Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF HUMIDITY SENSOR BY OPTICAL MICROFIBER FOR MEDICAL INDUSTRY

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Bachelor of Electronics Engineering Technology with Honours

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DEVELOPMENT OF HUMIDITY SENSOR BY OPTICAL MICROFIBER FOR MEDICAL INDUSTRY

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A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electronics Engineering Technology with Honours

Faculty of Electrical and Electronic Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this project report entitled “Development Of Humidity Sensor By Optical Microfiber For Medical Industry. “ is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

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

Signature :

Supervisor Name : Dr. Md Ashadi Bin Md Johari

Date : 11/01/2022

Signature :

Co-Supervisor Name (if any) :

Date :

DEDICATION

Alhamdulillah, all praise to Allah.
I dedicate this report to my beloved parents, Ibrahim Bin Hasan and Fauziah Binti Shaari,
As well as my precious siblings,
And to all my families, friends, partner in crime,
And those who supported me along this long journey,
Cheers to their constant encouragement and endless, repetitive motivational rants.

ABSTRACT

Humidity refers to how much water vapour is in the air. This project aims to design and develop the humidity sensor based on optical microfiber technology for medical industry. The optical microfibers possess outstanding optical and mechanical properties such as higher resistance to water and corrosion, the resistance to electromagnetic interference and nuclear radiation, and the ability to perform well in a low-temperature environment along with its high sensitivity.

The main purpose of this project is particularly directed at the medical industry. The medical industry standard requires a higher precision of measurement, along with the lower interference in radio frequency (radiation) in order to precisely obtain the information of the patients without any environment interference.

ABSTRAK

Kelembapan merujuk kepada seberapa banyak wap air di udara. Projek ini bertujuan untuk merancang dan mengembangkan alat pengesan kelembapan berdasarkan teknologi mikrofiber optik untuk industri perubatan. Serat mikro optik mempunyai sifat optik dan mekanikal yang luar biasa seperti ketahanan yang lebih tinggi terhadap air dan kakisan, ketahanan terhadap gangguan elektromagnetik dan radiasi nuklear, dan kemampuan untuk berprestasi dengan baik dalam persekitaran suhu rendah bersama dengan kepekaannya yang tinggi.

Tujuan utama projek ini ditujukan terutamanya kepada industri perubatan. Piawaian industri perubatan memerlukan ketepatan pengukuran yang lebih tinggi, bersama dengan gangguan frekuensi radio (radiasi) yang lebih rendah untuk mendapatkan maklumat pesakit dengan tepat tanpa gangguan persekitaran.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor, Dr Md Ashadi Bin Md Johari, for his excellent advice, suggestions, wise words, and patience during this project's development.

My deepest gratitude goes out to my parents, Ibrahim Hasan and Fauziah Shaari, and other family members for their blessings, support and prayers during my studies. Furthermore, for all of the inspiration and understanding, I would like to extend a special thank you to my co-worker, Adilah Darus, who constantly encouraged me to further my study for Bachelor's Degree.

Not to mention my other classmates and colleagues, who were all eager to share their brilliant views and futuristic ideas on the project with me.

Finally, I would like to express my gratitude to all of the staff members at the FTKEE and lecturers, other colleagues and classmates, the Project Panels, and other persons not named here for their utmost cooperation and assistance.

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δ	-	Voltage angle
λ	-	Wavelength
c	-	Speed of light
n	-	Cavity length
	-	
	-	
	-	
	-	

LIST OF ABBREVIATIONS

FBG	-	Fiber Bragg Grating
ORL	-	Optical Return Loss
ISAM	-	Indexed Sequential Access Method
LAN	-	Local Area Network
FSR	-	Free Spectral Range
IPA	-	Isopropyl Alcohol
OTDR	-	Optical time domain reflectometer
PMD	-	Polarization Mode Dispersion
COD	-	coefficient of determination
FOS	-	Fiber Optic Light Source
	-	
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LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will concisely discuss the background and the objective of the project. It will also explain the problem statement and the project planning comprises the identification and documentation of a list of project objectives, deliverables, features, tasks, timelines and the expenses to accomplish the project.

1.2 Background

Optical fiber is a light-pulse-based data transfer technique that transmit along a fiber, usually made out of plastic or glass. Electromagnetic interference has no impact on optical fibers. Total internal reflection of light is applied in the fiber cable for the signal transmission. The fibers are intended to assist the transmission of light together with the optical fiber, based on the optical power source and transmission distance requirements. Long-distance transmission is done with single-mode fiber, whereas short-distance transmission is done with multimode fiber. Due to the sensitive and soft material, the outer claddings of fiber optic require more protection than metal wires.

Fiber optic sensors use optic fiber cables to detect things accurately in a variety of applications. The fiber optic sensor is a type of sensing device that uses fiber optic technology to monitor physical quantities such as temperature, humidity, pressure, strain, voltages, and acceleration. When used as a sensing element, it is referred to as an intrinsic sensor. When used to transport signals from a remote sensor to a signal processing module, it is known as an optical fiber transfer system (extrinsic sensor). Fiber optic sensors are becoming more popular as the sensor of choice for many sectors since they are resistant to electromagnetic interference and can withstand severe temperatures.

The optical fiber sensors have higher sensitivity to the environment, possibly the best tolerance to electromagnetic interference, small size, low weight, resilience, flexibility, and the ability to provide multiplexed or dispersed sense. For example, a Fabry-Perot (FP) based optical sensor as a sensing element is one of the most common sensors because to its high sensitivity, compact size, and endurance in difficult environments. While the spectrum demodulation method is frequently more expensive or not fast enough to demodulate acoustic waves of high frequency or rapidly fluctuating pressure signals for high bandwidth applications requiring rapid response time, when compared to the intensity demodulation method it is frequently more expensive or not fast enough.

This project aims to design and develop the humidity sensor based from optical microfiber technology for medical industry. The optical microfibers possess outstanding optical and mechanical properties such as higher resilience to water and corrosion, the resistance to electromagnetic interference and nuclear radiation, and the ability to perform well in a low-temperature environment along with its high sensitivity. The main purpose of this project is particularly directed at the medical industry. The medical industry standard requires a higher precision of measurement, along with the lower interference in radio frequency (radiation) in order to precisely obtain the information of the patients without any environment interference.

1.3 Problem Statement

The standard of the quality of product in Medical Industry is really high. The demands of a precise and durable sensors system is increased due to the technology and applications of optical microfibers in medical industry have advanced rapidly in recent years. The replacement of the traditional electrical sensor counterpart with a wireless and light-weighted material with a better performance is needed to improve the quality of accurate measurements.

1.4 The Objective of Project

The aim of this project is to develop an effective and appropriate approach for assessing the usage of humidity sensors with excellent precision utilizing an optical fiber distribution network. There are several objectives that will be achieved in this study as shown below :-

a) To study the operation and the performance of humidity sensor by using optical microfiber technology.

b) To design the humidity sensor using optical microfiber and testing its sensitivity and performance in several humidity level tests.

c) To analyze the performance of Humidity Sensor using optical microfiber in different environment and experiments.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the basic principle of fiber-optics is discussed, as well as the fiber-optic sensor. Previous projects and additional materials such as journals, papers, and books linked to the topic are the primary sources for this project. The theoretical foundation and functioning of fiber optic sensors are detailed towards the conclusion of this chapter. This chapter also goes through all of the research that has been done on the subject.

2.2 Fiber Optic

Fiber optics are minuscule strands made of extremely clean glass with a diameter of roughly the same as human hair. These optical fibers are bundled together in fiber optic to send light messages across large distances.

The jacket, which is the outside covering of the cable, protects the bundles and comprises three layers: buffer coating, cladding, and core. The buffer coating is a plastic coating applied to the fiber to protect it from moisture and damage. Cloaking refers to the outer optical substance that surrounds the core and reflects light into the inside of the core. The core of a fiber optic cable is the thin glass center of the fiber, through which the light is transmitted and received.

There are two types of fiber optic: single-mode and multi-mode. The single-mode has a smaller core; it is utilized over long distances communication and transmits infrared laser light. The multi-mode has larger cores, and it is often employed over short distances.

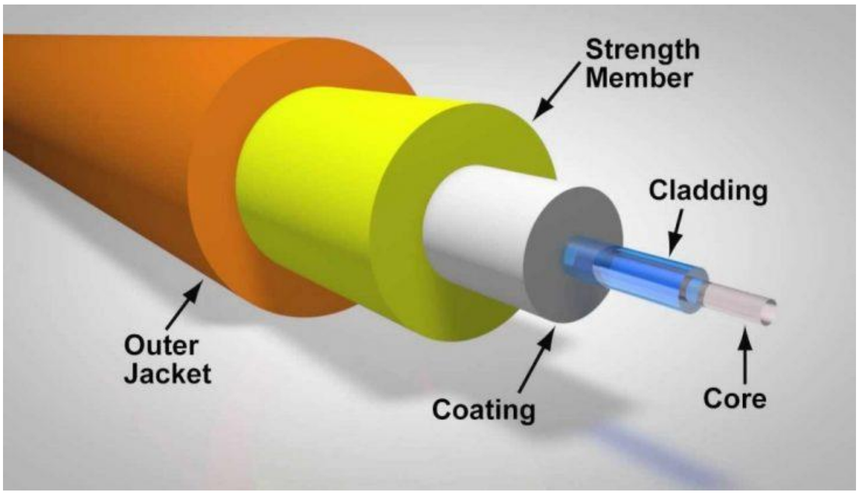


Figure 2.1 Cross section of fiber optic cable

Even though the fiber optic system is identical to the copper wire system, fiber optics progressively replaces copper wires as a dependable means of signal transport in communication systems and other applications. Fiber optics provide several advantages over copper, including lower costs, thinness, and improved carrying capacity. When it comes to transporting digital data, optical fibers are the best option. Because there is no electricity, the possibility of a fire sparked is reduced. Cables made of fiber optics are tiny, lightweight, and flexible.

2.2.1 Single Mode Fiber Optic

The fiber is developed as a step-index, which means the core will only have one index of refraction for transmitting the light signal. The single-mode optical fiber allows the light travels in just one path or mode. The single-mode fiber has a 5µm to 10µm core diameter and a 125µm cladding. Figure 2.2 shows the diagram of the single mode fibe optic' diameter size.

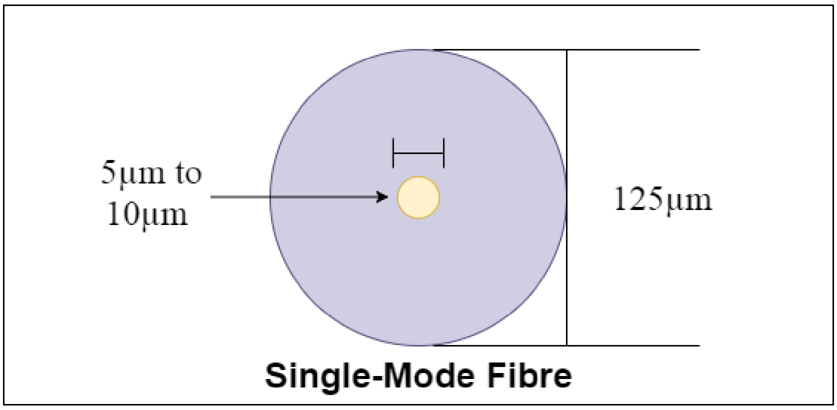


Figure 2.2 The diameter of single-mode fiber optic cable

Single-mode fibers are being used in applications where minimal signal loss and fast data rates are required, like long distances between repeaters and amplifiers, to transmit data at fast rates. Furthermore, because single-mode fiber only allows for the transmission of a single mode or ray (the lowest-order mode), it does not suffer from modal dispersion, as does multimode fiber, allowing it to be used for applications requiring higher bandwidth. Figure 2.3 depicts the propagation of light across a single mode fiber optic cable.

