CHAPTER 5
RESULTS AND DISCUSSIONS

This chapter presents the results and discussion for the experiments conducted in the project. The objectives of these experiments are to get the maximum and minimum readings from the system, to test the system functionality and to estimate the number density of water droplets. The experiments that have been conducted are the determination of initial conditions of the light intensity power meter, determination of absorbance and molar absorptivity of Hexane solution and determination of the number density of water droplets.

5.1 Initial Conditions of Light Intensity Power Meter

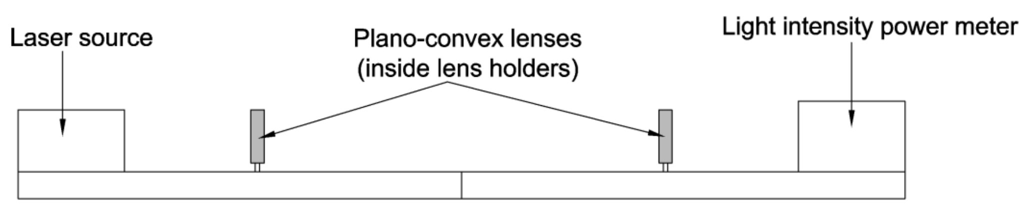

Figure 5.1: The setting and condition when the laser source is turned off

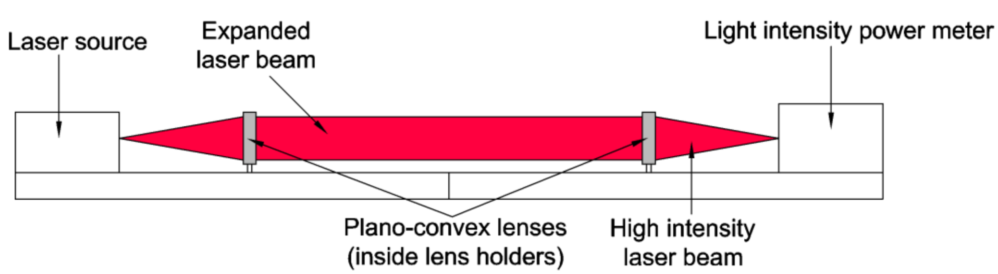

Figure 5.2: The setting and condition when the laser source is turned on

The components of laser attenuation measurement system such as laser source, lens holders and light intensity power meter are placed on the platforms, as shown in Figure 5.1.

The setting shown in the first figure is used to obtain the maximum voltage reading when the laser source is turned off. The minimum reading is obtained by turning on the laser source as shown in Figure 5.2. The plot in Figure 5.3 is the result of initial conditions during the experiment without any object introduced in the measurement area.

When the laser source is turned off, the light intensity power meter gives the maximum voltage of 5.0V with the standard deviation of 0.0016 but when the laser source is turned on the voltage is reduced to an average value of 1.2V and its standard deviation is 0.0165. The voltage decreases when the laser beam hits directly the light dependent resistor (LDR) and it causes the resistance to be increased. The lines in the plot are not smooth because of the electrical noise either from the laser source or power meter. The voltage can not be further lowered due to the battery power of laser pointer. The higher the battery power of laser pointer, the lower the minimum voltage will be.

