Study of Suspended Droplets by Laser Attenuation Method

by

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Dissertation report submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

MAY 2011

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A Dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(Ir. Dr. Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FARAH QURSIAH BINTI YASIN

ABSTRACT

This study investigates the properties of suspended particles by using laser attenuation measurement system with reference to the Beer-Lambert's Law. These suspended particles either solid particles or liquid droplets are not visible in the air due to their fine sizes (smaller than 2.5 μm). Fundamentally, laser attenuation is defined as a technique in measuring reduction or attenuation of light intensity of a laser beam due to its passage through a body. The portion of incident flux is reflected at the entrance and exit surfaces and another portion is absorbed while the remainder is transmitted. Quantification of the properties of particles and droplets is important due to various applications; for instance, to measure size and velocity of droplets of spray painting to reduce the environmental effects, to study flows inside engines and obtaining important data on the fuel injection to improve the fuel efficiency. A system that applies laser attenuation was developed in a past research work and was proved as a reliable measurement system but to deepen the understanding in suspended particles, several experiments have been added and some modification has been done to improve the measurement system. The objectives of this project are to study experimentally the properties of various specimens by using laser attenuation method and to improve power meter system as well as laser system. For the methodology, it includes gathering information, planning the experiments, modification of the existing measurement system and conducting experiments of smoke, sea water, fog and diesel spray. First experiment which is comparison of both power meters with new modified circuit that afterwards was proved reliable due to increment of voltage value. It will be continued by experiment with smoke. This experiment was conducted to quantify the extinction coefficient of smoke. The laser beam was incident to a Perspex container containing sea water and fresh water for third experiment which concern with absorbance value. The sea water has greater absorbance compared to fresh water as the voltage recorded is much lower. Next was experiment to study the scattering effect of fog. Last but not least was the experiment with diesel spray where the diesel atomization was introduced within the measurement system in order to quantify the number density. As the pressure of diesel was increased, more particles will absorb the laser beam due to higher angle of spray.

ACKNOWLEDGEMENTS

Alhamdulillah, praise to Allah and thanks to Him for giving me the strength and health to complete this final report successfully on time upon completing my Final Year Project.

First and foremost, my deepest appreciation goes to my supervisor, Ir. Dr. Shaharin Anwar Sulaiman for giving me opportunity to conduct a project under his supervision. His encouragement, guidance and support from the initial to the final level of this final year project enabled me to develop an understanding of almost everything.

Furthermore, I would like to show my gratitude to all the technicians from Mechanical Engineering Department especially Mr. Khairul Anwar Hj Ahmad and Mr. Jani Alang Ahmad for helping me undoubtedly with experimental session as well as improving the measurement system. They have given me valuable ideas, sharing their knowledge and sacrificing their time in order to help me. I also owe my deepest gratitude to Mr. Mohamad Yasin Baharudin, Mrs. Siti Hawa Tahir, Mrs. Noorsyawaliza Idris, and Mr. Isnani Alias, the technicians from Electrical and Electronic Department. They have made available their support in a number of ways, keeping me on the right track and offering kind of encouragement upon completing power meter printed circuit board as well as construction of laser system. Last but not least, special thanks to my parent for their love and endless supports. Thank you.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

FYP	Final Year Project
LDA	Laser Doppler Anemometry
LDR	Light Dependent Resistor
PDA	Phase Doppler Anemometry

NOMENCLATURES

A	Absorbance
D_{20}	Average diameter of droplets (μm)
C	Concentration (moles/cm^3)
σ_e	Extinction cross section (cm^2)
I	Intensity
L	Length of container (cm)
ε	Molar absorptivity (cm^2/mol)
$\overline{Q}_e$	Mean extinction efficiency
N_d	Number density (droplets/cm^3)
T	Transmittance
V	Voltage

CHAPTER 1
INTRODUCTION

1.1 Background of the study

Quantification of properties of suspended particles and droplets are significant due to important role in various technical applications. For example, the over-high concentration and over-large size of particles in the gas will damage or erode the blades of exhaust turbines. Moreover, they have been used in reducing the environmental effects of spray painting by measuring size and velocity of droplets, studying the complex flows around ships, bridges and offshore structures, to study flows inside engines and obtaining important data on the fuel injection to improve the fuel efficiency.

Suspended particles can be classified as solid and liquid types. The sizes of the particles are characterized by five terminologies which are colloidal, dust, fine, average and coarse. For determination of the properties of suspended particles and droplets, various techniques have been developed such as Phase Doppler Anemometer for quantifying the size and concentration of suspended particles as well as Particle Image Velocimetry (PIV) and Laser Doppler Anemometry (LDA) for quantifying the velocity of the suspended particles. Figure 1.1 shows measurement of velocity and size of individual droplet passing through a small measurement volume by Phase Doppler Anemometry (PDA).

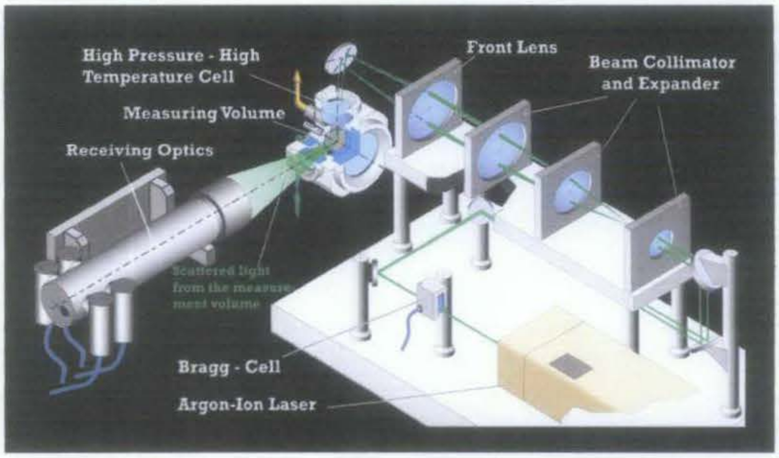

Figure 1.1: Measurement of velocity and size of individual droplets passing through a small measurement volume by PDA (Graycom, 2008)

Examples of the devices available in the market are Automated Parenteral Sampling System, APSS-200 for USP 788 (Particle Counter for Injectibles), Malvern Spraytec, Phase Doppler Particle Analyzer (PDPA) and Interferometric Laser Imaging Droplet Sizer (ILIDS).

In the present work, a technique based on the laser attenuation is experimented for quantifying the properties of suspended particles and droplets. Laser attenuation is also known as the light extinction technique. The laser attenuation technique measures the reduced or attenuated light intensity of a laser beam due to its passage through a specific fluid medium. As the laser passes through the droplet clouds, it is partially absorbed by the droplets, resulting in a lower light intensity. The results are presented in terms of light attenuation, which also implies the amount of droplets in the system. By using multiple lenses and light power meters that are mounted at various locations, the spatial distribution of light intensities that pass through droplet clouds could be measured. The reasons of using laser attenuation are because of it safe, reliable, and flexible and it utilizes the good properties of laser beam such monochromatic, coherent and highly-directional. Besides, the setting of the laser attenuation system is simple and low in costs. Figure 1.2 shows example of experimental set-up for light extinction measurements.

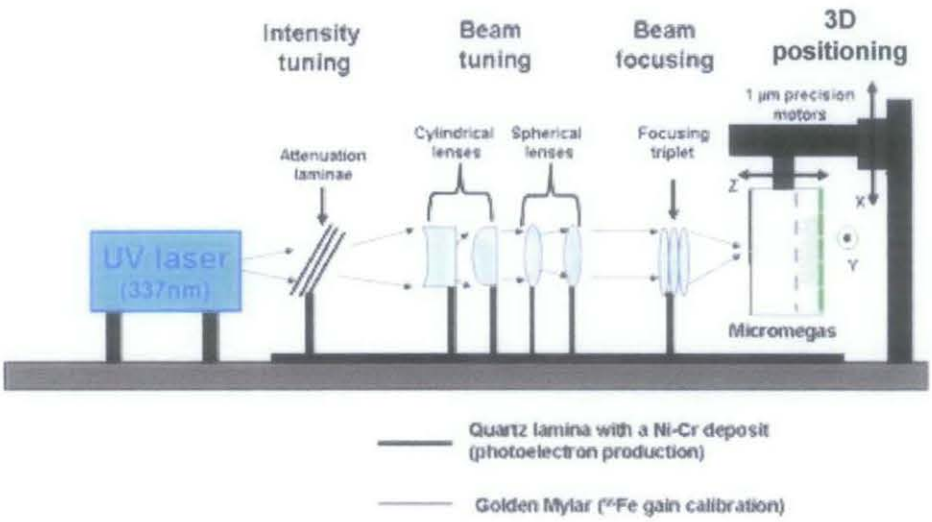

Figure 1.2: Example of experimental set-up for light extinction measurements

(Institut de Physique Nucléaire d'Orsay, 2003)

1.2 Problem Statement

The study about quantifying the properties of suspended particles and droplets by using laser attenuation measurement system with reference to Beer Lambert's law is broadly done. The laser attenuation technique works based on the principal that droplets absorb light and that the greater is the number of droplets the more will be the light absorbed. In other words, light intensity of a laser beam is reduced after passing through a specific fluid medium. Basically, a system that applies laser attenuation to quantify suspended particles has been developed in the past research work and several experiments have been conducted with the system. However, to have a deeper study on suspended particles, several experiments have been added by using different specimens.

1.3 Objectives

The objectives of this project are to study experimentally the properties of various specimens as well as to improve power meter system and laser system. The study includes absorbance effect of droplet, quantifying number density and scattering effect. Analysis of the results will be done as it will show performance and the reliability of the system. These performance and reliability could be measured by testing and calibrating, thus, it is important to have them in the project. By improving the measurement system, the efficiency of the system would also be increased.

1.4 Scope of Study

The scope of the study includes researching, improving, modifying, testing and calibrating as well as analyzing. Analysis is needed in every project so that the results of the project could be understood well. Further testing must be done in order to improve the efficiency of the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Principle of operation

The laser attenuation technique is defined as a measurement of reduction or attenuation of light intensity of a laser beam due to its passage through a specific medium. This technique has been long established mainly to measure properties of particles by using Beer-Lambert law (Bachalo et al., 1991).

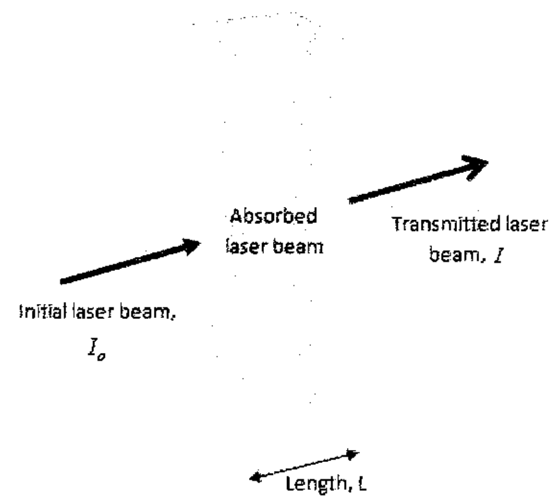

Figure 2.1: The basic process of laser attenuation

Figure 2.1 shows the basic process of laser attenuation. When a body is crossed by a radiation beam, an amount of the incident flux Φ_i is reflected at the entrance and exit surfaces while another amount of Φ_i is absorbed and the remainder is transmitted. The reflected flux is denoted by Φ_r while absorbed flux and transmitted flux are denoted by Φ_a and Φ_t respectively.

For determination of the number density, (N_D), a classical Beer-Lambert equation is used in the experiment:

$$\frac{I}{I_o} = \exp(-N_d \sigma_e L) \tag{2.1}$$

where I_o and I are the light intensities detected by the power meter before and during the expansion process, N_d is the droplet number density, L is the length and σ_e is the extinction cross section for visible frequencies. Bachalo et al (1991) defined the extinction cross section as:

$$\sigma_e = \frac{\Pi}{4} \overline{Q}_e D_{20}^2 \tag{2.2}$$

where $\overline{Q}_e$ is the mean extinction efficiency and they used $\overline{Q}_e = 2$ for the particles of D_{20} between 5 to 50 microns. The equation of $A = \Phi_a / \Phi_i$ gives the information on the extinction of the body or the absorption factor if the absorption is a predominant phenomenon Φ_r, Φ_a and Φ_t are proportional to Φ_i.

As for comparison purpose, an input-output calibration by using asorptive neutral density filters of known attenuation was conducted by Ismail (2010). Based on the calibration curve shown in Figure 2.2, curve from Ismail's calibration intercepts the x-axis at zero value compared to curve from Marquez (2003) that intercept at a value greater than zero. Thus, shows that calibration done by Ismail (2010) was better in accuracy than the calibration done by Marquez. The equations which denotes the result is:

$$I/I_0 = \frac{V/V_0}{1.76} \tag{2.3}$$

The droplet number density N_d can be calculated by using this equation:

$$N_d = \frac{\ln(I/I_o)}{\sigma_e L} \quad (2.4)$$

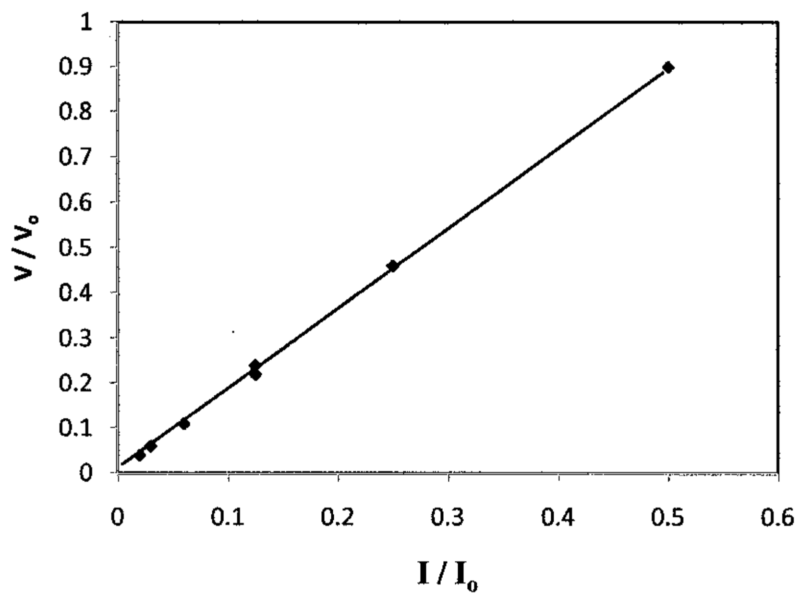

Figure 2.2: Calibration curve for laser power meter, using neutral density filters of known level of transmittance and approximation of Ismail's curve

2.2 Smoke

Smoke is a colloid and comprises a collection of airborne solid and liquid particulates and gases emitted when a material undergoes combustion or pyrolysis, together with the quantity of air that is entrained or otherwise mixed into the mass. Smoke particles are an aerosol (or mist) of solid particles and liquid droplets that are close to the ideal range of sizes for Mie scattering of visible light.