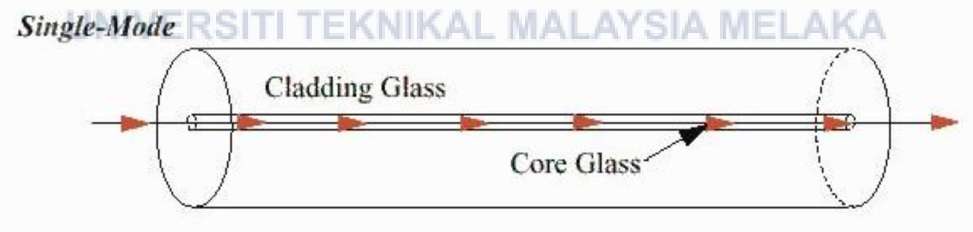


Figure 2.3 The Single-Mode Light Propagation

Although modal dispersion has no impact on single-mode fiber, chromatic dispersion can significantly influence higher data rates. There are numerous ways to solve this problem. For example, one can transmit at a wavelength where the index of refraction of glass is relatively constant (±1300 nm), utilize an optical source with a very narrow output spectrum, utilize an exceptional dispersion compensating fiber or utilize a combination of these strategies.

Single-mode fiber is used in a variety of high-bandwidth, long-distance operations, including long-distance telephone lines, cable TV head-ends, high-speed local and wide-area network (LAN and WAN) backbones, among others.

Because of its small core size, single-mode fiber is difficult to deal with (for example, splicing and termination). In addition, due to the large coupling losses associated with LEDs, single-mode fiber is typically employed solely with laser sources.

2.2.2 Multi-Mode Fiber Optic

Multimode optical fiber refers to how multiple transmitted modes or light rays support each other through a waveguide at the same time. Multimode has a core size that is five to six times bigger than single-mode, allowing for substantially increased light-gathering capacity and the employment of less expensive electro-optic equipment. In addition, multiple modes or light paths go down the fiber simultaneously, limiting transmission distance and bandwidth in the past.

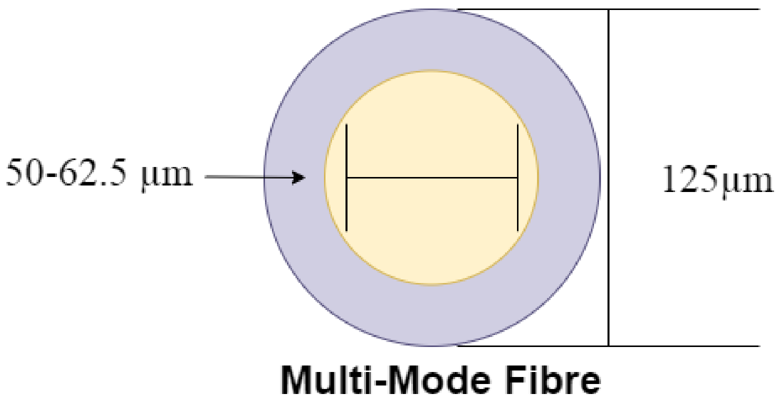


Figure 2.4 The diameter of multi-mode fiber optic cable

Because of its greater core diameter, multimode fiber has a greater attenuation compared to single-mode fiber. Even though the fiber core of single-mode cable is relatively small, light passing through these fiber optic cables is not reflected very often, resulting in minimal attenuation. A standard multimode fiber for telecommunications has a 50-62.5 µm core diameter and 125 µm cladding diameter. It is resulting in the possibility of multiple modes propagates through the fiber.

Multi-mode fiber is utilized in various operation like a local area network system that demands high capacity (over 1GHz) across small distances (under 3km). The following are some of the most significant advantages of multimode fiber. First and foremost, it is a reasonably simple to deal with. Because of its bigger core size, the light is easily associated with it. It may also be utilized as sources with lasers and LEDs. Coupling losses are smaller than single-mode fiber.

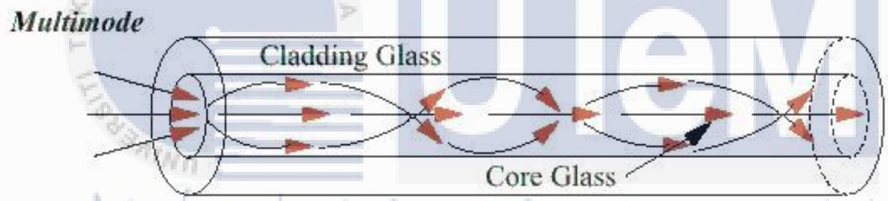


Figure 2.5 The Multi-Mode Light Propagation

The disadvantage is that modal dispersion occurs due to allowing many modes to propagate. In addition, because of the modal dispersion, bandwidth is limited, resulting in lower data rates.

2.3 The Propagation of Light through Optical Fiber

Fiber optics is the study of light energy propagation via transparent optical fibers. The nature of the light and the optical fiber structure determine how a fiber optic cable directs it. The transmission of light energy across an optical fiber is referred to as wave motion in fiber optics. Likewise, a repeating disturbance progressing across space with or without a physical medium is referred to as wave motion.

2.3.1 Reflection and Refraction of light in Fiber Optic

Optical fiber is made up of different components. A fiber optic cable's construction includes a core, cladding, coating buffer, strength member, and outer jacket. The light-carrying element at the center is known as the optic core.

The optical principle of total internal reflection collects light through an optical fiber and restricts it to its core. A light-carrying core is at the middle of an optical fiber, surrounded by a cladding that traps light in the core. A plastic buffer covering protects glass fiber from the environment while also allowing for simple splicing and termination.

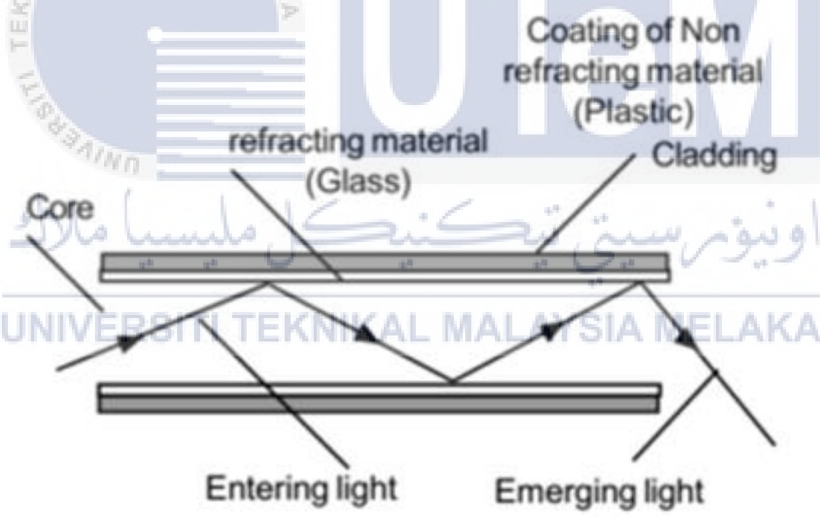


Figure 2.6 The Total Internal reflection in Fiber Optic Cable

The glass refraction index is a measurement of the speed of light ($3x10^8$ m/s) in the material, and alterations in the index of refraction cause light to bend. Refraction causes light to be reflected from the surface beyond a specific angle. Optical fibers utilize this reflection to transmit light in the core by selecting core and cladding materials with the appropriate index of refraction that reflects all light if the angle of light is below a specified angle.

For each given fiber, there is an angle that specifies complete internal reflection. A beam of light will still be refracted at greater angles, but not enough to be reflected into the core. Therefore it will be lost in the fiber's cladding. However, it will be reflected into the fiber's core and sent to the fiber's end if it is below that angle. The numerical aperture of fiber is defined by the angle of total internal reflection, which is a standard fiber parameter.

2.3.2 Total internal Reflection - Step Index Multimode Fiber

The core of a step-index multimode fiber is entirely formed of one type of optical material, while the cladding comprises a different kind of optical material with different optical properties. Due to dispersion induced by the varied route lengths of the various modes going through the core, it has increased attenuation and is too sluggish for many applications. Figure 2.7 shows the total internal reflection in step index multimode fiber.

Figure 2.7 The Total Internal reflection in Step Index Multimode Fiber

2.4 Various Type of Fiber Optic Sensor

Due to recent breakthroughs in fiber-optic technology, the telecommunications business has developed dramatically. The capacity to transport gigabit data at the speed of light increased the research potential of optical fibers. Rapid advancement and cost reductions in optoelectronic components led to the development of new products. Designers have linked optical fibers with optoelectronic devices in the last revolution to make fiber optic sensors. With almost non-existent material losses and increased sensitivity to losses, it was quickly found that changes in phase, intensity, and wavelength of external disturbances could be perceived. As a result, fiber optic sensors were born.

The technology of optical sensors for the optoelectronic and fiber optic communications industry has been a major one. Many of the components utilized were initially intended for the use of fiber optic sensors in these areas. The production and subsequent mass production of components for these companies often accelerated fiber optic sensor technologies. Moreover, replacing traditional sensors with fiber optic sensors has grown as component prices have declined and quality increased.

2.4.1 Evanescent wave sensors

Using exponentially fading evanescent fields surrounding the cladding area of a fiber optics, many types of intensity modulated Fibre Optic Sensors may be produced (FOS). Evanescent wave absorption in an external medium can be done by physically altering the fiber, such as by eliminating etching from the cladding, generating a taper, or bending the fibre to facilitate contact of the evanescent field with the target item. After being physically distorted, the fibre structures are then covered with a species-specific overlay that responds to an external measure, in this instance humidity changes. This allows for the measurement of relative humidity. Corres et al. presented a single-mode tapered fiber covered with a [PDDA/Poly R-478] nanostructured overlay, with the thickness of the overlay adjusted to enhance the sensor's sensitivity by ending the deposition process when the transmitted signal's maximum slope was reached. The relative humidity sensor's internal construction is seen in Figure 2.8.

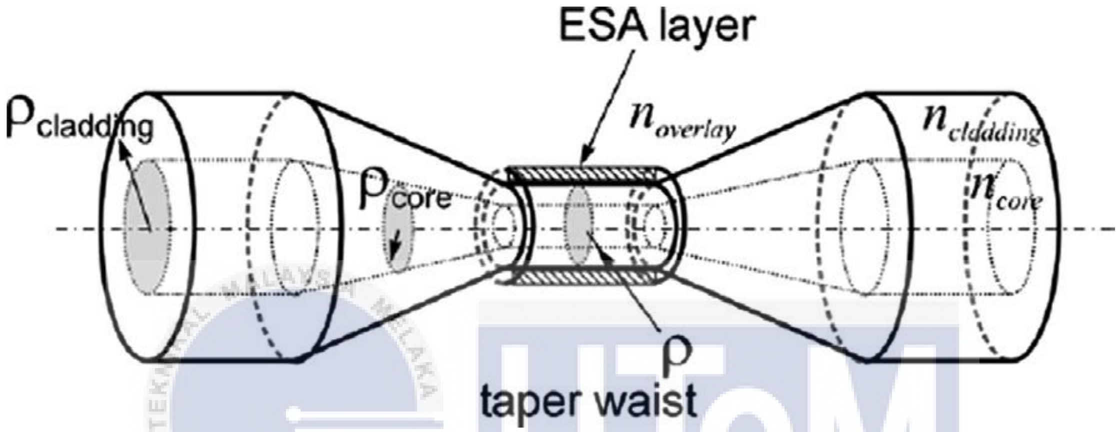


Figure 2.8 ESA overlay on a taper humidity sensor structure

With a response time of 300ms and variations in relative humidity from 75 percent to 100 percent, an optical power fluctuation of 16 dB was attained for variations in relative humidity from 75 percent to 100 percent. Because of its fast response (compared to many other relative humidity sensors), high dynamic performance, and low-temperature cross-sensitivity, the sensor was developed for applications such as human breathing monitoring, the control of highly humidity-dependent chemical processes, and weather prediction. The parameters of the sensor system for changeable relative humidity are depicted in Figure 2.9, as well as the findings of a capacitive relative humidity sensor that is commercially accessible in the marketplace.