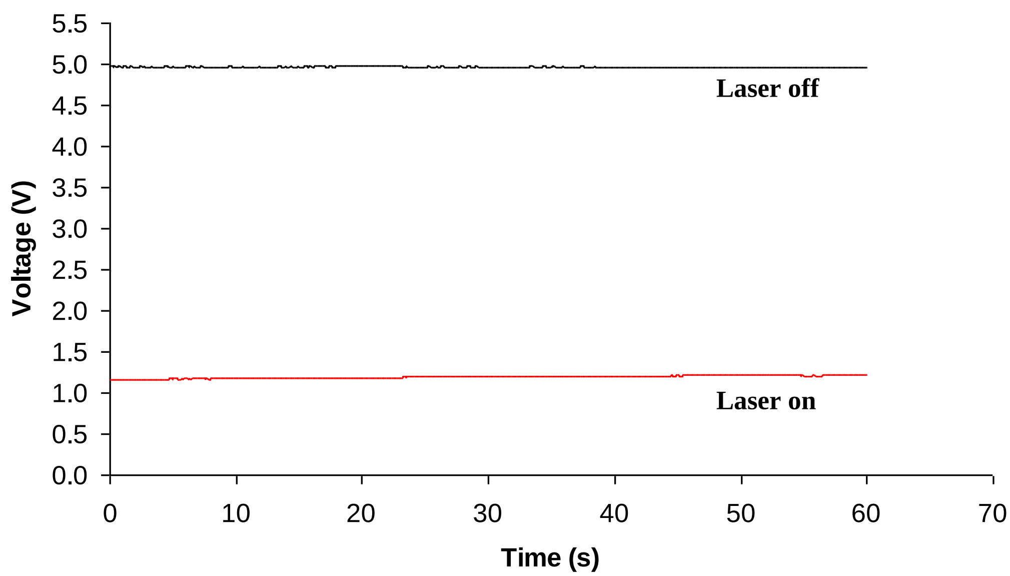

Figure 5.3: The maximum and minimum voltages

5.2 Experiment with Hexane Solution

The purpose of this experiment is to alternatively calibrate the measurement system by adopting the absorbance principle from the Beer-Lambert law. Hexane is a colorless hydrocarbon from alkane family with the chemical formula of C_6H_{14} or $CH_3(CH_2)_4CH_3$. The word "hex" refers to the six carbons and "ane" indicates that those carbons are connected by single bonds. According to the law, for each wavelength of light passing through a sample (i.e. Hexane), some of the light is absorbed and this phenomenon is called absorbance. Molar absorptivity denotes how strong the sample absorbs the light. The equation of absorbance is

$$A = \ln \frac{I_i}{I_o} = \varepsilon LC \tag{5.1}$$

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 450ml of Hexane solution is poured into a Perspex container. The length, height and width of this container are $7cm$, $10cm$ and $7cm$. Figures 5.4 and 5.5 show the settings used and conditions occurred in the experiment. Referring to Figure 5.6, the initial average voltage when the container has not been placed in the system is $1.20V$ but when the empty container is placed in the measurement area the voltage increases to $1.36V$ and the voltage keeps increasing to an average value of $1.95V$ when the Hexane solution is poured into the container.

The increase of voltage from $1.20V$ to $1.36V$ which denotes the decrease in intensity of the laser beam is caused by the presence of empty container in its path. The laser beam is reflected by at the entrance and exit of container. The further increase of voltage to $1.95V$ occurs due to the presence of Hexane solution in the container. Besides being reflected at the entrance and exit, some of the laser beam is absorbed by the particles of Hexane solution and it causes the intensity of laser beam to be reduced thus the voltage recorded by the light intensity power meter is high.

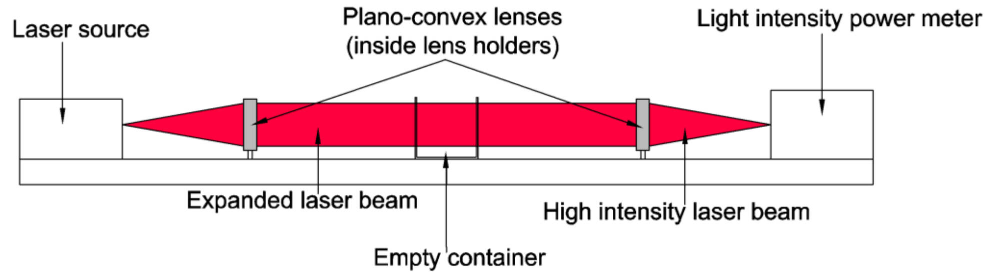

Figure 5.4: The initial condition when the empty container is used

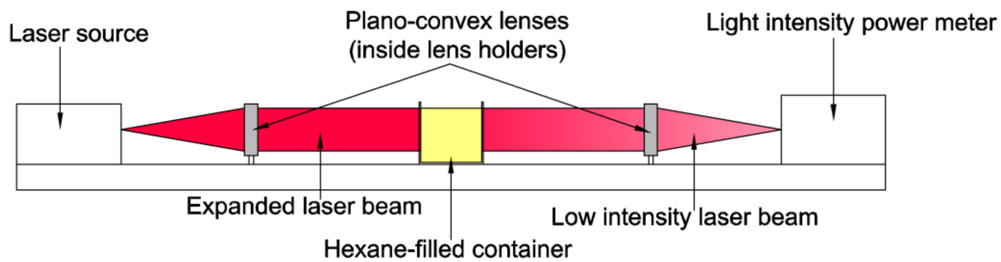

Figure 5.5: The final condition when the Hexane-filled container is used

The lines in the plot are not smooth due to the electrical noise from either the laser source or power meter. A simple calculation to determine the absorbance and molar absorptivity of Hexane solution based on the Beer-Lambert Law by using the data from the experiment is shown below. The molecular weight (M), density (ρ) and volume (V) of Hexane solution are $86.18\, g/mol$, $0.6548\, g/ml$ and $450ml$, respectively.