Smoke particulates have three modes of particle size distribution:

- nuclei mode, with geometric mean radius between 2.5–20 nm, likely forming by condensation of carbon moieties
- accumulation mode, ranging between 75–250 nm and formed by coagulation of nuclei mode particles
- coarse mode, with particles in micrometer range

For this project, the smoke will be generated from the smoke generator available in the laboratory and will be filled into a container made of perspex and then a beam of laser will be incident to the smoke. Before turning on the laser, the smoke is left for several minutes to fill the container evenly. Then, the transmitted laser beam will be detected by the light dependent resistor (LDR).

2.3 Fog

Disability glare affecting road safety at night may result either from intraocular light scattering or from external conditions such as fog. Fog is defined as a water droplet density that restricts the visibility to less than 1km. Fog forms when the difference between temperature and dew point is generally less than 2.5 °C or 4 °F. It begins to form when water vapor condenses into tiny liquid water droplets in the air.

The knowledge of fog droplet concentration, size distribution, and nature of aerosol particles interacting with droplets is essential for realistic modeling of fog evolution, for investigation of visibility, and for the study of radioactive energy transfer. Besides, fog attenuation also may cause to the disturbance of radio wave of satellite communications.

Fog is characterized as advection fog and radiation fog where advection fog is caused by a horizontal movement of a warm air mass over cold water and radiation fog is caused by the cooling of air overnight. Below are the properties of both types of fog:

Table 2.1: Fog characteristics

	Radiation Fog	**Advection Fog**
Average Drop Diameter (μm)	10	20
Typical Drop Size Range (μm)	5-35	7-65
Liquid water Content (g/m^3)	0.11	0.17
Droplet Concentration (/cm3)	200	40
Visibility (m)	100	200

2.4 Attenuation

Attenuation is a general term that refers to any reduction in the strength of a signal where energy is loss as it travels. Being refer as extinction as well, it can be expressed as change in intensity of any kind of flux through a medium.

Basically, attenuation is a natural consequence of signal transmission over long distances. The extent of attenuation is usually expressed in units called decibels (dBs). In many cases, attenuation is an exponential function of the path length through the medium which is known as the Beer-Lambert law. (Wikipedia, 2011)

Furthermore, attenuation can also be expressed in terms of voltage. If A_v is the voltage attenuation in decibels, V_s is the source signal voltage, and V_d is the destination signal voltage, then:

$$A_v = 20 \log_{10}(V_s/V_d) \tag{2.5}$$

2.5 Attenuation Coefficient

The absorption coefficient determines degree of a material light of a particular wavelength can penetrate before it is absorbed. A large absorption coefficient means that the beam is highly absorbed as it passes through the medium, and if the material is thin enough, it will appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. The absorption coefficient, α, is related to the extinction coefficient, k, by the following formula where λ is the wavelength:

$$\alpha = 4\,\pi\, k/\,\lambda \tag{2.6}$$

In general, the absorption coefficient is also called attenuation coefficient. However, in certain situations they are distinguished where absorption coefficient measures how quickly the beam would lose intensity due to the absorption alone, while attenuation coefficient measures the total loss of narrow-beam intensity, including scattering as well (Wikipedia, 2011).

2.6 Sources of attenuation

The attenuation that results from the interaction between penetrating radiation and matter is a complex process. A single interaction event between a primary x-ray photon and a particle of matter does not usually result in the photon changing to some other form of energy and effectively disappearing. Several interaction events are usually involved and the total attenuation is the sum of the attenuation due to different types of interactions. These interactions include the photoelectric effect, scattering, and pair production.

2.6.1 Photoelectric effect (PE)

Absorption of x-rays occurs when the x-ray photon is absorbed, resulting in the ejection of electrons from the outer shell of the atom, and hence the ionization of the atom. Subsequently, the ionized atom returns to the neutral state with the emission of an x-ray characteristic of the atom. Photoelectron absorption is the dominant process for x-ray absorption up to energies of about 500 KeV and for atoms of high atomic numbers. Figure 2.3 shows the interaction of incident photon.

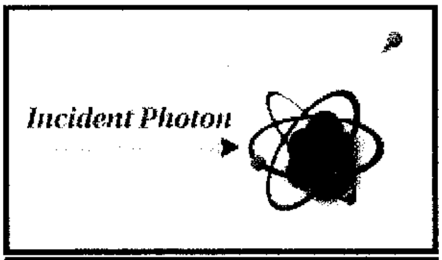

Figure 2.3: Interaction of incident photon in photoelectric effect

2.6.2 Compton scattering (C)

Compton scattering occurs when the incident x-ray photon is deflected from its original path by an interaction with an electron. The electron gains energy and is ejected from its orbital position. The x-ray photon loses energy due to the interaction but continues to travel through the material along an altered path. Based on Planck relationship, when the scattered x-ray photon has less energy, it has a lower frequency and longer wavelength than the incident photon.

The event is also known as incoherent scattering because the photon energy change resulting from an interaction is not always orderly and consistent. The energy shift depends on the angle of scattering and not on the nature of the scattering medium. Figure 2.4 shows interaction of incident photon in Compton scattering.

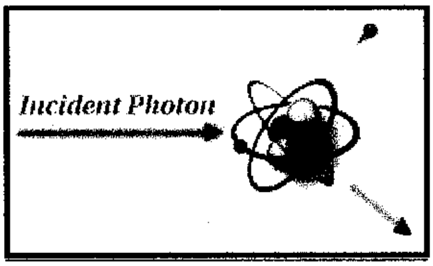

Figure 2.4: Interaction of incident photon in Compton scattering

2.6.3 Pair production (PP)

Pair production can occur when the x-ray photon energy is greater than 1.02 MeV, but only becomes significant at energies around 10 MeV. It occurs when an electron and positron are created with the annihilation of the x-ray photon. Positrons are very short lived and disappear (positron annihilation) with the formation of two photons of 0.51 MeV energy. Pair production is of particular importance when high-energy photons pass through materials of a high atomic number. Figure 2.5 shows the incident photon in pair production process.

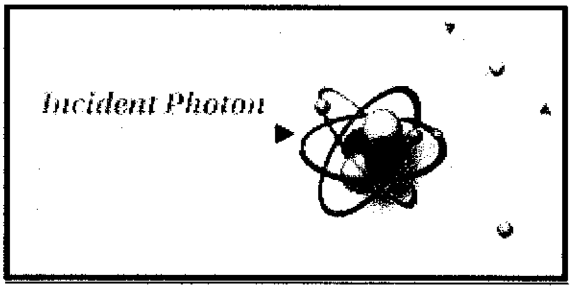

Figure 2.5: Incident photon in pair production

2.7 Light Scattering

Light scattering can be defined as the deflection of a ray from a straight path, where it is forced to deviate from a straight trajectory by non-uniformities in the medium. For example, irregularities in the propagation medium, particles, or in the interface between two media that causes light to scatter.

When these irregularities such as particles, bubbles, and droplets are considered to be random and dense enough that their individual effects average out, this kind of scattered reflection is commonly referred to as diffuse reflection. For non-scattered reflections, they are called specular (mirror-like) reflections. Figure 2.6 shows mechanism of diffuse reflection including surface scattering from roughness and subsurface scattering from internal irregularities.

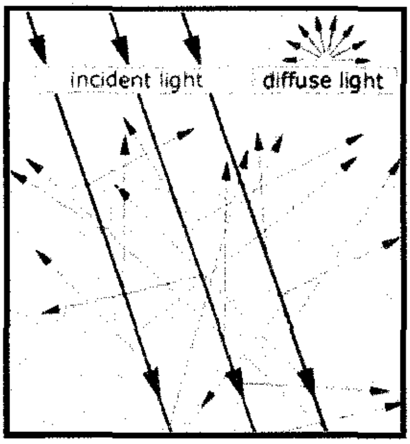

Figure 2.6: Mechanisms of diffuse reflection

Basically, light scattering has been used to measure thermal properties of liquids and solids ever since Einstein showed that the intensity of light scattered by density fluctuations is proportional to the isothermal compressibility of the fluid. This theory provides the connection between the spectrum of the scattered light and various thermodynamic and transport properties of the fluid (Mountain, 1966).

Moreover, scattering of light by small water droplets in fogs and clouds has been studied extensively for many years. It is well established that the scattering of light from conventional sources can be described with independent Mie scattering theory (Reisman, 1967).

2.8 Types of light scattering

Formal light scattering theory may be categorized in terms of two theoretical frameworks. One is the theory of Rayleigh scattering that is strictly speaking as originally formulated, applicable to small, dielectric (non-absorbing), spherical particles. The second is the theory of Mie scattering that encompasses the general spherical scattering solution, absorbing or non-absorbing without a particular bound on particle size (Hahn, 2009).

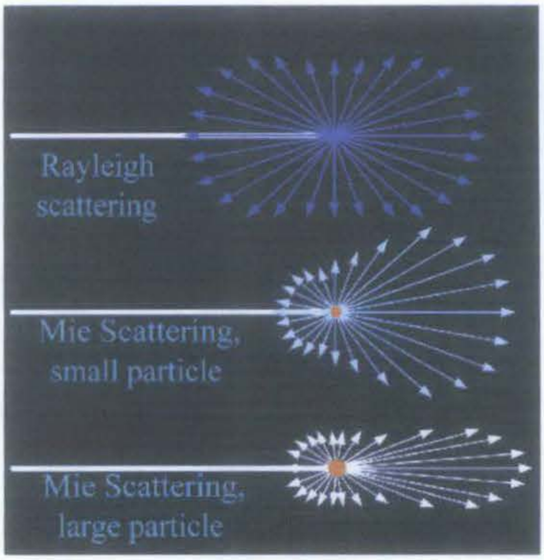

Figure 2.7: Modes of light scattering

2.8.1 Rayleigh scattering

Rayleigh is elastic scattering from small particles such as atoms or molecules, resulting in scattered radiation that occurs in all directions uniformly. It occurs when light penetrates gaseous, liquid, or solid phases of matter and its intensity has a very strong dependence on the size of the particles. Rayleigh scattering is also a wavelength dependent with shorter wavelengths being more scattered. This type of scattering is therefore responsible for the blue color of the sky during the day and the orange colors during sunrise and sunset.

2.8.2 Mie scattering

Mie scattering is a broad class of scattering of light by spherical particles of any diameter. It is an elastic scattering mechanism which occurs from relatively large particles or molecules with dimensions comparable with the wavelength of the incident radiation or larger and the resulting scattered radiation is non-uniform. The effect is not very wavelength dependent. This process gives rise to the white scattered light seen in clouds or fog.

2.9 Phase Doppler Anemometry

Particle Dynamics Analysis (PDA) is an optical technique to measure the size and velocity of spherical particles simultaneously. These particles can be droplets, bubbles or solid particles and liquid atomization. This method is based upon the principles of light scattering interferometer. It requires no calibration because the measured particle size and velocity are dependent only on the laser wavelength and optical configuration. Basically, scattered light from a particle moving through the probe volume is picked up by a receiving lens strategically located at an off-axis collection angle. This light is split and a portion is projected onto several detectors. Each detector produces a Doppler burst signal with a frequency proportional to the particle velocity. The phase shift between the Doppler burst signals from the different detectors is proportional to the size of the spherical particles. Figure 2.8 shows the optical setup of a PDA.

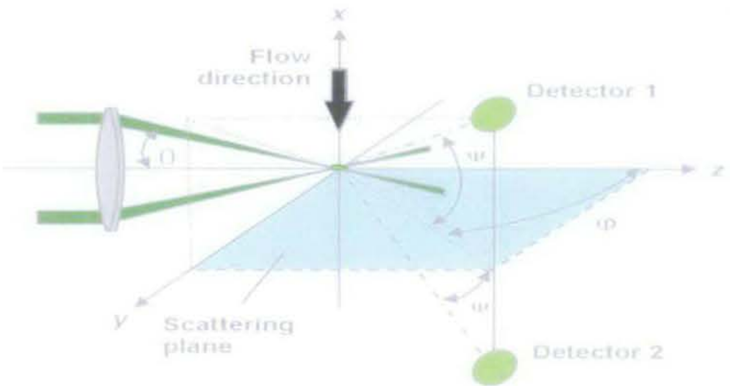

Figure 2.8: Optical setup of a PDA

PDA technique is an extension of laser Doppler anemometry. The measurements of phase Doppler anemometer are introduced to analyze instantaneous patterns of droplets velocity size and number density into fuel spray. Basic mechanisms on fuel spray or in more general, liquid atomization are extensively subjected to numerous investigations in the parts of fundamental theory by Edwards (1997), experimental verification techniques and application aspects by Hiroyasu (1985).

Figure 2.9 shows the spray flow visualization and figure 2.10 optical set up for PDA system based on the Aerometrics Phase Doppler Particles Anemometry.

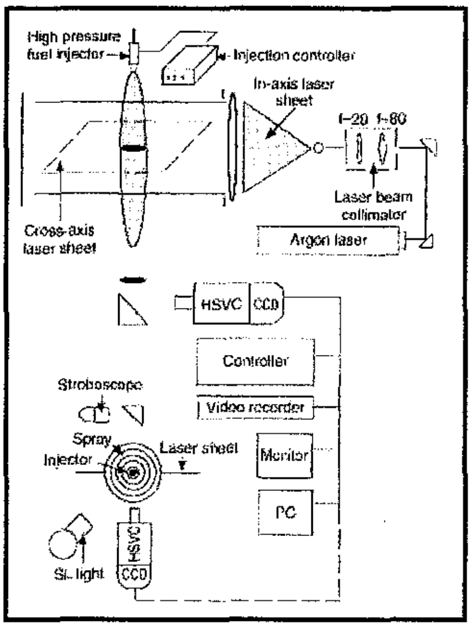

Figure 2.9: Spray flow visualization

Laser wavelength	0.6238 μm
Laser beam diameter (1/e)	0.68 mm
Focal length of collimating lens	160 mm
Focal length of transmitting lens	495 mm
Beam separation	12.6 mm
Intersection beam waist	330 μm
Fringe spacing	24.9 μm
Nominal fringe count	13
Maximum velocity	200 m/s
Off-axis receiving angle	30°
Focal length of receiving lens	495 mm
Theoretical droplet size spans (min)	1.9 μm
Theoretical droplet size spans (max)	276.1 μm

Figure 2.10: Optical setup for PDA system

2.10 Helium Neon Laser

A helium–neon laser or HeNe laser, is a type of gas laser whose gain medium consists of a mixture of helium and neon inside of a small bore capillary tube, usually excited by a DC electrical discharge. The mixture of helium and neon is in proportions of between 5:1 and 14:1, respectively.