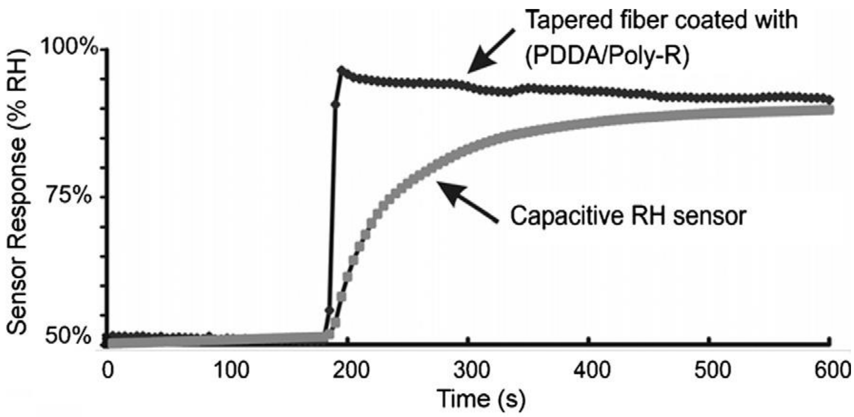


Figure 2.9 Tapered fiber sensor relative humidity step response compared to commercial capacitive relative humidity sensor

Mathew et al. recently suggested another evanescent wave-based sensor for human breathing monitoring, which used a buffer-stripped bent SMF with resonant peaks in the transmission response due to the coupling of the fundamental mode to cladding modes. Concerning the bend radius and wavelength, this response oscillates, and it also varies with ambient RI. If the bend fiber's surrounding RI is changed, the coupling conditions will change, resulting in a shift in the wavelength of the resonant peaks. The hydroscopic polymer Polyethylene Oxide (PEO) was used to cover the bend to sensitive to relative humidity. A high bend loss fiber (1060XP) with a bend radius of 15 mm was employed to produce better sensitivity for the humidity sensor. Figure 2.10 depicts the experimental setup as well as the coated fiber bed.

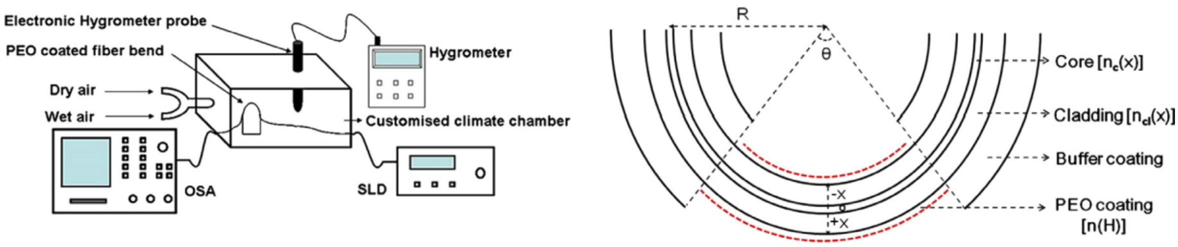


Figure 2.10 The Humidity Response Experimental Setup

Although the sensor was tested against relative humidity spanning the range from 30% to 90%, no appreciable wavelength attenuation band was found below 85% relative humidity. This was because the coated PEO film's RI was above the cladding's RI, and hence the PEO coating acts as an absorption layer. However, due to mode coupling, as the surrounding relative humidity grows above 85%, relative humidity resonant dips occurred in the transmission spectrum and experienced a redshift with relative humidity increase.

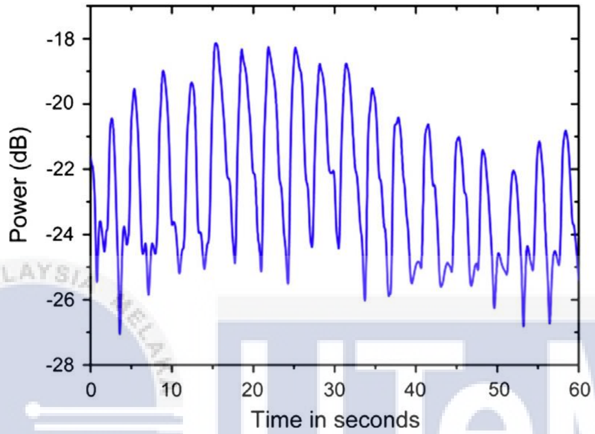


Fig. 2.11 Continuous human breathing response of the sensor

To illustrate the practicality of using the sensor as a breath rate monitor, it was placed about 2 cm from the nose tip, and the sensor's ensuing breath relative humidity response for 1 minute was recorded as shown in Figure 2.11.

A reasonably fast sensor recovery and accuracy were achieved for the target application. Another fascinating evanescent field relative humidity sensor in a U-bend configuration was suggested by the same group utilizing humidity-sensitive *Agarose* coating on an SMF. The sensor response to a step-change in relative humidity is illustrated in Figure 2.12.

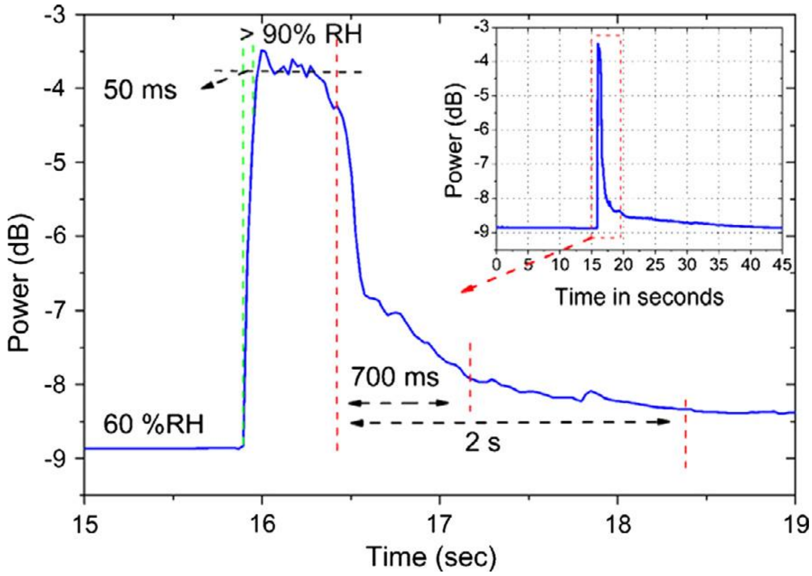


Figure 2.12. The step-change in relative humidity.

2.4.2 Fabry–Perot Interferometric sensors

Optical interferometry is a capable technology used in optical fiber sensing to deliver high standard fiber optic sensors. In addition to the benefits of fiber optics, fiber optic *interferometric* sensors often give geometric diversity in terms of sensor design and high measurement sensitivity. The sensing process is based on disturbing the phase characteristics of the light signal traveling through the optical fiber introduced by an external environment.

In order to detect phase shifts, it is necessary to combine the signal of interest with a reference signal, which converts a phase difference between the two signals into an optical intensity shift. As seen in Figures 2.13 and 2.14, the proposed sensor design consists of a thin film Fabry–Perot interferometer that is formed at the optical fiber tip.

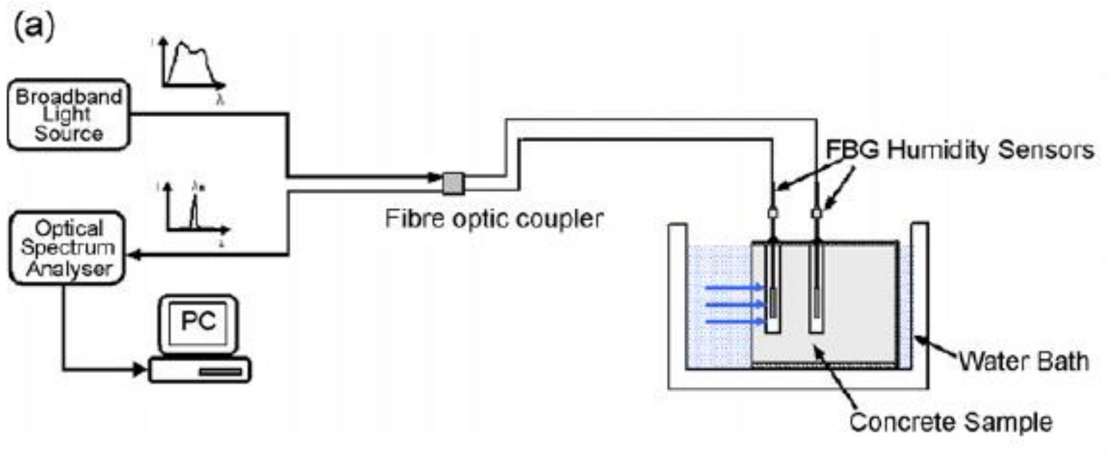


Figure 2.13 Moisture ingress rate measurement using Fiber Bragg grating humidity sensors

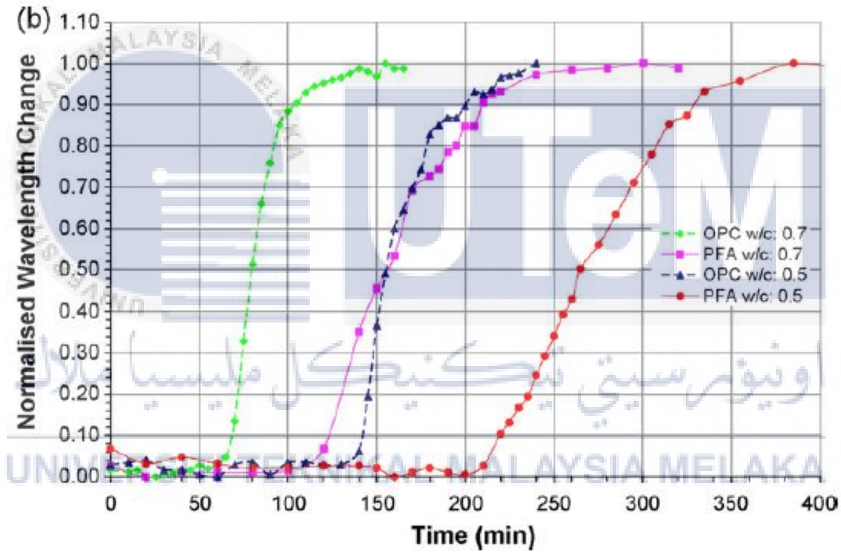


Figure 2.14 Sensor measurements

At specific wavelengths, the interference of optical signals reflected by the mirror at both ends of the cavity causes a spectrum response that results in the production of maximum intensity output (resonances). The free spectral range (λFSR) separates these various resonances, defined by;

$$\lambda\mathrm{FSR} = \frac{c}{2nd}$$

Where c is the speed of light, n is the cavity's refractive index, and d is the cavity length.

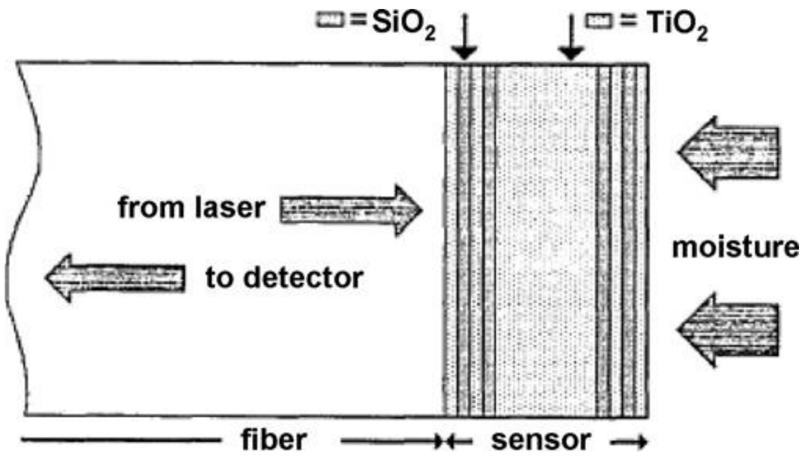


Figure 2.15. Fiber optic Fabry–Perot interferometric humidity sensor

The Fabry–Perot cavity was constructed by sandwiching a layer of titanium dioxide between two partially reflecting mirrors, with the cavity thickness optimized to fit the operation at the wavelength of the input diode laser source, as illustrated in Figure 2.15 above.

Because the refractive index of the cavity material is affected by humidity, the resonance shifted in reaction to humidity changes, which may be easily identified by measuring intensity at a fixed wavelength. A suitable compensation technique can be used to rectify the sensor's cross-sensitivity to temperature. It did, however, exhibit a good response between 0 and 80% relative humidity, with a response time of less than a minute. Bilayers of alternating cationic and anionic polymers were stacked at the fiber tip to create a conventional multilayer thin film *interferometric* cavity. This was accomplished by employing the ISAM technology, which allows for precise control of cavity length and material composition for each coating layer.

Sensors having a cavity length (or the number of bilayers) optimized for a particular operating wavelength have been found to work in a wide humidity range. The sensor has been indicated as a prospective diagnostic tool for monitoring human respiration, with a reaction time of less than a few seconds.