The mass of Hexane solution (m_{Hexane}) is obtained by multiplying its density (ρ_{Hexane}) with volume (V_{Hexane}) as shown in Equation 5.2.

$$
\begin{aligned}
m_{Hexane} &= \rho_{Heane} \times V_{Hexane} \\
&= 0.6548\, g/ml \times 450ml = 294.66\, g
\end{aligned}
\tag{5.2}
$$

In Equation 5.3, the mole of Hexane (N_{Hexane}) is calculated by dividing m_{Hexane} with the molecular weight (M).

$$N_{Hexane} = \frac{m_{Hexane}}{M} \tag{5.3}$$

$$= \frac{294.66\,g}{86.18\,g/mol} = 3.42\ moles$$

As shown in Equation 5.4, the concentration (C) is then obtained by dividing N_{Hexane} with V_{Hexane}.

$$C = \frac{N_{Hexane}}{V_{Hexane}} \tag{5.4}$$

$$= \frac{3.42\,moles}{450\,cm^3} = 7.6 \times 10^{-3}\ moles/cm^3$$

Then, the absorbance (A) is obtained by taking the average reading of the empty container (V_o) and Hexane-filled container (V_i) and putting them in Equation 5.5.

$$A = \ln \frac{V_i}{V_o} \tag{5.5}$$

$$= \ln \frac{1.95}{1.36} = 0.3603$$

Finally, the molar absorptivity (ε) is calculated by dividing the absorbance (A) with the multiplication product of the length of container (L) and concentration of Hexane solution.

$$\varepsilon = \frac{A}{L \times C} \tag{5.6}$$

$$= \frac{0.3603}{7cm \times \left(7.6 \times 10^{-3}\ moles/cm^3\right)} = 6.77\ cm^2/mol$$

As mentioned earlier, absorbance is a measurement on how much the light has been absorbed. Absorbance varies with the concentration of the solution and length of container.

The value of A obtained from this experiment is 0.3603 and it means that 36.03% of the laser beam has been absorbed by the Hexane solution. According to Beer-Lambert law, an absorbance of 0 means that no light of that particular wavelength has been absorbed while an absorbance of 1 happens when 90% of the light at that wavelength has been absorbed.

Molar absorptivity is a measurement on how strong a sample absorbs the light. The value of ε obtained from the experiment is $6.77\,cm^2/mol$. Since the absorbance varies with the concentration and length, molar absorptivity compensates for this by dividing both the concentration and length; thus comparison can be easily made for the different solutions without having to worry about the concentration and length.

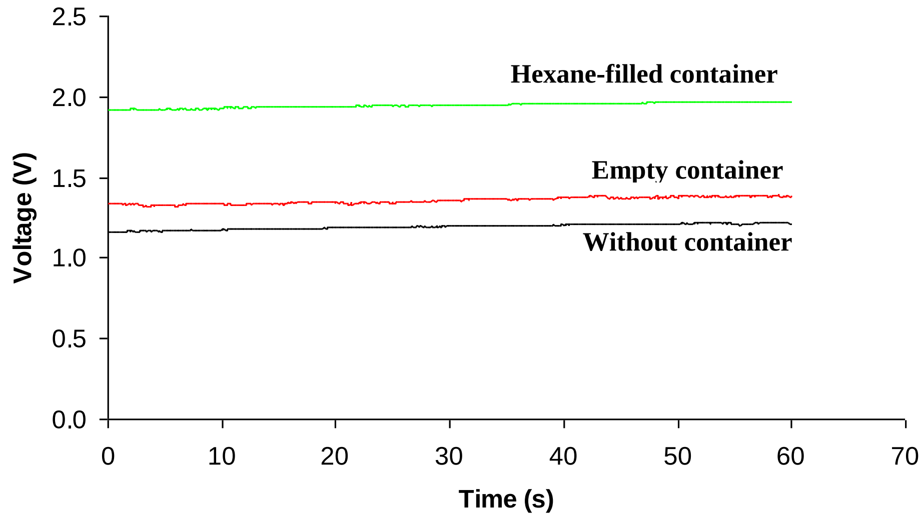

Figure 5.6: The result of experiment with Hexane solution

5.3 Experiment with Water Spray

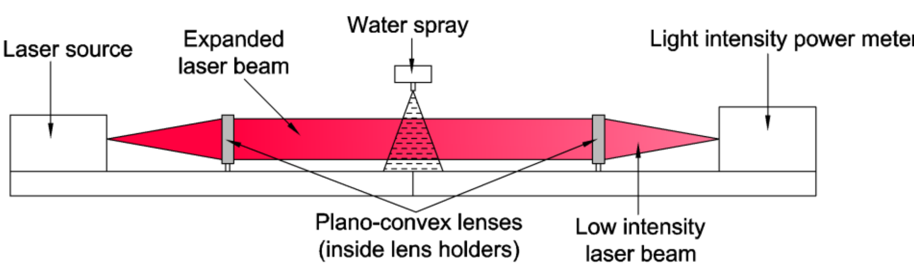

Figure 5.7: The condition when the water spray is introduced into the measurement area