The collimation of the beam is accomplished by mirrors on each end of the evacuated glass tube which contains about 85% helium and 15% neon gas at 1/300 atmospheres pressure (Metrologic). These mirrors could be both flat, but this requires great precision in alignment, so the common laboratory He-Ne lasers are manufactured with the semiconfocal mirror arrangement shown in Figure 2.11. The power supply needed is 10kV to start laser emission and 1-2kV to maintain it.

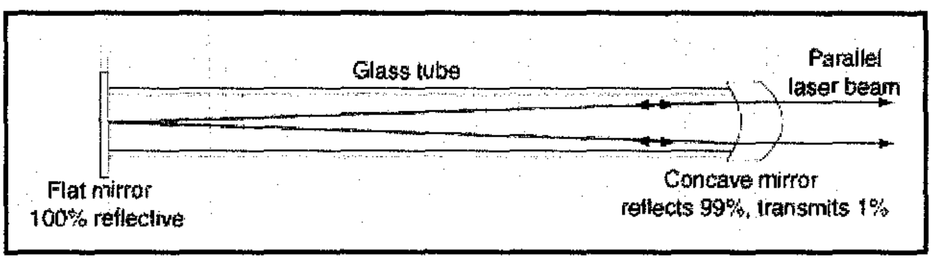

Figure 2.11: Lasers with the semiconfocal mirror arrangement

2.11 The laser principal

There are three basic interaction process of light with matter that are important for the laser; absorption, stimulated emission, and spontaneous emission. Assuming that two states, of energies E_1 and E_2, take part in the interaction, absorption is when a photon of energy hv strikes an atom of the laser medium in the state E_1 and disappears, exciting the atom to the higher state E_2. The photon can only be absorbed, if the absorption energy is hv E_2 E_1. When no suitable energy level is available, no absorption takes place, and the medium is transparent for photons of this energy.

In stimulated emission when the atomic system has absorbed the energy hv and thus the upper level is occupied, a second photon of energy hv may cause this energy to be emitted as a photon. Then two photons having identical properties leave the atom. Upon absorption, the atomic system starts from the state of lower energy, upon stimulated emission it starts from the state of higher energy. The transmission probability is equal for both processes.

In spontaneous emission the atomic system in the state of higher energy, E_2, decays into a state of lower energy, E_1, by the emission of a photon. The frequency is given by

$$v = \frac{E_2 - E_1}{h} \tag{2.7}$$

where E_1 is energy level 1, also called ground level, E_2 is energy level 2 or excited level, h is Planck constant and v is frequency. Figure 2.12 shows the depletion of spontaneous emission.

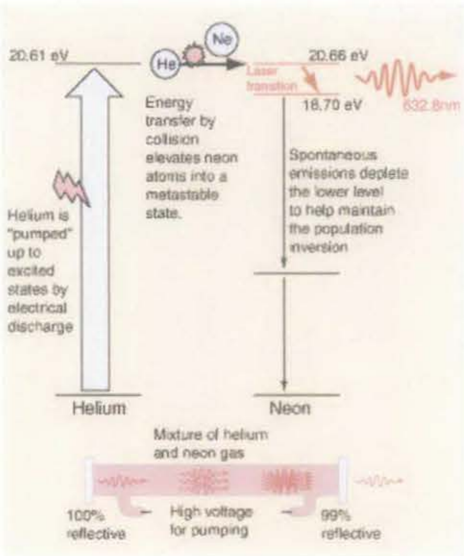

Figure 2.12: Depletion of spontaneous emission

2.12 Properties of green laser

In this project, a green laser was used. Basically, there are various different colours of laser beam. The colours of laser beam depend on the wavelength of the laser. For green laser, it emits light with a wavelength in the green spectral region from 495nm to 570nm. The typical wavelength for green lasers is 532nm which is the wavelength of the laser that has been used in this project. The colour of the beam is basically emerald green. Figure 2.13 shows the colours of laser beam based on wavelength.

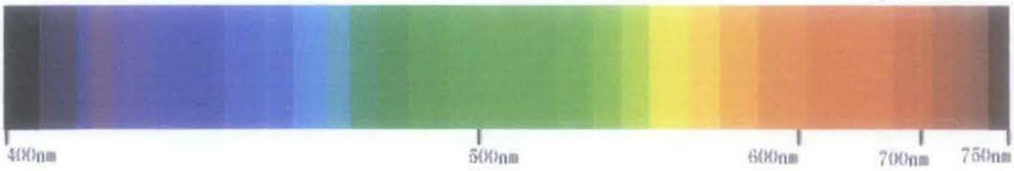

Figure 2.13: Laser colours based on wavelength

Besides, in comparing with red lasers, the green lasers have better beam visibility which can appear to be roughly 50 times brighter than red lasers. The human eye is most sensitive to light with a wavelength of approximately 555nm (yellow/green) which makes green lasers much more visible than red lasers.

Furthermore, construction of green lasers is quite complex due to no green laser diodes that can be used. Instead, an infrared with 808nm diode is used with a combination of special crystals and a filter to produce green laser light. Figure 2.14 shows the construction of lasers.

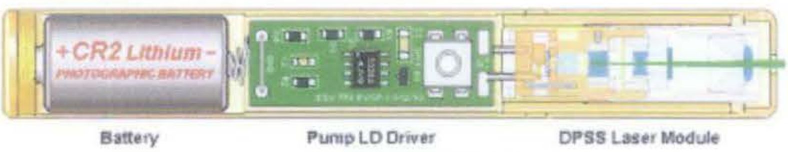

Figure 2.14: Lasers construction

CHAPTER 3
METHODOLOGY

3.1 Methodology

The study of suspended droplets by laser attenuation system will be conducted based on this methodology accordingly to meet the objective of the project. The project will be started by understanding the law that applied to this project which is Beer Lambert Law. In the mean time, information as well as research about the project will be gathered and understood. Then, lab introduction briefing of Laser Doppler Anemometry and Particle Dynamics Analysis (LDA/PDA) will be attended. The purpose of Laser Doppler Anemometry and Particle Dynamics Analysis (LDA/PDA) measurement system is to quantify droplet size that is to determine the value of D_{20}.

The step continues with planning of improving the laser attenuation measurement system. From the re-assembly of the laser attenuation measurement system, power meter circuit could be improved by replacing current standard circuit to printed circuit board (PCB). There are many advantages of PCB. For instance, the location of electronic parts is fixed and so it simplifies components identification and maintenance of equipment as well as chances of miswiring or short-circuited wiring are minimized. The new construction of the circuit is done with the help from the technician of electrical and electronic department. The construction is only started once the film of the printed circuit board is finished and the circuit has been successfully tested in bread board.

Then, the design of new laser system will be done. The purpose of this design is to ease the process of conducting the experiments by adding switch in the system. Thus, the laser will no longer have to be held manually all the time during experiment which slightly affects the voltage reading. The materials that have been used are including a small portion of platinum, wires and toggle switch.

Next is conducting the experiments. However some research, plans on designing the experiments as well as material purchasing should be done before the experiments could be conducted. Once finished, the experiments on testing the functionality of power meters were conducted. It is followed by another four experiments which were quantification of extinction coefficient of smoke, absorbance of sea water, scattering effect of fog and last but not least quantification of number density of diesel spray.

Experiment with smoke was done in laboratory due to the needs of smoke generator. Once smoke was generated, it was left for few minutes before the laser beam was incident through the smoke. The average voltage was obtained based on different interval. Next was the experiment to compare the absorbance of sea water with fresh water. Seawater is denser than both fresh water and pure water (density 1.0 g/ml @ 4 °C (39 °F)) because the dissolved salts add mass without contributing significantly to the volume. On average, seawater in the world's oceans has a salinity of about 3.5% (35 g/L, or 599 mM). The average density of seawater at the ocean surface is 1.025 g/ml. For this project, laser beam will be transmitted through the water and the average voltage is then recorded by the power meter. Both types of waters is used at the same volume.

The scattering effect of fog was studied through the third experiment. There were two types of fog which were radiation fog and advection fog. In this experiment, advection fog is considered as it is nonintrusive, temporally resolved, and convenient to implement. Besides, the way to make this type of fog is easier where a very hot water is filled up in the glass about 60 second before being poured out all but an inch of the hot water. A plastic bag of ice cubes is then placed on top of the glass. The hot water vapor passing over cool air produces condensation around nuclei in the air, thus producing tiny droplets that are called fog. Two power meters are used in this experiment with one power meter will be the reference for the second one. Experiments are done from the both side of the first power meter; right and left. Angle is varies maximum to the 90° from the reference power meter.

The fourth experiment was to quantify the density number of diesel spray based on pressure difference as well as to study on the scattering effect. Basically, diesel spray flow fields are particularly difficult to measure quantitatively. The flow contains numerous spray droplets, which obstruct the passage of visible light through the spray. The droplets can also scatter incoming light in multiple directions, confounding diagnostics which rely on scattered light. In this project, the diesel was sprayed through the nozzle at different pressure, then the laser source is turned on and voltage reading in power meter is taken. LDA/PDA was used to measure the diameter of droplet.

After finished conducting the experiments, the result will be analyzed and if the results obtained are not as expected or incorrect, thus the tests need to be redone and certain parameters need to be corrected. Figure 3.1 shows the flow chart of methodology while Figures 3.2 and 3.3 show the project activities for the two semesters.

Figure 3.1 is the simplified methodology which has been explained earlier while Figure 3.2 shows the project activities for two semesters.