2.5 Comparison of Research Paper

Table 2.1 Literature Review

No	Title	Author	Source	Remark
1	The Phenomenon of Total Internal Reflection and Acceleration of Light in Fiber Optics	[1]	Fiber Optic Communication	Refraction and Reflection
2	Advances in Fiber Optics	[2]	Fiber optic Communication	
3	An Introduction to Fiber Optic	[3]	Fiber Optic Communication	Introduction to Fiber Optic
4	Fiber Optic Sensors And Their Applications	[4]	Fiber optic sensor	Application of Fiber Optic Sensor
5	Recent Developments in Fiber Optics Humidity Sensors	[5]	Fiber optic sensor	The new technology of fiber optic sensor
6	Intrinsic Fiber-optic Sensors	[6]	Fiber optic Sensor	Intrisic and Extrisic Sensor.
7	Fiber-Optic Sensors for Biomedical Applications	[7]	Fiber optic sensor	Fiber-Optic Sensors in Medical Industry
8	Fibre-optic sensor technologies for humidity and moisture measurement.	[8]	Fiber optic sensor	Development of fiber optic humidity sensor
9	A Highly Stable Optical Humidity Sensors Based On Nano-Composite Film	[9]	Fiber optic sensor	Development of fiber optic humidity sensor
10	Characterization of a fiber optic sensor based on LSPR and specular reflection	[10]	Fiber optic sensor	Characterization of Fiber Optic Sensor
11	High Sensitivity Humidity Fiber-Optic Sensor Based on All-Agar Fabry–Perot Interferometer	[11]	Fiber optic sensor	Humidity sensors based on Fabry–Perot Interferometer
12	A Study of Relative Humidity Fiber Optic Sensors	[12]	Fiber optic sensor	Development of fiber optic humidity sensor

No	Title	Author	Source	Remark
13	Fiber-optic Fluorosensor for Oxygen and Carbon Dioxide	[13]	Fiber optic sensor	Development of fiber optic Gasses sensor
14	Whispering gallery modes on optical micro-bottle resonator	[14]	Fiber optic sensor	Development of fiber optic humidity sensor

2.6 Summary

In addition to having several benefits over traditional sensing technologies, fiber-optic sensing technology is a viable alternative to traditional moisture/humidity monitoring. Therefore, a detailed assessment of the various optical fiber sensing methods employed in the study for humidity monitoring closes the review. Finally, it is advisable to examine various extrinsic and intrinsic approaches that have been published throughout the years, with many of them focused on sensory characteristics obtained in a controlled laboratory environment.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss in detail the methods to complete the objective of the project. It will also explain the procedure needed to strip the fiber optic cable, splicing the fiber optic cable, and the characterization of the fiber optic sensor. This chapter will explain the overall procedure to complete the project and the ways to overcome the difficulties to achieve the objective of the project. Figure 3.1 below describe the entire process of this project.

3.2 Flow of the Project

The following objectives are achieved to explain how to accomplish the project's goal:

1. Search for a title that is relevant to the area being studied
    - Conduct research using journals, online websites, and discussions with the project supervisor.
2. Gathering relevant information from the books.
    - Analyze and identify the methods that this project may employs based on the past successful project.
3. Choosing the raw materials for this project.
    - Discuss the parameters and equipment that will be used in this project with the supervisor, including the process of stripping and splicing the fiber optic cable.

4. Design a sensor from the listed raw materials.

- Develop a humidity fiber optic sensor, based on the result of humidity level test in different types of environment.

5. Sensor testing analysis to identify the sensitivity and the efficiency of the humidity sensor to detect the level of humidity in different environment.

6. Examine the data obtained from the sensor.

- Analyze the data collected from the humidity sensor to decide any chances of improvement of the sensor credibility and reliability.
- Comparing the result obtained with another type of sensor (traditional electric sensor and other humidity sensor).

7. Preparing a formal report.

- To record the entire proces of developing the humidity sensor by optical microfiber for medical industry. The data results are recorded to ensure the capability of optical fiber humidity sensor to measure the humidity level with the standard for medical industry.

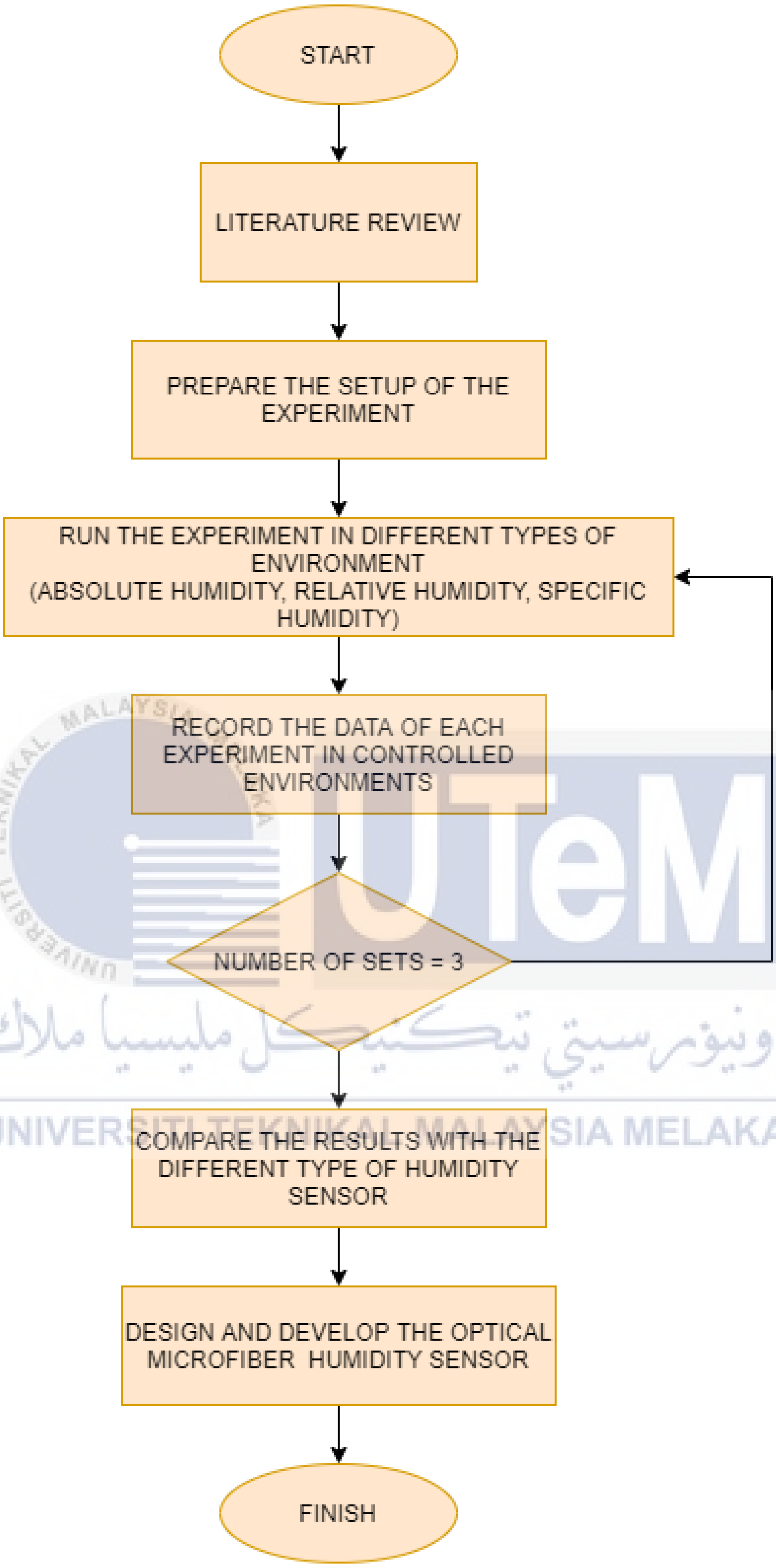


Figure 3.1 The Flow Chart of develoment of humidity sensor by optical microfiber for medical industry.

3.3 Stripping and cleaving of fiber optic cable.

Stripping is the way to remove the protective polymer coating around optical fiber for fusion splicing. The splicing procedure begins with the preparation of both fiber ends for fusion, which entails removing or stripping all protective covering from the ends of each fiber. A special stripping tool may be used to remove the coating off fiber optics. Mechanical instruments used for stripping fiber are comparable to copper wire strippers. Figure 3.2 shows the stripping process for fiber optic cable.

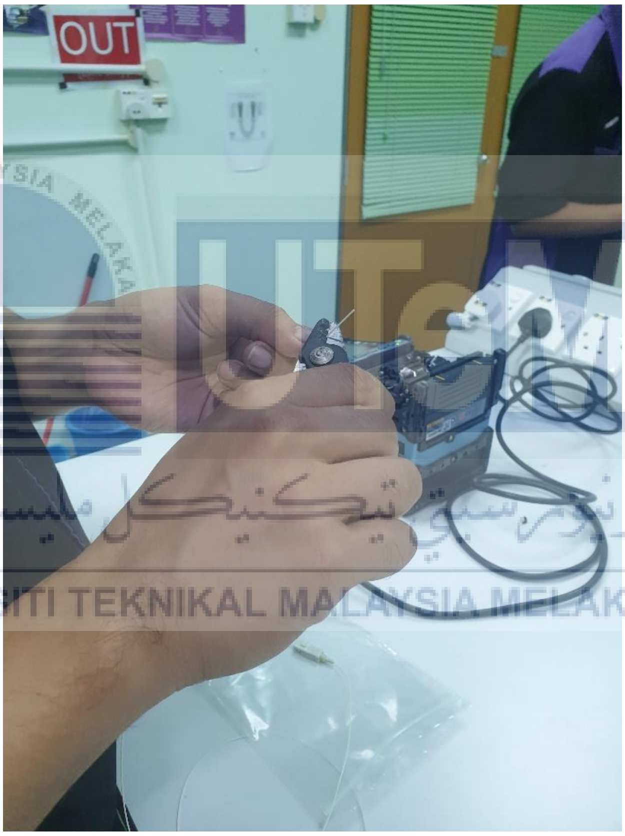


Figure 3.2 Stripping process for fiber optic cable.

Mechanical splice or fusion splice is the most common methods for attaching two optical fibers. The fiber tips must have a smooth end face perpendicular (90°) to the fiber axis for optical fiber splicing procedures, as shown below. Moreover, an optical fiber cleaver is a tool used to cut (or cleave in the fiber optic industry) the fiber in a clean 90° cut. Figure

3.3 and 3.4 shows the mechanical cleaver of fiber optic cable and the differences between a good cleaving technique and a bad cleaving technique respectively.

Figure 3.3 Cleaver tools for fiber optic cable.

Figure 3.4 The differences between a good and bad cleaving technique.

3.4 Fiber Optic Cable Splicing Procedure

Fiber optic splicing is a technique for linking two fiber optic cables together. As a result, the new cable can transport data at the same speed and efficiency as a standard fiber optic connection when done correctly. Mechanical splicing is less expensive than fusion splicing, but the fusion splicing lasts longer. The fiber cores are fused with less attenuation using the fusion process, with insertion loss of less than 0.1dB. Figure 3.5 shows the fusion splicing machine.

Figure 3.5 Fujikura Fusion Splicing Machine

A specialized fusion splicer equipment is used to precisely align the two fiber ends. The fiber ends are fused or welded together using an electric arc or another sort of heat in the fusion splicing process. The results are a transparent, non-reflective, and continuous connection between the fibers, allowing for lesser light loss. Figure 3.6 shows the splicing technique using fusion splicing machine.

Figure 3.6 The splicing technique using fusion splicing machine.

First, to align the two fibers precisely. Second, to splice single-mode and multimode fiber cables, create a short electric arc to melt the fibers and weld them together. Fusion splicing has several advantages, including decreased splicing loss (about 0.1dB) and less back reflection. Figure 3.7 and Figure 3.8 shows the splicing technique and loss in splicing process respectively.

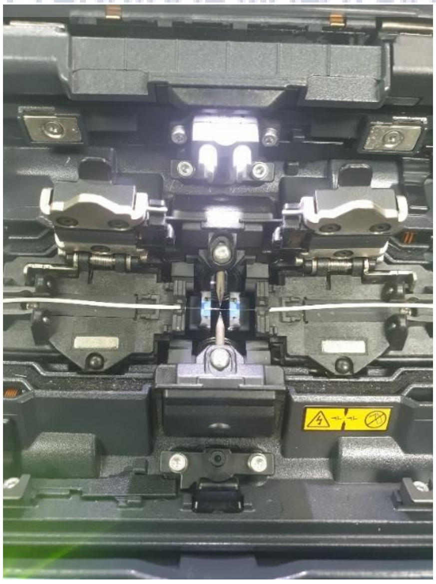


Figure 3.7 Fiber cable splicing technique.

