CERTIFICATION OF APPROVAL

Fundamental Study of Alcohol Sprays

by

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Approved by,

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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.

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ABSTRACT

Nowadays, the transportation industries are still growing although sources of petroleum fuels are depleting. Thus, to meet the demand for fuels, alternative fuels such as alcohol fuel and bio fuel could be used. Many countries such as Brazil, United States and Germany have started using alcohol based fuels for transportation instead of petroleum fuels. Spray concept is applied in the combustion chamber. However, the characteristics of alcohol sprays are not well understood. Thus, there is a need to develop a fundamental study on alcohols spray. The objective of the project is to study the characteristics of different types of alcohol sprays in relation to combustion. The study will focus on two major components. Firstly, the study will focus on microscopic characteristics such as droplet size and mean velocity. To determine the microscopic characteristics, Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA) shall be used. LDA is used to measure mean velocity while PDA is used to measure the size of fuel droplets. The second component is on the observation of the structure of alcohol sprays at the nozzle exit. The observation shall be done using a high speed camera. All the results are analyzed to further understand on the characteristics of alcohol sprays.

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ABBREVIATIONS AND NOMENCLATURES

LDA	Laser Doppler Anemometry
PDA	Phase Doppler Anemometry
Re	Reynolds Number
We	Weber Number
IC	Internal Combustion
SMD	Sauter Mean Diameter

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Alcohol fuels have been more expensive than gasoline because of the steps involved in the manufacturing processes such as fermentation and distillation. However, with deteriorating crude oil supplies lately, the price of gasoline is skyrocketing because it has to be manufactured synthetically at a much higher cost due to the process complexity (Keenan 2008). Thus, alcohol-based fuels such as ethanol and methanol could be used as alternatives. Besides, alcohol was used for internal combustion engine, which was patented by Nikolaus Otto in 1877 (Philadelphia 1876) before gasoline had been discovered. After petroleum was commercialized, there was no market for alcohol fuel anymore. However, alcohol fuels based are widely used nowadays. Below is the table showing consumption of bioethanol in the European Union.

Table 1.1: Consumption of Bioethanol in the European Union (EurObserv'ER 2007)

Consumption of Bioethanol in the European Union (GWh)[71][72]

No	Country	2005	2006	2007
1	Germany	1,682	3,544	3,408
2	France	871	1,719	3,174
3	Sweden	1,681	1,894	2,113
4	Spain	1,314	1,332	1,310
5	Poland	329	611	991
6	United Kingdom	502	563	907
7	Bulgaria	-	0	769
8	Austria	0	0	254
9	Slovakia	0	4	154
10	Lithuania	10	64	135
11	Hungary	28	136	107
12	Netherlands	0	179	101
13	Denmark	-	42	70
14	Ireland	0	13	54
15	Latvia	5	12	20
16	Luxembourg	0	0	10
17	Slovenia	0	2	9
18	Czech Republic	0	13	2
19	Italy	59	0	0
20	Finland	0	10	n.a.
27	EU	6,481	10,138	13,563

1 toe = 11.63 MWh, n.a. = not available

Production of Bioethanol in the European Union (GWh)[71]

No	Country	2005	2006
1	Germany	978	2,554
2	Spain	1,796	2,382
3	France	853	1,482
4	Sweden	907	830
5	Italy	47	759
6	Poland	379	711
7	Hungary	207	201
8	Lithuania	47	107
9	Netherlands	47	89
10	Czech Republic	0	89
11	Latvia	71	71
12	Finland	77	0
27	Total	5,411	9,274

100 l bioethanol = 79.62 kg.
1 tonne bioethanol = 0.64 toe

In the USA, E85 fuel, a blend of 85% ethanol and 15% unleaded gasoline (Bechtold 2002) has been used widely and it is considered as an alternative fuel. Since E85 fuel uses corn as the most common source, it is considered as a renewable resource. Therefore, many major motor vehicles like Daimler Chrysler and Ford are doing their parts to manufacture flexible fuel vehicles (Bechtold 2002). Economically, the price of E85 is lower than unleaded gasoline by US$0.80 per gallon (Beam 2008). However, the price varies according to the states in the USA. The price of E85 is much lower compared to gasoline, which is shown in Figure 1.1 (NEVC 2008). Although, the usage of fossil fuels is commercialized widely, alcohol fuels actually have excellent characteristics which will affect engine performance. Its high "octane" rating is one of the good characteristics, which prevents engine detonation under load and it can stand much greater compression ratios (Ganesan 2008). Besides that, alcohol also allows clean burning compared to gasoline and environmentally friendly fuel. This is based on the emission of light vehicles used in Brazil which is shown in Figure 1.2.

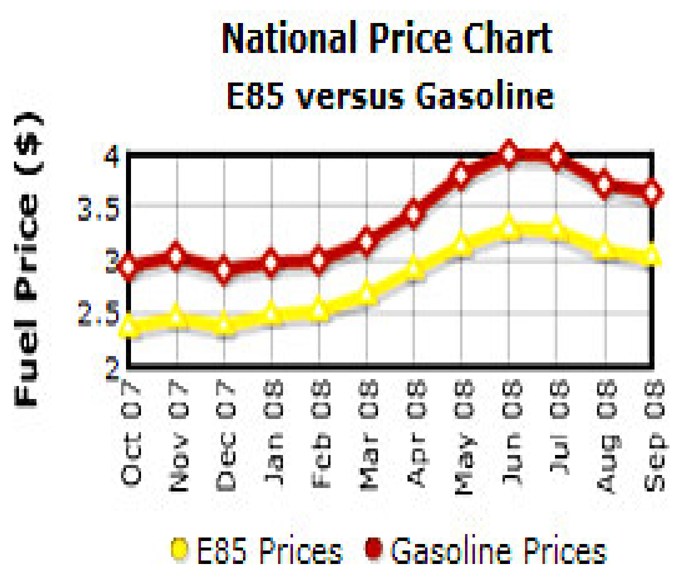


Figure 1.1: Chart of National Price Chart E85 versus Gasoline in the USA (Beam 2008)

