476.328 | B | -7.453 | 1 |
| 58 | SIngle mode | 32.569 | 1331.117 | B | -7.352 | 1 |
| 59 | SIngle mode | 36.698 | 1438.861 | B | -7.43 | 1 |
| 60 | SIngle mode | 55.306 | 1486.577 | B | -7.458 | 1 |
| 61 | SIngle mode | 44.416 | 1348.783 | B | -7.359 | 1 |
| 62 | SIngle mode | 37.366 | 1342.543 | B | -7.358 | 1 |
| 63 | SIngle mode | 32.134 | 1361.316 | B | -7.374 | 1 |
| 64 | SIngle mode | 55.866 | 1402.85 | B | -7.395 | 1 |
| 65 | SIngle mode | 47.18 | 1426.369 | B | -7.416 | 1 |
| 66 | SIngle mode | 45.046 | 1313.824 | B | -7.333 | 1 |
| 67 | SIngle mode | 55.589 | 1489.943 | B | -7.46 | 1 |
| 68 | SIngle mode | 30.173 | 1465.806 | B | -7.454 | 1 |
| 69 | SIngle mode | 59.74 | 1353.262 | B | -7.356 | 1 |
| 70 | SIngle mode | 59.842 | 1529.23 | B | -7.488 | 1 |
| 71 | SIngle mode | 53.504 | 1419.194 | B | -7.408 | 1 |
| 72 | SIngle mode | 34.554 | 1450.469 | B | -7.44 | 1 |
| 73 | SIngle mode | 36.086 | 1484.023 | B | -7.465 | 1 |
| 74 | SIngle mode | 30.026 | 1338.777 | B | -7.358 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 75 | SIngle mode | 53.809 | 1507.481 | B | -7.474 | 1 |
| 76 | SIngle mode | 40.486 | 1362.675 | B | -7.372 | 1 |
| 77 | SIngle mode | 34.278 | 1500.499 | B | -7.478 | 1 |
| 78 | SIngle mode | 49.622 | 1436.306 | B | -7.423 | 1 |
| 79 | SIngle mode | 36.108 | 1311.721 | B | -7.335 | 1 |
| 80 | SIngle mode | 37.565 | 1511.387 | B | -7.484 | 1 |
| 81 | SIngle mode | 51.67 | 1464.901 | B | -7.443 | 1 |
| 82 | SIngle mode | 37.508 | 1517.847 | B | -7.489 | 1 |
| 83 | SIngle mode | 47.412 | 1344.158 | B | -7.355 | 1 |
| 84 | SIngle mode | 37.887 | 1446.619 | B | -7.436 | 1 |
| 85 | SIngle mode | 31.462 | 1411.064 | B | -7.412 | 1 |
| 86 | SIngle mode | 52.677 | 1524.204 | B | -7.487 | 1 |
| 87 | SIngle mode | 47.858 | 1457.261 | B | -7.439 | 1 |
| 88 | SIngle mode | 40.656 | 1412.172 | B | -7.409 | 1 |
| 89 | SIngle mode | 56.079 | 1371.453 | B | -7.371 | 1 |
| 90 | SIngle mode | 56.358 | 1499.47 | B | -7.467 | 1 |
| 91 | SIngle mode | 49.104 | 1326.175 | B | -7.34 | 1 |
| 92 | SIngle mode | 45.483 | 1324.888 | B | -7.341 | 1 |
| 93 | SIngle mode | 30.201 | 1345.494 | B | -7.363 | 1 |
| 94 | SIngle mode | 36.352 | 1326.906 | B | -7.347 | 1 |
| 95 | SIngle mode | 39.689 | 1523.725 | B | -7.493 | 1 |
| 96 | SIngle mode | 34.89 | 1461.793 | B | -7.448 | 1 |
| 97 | SIngle mode | 56.016 | 1399.226 | B | -7.392 | 1 |
| 98 | SIngle mode | 48.825 | 1471.8 | B | -7.45 | 1 |
| 99 | SIngle mode | 49.16 | 1388.844 | B | -7.387 | 1 |
| 100 | SIngle mode | 32.647 | 1537.176 | B | -7.506 | 1 |