Figure 3.8 Fiber cable spliced successfully with 0 loss.

Figure 3.9 Fiber cable spliced successfully with 0 loss.

Then, the spliced cable as shown on Figure 3.9 above will be placed carefully inside a container. The quantity of moisture in the container is affected by the weather, the amount of light available, and nearby heat sources. As a result, the container walls may become cold, while the air within the container may remain or become warmer. In this case, dehumidifier agent, for example, Silica (SiO_2) and Calcium Chloride ($CaCl_2$) acted as the humidity controller and the data is taken during the observation. Figure 3.10 shows the setup for Humidity Sensor by optical fiber.

Figure 3.10 The setup for Humidity Sensor by optical fiber.

3.5 The Characterization of Fiber Optic Cable

Before inspecting the sensor, it is compulsory to check the fiber cable. The fiber cable characterization can measure insertion loss, optical return loss, polarization, and dispersion to determine that the fiber can carry transmission and set a standard for debugging and troubleshooting.

3.5.1 Connector Inspection

Dirty connectors are a significant issue in fiber optics, generating high connection loss, high reflectivity, and transceiver contamination. According to network operators, dirty connectors induce connection problems in 50% of all network failures.

Using 99% isopropyl alcohol and a lint-free wipe, the pigtail connector surface is wiped to ensure there is no contamination. Isopropyl alcohol (IPA) is a solvent for removing most greasy contaminants and was not harmful to the epoxies used in fiber termination. Figure 3.11 shows the comparison between contaminated and clean pigtail connector.

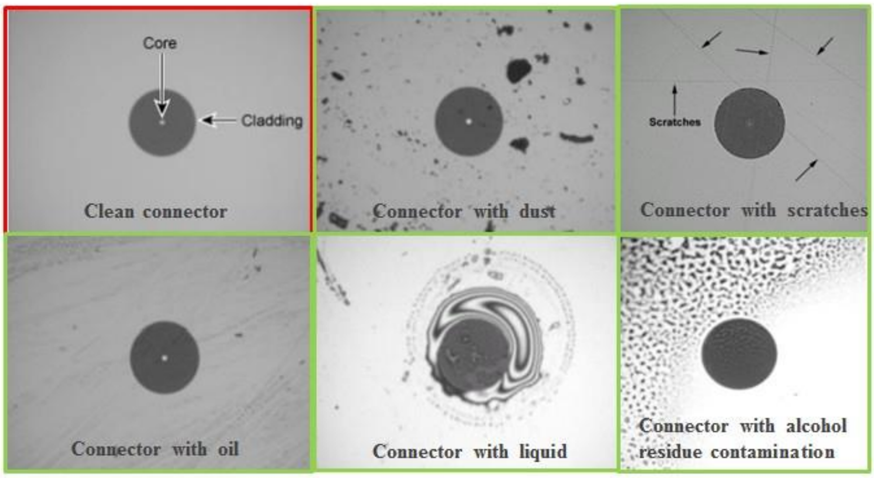


Figure 3.11 The Comparison Between Contaminated And Clean Pigtail Connector

3.5.2 Insertion Loss

The most accurate technique to give end-to-end loss values on an optical span, including fiber attenuation and the beginning and end connections of the fiber under test, is to use a Power Meter and Light Source combination (Loss Test Set). Figure 3.12 shows the Insertion Loss Test.

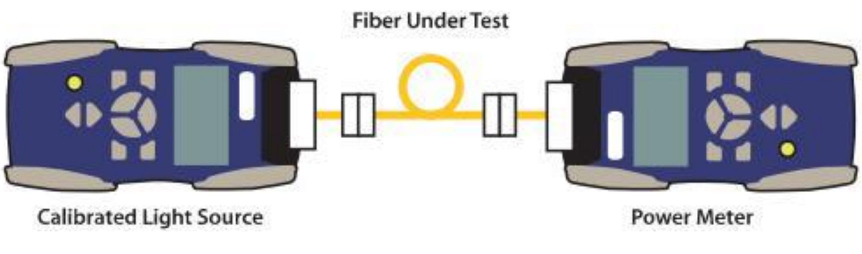


Figure 3.12 Power Meter and Light Source Test

Continuous-wave light is sent from the source to the power meter using a power meter and a light source. The overall span loss is the difference in power. The purpose of an insertion loss test is to simulate link operation circumstances by launching power into the fiber or cable under test and measuring the loss at the other end with a power meter.

3.5.3 Optical Return Loss (ORL)

The light source's output power ratio to the total amount of back-reflected power is known as optical return loss (reflections and scattering). It is a positive quantity, according to the definition. Using ORL, it is possible to determine how much total light is reflected into the transmitter by a fiber and its components, such as connector pairs, mechanical fusion splices, etc. It may also be used to measure the total efficiency of a fiber plant by reading light that does not reach the other end of the fiber. Figure 3.13 depicts the direction of light that is reflected into the transmitter from the receiver.

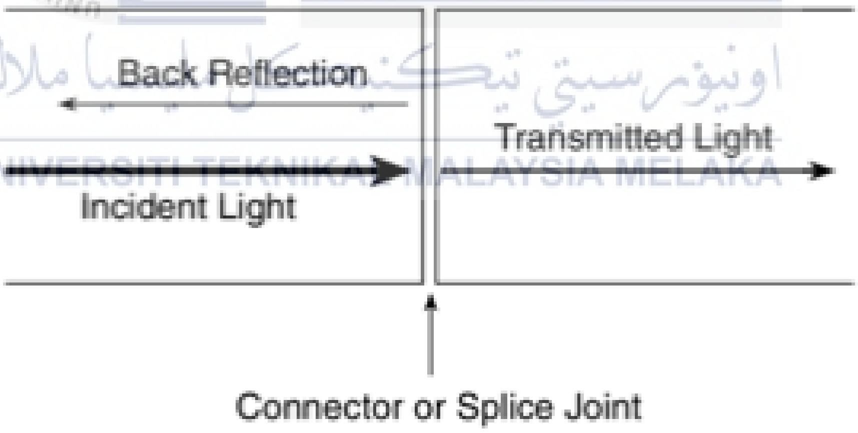


Figure 3.13 The direction of light reflected back into the transmitter

All connection pairs and mechanical splices are considered reflective occurrences. ORL is expressed as a +dB value; the higher the ORL value, the better the reflections in the test fiber. The goal of this test is to look for locations of reflectance problems.

3.5.4 Polarization Mode Dispersion

The differential arrival time of the multiple polarization components of an input light pulse transmitted by an optical cable is known as PMD (Polarization Mode Dispersion). This light pulse can be split into two orthogonal polarization modes at any time. The fiber's refractive index generates a slow and fast axis, which causes these polarization modes to propagate at different speeds. Figure 3.14 below shows the differential of arrival time.

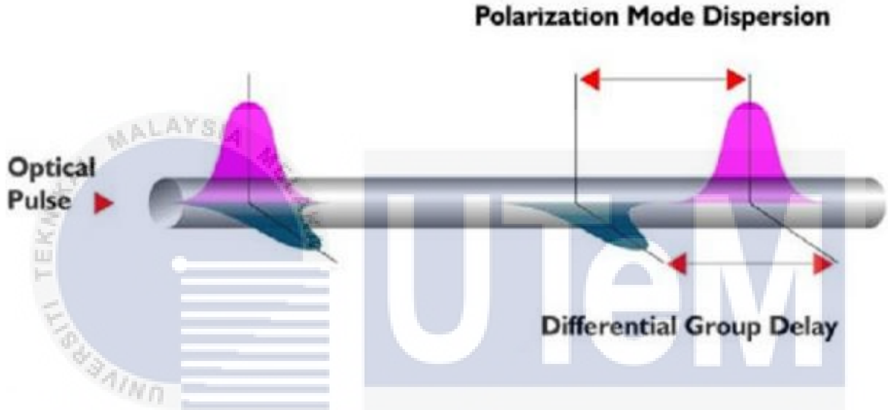


Figure 3.14 The Differential Of Arrival Time

Non-perfect concentricity and homogeneity of the optical fiber in manufacturing design and external stressors imposed on the fiber cable, such as bends or twists, are the significant causes of this refractive index.

3.5.5 Chromatic Dispersion Test

Chromatic Dispersion is the effect when various wavelengths move at different rates because of the non-zero spectral width of transmitters. The variation in arrival time of each wavelength creates pulse spreading or dispersion since transmitters are made up of numerous wavelengths that move at various speeds. The ps/nm scale is used to measure this phenomenon. Figure 3.15 shows the longer wavelengths traveling faster induce chromatic dispersion in the fiber.

Figure 3.15 Longer wavelengths traveling faster induce chromatic dispersion in the fiber.

Chromatic dispersion is caused by two factors: material dispersion and waveguide dispersion. The variations of the index of refraction of a particular material across wavelength cause material dispersion. The dispersion of waveguides is more complicated. Because the wavelength of light in single-mode fiber is not larger than the diameter of the core, light flowing down the fiber travels in an area that surpasses the diameter of the core. Thus, longer wavelengths travel in a greater mode field diameter, whereas shorter wavelengths travel in a smaller field diameter.

The OTDR test technique allows testing in the field from one end of the cable by taking traces at many discrete wavelengths and calculating Chromatic Dispersion from the data collected from the traces.

3.6 The Characterization of Fiber Optic Sensor

The fiber optic sensor characterization is a set of tests performed on a fiber optic sensor to verify the sensor's integrity, installation procedures, and performance at a specific environment type. This is critical because, as data rates rise and systems become more sophisticated, various variables can degrade system performance.

The fiber-optic humidity sensor (FOHS) based on an optical time-domain reflectometer (OTDR) was developed to measure the humidity level. Single-mode optical fiber and a moisture-sensitive material that changes its refractive index in response to relative humidity make up the detecting probe of a fiber optic humidity sensor. By using the dip-coating procedure, the moisture-sensitive substance was coated onto the end of the fiber.

The optical power of the OTDR fluctuates with relative humidity due to Fresnel reflection between the sensing material and the single-mode fiber. It is advisable to assess the change of optical power according to the contents of the laser source's moisture-sensitive material and wavelengths to optimize the fiber optic humidity sensor. As a result, the humidity measurement will be determined by the moisture-sensitive material, as well as the sensor's sensitivity level.

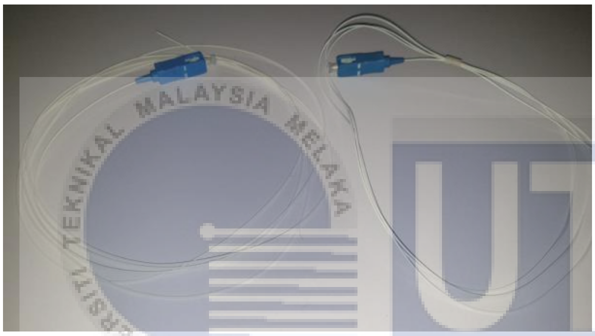
3.7 Equipment Used for the experiment.

These instruments are implemented to carry out an experiment or take measurements while collecting data in most cases.

a) Amplified Spontaneous Emission (ASE)

b) Optical Spectrum Analyzer

c) Fiber Pigtail (2 pcs)



d) Splicing Machine

e) Stripper / Cutter

f) Cleaver

g) Alcohol Cleaning Pad

h) Dehumidifier Agent

a) Calcium Chloride ($CaCl_2$)

b) Silica ($SiO2$)

3.8 Summary

In this chapter, the methodology used to complete the objective of the project is explained in details. In addition, the overall procedure to complete the project and the ways to overcome the difficulties to achieve the objective of the project is also discussed in detail.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter explained the results and data measurement on the development of humidity sensor by optical microfiber for medical industry. The project's performance is demonstrated through a series of tests. The performance of the sensor will be tested based on these criteria which are sensitivity and linearity, result of the tests, capability, and repeatibility of the sensor to operate. It is essential to mention that the purpose of these tests is to aid in the development of the sensor.

4.2 Results and Analysis

4.2.1 10% of Dehumidifier (1 pack of Silica) tested on 1550nm wavelength

Figure 4.1: The setup for 10% of Dehumidifier test.