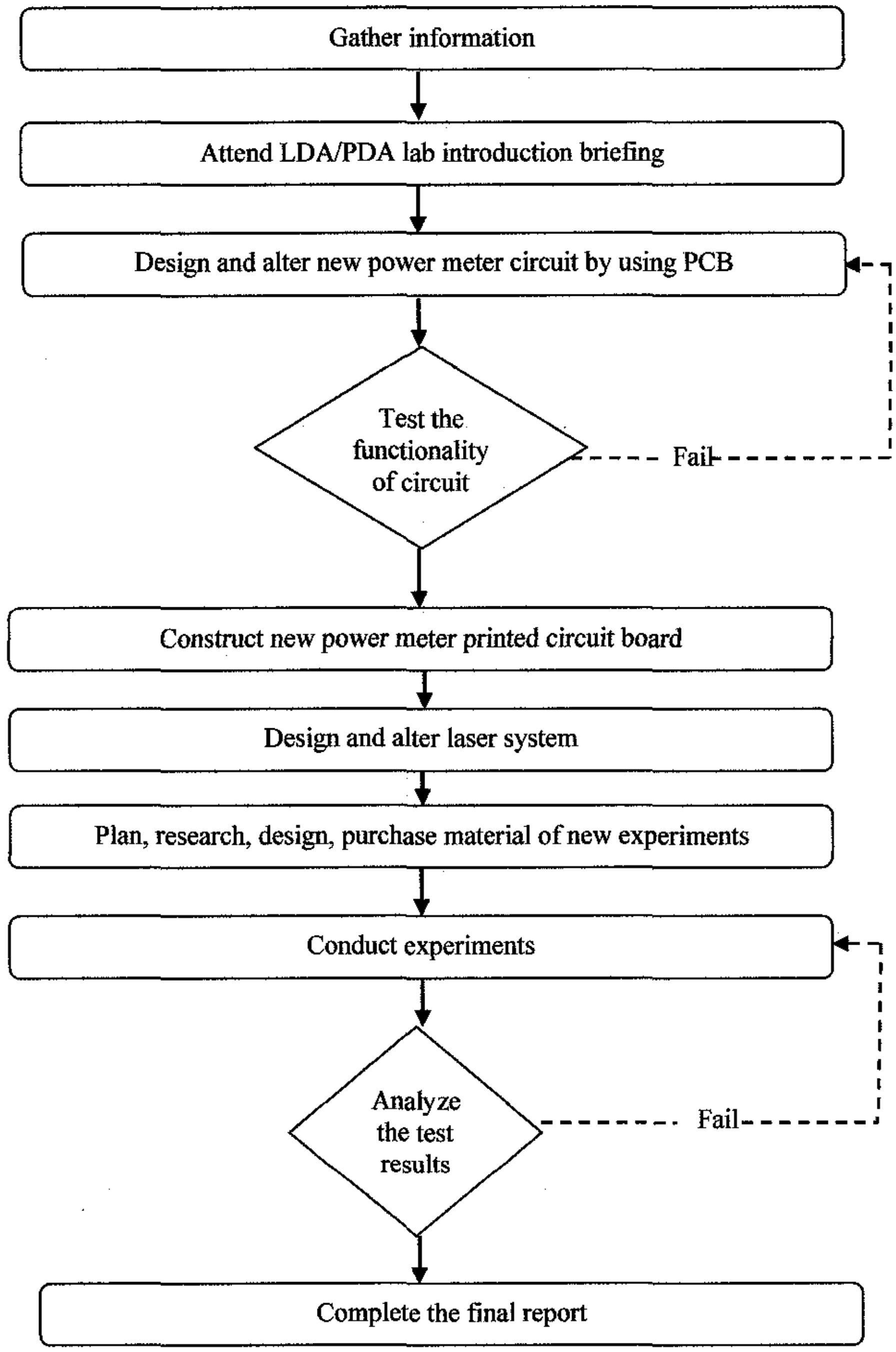

Figure 3.1: The flow chart of methodology

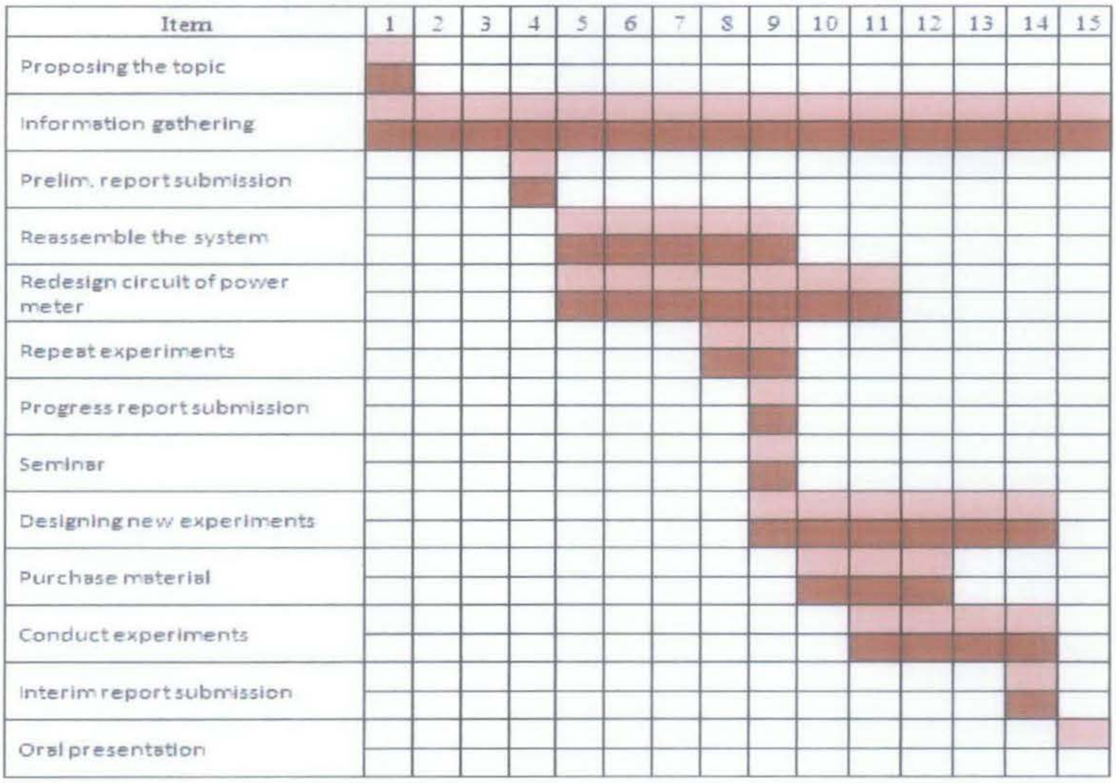

Figure 3.2: Gantt chart for FYP 1

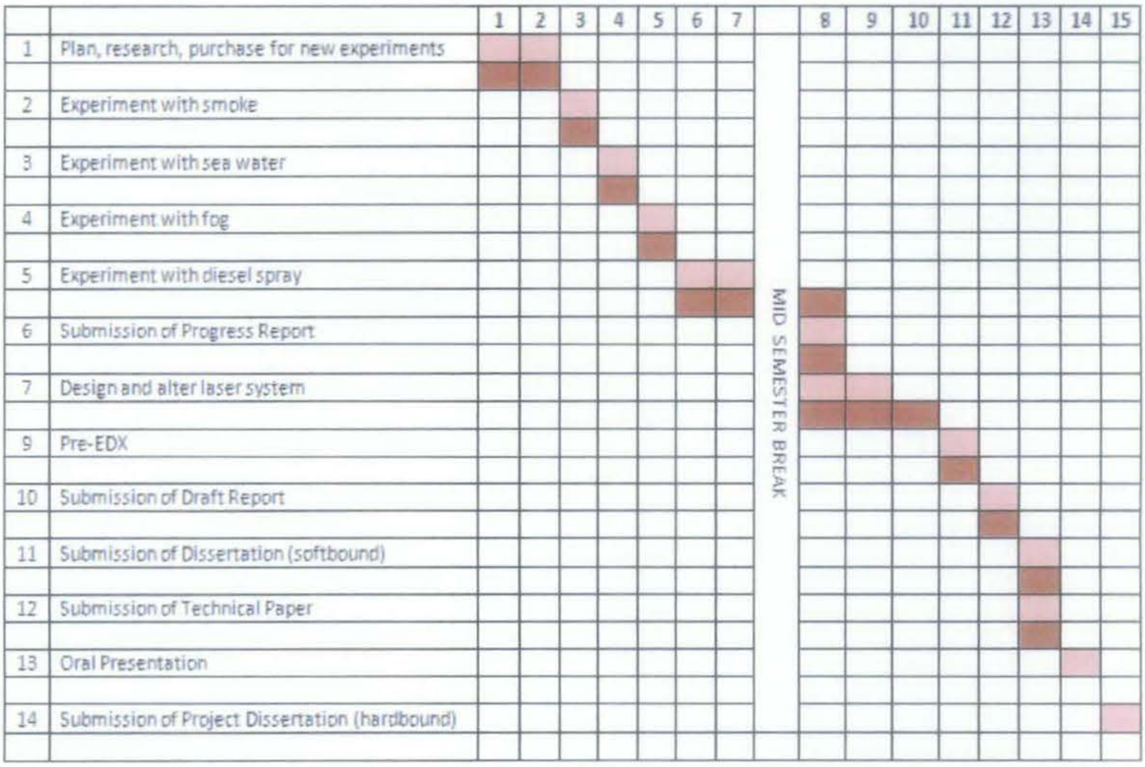

Figure 3.3: Gantt chart for FYP 2

3.2 Construction of a laser system

Green laser pointer is used for this measurement system. In order to ease the experiment process, the laser pointer has slightly being modified. It is designed to have a toggle switch in the system which will greatly ease the process of turning on and off of the laser. Having to turn on laser manually has slightly obstructs the experiment process where the result will be a bit fluctuating due to the shaking of hand. Figure 3.4 shows the internal view of the laser source. The toggle switch is placed at the top side of the casing so that it is easier to switch on the laser.

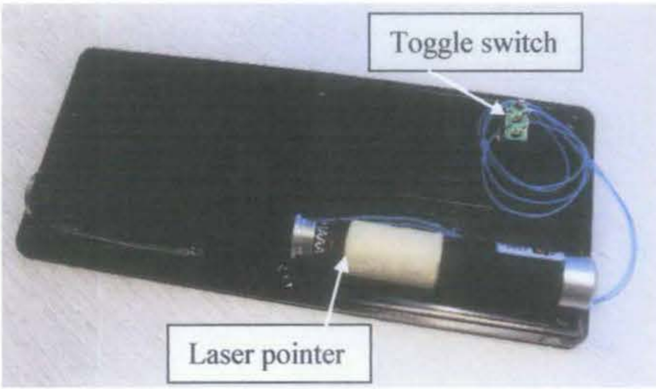

Figure 3.4: Internal view of laser system

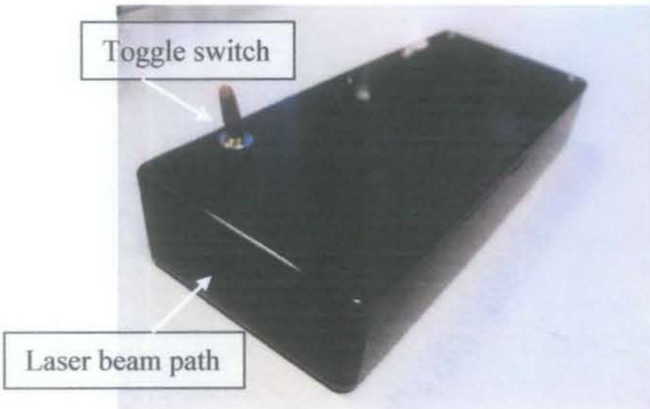

Figure 3.5: External view of laser system

Figure 3.5 shows the outer view of the laser pointer. The dimension of the casing is 17 x 7 x 2.5 cm. Other than stable and light, this casing also is safe and reliable. Furthermore, a small hole was drilled at the front casing to allow the laser beam pass through it.

For the electrical part, a small piece of platinum has been used in constructing the laser system. It connects the two batteries with the switch. The platinum is firstly connected to the wire before being placed in between the batteries and connected to the toggle switch. The batteries are still being used due to no significant difference when using power supply unit. Hence, there are some difficulties in borrowing the power supply unit from the laboratory. Figure 3.6 shows the platinum that is being used in between the batteries.

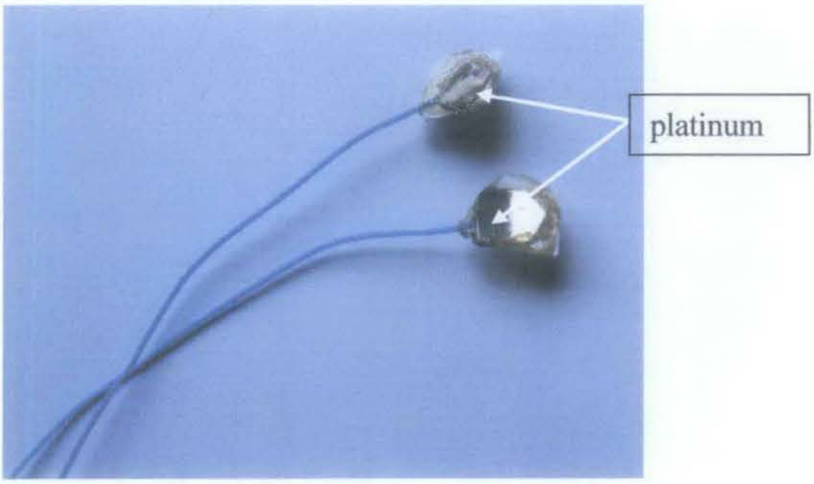

Figure 3.6: Small portion of platinum

3.3 Power meter printed circuit board

Light intensity power meter is a device that is used to record laser beam intensity and displays the reading in voltage. The available power meter circuits are function but have several weaknesses that could be improved. Basically, the power meter has several misconnections of the wires and the wires that are used also are long enough that makes the circuit untidy.

Figure 3.7: External view of power meter

Thus, in order to improve the light intensity power meter, modification has been made to the power meter circuit. Through research and consultation, printed circuit is preferred to replace the old circuit. A printed circuit board, PCB is used to mechanically support and electrically connect electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate. It has several advantages which are the circuit is more neat, inspection time is reduced because printed circuitry eliminates the probability of error and also reduce chances of misconnection of wiring.

3.3.1 Constructing power meter circuit

Power meter circuit is designed by using Easily Applicable Graphical Layout Editor, or EAGLE software. It is an easy-to-use, yet powerful tool for designing printed circuit boards. The program consists of three main modules:

- A layout editor
- A schematic editor
- An auto-router

The process of designing the circuit is quite difficult, thus, causes several times of modification to the circuit and this has causes longer time consumption.

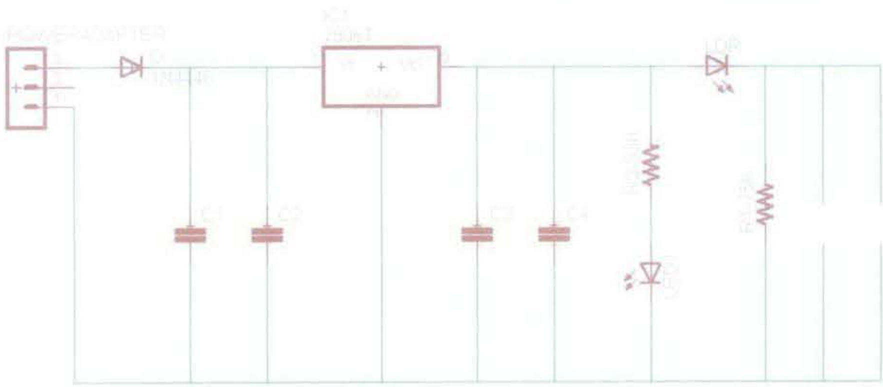

Figure 3.8: Power meter schematic diagram

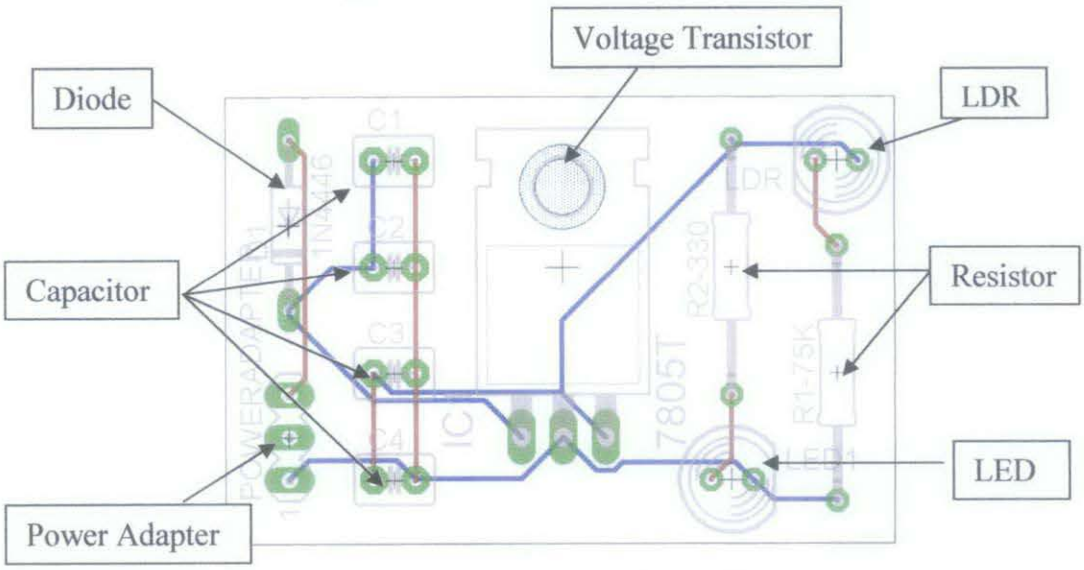

Figure 3.9: Power meter board diagram

3.3.2 Testing of power meter circuit

The next step is to test the circuit. The objectives of testing the ciruit is to test functionality of the circuit thus will also avoid from wasting the film to print the circuit. Basically, the circuit is tested on bread board. Bread board is a temporary, no soldering board. This is a way of making a temporary circuit, for testing purposes or to try out an idea. No soldering is required and all the components can be re-used afterwards. It is easy to change connections and replace components.