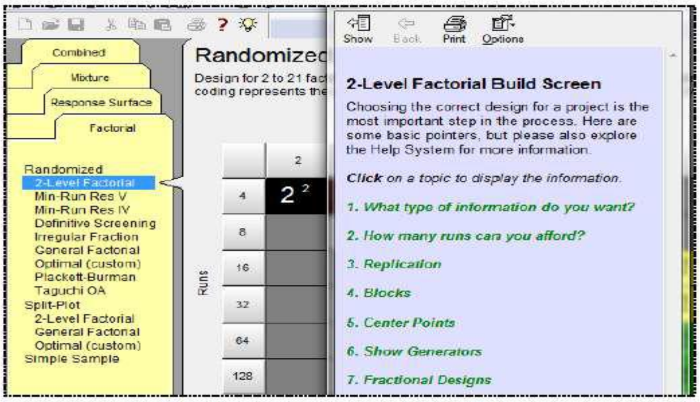
**Multimode optimize combination for each parameter**

| Number | Type of Fiber | TIme | Light Source | Brand | Power | Desirability |
|---|---|---|---|---|---|---|
| 1 | Multimode | 56.713 | 1322.379 | A | -7.675 | 1 |
| 2 | Multimode | 60 | 1550 | B | -7.557 | 1 |
| 3 | Multimode | 30 | 1310 | B | -7.713 | 1 |
| 4 | Multimode | 60 | 1550 | A | -7.498 | 1 |
| 5 | Multimode | 30 | 1550 | B | -7.543 | 1 |
| 6 | Multimode | 30 | 1310 | A | -7.697 | 1 |
| 7 | Multimode | 30 | 1550 | A | -7.512 | 1 |
| 8 | Multimode | 60 | 1310 | B | -7.727 | 1 |
| 9 | Multimode | 51.31 | 1317.999 | B | -7.717 | 1 |
| 10 | Multimode | 54.061 | 1323.566 | B | -7.715 | 1 |
| 11 | Multimode | 34.294 | 1368.132 | B | -7.674 | 1 |
| 12 | Multimode | 40.904 | 1532.676 | B | -7.56 | 1 |