Figure 4.1 above shows the experiment setup for fiber optic humidity sensor. By using the wavelength of 1550 nm, the optical fibre test was performed on 10% of the dehumidifier, as indicated in Table 4.1 below. This table includes the percentage of humidity that corresponds to the amount of time it took to complete this experiment. It was necessary to repeat this experiment every 3 minutes in the span of 30 minutes. The reading from the power metre (in decibels) is also provided in the following Table 4.1. This experiment was carried out three times for every test. After each takes, the pack of Silica will be replaced, and the Power Meter will be reset before continuing with the next cycle.

Table 4.1 indicates the data taken for 10% of dehumidifier (1 pack of Silica)

Time Interval (Min)	Percentage (%)	Power Meter Reading (dBm)		
		Cycle 1	Cycle 2	Cycle 3
0	100	-7.26	-7.29	-7.34
3	92.5	-7.25	-7.28	-7.34
6	86	-7.24	-7.28	-7.34
9	77.5	-7.23	-7.28	-7.34
12	70	-7.22	-7.27	-7.33
15	62.5	-7.22	-7.27	-7.33
18	55	-7.24	-7.27	-7.33
21	47.5	-7.26	-7.27	-7.33
24	40	-7.27	-7.26	-7.33
27	32.5	-7.28	-7.26	-7.33
30	25	-7.28	-7.27	-7.32

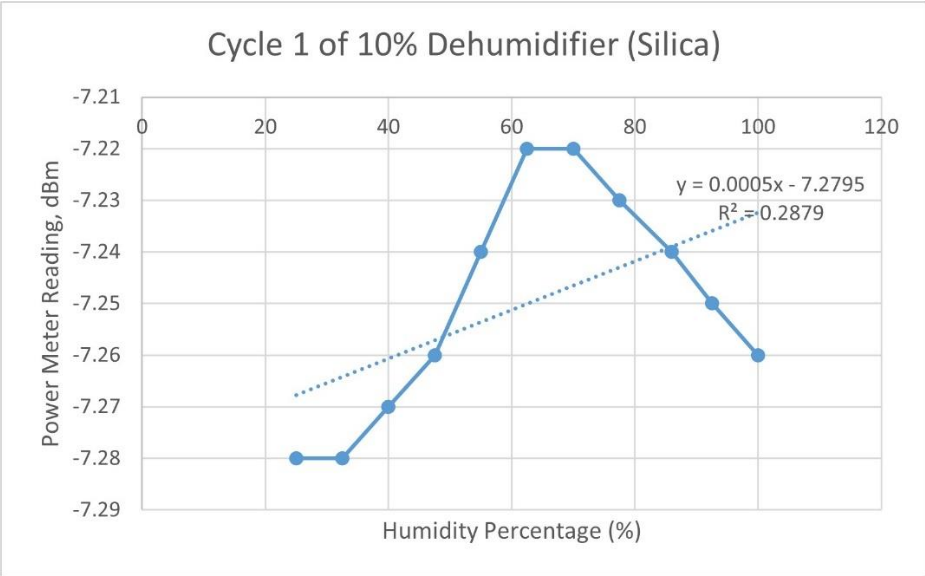


Figure 4.2: First cycle for 10% of Dehumidifier (Silica) test.

As seen in Figure 4.2 above, the starting point for this experiment at 0 min is 100% relative humidity, which produces a power metre output of -7.26dBm, then gradually increases to -7.22dBm at 70%. Then, at 70% and 62.5% it remain constant at -7.22dBm. From -7.22dBm, it then decreases to -7.24dBm and drop to -7.26dBm at 47.5% humidity. It then continually drop -7.27dBm and -7.28dBm at 40% and 32.5% respectively. Lastly, it remains constant at -7.28dBm at 25% of humidity.

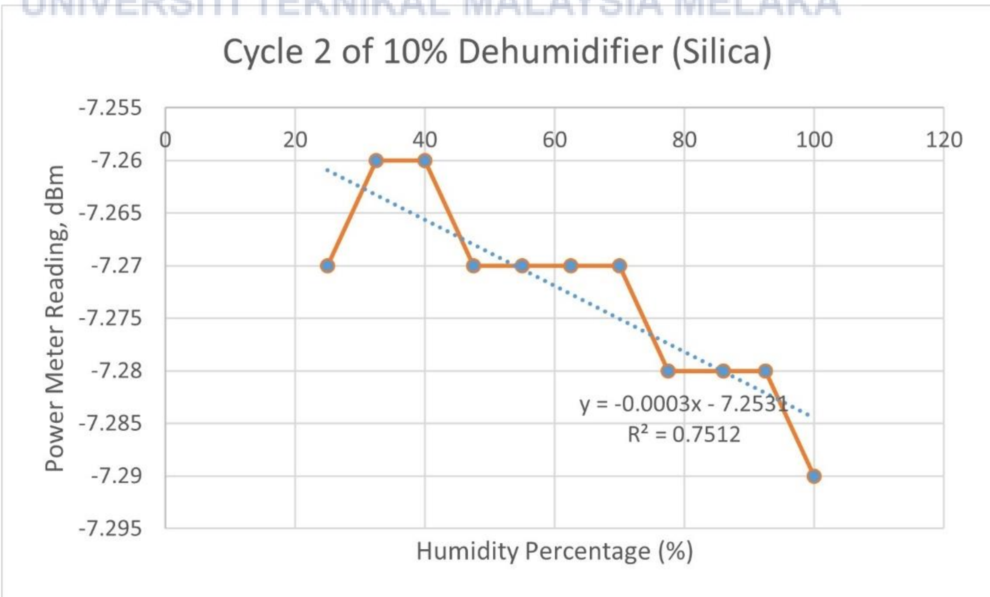


Figure 4.3 Second cycle for 10% of Dehumidifier (Silica) test.

In the Figure 4.3 above, it starts with -7.29dBm at 100% of humidity. Then it rose to -7.28 dBm at 92.5% and remained constant until 77.5% of humidity. The output then increases significantly to -7.27dBm and is constant until it reaches 47.5% of humidity. The data increased to -7.26dBm at 40% and decreased to -7.27dBm from 32.5% to 25% of humidity.

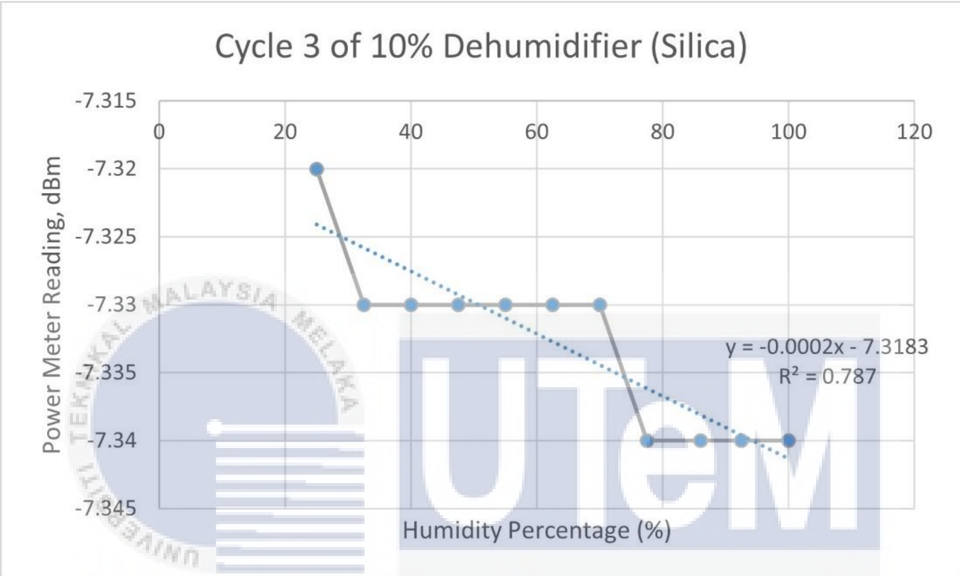


Figure 4.4 Third cycle for 10% of Dehumidifier (Silica) test

Based on Figure 4.4 above, the starting power is -7.34dBm at 100% for the third cycle, and it remains constant until 77.5%. After that, the graph significantly rises to -7.33dBm at 70% and remain stable until 32.5% of humidity. Lastly, the power meter reading increased to -7.32dBm at 25% humidity.

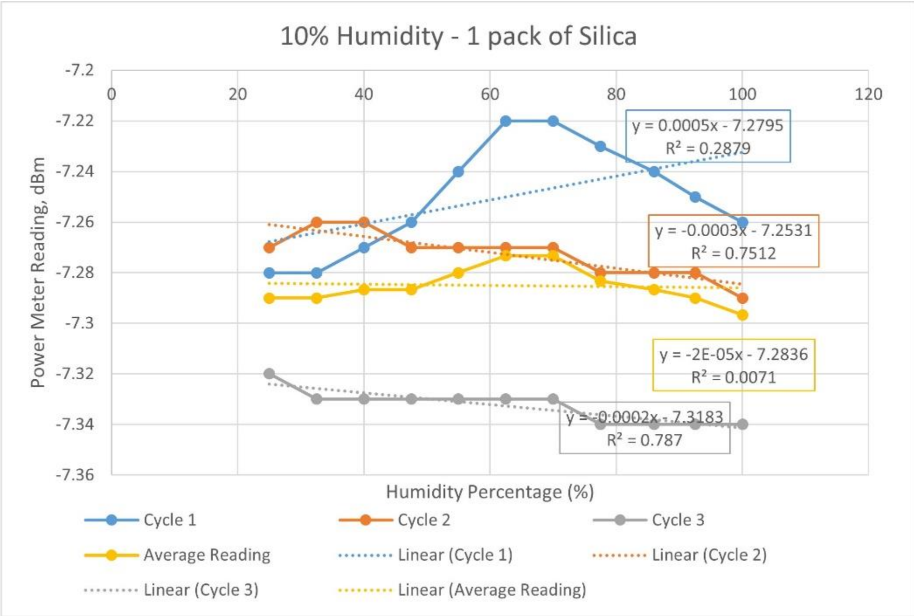


Figure 4.5 Graph comparison for each cycles in 10% of Dehumidifier (Silica) test

Table 4.2 The data comparison for 10% of dehumidifier (1 pack of Silica)

	1st Cycle	2nd Cycle	3rd Cycle
Linear range (Percentage)	**100 ~ 25**	**100 ~25**	**100 ~ 25**
Correlation R	**0.5365**	**0.8667**	**0.8871**
COD (%)	**53.65%**	**86.67%**	**88.71%**
Sensitivity	**-0.0005**	**-0.0003**	**-0.0002**

The correlation coefficient R is associated with the precision data acquired during the experimental process. Because the reference used to identify the data is accurate, the correlation R must be near 1.0, signifying that the data has a high degree of precision. According to Table 4.2, the least precise correlation R is 0.5365 (1st Cycle), and the highest exact correlation R is 0.8871 (3rd Cycle). Following that, the coefficient of determination (COD) determines the molecular difference caused by humidity. According to Table 4.2, the highest percentage of molecule reactions is 88.71%, and the lowest rate of molecule reactions is 53.65%. Finally, the Fiber Optic Light Source (FOS) sensitivity is defined as its sensitivity to the parameter tested in this experiment. The closest value indicates that FOS is the most sensitive to detecting the humidity when it comes to sensitivity. According to the statistics presented above, the third cycle, which has a significant percentage of humidity molecules, has the best reading of all.

4.2.2 30% of Dehumidifier (3 pieces of Calcium Chloride) tested on 1550nm wavelength

Figure 4.6 The setup for 30% of Dehumidifier test

Figure 4.6 displays the fibre optic humidity sensor experiment setup of 30% dehumidifier. The optical fibre test was done on 30% of the dehumidifier using a 1550nm wavelength, as shown in Table 4.3. This table shows the relative humidity based on its time to finish the experiment.

The experiment is repeated every 3 minutes for 30 minutes. A new 3 pieces of Calcium Chloride will be added after each take, and the Power Meter will be reset before continuing. The water remains also wiped out before each cycle starts. Table 4.3 shows the data taken for 30% of dehumidifier.