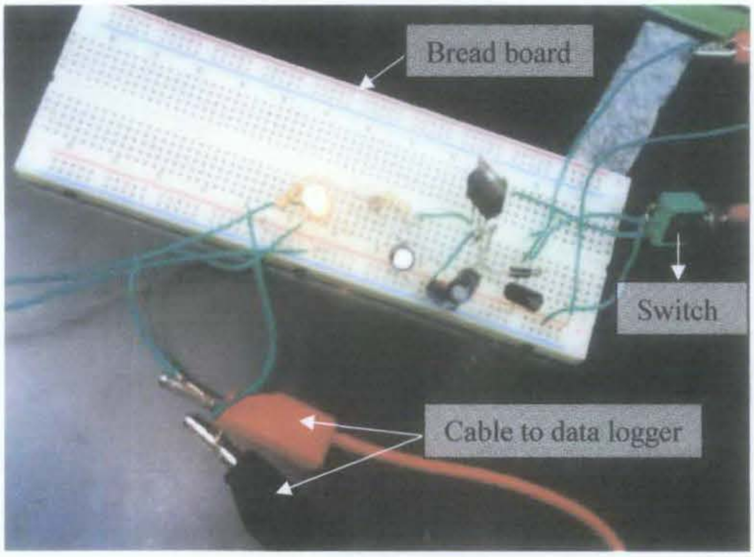

Figure 3.10: Testing on bread board

The testing starst with the arrangement of the components. The compeonents is arranged based on the available circuit. Then, the circuit is connected to the power supply available in the laboratory as well as to the data logger. The circuit is only functions after several modifications done. After complete testing, the circuit is sent to be printed out. It takes several time to print that out due to one film is for several circuits.

3.4 Components of the System

Figure 3.11 below shows the measurement system of the experiment. It is divided into four major components which are the laser, optical, measurement and base system.

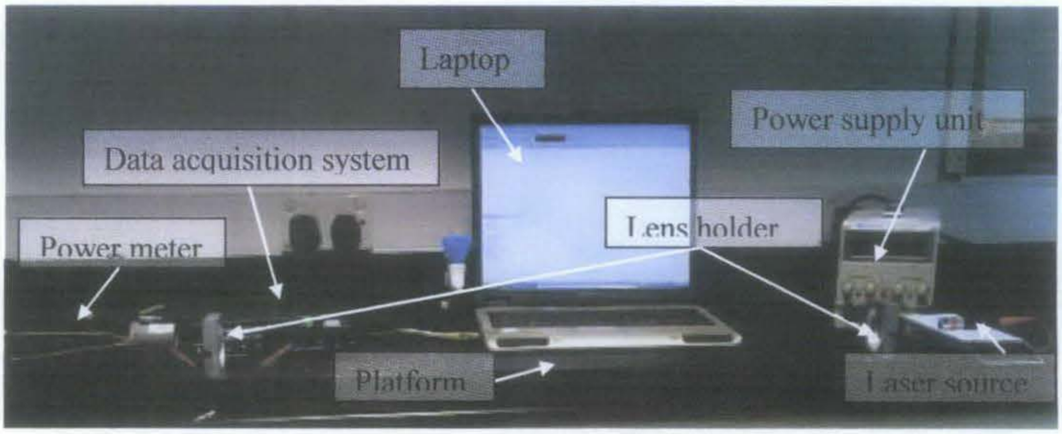

Figure 3.11: Laser measurement system

3.4.1 Laser Source

A laser pointer that is used in these experiments is a helium–neon laser or HeNe laser. It is a type of gas laser whose gain medium consists of a mixture of helium and neon inside of a small bore capillary tube, usually excited by a DC electrical discharge. This laser pointer is small, lightweight and portable. It is classified under class IIIb which having the wavelength of 532nm, maximum output power of 30 mW and operating voltage of 9V.

3.4.2 Light Intensity Power Meter

The light intensity power meter is used to record the laser beam intensity where the beam will be detected by light dependant resistor (LDR) in term of voltage reading. The main components of the power meter are the circuit, casing and digital multimeter. During this project period, the circuit has been modified from the standard electronic circuit into printed circuit board. Figure 3.13 shows the internal view of the power meter.

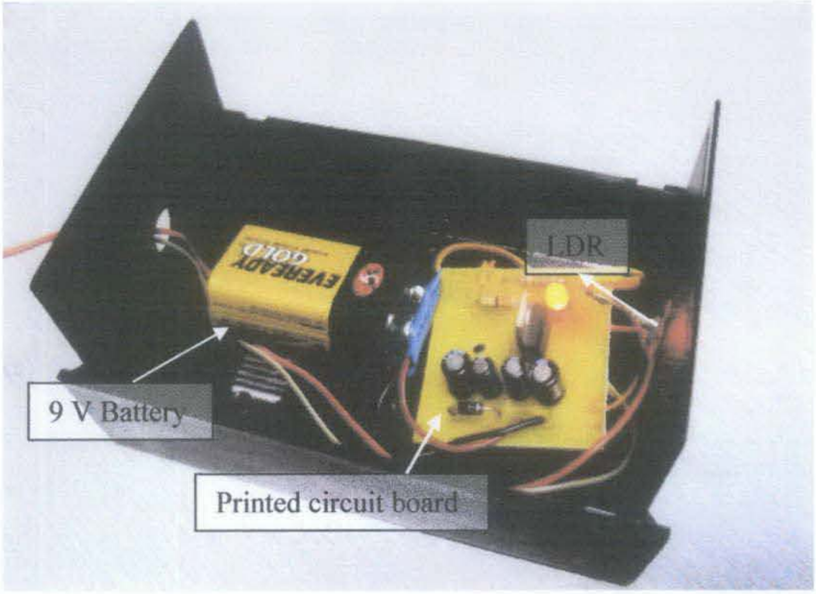

Figure 3.13: Internal view of power meter

3.4.3 Platforms

Two Aluminum U-channels from the previous FYP are used as the platforms for the measurement system. The dimension of each platform is 7.6 cm × 60.0 cm × 2.5 cm. These two platforms are able to be attached and detached to fit the various conditions of testing and also for the flexibility.

3.4.4 Lens Holders

The lens holders are already fabricated during the past FYP. There are two aluminum plates which are milled by using Computer Numerical Control (CNC) into a square plate of 60 mm × 60 mm with 15 mm thickness. A through hole of 48 mm ± 0.50 mm and 50 mm ± 0.50 mm in diameter is drilled. Figures 3.14 and 3.15 show the milled plates with two different diameters and completed lens holder while Figure 3.16 shows the 5cm diameter plano-convex lenses with the focal length of 15 cm.

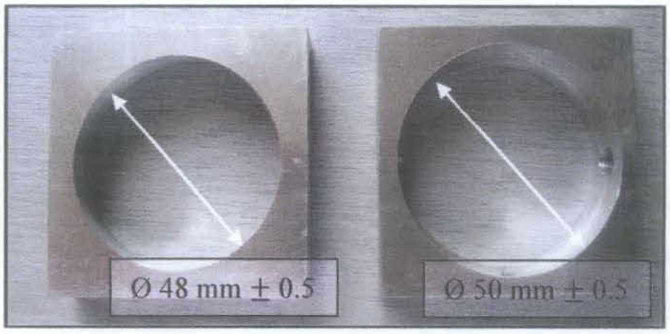

Figure 3.14: Diameter of the lens holders

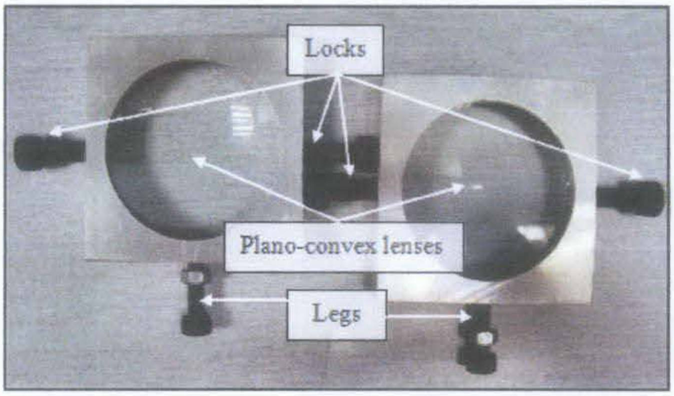

Figure 3.15: The completed lens holders with plano-convex lens

3.4.5 Data Acquisition System

Data acquisition system that has been used in this project is ScienceWorkshop 750 Interface (Model CI-7599) from Pasco as shown in Figure 3.17. This system has three different fixed gains which are 1, 10 and 100 while the sampling rates are 250 kHz, 100 kHz, 50 kHz, 20 kHz, 10 kHz and <100 Hz. By referring to the manual, it is recommended to use the setting of gain of 1 and sampling rate of 10 Hz.

Figure 3.16: ScienceWorkshop 750 Interface from Pasco

The system ScienceWorkshop 750 is used to record the data from the light intensity power meter and transfer them to the computer. It is connected to the computer by using a Universal Serial Bus (USB) cable and a voltage-sensor cable is used to connect the light intensity power meter to the analog channel. DataStudio software must be installed in the computer first before the data can be transferred in.

3.5 Measurement of droplet size using PDA system

One of the values needed in experiments with diesel spray is to calculate the number density of diesel sprays. Thus, Phase Doppler Anemometry (PDA) has been used to measure the droplet size. The droplet size, D_{20} must be measured first before determining the number density of fluid sprays.

Arrangement of the LDA/PDA systems in the lab is shown in Figure 3.18. Fluid will be sprayed through the nozzle and laser will be incident to the spray.

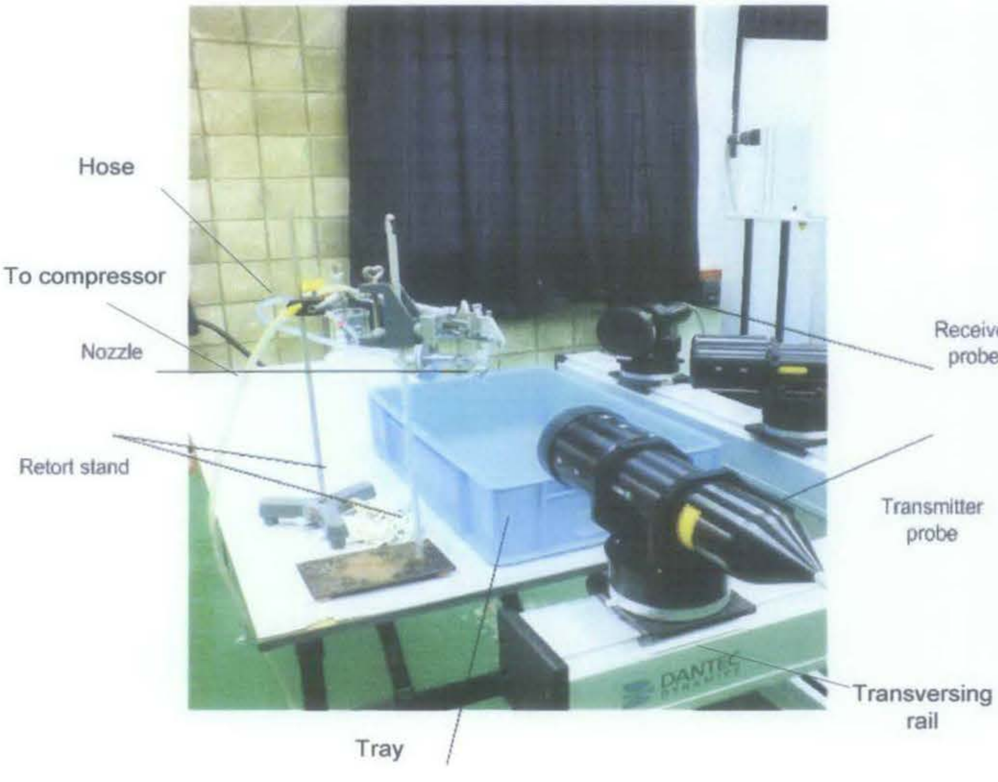

Figure 3.17: Arrangement of LDA/PDA systems in the lab

The system consists of a transmitter, a receiver, a signal processor and a computer. Laser is split by utilization of Beam Splitter and Frequency Shift Module. These two lasers intersect again at a point, which is called probe volume. When a drop passes through the probe volume, the scattered light forms an interference fringe pattern as in Figure 3.19. This is when the diameter and mean velocity of the particle is measured. (Ismail, 2010)

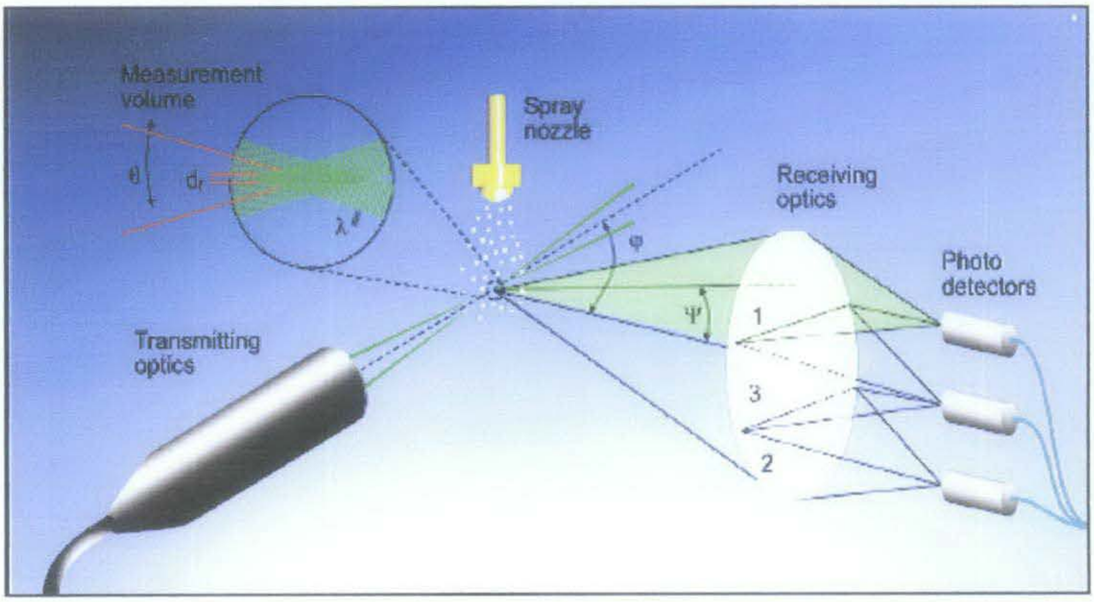

Figure 3.18: Picture showing intersection point for volume measurement (Dantec Dynamics, 2009)

RESULT AND DISCUSSION

4.1 Functionality of power meters

There are seven experiments that have been conducted throughout the project which are comparison of voltage reading of warm up period, voltage reading of both power meter as well as the effect of covering the light dependant resistor. Besides, there are also experiments to quantify extinction coefficient of smoke, determine absorptivity of sea water, and define scattering effect of fog as well as to quantify number density of diesel spray.