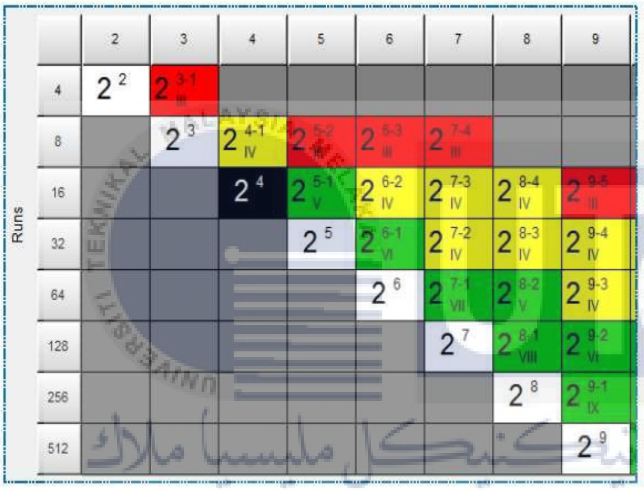
| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | Multimode | 40.273 | 1447.056 | B | -7.621 | 1 |
| 14 | Multimode | 53.858 | 1420.347 | B | -7.646 | 1 |
| 15 | Multimode | 43.076 | 1523.946 | B | -7.568 | 1 |
| 16 | Multimode | 36.488 | 1368.051 | B | -7.675 | 1 |
| 17 | Multimode | 33.297 | 1385.696 | B | -7.661 | 1 |
| 18 | Multimode | 47.373 | 1371.992 | B | -7.677 | 1 |
| 19 | Multimode | 46.355 | 1484.143 | B | -7.597 | 1 |
| 20 | Multimode | 51.191 | 1533.363 | B | -7.565 | 1 |
| 21 | Multimode | 48.368 | 1315.435 | B | -7.718 | 1 |
| 22 | Multimode | 44.244 | 1425.783 | B | -7.638 | 1 |
| 23 | Multimode | 31.303 | 1549.269 | B | -7.544 | 1 |
| 24 | Multimode | 50.772 | 1427.251 | B | -7.64 | 1 |
| 25 | Multimode | 30.725 | 1422.639 | B | -7.634 | 1 |
| 26 | Multimode | 54.607 | 1491.504 | B | -7.596 | 1 |
| 27 | Multimode | 31.76 | 1341.879 | B | -7.691 | 1 |
| 28 | Multimode | 44.451 | 1518.312 | B | -7.572 | 1 |
| 29 | Multimode | 55.443 | 1367.639 | B | -7.684 | 1 |
| 30 | Multimode | 53.136 | 1311.883 | B | -7.722 | 1 |
| 31 | Multimode | 56.775 | 1522.6 | B | -7.575 | 1 |
| 32 | Multimode | 41.006 | 1520.353 | B | -7.569 | 1 |
| 33 | Multimode | 40.512 | 1350.92 | B | -7.689 | 1 |
| 34 | Multimode | 47.164 | 1430.498 | B | -7.636 | 1 |
| 35 | Multimode | 36.855 | 1400.366 | B | -7.652 | 1 |
| 36 | Multimode | 52.645 | 1542.175 | B | -7.559 | 1 |
| 37 | Multimode | 34.735 | 1374.239 | B | -7.67 | 1 |
| 38 | Multimode | 46.106 | 1457.304 | B | -7.616 | 1 |
| 39 | Multimode | 47.362 | 1356.535 | B | -7.688 | 1 |
| 40 | Multimode | 53.869 | 1382.586 | B | -7.673 | 1 |
| 41 | Multimode | 41.562 | 1327.912 | B | -7.706 | 1 |
| 42 | Multimode | 52.098 | 1346.546 | B | -7.697 | 1 |
| 43 | Multimode | 48.537 | 1427.099 | B | -7.639 | 1 |
| 44 | Multimode | 51.967 | 1425.432 | B | -7.641 | 1 |
| 45 | Multimode | 37.476 | 1507.689 | B | -7.577 | 1 |
| 46 | Multimode | 40.579 | 1503.083 | B | -7.581 | 1 |
| 47 | Multimode | 50.822 | 1316.666 | B | -7.718 | 1 |
| 48 | Multimode | 51.301 | 1431.371 | B | -7.637 | 1 |
| 49 | Multimode | 34.473 | 1348.351 | B | -7.688 | 1 |
| 50 | Multimode | 57.246 | 1378.154 | B | -7.677 | 1 |
| 51 | Multimode | 47.225 | 1418.746 | B | -7.644 | 1 |
| 52 | Multimode | 40.302 | 1501.364 | B | -7.582 | 1 |
| 53 | Multimode | 57.079 | 1362.228 | B | -7.689 | 1 |
| 54 | Multimode | 44.688 | 1437.924 | B | -7.629 | 1 |
| 55 | Multimode | 52.566 | 1358.076 | B | -7.689 | 1 |
| 56 | Multimode | 47.658 | 1334.606 | B | -7.704 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 57 | Multimode | 55.913 | 1441.431 | B | -7.632 | 1 |
| 58 | Multimode | 39.914 | 1325.856 | B | -7.706 | 1 |
| 59 | Multimode | 39.642 | 1433.861 | B | -7.63 | 1 |
| 60 | Multimode | 46.646 | 1420.961 | B | -7.642 | 1 |
| 61 | Multimode | 39.39 | 1429.918 | B | -7.632 | 1 |
| 62 | Multimode | 49.672 | 1389.319 | B | -7.666 | 1 |
| 63 | Multimode | 44.488 | 1510.832 | B | -7.578 | 1 |
| 64 | Multimode | 32.569 | 1434.211 | B | -7.626 | 1 |
| 65 | Multimode | 47.508 | 1517.141 | B | -7.574 | 1 |
| 66 | Multimode | 39.301 | 1321.034 | B | -7.71 | 1 |
| 67 | Multimode | 45.933 | 1406.093 | B | -7.652 | 1 |
| 68 | Multimode | 50.26 | 1470.739 | B | -7.609 | 1 |
| 69 | Multimode | 46.827 | 1433.153 | B | -7.634 | 1 |
| 70 | Multimode | 38.936 | 1499.786 | B | -7.583 | 1 |
| 71 | Multimode | 44.877 | 1496.704 | B | -7.588 | 1 |
| 72 | Multimode | 45.782 | 1352.026 | B | -7.691 | 1 |
| 73 | Multimode | 53.373 | 1410.203 | B | -7.653 | 1 |
| 74 | Multimode | 41.562 | 1500.05 | B | -7.584 | 1 |
| 75 | Multimode | 43.809 | 1537.891 | B | -7.558 | 1 |
| 76 | Multimode | 46.032 | 1394.76 | B | -7.66 | 1 |
| 77 | Multimode | 30.22 | 1384.954 | B | -7.66 | 1 |
| 78 | Multimode | 56.839 | 1327.759 | B | -7.713 | 1 |
| 79 | Multimode | 36.764 | 1358.558 | B | -7.682 | 1 |
| 80 | Multimode | 35.331 | 1365.867 | B | -7.676 | 1 |
| 81 | Multimode | 34.966 | 1493.394 | B | -7.585 | 1 |
| 82 | Multimode | 52.953 | 1379.517 | B | -7.674 | 1 |
| 83 | Multimode | 57.906 | 1525.182 | B | -7.573 | 1 |
| 84 | Multimode | 38.112 | 1348.208 | B | -7.69 | 1 |
| 85 | Multimode | 46.288 | 1458.129 | B | -7.616 | 1 |
| 86 | Multimode | 31.066 | 1535.054 | B | -7.554 | 1 |
| 87 | Multimode | 33.01 | 1347.764 | B | -7.688 | 1 |
| 88 | Multimode | 51.316 | 1483.039 | B | -7.6 | 1 |
| 89 | Multimode | 30.034 | 1322.794 | B | -7.704 | 1 |
| 90 | Multimode | 37.652 | 1466.277 | B | -7.606 | 1 |
| 91 | Multimode | 42.938 | 1386.16 | B | -7.665 | 1 |
| 92 | Multimode | 36.907 | 1320.228 | B | -7.709 | 1 |
| 93 | Multimode | 36.272 | 1545.715 | B | -7.549 | 1 |
| 94 | Multimode | 31.65 | 1339.054 | B | -7.693 | 1 |
| 95 | Multimode | 56.371 | 1465.695 | B | -7.615 | 1 |
| 96 | Multimode | 44.38 | 1442.45 | B | -7.626 | 1 |
| 97 | Multimode | 33.733 | 1410.899 | B | -7.643 | 1 |
| 98 | Multimode | 38.608 | 1491.419 | B | -7.589 | 1 |
| 99 | Multimode | 55.605 | 1359.855 | B | -7.69 | 1 |
| 100 | Multimode | 34.687 | 1383.443 | B | -7.663 | 1 |