The setting shown in Figure 5.7 has been used in the third experiment which is conducted by using water spray. Approximately, about 380ml of water at the temperature of $30^{\circ}C$ is filled into a spray container. The water spraying starts at $t = 20s$ and stops at $t = 40s$. Two types of water spraying have been used in this experiment and the types are continuous-and-rapid and continuous-and-slow water sprays. For every 1 second, 10 data are recorded by the data acquisition system.

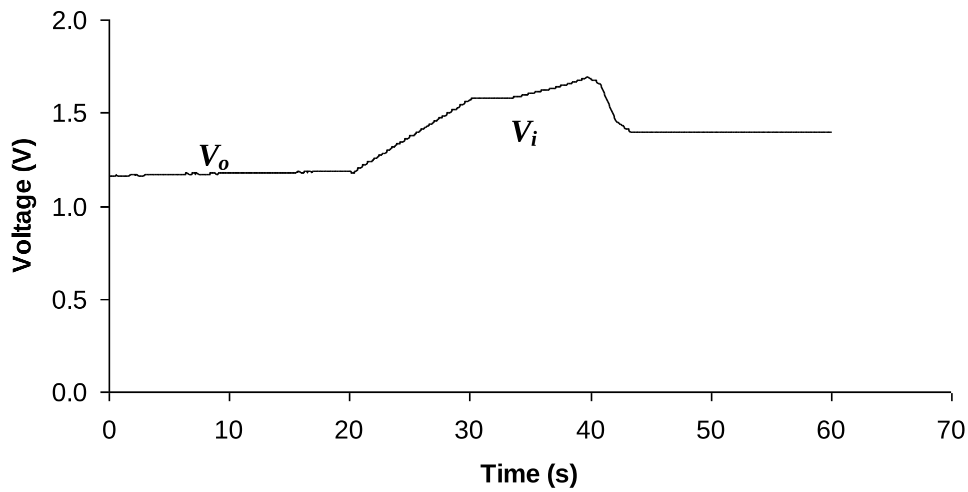

Figure 5.8: The result of continuous-and-rapid water spraying experiment

Referring to Figure 5.8, the average voltage reading (V_o) of this experiment for 60 seconds is $1.3637V$ and there is a slight fluctuation in the first 10 seconds which caused by the electrical noise. A calculation is done to determine the number density of water droplets in the measurement area at any time within $t = 20s$ and $t = 40s$. The average voltage reading at $t = 30s$ (V_i) is $1.5788V$ and this value is used in the sample calculation below. The average diameter of each water droplets is assumed to be within $10\mu m$ and $50\mu m$. The length of measurement area is $40cm$. By using the mean extinction efficiency $(\overline{Q}_e)$ equals to 2, the calculation of extinction cross section (σ_e) is shown in Equation 5.7

$$\sigma_e = \frac{\pi}{4} \times \overline{Q}_e \times D_{20}^2 \tag{5.7}$$

$$= \frac{\pi}{4} \times 2 \times (0.001cm)^2 = 1.5708 \times 10^{-6} cm^2$$

Then, the number density of water droplets is obtained by inserting the calculated value of σ_e into Equation 5.8. The calculation of droplet number density is also done for different sizes of water droplet and values of $\overline{Q}_e$. Table 5.1 summarizes the number density of water droplets for different parameters.

$$N_d = \left[\frac{\ln\left(V_i / V_o \right)}{\sigma_e L} \right] \tag{5.8}$$

$$= \left[\frac{\ln\left(1.5788 / 1.3637 \right)}{\left(1.5708 \times 10^{-6} cm^2\right)(40cm)} \right] = 2331 \ droplets/cm^3$$

Table 5.1: The droplet density numbers for the different droplet sizes and $\overline{Q}_e$ for continuous-and-rapid water spraying experiment

Droplet size (μm)	$\overline{Q}_e$	$\sigma_e (cm^2)$	$N_d (droplets/cm^3)$
10	2	1.5708×10^{-6}	2331
	5	3.9270×10^{-6}	933
20	2	6.2832×10^{-6}	583
	5	1.5708×10^{-5}	233
30	2	1.4137×10^{-5}	259
	5	3.5343×10^{-5}	104
40	2	2.5133×10^{-5}	146
	5	6.2832×10^{-5}	58
50	2	3.9270×10^{-5}	93
	5	9.8175×10^{-5}	37