4.1.1 Experiment to determine warm-up period of laser source

The laser source, plano-convex lenses and power meter were aligned on the platform. The laser source then is turned on and the voltage is taken up until 20 seconds. Figure 4.1 shows comparison of warm up period for the two experiments. After 20 seconds, the power meter measured consistent light intensity of 4.951 V with standard deviation of 0.788V.

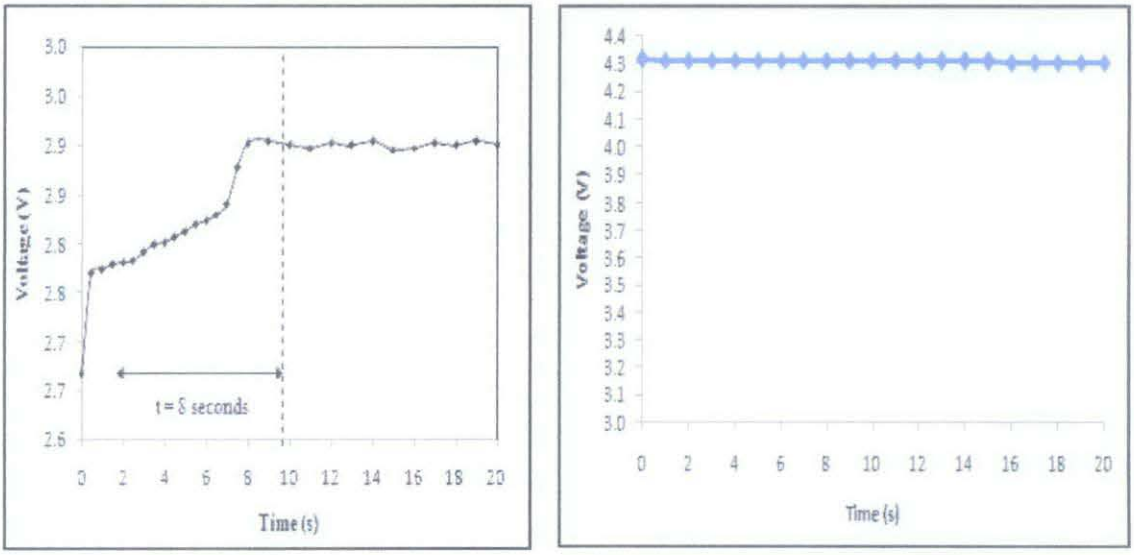

Figure 4.1: Comparison of warm up period

The graphs show apparent difference of voltage reading between current laser and old laser. The reasons might be because of the experiment has been conducted with the lights on thus affects the result as light dependent resistor is a light-sensitive device.

4.1.2 Experiment using the first and second power meter

The first power meter was aligned on the platform along with the laser source and plano-convex lenses. Voltage readings were taken when the laser source was turned off and also turned on for 60 seconds. After finish, the experiment is repeated by using second power meter. Figure 4.2 shows comparison of previous experiments compared with the new experiments.

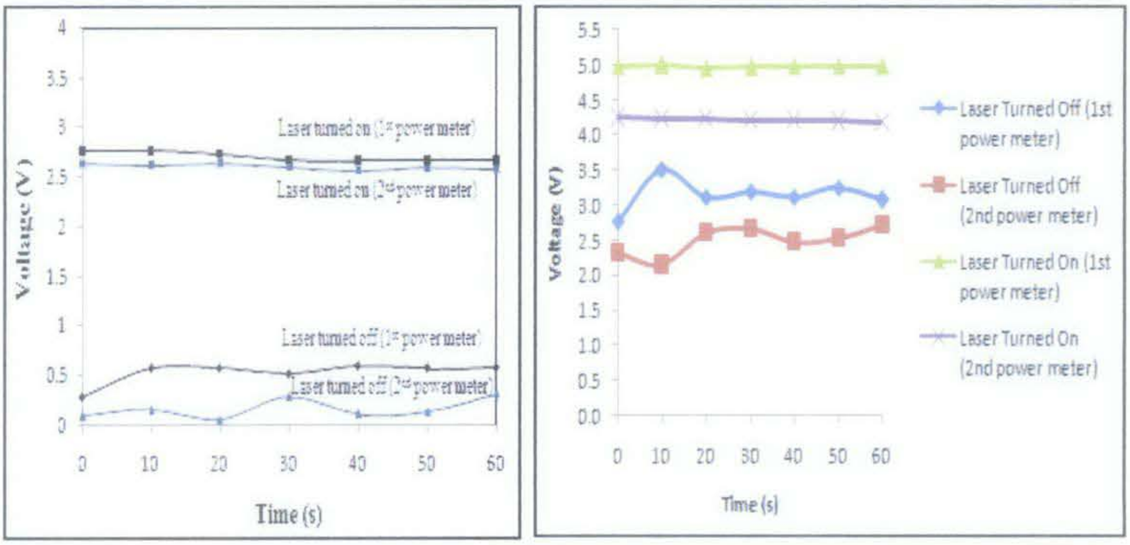

Figure 4.2: Comparison of previous experiment with current experiments using both of power meters

In the current experiment, for the first power meter, when the laser source was turned off, the light intensity power meter gives the average voltage reading of 3.120 V with a standard deviation of 0.138 V. Next, when the laser source was turned on, the average voltage reading displayed was 4.780V with a standard deviation of 0.702 V. For the second power meter, when the laser source was turned off, the light intensity power meter gives the average voltage reading of 2.438V with a standard deviation of 0.204V. Next, when the laser source was turned on, the average voltage reading displayed was 4.204 V with a standard deviation of 0.017 V.

Based on the results, there were distinct differences of voltage reading of the first and second power within the 60 seconds. There are several possibilities that could cause these to happen. Firstly, electronic noise in the power meter or data acquisition system hardware could affect the efficiency of the device to function. Besides, deviation in positioning of the hole made to the casing of power meter to position the LDR also could be the causal factor as well as the length of wires connecting between the multimeter and LDR to the circuit were not the same between both power meters. Longer wires means higher resistivity, thus this factor can also contribute to the slight deviation of the voltage reading.

4.1.3 Experiments of comparing covered LDR with uncovered LDR

Light dependent resistor (LDR) is used to detect the intensity of light. It is a resistor whose resistance decreases with increasing incident light intensity to allow current to pass through it. Due to its sensitivity to light, the LDR then is covered with hard dark paper around it. This is to avoid it from detecting light surrounding thus affecting the result of the experiments. The power meter then is aligned on the platform with other equipments. Figure 4.3 shows the graph of voltage versus time of comparing covered LDR with uncovered LDR:

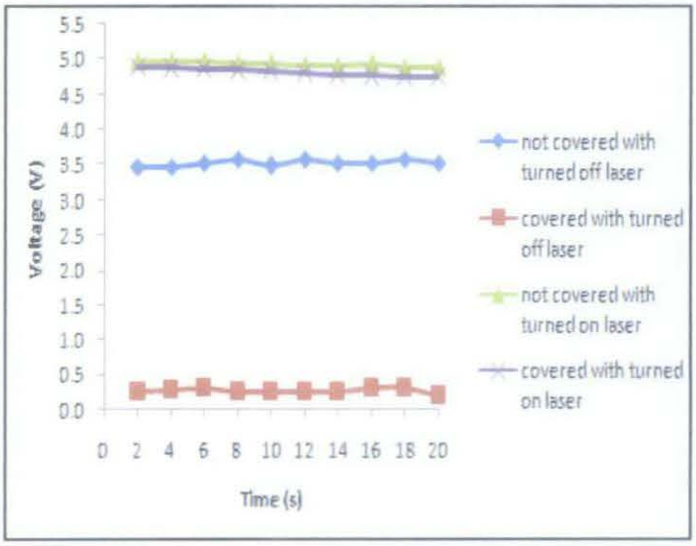

Figure 4.3: Comparison of voltage at different condition of LDR

From the graph, when the laser source without cover was turned off, the light intensity power meter gave the average voltage reading of 3.477 V with a standard deviation of 1.102E-4 V. Next, when the laser source without cover was turned on, the average voltage reading displayed was 4.646 V with a standard deviation of 0.559 V. For the experiments laser with cover, it shows that when the laser was turned off, the light intensity power meter gave the average voltage reading of 0.221 with standard deviation of 2.265E-3V. When the laser was turned off, the average voltage reading showed was 4.467V.

Based on overall result, it shows that when laser was turned off, voltage reading of LDR with cover is much lesser than voltage reading of LDR without cover. This proves that LDR is a sensitive device that detects light around. In contrast, the difference values of voltage reading when the laser was turned on are not really differs either with cover or without cover. This might be because of variation of light intensity in the laboratory as well as weather change that affects the reading of the experiments.

4.2 Experiment with smoke

The experiment was done in a laboratory where smoke generator was used to generate the smoke. A container with length, width and height of 7cm x 7cm x 10cm was used to be supplied with the smoke. A small hole was made so that the smoke can pass through to the container. The laser source, container, lens and power meter were aligned on the platform as shown in Figure 4.4 below.

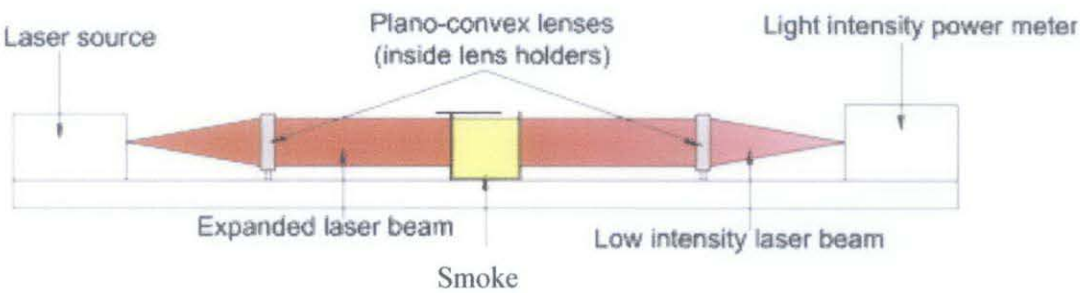

Figure 4.4: The condition when smoke was supplied into the container

The smoke generator was first turned on to generate the smoke before supplying the smoke to the container. It was done in a chamber where the excessive smoke could pass through directly to the outside area. The smoke then was left for few minutes so that it will spread more even in the container before turning on the laser.

The objective of this experiment is to calculate extinction coefficient of the smoke with regards to time. Extinction coefficient is a quantity that characterizes how easily a material or medium can be penetrated by a beam of light, sound, particles, or other energy or matter. The larger the attenuation coefficient the faster the beam is attenuated as it passes through the specimen and a small attenuation coefficient means that the medium is relatively transparent to the beam.

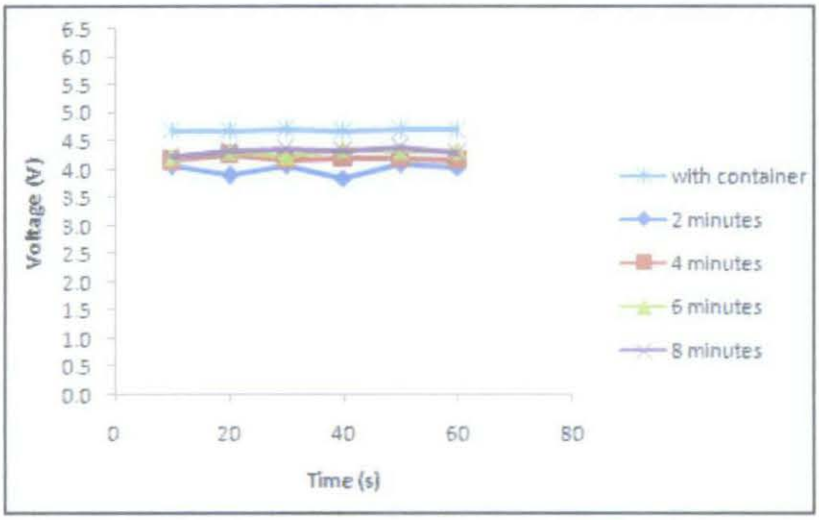

Figure 4.5: Plot of voltage versus time of smoke

Based on the result shown in Figure 4.5, average voltage is the lowest at 2 minutes which is 3.989 V. At 4 minutes, the average voltage increases to 4.166 V and keeps on increasing to 4.297V at 6 minutes. The highest value is recorded at 8 minutes which is 4.303 V. From the average voltage gained, it shows that with increasing of time, the value of average voltage is also increasing. This means that at the early experiment, where the amount of smoke is still large, the average voltage recorded is small due to portion of the laser beam is absorbed by the smoke, thus leads to low value of voltage recorded.

Beer Lambert's law relates the ratio of the transmitted and incident intensities to the mass concentration of smoke M_s (mass/volume), the path length through the smoke, L, and extinction coefficient, k_s via the following expression:

$$I/I_0 = \exp(-k_s M_s L) \tag{4.1}$$

The intensity is calculated by using equation 2.3. By taking mass concentration of smoke,Ms 0.3529 (g/m3) and path length of 4.6m, the extinction coefficient is calculated by using equation 4.1. Table 4.1 and Table 4.2 show the value of intensity and extinction coefficient.

Table 4.1: Intensity

Duration (minute)	**Average Voltage (V)**	**I/I_0**
2	3.989	0.484
4	4.166	0.505
6	4.297	0.521
8	4.303	0.522

Table 4.2: Extinction coefficient

Duration (minute)	**Average Voltage (V)**	**I/I0**	**Ks**
2	3.989	0.484	0.447
4	4.166	0.505	0.421
6	4.297	0.521	0.402
8	4.303	0.522	0.401

Based on the calculation above, the highest extinction coefficient is obtained at 2 minutes which means the quickest beam that is being attenuated or weakened as it passes through the medium. This lead to bigger portion of laser beam that is being absorbed by the smoke thus leads to the lowest value of average voltage being recorded.

4.3 Experiment with sea water

The purpose of this experiment is to quantify the absorbance value of sea water and fresh water by adopting absorbance principle from the Beer Lambert Law. As mentioned in chapter 2, the average density of seawater at the ocean surface is 1.025 g/ml. Seawater is denser than fresh water (density 1.0 g/ml @ 4 °C (39 °F)) because the dissolved salts add mass without contributing significantly to the volume.

According to the law, for each laser beam encountering the liquid droplets (sea water and fresh water), a portion of the incident flux is reflected at the entrance and exit surfaces, another portion is absorbed and the remainder is transmitted. Figure 4.6 shows the setting and condition when sea water and fresh water are introduced to the measurement area.