## Appendix C- Software Guide (Design Expert 10)



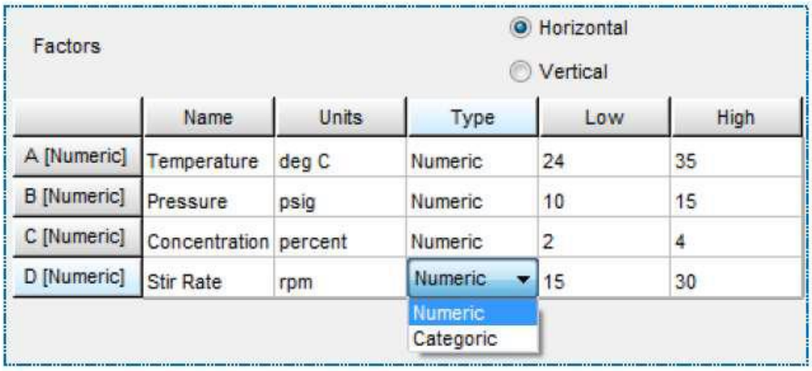
*Screen tips for factorial design builder*



*Selecting a full, two-level design on four factors which produces 16 runs*



Click the **Continue** button. You can now enter the names, units of measure, and levels for your experimental factors. Use the arrow keys, tab key, or mouse to move from one space to the next. The Tab (or Shift Tab) key moves the cursor forward (or backward) between entry fields. Enter for each factor (A, B, C and D) the **Name**, **Units**, **Low** and **High** levels shown on the screen shot below.




| | Name | Units | Type | Low | High |
|---|---|---|---|---|---|
| A [Numeric] | Temperature | deg C | Numeric | 24 | 35 |
| B [Numeric] | Pressure | psig | Numeric | 10 | 15 |
| C [Numeric] | Concentration | percent | Numeric | 2 | 4 |
| D [Numeric] | Stir Rate | rpm | Numeric | 15 | 30 |

*Factors – after entering name, units, and levels (plus a peek at options for "Type")*