Figure 5.9 shows the result of continuous-and-slow water spraying experiment. The average voltage for 60 seconds (V_o) is $1.2673V$ and the average voltage (V_i) at $t = 30s$ is $1.3969V$. The calculation steps for the extinction cross section and number density of water droplets are the same as in the continuous-and-rapid water spraying experiment which using the Equations of 5.7 and 5.8. The overall result for this experiment is tabulated in Table 5.2.

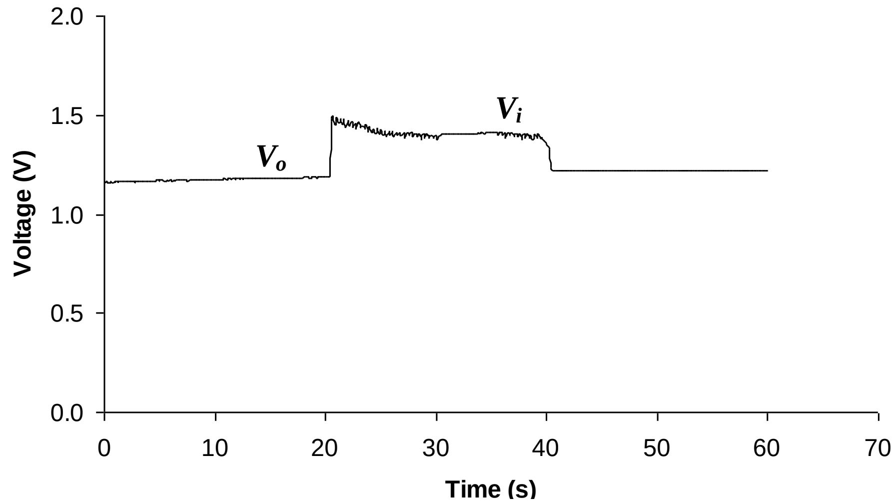

Figure 5.9: The result of continuous-and-slow water spraying experiment

Table 5.2: The droplet density numbers for the different droplet sizes and $\overline{Q}_e$ for continuous-and-slow water spraying experiment

Droplet size (μm)	$\overline{Q}_e$	$\sigma_e(cm^2)$	$N_d(droplets/cm^3)$
10	2	1.5708×10^{-6}	1550
	5	3.9270×10^{-6}	620
20	2	6.2832×10^{-6}	387
	5	1.5708×10^{-5}	155
30	2	1.4137×10^{-5}	172
	5	3.5343×10^{-5}	69
40	2	2.5133×10^{-5}	97
	5	6.2832×10^{-5}	39
50	2	3.9270×10^{-5}	62
	5	9.8175×10^{-5}	25

According to Bachalo (2003), σ_e is related to the measured drop area mean diameter (D_{20}). This is the diameter of a drop that has the same area as the entire spray. By referring to Tables 5.1 and 5.2, the number density of water droplets is high when the value of $\overline{Q}_e$ is smaller for the same size of water droplets. As seen in the both tables, the number density decreases when the size of water droplets increases. Five different sizes of water droplets and two different values of $\overline{Q}_e$ are used to show the pattern of water droplets number density when both parameters are changed. The fluctuations occurred in the plots of those three experiments are caused by the electrical noise; possibly from the laser source or light intensity power meter.

By referring to the Beer-Lambert law, Equation 2.1 is used to find the ratio of light intensity while Equation 2.5 is used to find the number density of suspended particles. Equations 5.5 and 5.8 are used to find the absorbance of Hexane solution and number density of water droplets. Both equations need the ratio of final intensity over initial intensity of laser beam. The final and initial intensities of laser beam are assumed the same as the final and initial voltages recorded by the light intensity power meter. Supposedly, the final voltage (V_i) must be lower than the initial voltage (V_o) and this negative sign is used to make the negative-value outcomes of absorbance and number density calculations become positive.

However, the negative sign is omitted in both Equations 5.5 and 5.8. It happens because this light intensity power meter records the maximum voltage when there is no laser beam supplied to the LDR and it records the minimum voltage when the laser beam hits the LDR. When V_i is larger than V_o, the negative sign is omitted from $\ln(V_i/V_o)$ because the outcomes of both calculations are already in positive values. Lastly, it is stressed here that the light intensity power meter for this project records a lower voltage reading when the laser beam hits the LDR.