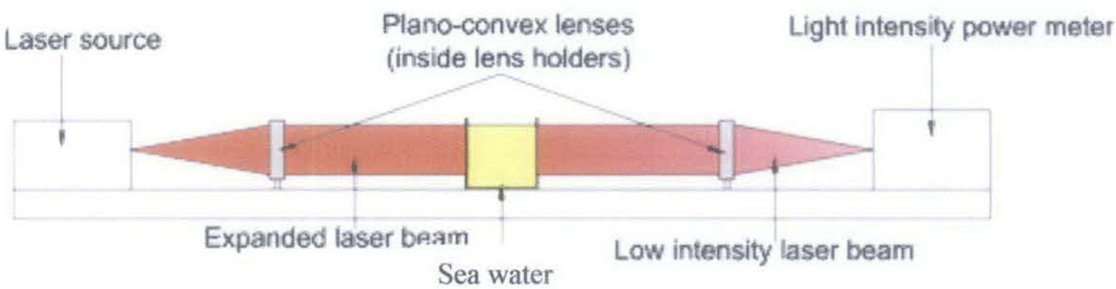

Figure 4.6: The condition when sea water was poured into the container

The amount of solution used for both sea water and fresh water is 300ml. The solution is then poured into a Perspex container where the length, height and width of the container is 7 cm, 10 cm and 7 cm.

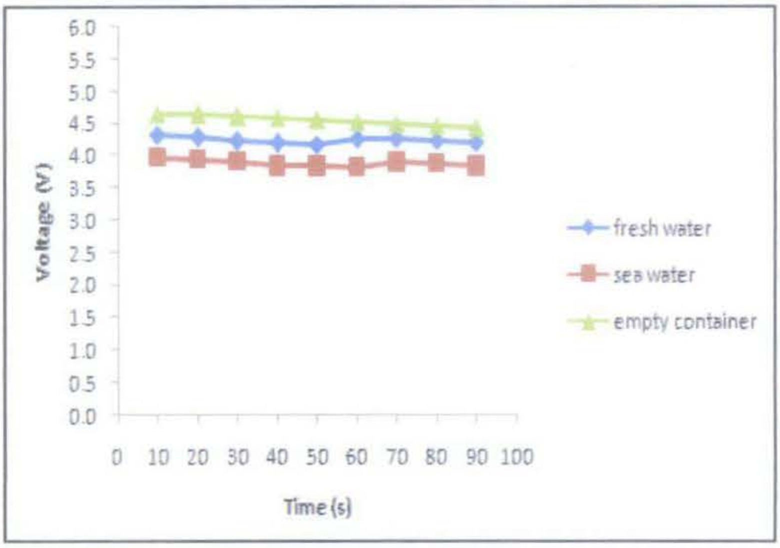

Figure 4.7: Plot of voltage versus time for sea water and fresh water

Figure 4.7 shows the result of the experiment with sea water and fresh water. The initial average voltage when the empty Perspex container was placed in the system is 4.554 V. The fresh water then was poured into the container and gave the average value 4.233 V. The average voltage kept on decreasing when sea water was poured into the container where the average value of voltage was 3.879.

The decrease of voltage means that the decrease of intensity of the laser beam due to obstruction in the path of the laser beam. The first decreasing voltage which is from 4.554 V to 4.233V occurs due to presence of fresh water in the container. This is linear with the accordance law where laser beam is reflected at the entrance and exit of container and some of the laser beam is absorbed by the particles of fresh water. This causes the intensity of laser beam to be reduced thus lowering the voltage value recorded by the light intensity power meter. The voltage keeps on decreasing when the fresh water is replaced by the sea water. The voltage value of fresh water and sea water differs due to different properties of the waters.

Below is the calculation to determine the absorbance and molar absorptivity of different water based on the Beer-Lambert Law. Since chloride is the dominant dissolved salt in sea water compared to the others, the molecular weight of chloride is taken into calculation. The properties of the sea water ad fresh water are tabulated as below:

Table 4.3: Properties of sea water and fresh water

Properties	Sea Water	Fresh Water
Molecular weight, M (g/mol)	35.453	18.015
Density, ρ (g/ml)	1.025	1.000
Volume, V (ml)	200	200

The mass of sea water($m_{sea\ water}$), is obtained by multiplying its density ($\rho_{sea\ water}$) with volume ($V_{sea\ water}$) as shown below.

$$m_{sea\ water} = \rho_{sea\ water} \times V_{sea\ water} \tag{4.2}$$

$$1.025\ {}^{g}/_{ml} \times 200\ ml = 205\ g$$

Next, the mole of sea water $N_{sea\ water}$ is calculated by dividing $m_{sea\ water}$ with the molecular weight M.

$$N_{sea\ water} = \frac{m_{sea\ water}}{M} \tag{4.3}$$

$$\frac{205\ g}{35.453\ {}^{g}/_{mol}} = 5.782\ moles$$

The concentration, C is then obtained by dividing $N_{sea\ water}$ with volume of sea water $V_{sea\ water}$.

$$C = \frac{N_{sea\ water}}{V_{sea\ water}} \tag{4.4}$$

$$\frac{5.788\ moles}{200\ cm^3} = 0.0289\ \frac{moles}{cm^3}$$

The absorbance is calculated by using the equation below:

$$A = \ln \frac{I_i}{I_o} = \varepsilon LC \tag{4.5}$$

where the light intensity ratio of I_i/I_o is assumed to be the same as V_i/V_o in this experiment, (ε) is the molar absorptivity,(L) is the length of container and (C) is the concentration of the sample.

$$A = \ln \frac{V_i}{V_0} \tag{4.6}$$

$$\ln \frac{3.879}{4.554} = -0.1604$$

$$= 0.1604$$

The negative value of absorbance is ignored since absorbance is a measurement of how much light is absorbed. Thus, only the value is considered for further calculation.

Finally, to find molar absorptivity, ε the absorbance is divided with the product of length and concentration.

$$\varepsilon = \frac{A}{L \times C} \tag{4.7}$$

$$\frac{0.1604}{7\ cm \times 0.02894} = 0.792\ \frac{cm^2}{mol}$$

Below is the tabulation of concentration, absorbance and molar absorptivity for sea water and fresh water:

Table 4.4: Concentration, Absorbance and Absorptivity

	Sea Water	Fresh Water
Concentration, C (moles/cm^3)	0.0289	0.0555
Absorbance, A	0.160	0.073
Absorptivity, ε (cm^2/mol)	0.792	0.188

Absorbance ranges from 0 to 1 where an absorbance of 0 at some wavelength means that no light of that particular wavelength has been absorbed while absorbance of 1 happens when 90% of the light at that wavelength has been absorbed. Based on the calculation above, absorbance of sea water is 0.160 which means 16% of laser beam has been absorbed by the sea water. Compared to absorbance of fresh water which obtains 0.073 or 7.3%, the absorbance of sea water is higher. The higher the absorbance means that more portion of laser beam will be absorbed by the particles resulting in lower intensity of the beam that will be recorded by the power meter. Thus, the average voltage recorded by the power meter will be lower.

Molar absorptivity, is a measurement of how strongly a chemical species absorbs light at a given wavelength. From the experiments, sea water obtains 0.792 cm^2/mol of molar absorptivity while fresh water obtains 0.188 cm^2/mol.

4.4 Experiment with fog

Experiment on laser beam transmitted through dense water-droplet fogs has been conducted. A narrow, linearly polarized beam at 532 nm experiences various degrees of broadening on propagating through a 6 cm thick layer of fog. Fog is defined as a water droplet density that restricts the visibility to less than 1km where advection fog is caused by a horizontal movement of a warm air mass over cold water and radiation fog is caused by the cooling of air overnight. Figure 4.8 shows a line of laser beam is seen throughout the glass which means fog is being produced in the glass.

Figure 4.8: Fog in glass

Figure 4.9 shows the setting of experiment where the second power meter was used in this experiment to prove the scattering effect of light. In the figure, the second power meter was placed 30° to the right of the first power meter.

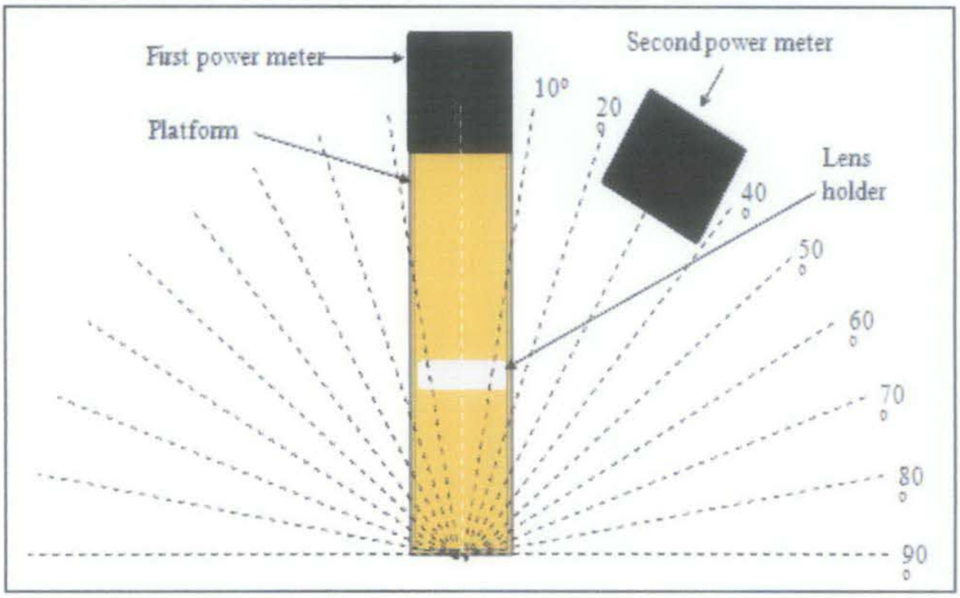

Figure 4.9: Half platform top view when the second power meter is placed 30° from the first power meter

In this experiment, average voltage is taken at each 90 seconds at different angles. The experiment started by the right side of the first power meter. Basically, the second power meter was moved by 10° with reference to the first power meter and the voltage reading displayed was recorded. After finishing with the right side of the first power meter, voltage reading of the second power meter placed at certain angles to the left side of the first power meter was recorded. The extent of the observed broadening has been found to exhibit a strong dependence on the receiver parameters. The result are as shown in Figure 4.11 and Figure 4.12.

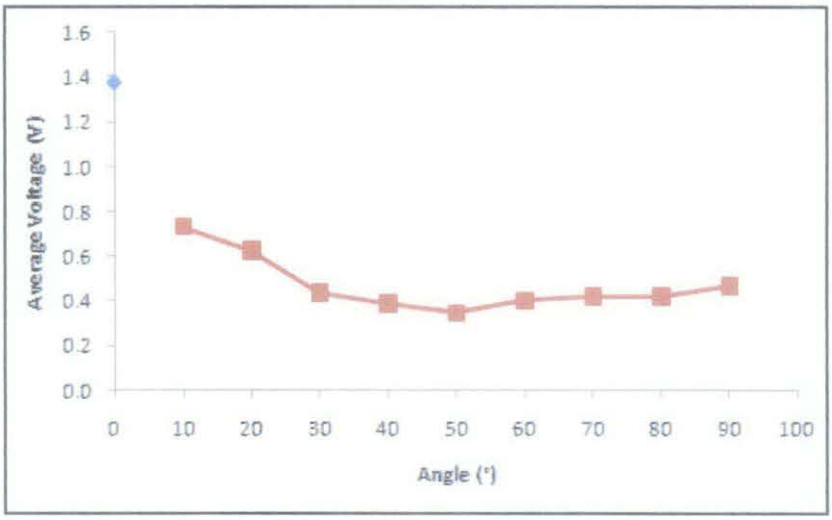

Figure 4.10: Average voltage displayed by second power meter at angles to the right of the first power meter

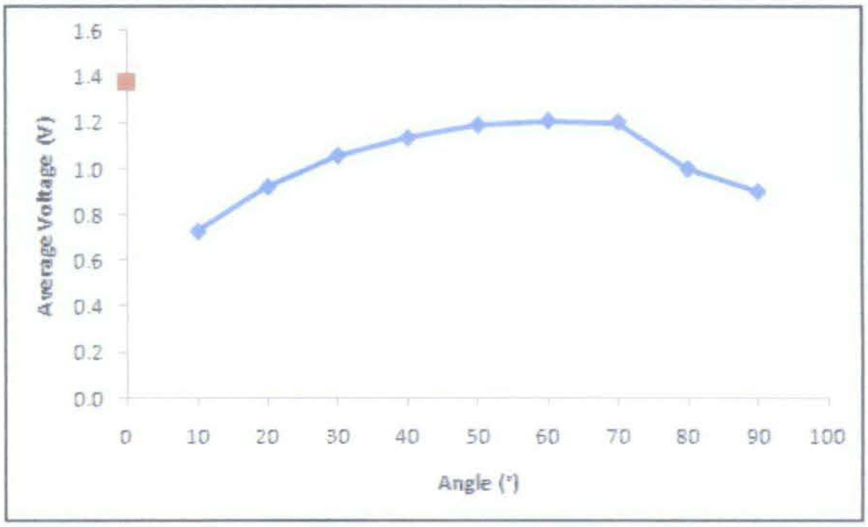

Figure 4.11: Average voltage displayed by second power meter at angles to the left of the first power meter

Light scattering refers to the deflection of a ray from a straight path due to irregularities in the propagation medium, particles, or in the interface between two media. In this experiment, an amount of the incident flux is reflected at the entrance and exit surfaces of the glass of fog while another amount is absorbed and the remainder is transmitted. Based on the results of the second power meter, there was a significant difference of average voltage between right side and the left side of the power meter. On the right side, the average voltages are recorded decreasing while on the left side, average voltages are increasing and decreasing. The increasing voltage reading at certain angles means that the LDR has detects some portion of the laser beam. Thus, a portion of the beam was scattered to the surrounding. The highest average voltage is recorded by the second power meter on the left side at angles of 60° and 70°.