Table 4.3 The data taken for 30% of dehumidifier (3pcs of Calcium Chloride)

Time Interval (Min)	Percentage (%)	Power Meter Reading (dBm)		
		Cycle 1	Cycle 2	Cycle 3
0	100	-7.41	-7.43	-7.41
3	92.5	-7.41	-7.42	-7.41
6	86	-7.40	-7.42	-7.41
9	77.5	-7.39	-7.42	-7.41
12	70	-7.39	-7.42	-7.41
15	62.5	-7.38	-7.41	-7.41
18	55	-7.38	-7.42	-7.41
21	47.5	-7.38	-7.41	-7.41
24	40	-7.37	-7.40	-7.40
27	32.5	-7.36	-7.41	-7.40
30	25	-7.37	-7.39	-7.40

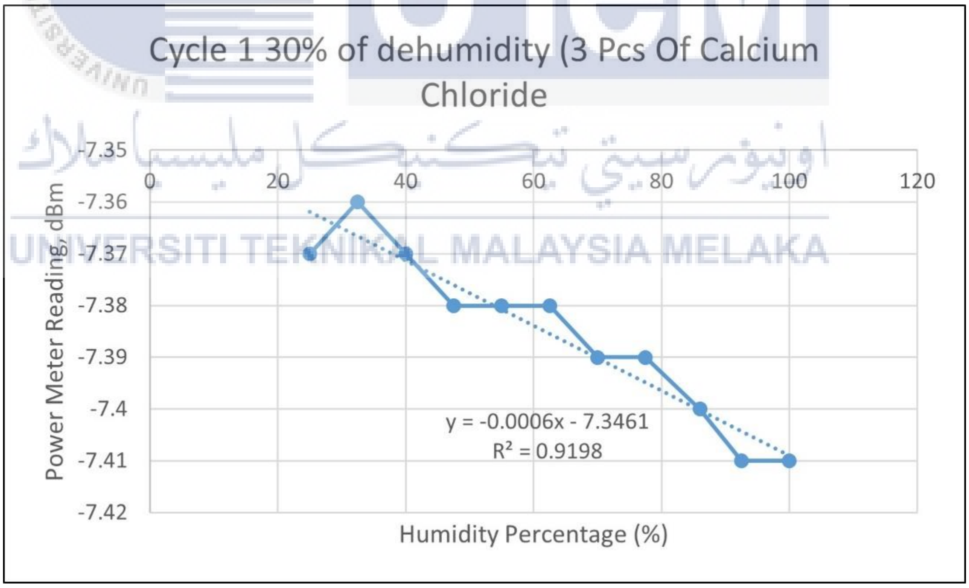


Figure 4.7 First Cycle for 30% of dehumidifier (3pcs of Calcium Chloride)

As seen in Figure 4.7 above, the starting point for this experiment at 0 min is 100% relative humidity, which produces a power metre output of -7.41dBm, then gradually increases to -7.40dBm at 86%. Then, at 62.5% until 47.5% it remains constant at -7.38dBm. From -7.38dBm, it increases to -7.36dBm and drops to -7.37dBm at 25% of humidity.

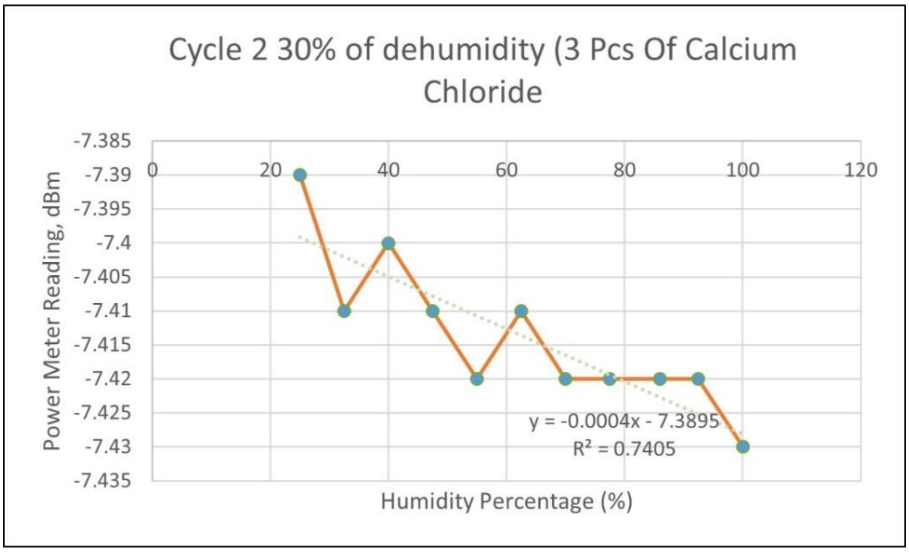


Figure 4.8 Second Cycle for 30% of dehumidifier (3pcs of Calcium Chloride)

As illustrated in Figure 4.8 above, it starts with -7.43dBm at 100% of humidity. Then it rises to -7.42 dBm at 92.5% and remains constant until 70% of humidity. The output then increases to -7.41dBm at 62.5% and decreases back to -7.42dBm at 55% before significantly increasing to -7.40dBm at 40% humidity. Then, it drops slightly to -7.41dBm at 32.5% and finally peaks at -7.39dBm at 25% humidity.

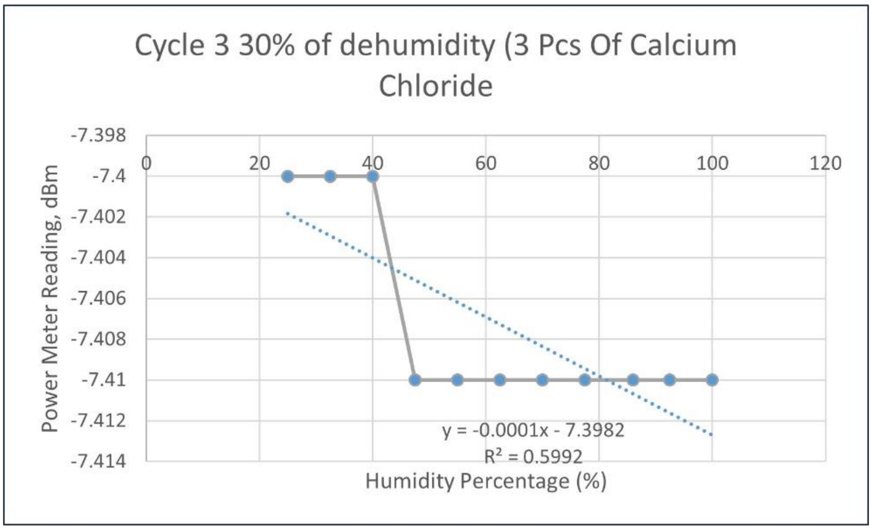


Figure 4.9 Third Cycle for 30% of dehumidifier (3pcs of Calcium Chloride)

The figure above shows that the power metre remains constant at -7.41dBm from 100% until 47.5% of humidity. Then, it rises notably at -7.4dBm and remains consistent from 40% until 25% of humidity.

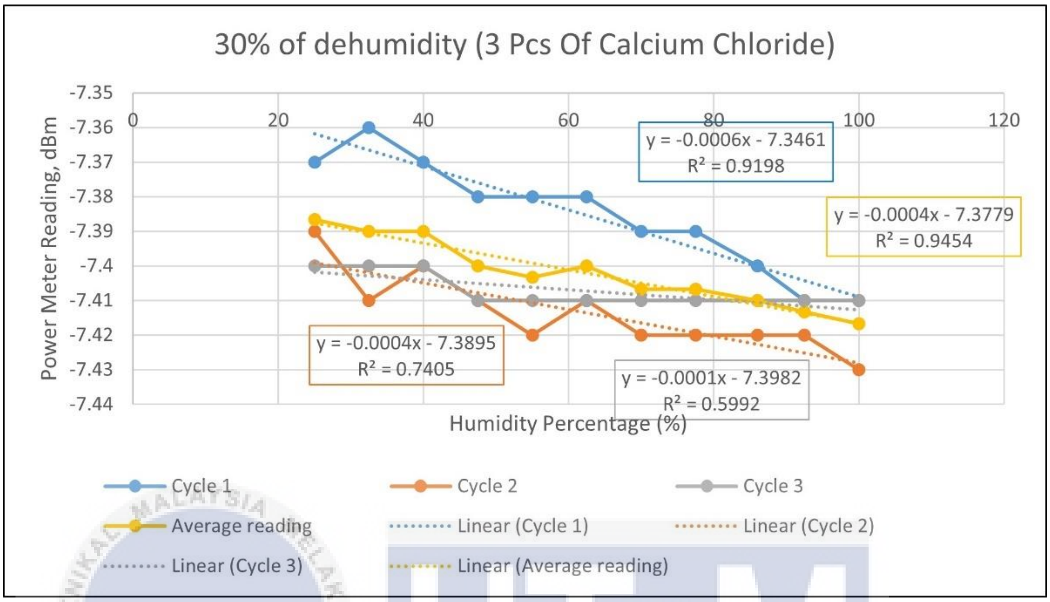


Figure 4.10 Graph comparison for 30% of dehumidifier (3pcs of Calcium Chloride)

Table 4.4 The data comparison for for 30% of dehumidifier (3pcs of Calcium Chloride)

	1st Cycle	**2nd Cycle**	**3rd Cycle**
Linear range (Percentage)	**100 ~ 25**	**100 ~25**	**100 ~ 25**
Correlation R	**0.959**	**0.8605**	**0.7740**
Coefficient of Determination COD (%)	**95.9%**	**86.05%**	**77.41%**
Sensitivity	**-0.0006**	**-0.0004**	**-0.0001**

Based on Table 4.4 above, the most accurate Correlation R is 0.959 (1st Cycle), and the least accurate is 0.7740 (3rd Cycle). The highest percentage of COD (%) is 95.9% (1st Cycle), and the lowest is 77.41% (3rd Cycle). Other than that, the highest sensitivity recorded is -0.0006 for the 1st Cycle, and the lowest is -0.0001, which is the 3rd Cycle of the test. As shown on the statistic above, the best reading of all the cycles is 1st Cycle of the test.

4.2.3 50% of Dehumidifier (5 pieces of Calcium Chloride) tested on 1550nm wavelength

Figure 4.11 The setup for 50% of Dehumidifier test (Calcium Chloride)

Figure 4.11 displays the fibre optic humidity sensor setup of 50% dehumidifier. The optical fibre test was done on 50% of the dehumidifier using a 1550nm wavelength. The experiment is repeated every 3 minutes in the span of 30 minutes. A new 5 pieces of Calcium Chloride will be added after each take, and the Power Meter will be reset before continuing. The water remains also wiped out before each cycle starts. The Table 4.5 below exhibit the data taken for 50% of dehumidifier.

Table 4.5 The data taken for 50% of dehumidifier (5pcs of Calcium Chloride)

Time Interval (Min)	Percentage (%)	Power Meter Reading (dBm)		
		Cycle 1	Cycle 2	Cycle 3
0	100	-7.37	-7.36	-7.33
3	92.5	-7.36	-7.36	-7.33
6	86	-7.36	-7.36	-7.33

9	77.5	-7.36	-7.36	-7.33
12	70	-7.36	-7.36	-7.33
15	62.5	-7.36	-7.35	-7.33
18	55	-7.36	-7.35	-7.33
21	47.5	-7.36	-7.34	-7.33
24	40	-7.36	-7.34	-7.33
27	32.5	-7.36	-7.34	-7.32
30	25	-7.36	-7.34	-7.32

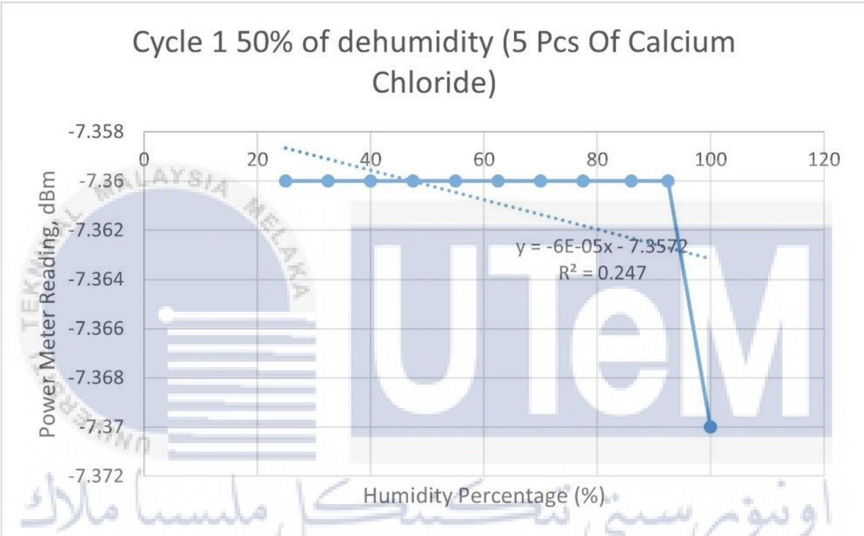


Figure 4.12 First Cycle for 50% of dehumidifier (5pcs of Calcium Chloride)

As illustrated in the figure above, it can be seen that the power meter reading starts at -7.37dBm at 100% humidity before it rises drastically to -7.36dBm at 92.5% humidity and remains stagnant until 25% humidity.