4.5 Experiment with diesel spray

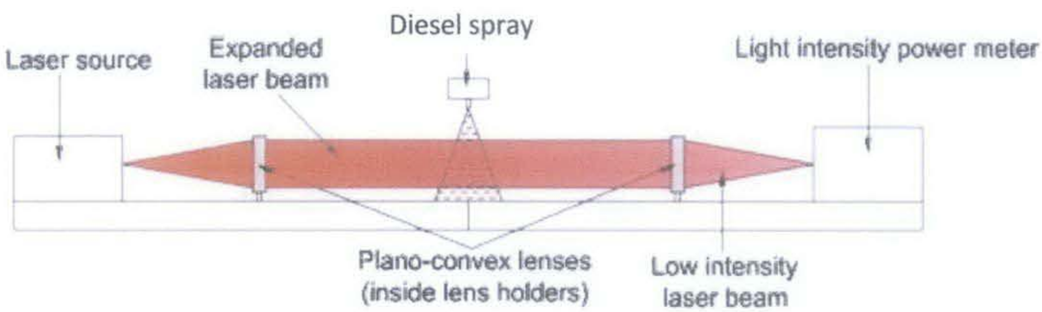

Figure 4.12: The condition when diesel is sprayed

Figure 4.12 shows the setting and condition when diesel spray is introduced to the measurement area. The equipments used to create the diesel spray for this experiment is similar to the equipment used for LDA/PDA systems. The experiments were conducted at the laboratory due to the needs of the pump usage. They were conducted at three different pressures which are 50 kPa, 100 kPa and 150 kPa. The penetration distance, which is the distance of spray measured from the nozzle, is 1.0 cm.

After spraying the diesel through the nozzle, the laser source was turned on and voltage reading of power meter was taken for 90 seconds. Figure 4.13 shows the graph of voltage versus time when diesel spray was introduced at different pressures.

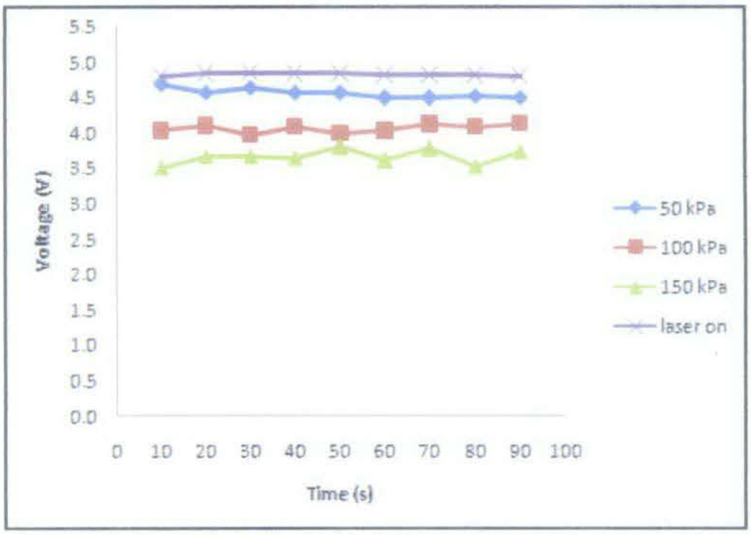

Figure 4.13: Plot of voltage versus time of diesel spray

Based on the graph, the average voltage reading when the laser was turned on is 4.805 V which also denotes the maximum voltage, $V_{o.}$ When the diesel was sprayed at 50 kPa, the voltage reading is 4.509 V followed by 4.049 V for 100 kPa and 3.634 V for 150 kPa. From this result, it shows the decreasing of average voltage value when the pressure is being increased. Basically, increasing the pressure will increase the angle of spray, resulting in more particles is being absorb by the laser beam. Thus, the voltage reading of power meter will decrease due to lesser transmitted laser beam that will be detected by the LDR. The calculation for average diameter of diesel droplets is shown below:

From LDA/PDA measurement system, the diameter of droplets was obtained as tabulated below:

Table 4.5: Diameter of droplets of diesel spray

Pressure (kPa)	Diameter of droplets, D_{20} (μm)
50	715.33
100	723.79
150	735.87

The extinction cross section, (σ_e) can be calculated by assuming mean extinction efficiency equals to 2. The calculation is shown in equation below:

$$\sigma_e = \frac{\pi}{4} \times \overline{Q}_e \times D_{20}^2 \qquad (4.8)$$

$$\frac{\pi}{4} \times 2 \times (0.07153)^2$$

$$= 8.0303 \times 10^{-3} cm^2$$

Then, the number density of water droplets is obtained by inserting the calculated value of σ_e into the equation below. The negative sign is omitted because only the value of number density is considered. Tabulation of number density for 100 kPa and 150 kPa is shown below:

$$N_d = \left[\frac{\ln\left({V_i}/{V_o} \right)}{\sigma_e L} \right] \qquad (4.9)$$

$$= \frac{\ln {4.509}/{4.805}}{(8.0303 \times 10^{-3})(10)}$$

$$= -0.79\ droplets/cm^3$$

$$= 0.79\ droplets/cm^3$$

Table 4.6: Tabulation of extinction cross section and number density for each diesel pressure

Water pressure (kPa)	σ_e ($10^{-3}cm^2$)	Number density ($droplets/cm^3$)
50	8.0303	0.79
100	8.2337	2.08
150	8.509	3.28

Number density can be described as the degree of concentration of particles within a space. Based on the calculation, number density recorded at 50 kPa is 0.79 droplets/cm^3 while for 100kPa, the number density is 2.08 droplets/cm^3. The highest number density recorded is 3.28 droplets/cm^3 at 150 kPa. As pressure increases, the number density is also increases. This is due to the increasing angle of spray when the pressure is increases thus lead to more particles absorbing the laser beam and resulting higher number density recorded.

In order to prove the scattering effect, the experiment was set up the same as the previous experiment with fog. Below are the figures of average voltages displayed by the second power meter when the diesel pressure was 50 kPa:

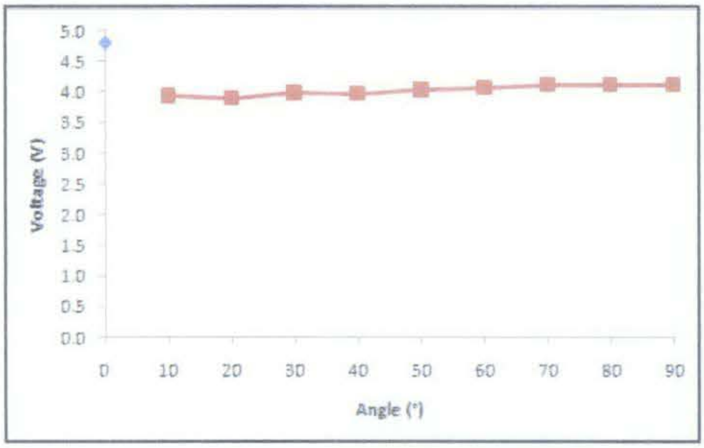

Figure 4.14: Average voltage displayed by both power meters at angles to the right of the first power meter

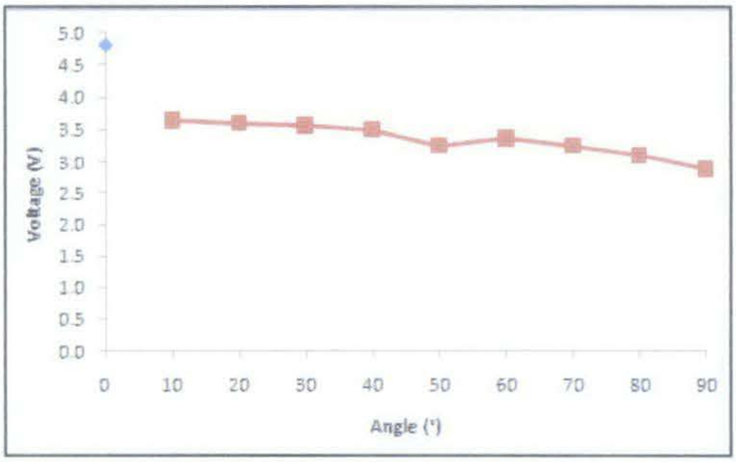

Figure 4.15: Average voltage displayed by both power meters at angles to the left of the first power meter

When the laser beam is incident to the diesel spray, there will be reflections and transmittance of the beam by the particles to the surrounding. Based on the results of the second power meter, the highest average voltage recorded to the right side of the first power meter is 4.117 V at the angles of 70° while for the left side is 3.634 V at the angles of 10°.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The first experiment was to compare the warm up period of the laser where the new laser has higher value of voltage. Next was comparison of both power meters with new modified circuit that afterwards was proved reliable due to increment of voltage value. It was continued by experiment with smoke. This experiment was conducted to quantify the extinction coefficient of smoke. The highest extinction coefficient was obtained at 2 minutes which means the quickest beam that was being attenuated as it passes through the medium. The laser beam was incident to a Perspex container containing sea water and fresh water for third experiment which concern with absorbance value. The sea water had greater absorbance compared to fresh water as the voltage recorded was much lower. Next was experiment to study the scattering effect of fog. Last but not least was the experiment with diesel spray where the diesel atomization was introduced within the measurement system in order to quantify the number density. The highest number density was obtained at 150kPa. As the pressure of diesel was increased, more particles will absorb the laser beam due to higher angle of spray.

5.2 Recommendations

As for recommendations, improvements need to be done to the measurement system to increase its functionality and accuracy. For power meter, the casing could be improved so that light dependant resistor will not be too exposed to the light surrounding that could obstruct the voltage recorded. Hence, the circuit can be modified where the switch could be added for easy controlling. There are some difficulties occurred when changing the battery, thus, a design which is more friendly-user should be applied for the laser system.

More experiments should be done to deepen the understanding of the suspended particles. For instance, calculate the number density of solid particles for example wood dust. The wood dust could be varies by having different type of woods or different size of woods dust. Besides, experiments where two different lasers are used should also be implemented. The lasers should either have same power but different wavelength or vice versa. From the experiments, the effect of wavelength or power could be analyzed. Fog is characterized as advection fog and radiation fog. The experiment with radiation fog could be done so that the result could be compared with the existing result of advection fog.

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APPENDIX I

EXPERIMENT TO COMPARE VOLTAGE READING OF BOTH POWER METERS

Voltage reading when laser is turned on and off:

Time (s)	Laser Turned Off		Laser Turned On	
	First power meter	Second power meter	First power meter	Second power meter
0	2.769	2.325	4.988	4.248
10	3.515	2.144	4.994	4.242
20	3.109	2.607	4.945	4.230
30	3.188	2.666	4.964	4.200
40	3.121	2.474	4.982	4.206
50	3.254	2.532	4.976	4.194
60	3.078	2.720	4.976	4.188

APPENDIX II

EXPERIMENT TO COMPARE VOLTAGE READING OF COVERED AND UNCOVERED LIGHT DEPENDENT RESISTOR (LDR)

Voltage reading when LDR is covered and not covered:

Time (s)	Laser Turned Off		Laser Turned On	
	not covered	covered	not covered	covered
2	3.475	0.243	4.971	4.883
4	3.474	0.283	4.959	4.873
6	3.526	0.298	4.951	4.863
8	3.576	0.248	4.94	4.844
10	3.476	0.248	4.926	4.824
12	3.576	0.248	4.906	4.800
14	3.526	0.248	4.913	4.771
16	3.526	0.298	4.926	4.76
18	3.576	0.298	4.885	4.751
20	3.526	0.199	4.878	4.747

APPENDIX III

EXPERIMENT WITH SMOKE

Average voltage reading of smoke:

Time (s)	Voltage reading (V)				
	With container	2 minutes	4 minutes	6 minutes	8 minutes
0	4.680	4.049	4.143	4.228	4.229
10	4.680	3.888	4.252	4.331	4.332
20	4.701	4.064	4.167	4.231	4.351
30	4.677	3.846	4.188	4.358	4.326
40	4.692	4.085	4.198	4.319	4.375
50	4.695	4.028	4.152	4.322	4.274
60	4.680	4.049	4.143	4.228	4.229

The calculation of extinction coefficient:

At 2 minutes,

$$I/I_0 = \frac{V/V_0}{1.76}$$

$$= \frac{3.989/4.684}{1.76}$$

$$= 0.484$$

Taking Ms = 0.3529 (g/m3)

L = 4.6 m

$$I/I_0 = \exp(-k_s M_s L)$$

$$0.484 = \exp[ks\ (0.3529)(4.6)]$$

$$ks = 0.447$$

The total results are tabulated as below:

Intensity

Duration (minute)	**Average Voltage (V)**	**I/I_0**
2	3.989	0.484
4	4.166	0.505
6	4.297	0.521
8	4.303	0.522

Extinction coefficient

Duration (minute)	**Average Voltage (V)**	**I/I0**	**Ks**
2	3.989	0.484	0.447
4	4.166	0.505	0.421
6	4.297	0.521	0.402
8	4.303	0.522	0.401

APPENDIX IV

EXPERIMENT WITH SEA WATER

Average voltage reading:

	Voltage reading (V)		
Time (s)	Empty container	Fresh Water	Sea Water
10	4.648	4.305	3.964
20	4.63	4.277	3.931
30	4.602	4.212	3.908
40	4.593	4.185	3.826
50	4.556	4.175	3.826
60	4.519	4.24	3.821
70	4.500	4.259	3.889
80	4.463	4.231	3.869
90	4.444	4.203	3.826

APPENDIX V

EXPERIMENT WITH FOG

Average voltage displayed by second power meter at angles to the right of the first power meter:

Time (s)	Average voltage (V)
10	0.731
20	0.627
30	0.436
40	0.388
50	0.347
60	0.400
70	0.42
80	0.42
90	0.467

Average voltage displayed by second power meter at angles to the left of the first power meter:

Time (s)	Average voltage (V)
10	0.727
20	0.920
30	1.055
40	1.132
50	1.188
60	1.205
70	1.201
80	0.999
90	0.901

APPENDIX VI
EXPERIMENT WITH DIESEL SPRAY

Voltage reading during experiment of diesel spray at different pressures :

Time (s)	Voltage reading (V)			
	Laser on	50 kPa	100 kPa	150 kPa
10	4.796	4.675	4.015	3.501
20	4.83	4.566	4.09	3.662
30	4.842	4.639	3.963	3.657
40	4.83	4.569	4.079	3.634
50	4.83	4.567	3.986	3.784
60	4.807	4.483	4.021	3.599
70	4.807	4.478	4.108	3.761
80	4.802	4.512	4.073	3.524
90	4.79	4.49	4.125	3.731
10	4.796	4.675	4.015	3.501

Average voltage displayed by second power meter at angles to the right of the first power meter:

Time (s)	Average voltage (V)
10	3.935
20	3.893
30	3.980
40	3.964
50	4.034
60	4.068
70	4.117
80	4.115
90	4.114

Average voltage displayed by second power meter at angles to the left of the first power meter:

Time (s)	Average voltage (V)
10	3.634
20	3.606
30	3.565
40	3.499
50	3.255
60	3.366
70	3.247
80	3.091
90	2.864