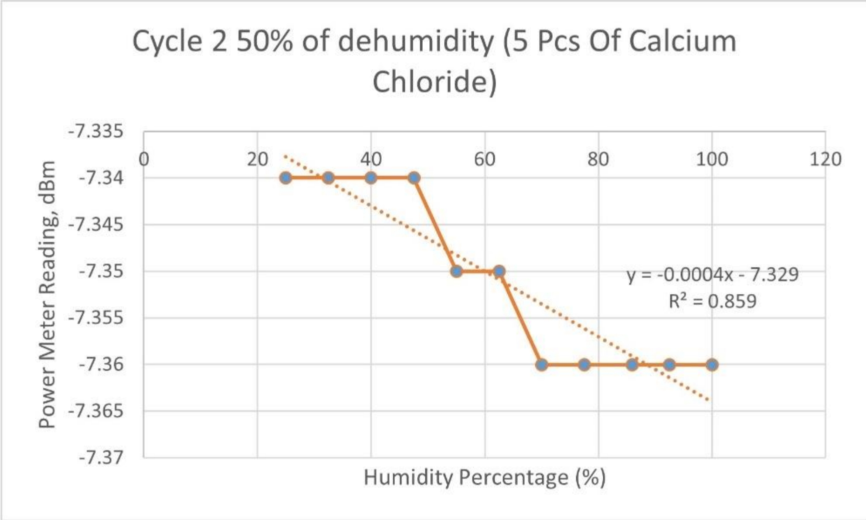


Figure 4.13 Second Cycle for 50% of dehumidifier (5pcs of Calcium Chloride)

As reflected in the figure above, it can be observed that the power meter starts at -7.36dBm in 100% humidity and remains static until 70%. Then, it started to rise sharply at -7.35dBm at 62.5% to 55% humidity. The power meter reading shoots up again towards -7.34dBm and in 47.5% humidity and remains unchanged until 25% humidity.

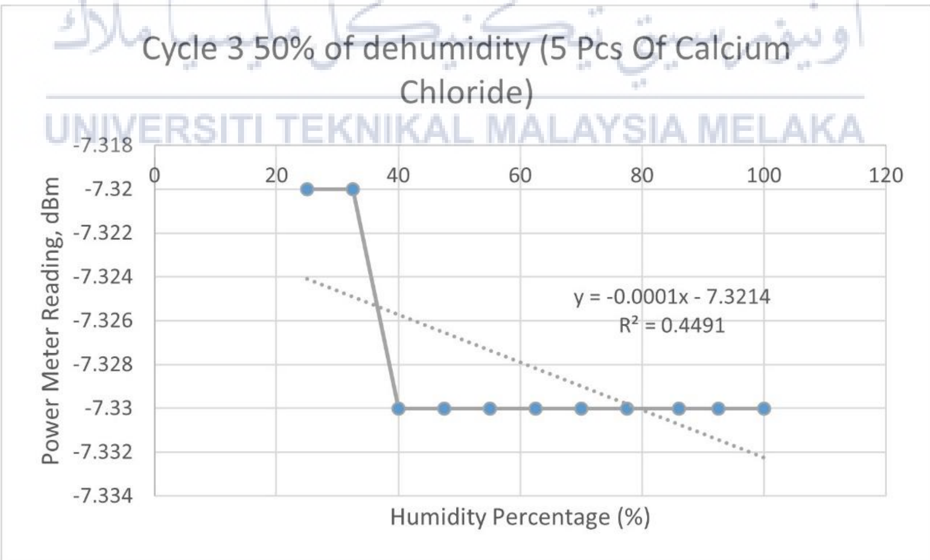


Figure 4.14 Third Cycle for 50% of dehumidifier (5pcs of Calcium Chloride)

As the figure above defines, the power meeting reading starts at -7.33dBm in 100% humidity and remains static up to 40%. Then, the meter rading shoots dramatically at -7.32dB in 32.5% humidity and does not change till 25%.

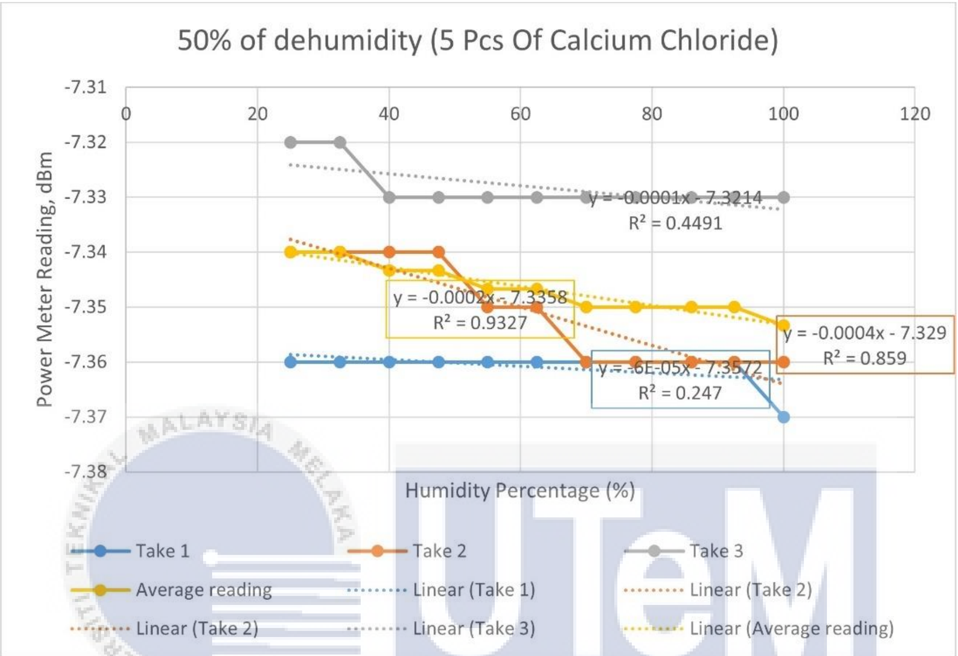


Figure 4.14 Graph comparison for 50% of dehumidifier (5pcs of Calcium Chloride)

Table 4.4 The data comparison for 50% of dehumidifier (5pcs of Calcium Chloride)

	1st Cycle	**2nd Cycle**	**3rd Cycle**
Linear range (Percentage)	**100 ~ 25**	**100 ~25**	**100 ~ 25**
Correlation R	**0.4969**	**0.9268**	**0.6701**
Coefficient of Determination COD (%)	**49.7%**	**92.68%**	**67.01%**
Sensitivity	**-0.00006**	**-0.0004**	**-0.0001**

Based on Table 4.5 above, the most accurate Correlation R is 0.9268 (2nd Cycle), and the least accurate is 0.4969 (1st Cycle). The highest percentage of COD (%) is 92.68% (2nd Cycle), and the lowest is 49.7% (1st Cycle). Other than that, the lowest sensitivity recorded is -0.00006 for the 1st Cycle, and the highest is -0.0004, which is the 2nd Cycle of the test. As shown on the statistic above, the best reading of all the cycles is 2nd Cycle.

4.2.4 Average data for 10%, 30% and 50% of dehumidifier. (Silica and Calcium Chloride)

Table 4.5 The average data comparison for 10%, 30% and 50% of dehumidifier

Dehumidifier Agent	Silica 10%	Calcium Chloride 30%	Calcium Chloride 50%
Linear range (Percentage)	**100 ~ 25**	**100 ~25**	**100 ~ 25**
Correlation R	**0.08426**	**0.9723**	**0.9657**
Coefficient of Determination COD (%)	**8.426%**	**97.23%**	**96.57%**
Sensitivity	**-0.0051**	**-0.0004**	**-0.0002**

Based on the statistic above, the highest average of Correlation R is 0.9723 of the 30% dehumidifier (3 pcs of Calcium Chloride), with a 97% of coefficient of determination. It was followed by 0.9657 of 50% dehumidifier (5 pcs of Calcium Chloride), with a 96.57% coefficient of determination. In contrast, the lowest is 10% of dehumidifier (Silica) with an 8.426% coefficient of determination. Therefore, this statistical data shows that Calcium Chloride ($CaCl_2$) is a better dehumidifier agent than Silica (SiO_2) in absorbing moisture or humidity in a confined space.

4.3 Summary

This chapter explains the result and analysis of the Humidity Sensor by Optical Fiber in depth by comparing the result of 3 different tests conducted to determine the sensor's sensitivity. The sensitivity test is performed on two dehumidifier agents, Calcium Chloride and Silica. In terms of repeatability, each test has three cycles, all conducted under the same condition and environment. The goal of the repetitive test is to figure out the correlation coefficient R, the coefficient of determination, and the sensitivity of fibre optic in detecting humidity changes. The correlation coefficient R is closely related to the data accuracy obtained during the experimental process. Therefore, the correlation R must be roughly close to 1.0, indicating that the data has a high degree of precision. The coefficient of determination (COD) calculates the molecular difference caused by moisture and humidity. Moreover, the Fiber Optic Light Source (FOS) sensitivity is determined as the parameter tested in this experiment.

CHAPTER 5

CONCLUSION

5.0 Conclusion

This chapter summarised the Development of Humidity sensors using Optical Fiber for the Medical Industry. The project is conducted based on the previous research and literature review from various universities regarding the usage of optical fibre as a sensor in the medical industry. The development of the sensor for the medical sector is crucial, as the medical industry needs precise equipment to save lives. The project's methodology involves stripping, cleaving and splicing the optical fibre cable. All of the methods above are implemented to complete the project. This project study two types of dehumidifier agent, Silica and Calcium Chloride, mainly to compare the accuracy of sensitivity of the humidity sensor using optical fibre. In the meantime, it also comparing the dehumidifier agents in terms of their ability to absorb moisture and water molecule in a confined space. The data is then recorded and analyzed based on the repeatability of the test. Each test has three cycles in terms of repeatability, all conducted under the same condition and environment.

At the end of the project, the data from this project conclude that relative humidity can be measured using humidity sensors by optical fibre, as a slight change in the humidity level can be detected by the experiment. However, developing a humidity sensor based on optical microfiber still needs a lot of development and improvement before being completed as a successful fibre optic sensor project for the medical industry.

5.1 Suggestion and Future Works.

The development of humidity sensor by optical microfiber for medical industry need various improvement before being completed for medical use. Some of the suggestions are as follows:

- A study of different types of dehumidity agent, in various places and environments.
- The invention of a sustainable container for the humidity sensor by optical fiber.
- An optical light source that can emits and maintain a stable connection for a long period of time.
- A development of a sterile and uncontaminated fiber cable.

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APPENDICES

A. PERANCANGAN PROJEK
PROJECT PLANNING (GANTT CHART)

Senaraikan aktiviti-aktiviti yang berkaitan bagi projek yang dicadangkan dan nyatakan jangka masa yang diperlukan bagi setiap aktiviti.
List all the relevant activities of the proposed project and mark the period of time that is needed for each of the activities.

	SEM I																			SEM BREAK					SEM II															
Aktiviti Projek *Project Activities*	**1**	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	13	**14**	15	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Finding articles, books, and journal as reference for Literature Review	x	x	x	x	x																																			
Study about fiber optics and types of fiber optic sensor.			x	x	x	x																																		
Study the procedure of stripping and splicing.						x	x	x	x																															
Finding research about glucose concentration in fiber optic sensor.										x		x	x	x	x	x																								
Start the process of stripping and splicing of fiber optic.											**SEMINAR PSM I**														x	x												**SEMINAR PSM II**		
Run the experiment with 2 different dehumidifier agent.																											x	x	x	x	x	x	x							
Collect data of experiment																											x	x	x	x	x	x	x							
Troubleshooting any problems occur																															x	x	x	x	x					
Final checking for the project																																			x	x	x			

Appendix A   Example of Appendix B

Time	Residential	Industrial	Commercial