Table 1.2: Emissions of light vehicles in Brazil (Negrão 2004)

YEAR	FUEL	POLLUTANTS (*) (grams per kilometer)			
		CO	HC	NO_X	ALDHEYDES
Before 1980	Gasoline	54	4,7	1,2	0,05
1986	Gasoline and ethanol mixture	22	2	1,9	0,04
	Ethanol	16	1,6	1,8	0,11
1990	Gasoline and ethanol mixture	13,3	1,4	1,4	0,04
	Ethanol	10,8	1,3	1,2	0,11
1995	Gasoline and ethanol mixture	4,7	0,6	0,6	0,025
	Ethanol	4,6	0,7	0,7	0,042
2000	Gasoline and ethanol mixture	0,73	0,13	0,21	0,004
	Ethanol	0,63	0,18	0,21	0,014

Based on the chart, alcohol (ethanol) fuel produces less overall emissions when compared with gasoline or gasoline mixtures with ethanol. Thus, alcohol-based fuels could be used widely as alternative fuels for in the future.

1.2 Problem Statement

The characteristics of alcohol sprays are not well understood although researches on the characteristics have been done. However, there is no specific study on different types of alcohols. The previous studies focus on the transition modes of droplet break up only. Thus, there is a need to study and understand its characteristics in comparison to different types of alcohols. The study will focus on the microscopic characteristics and the structure of break up zone of alcohols sprays. The results from the studies will provide data on the behavior of the alcohol sprays at various conditions.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The main objective of the present work is to study the microscopic characteristics of sprays which are droplet sizes and mean velocities, as well as the break up structure of different types of alcohol sprays such as ethanol, methanol, propanol and butanol.

1.3.2 Scope of Study

The present research covers the microscopic characteristics and the structure of break up zone of the sprays near the nozzle exit. Both studies are related to each other, and both characteristics are very important in relation to combustion process in the engines.

To evaluate the microscopic characteristics in greater detail, a study is done on droplet size and mean velocity, by using Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA) Systems. The study on the structure of the break up zone of alcohol sprays is done by taking pictures using a high speed camera. To understand the behaviour of alcohol sprays, key variables such as pressure, radial distance, penetration distance, and liquid types are taken into consideration.

CHAPTER 2
LITERATURE REVIEW

2.1 Alcohol versus Fossil-fuel

According to National Energy Policy Development Group (NEPDG) (Bechtold 2002), there is an imbalance between current petroleum fuels supplies and demands. Thus, corrections are needed to balance it. There is also a very major increase in gasoline since 2004 until 2005 as shown in Figure 2.1 and the price is expected to keep increasing because the world crude-oil market tightens (Energy Information Administration 2008). With the increasing fuel economy of new vehicles, there is a need to implement non-petroleum fuels as alternative solution. In April 1997, representatives of 105 in the USA signed the Kyoto Protocol (Kyoto Protocol 1997). The main aim is to reduce the atmosphere emissions of excess carbon dioxide which is produced by oil burning and fossil gas. Thus, by promoting renewable materials such as ethanol, harmful effects on the environment can be reduced gradually.

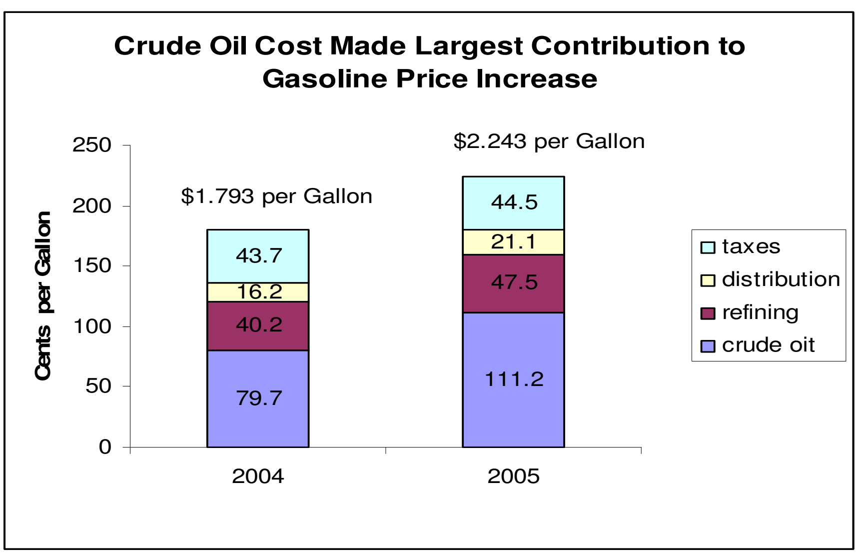


Figure 2.1: Chart of crude oil cost made largest contribution to gasoline price increase (Energy Information Administration 2008)

2.2 Characteristics of Alcohols

Alcohol is also called as an alternative fuel. The term alternative fuel is used to describe fuels other than gasoline or diesel fuel. It is considered as an attractive alternative fuel as it is obtained from both natural and manufactured sources. The advantages of alcohols fuels are (Beam & Ganesan 2008, 2004):

a. The sources can be obtained from both manufactured and natural.
b. Its high octane fuel with anti knock index numbers of over 100 allows the engine to run more efficient by using higher compression ratios.
c. The burning process in the chamber produces less overall emissions compared to gasoline.
d. More moles of exhaust gases are formed when alcohols are burned. Thus, it will give higher pressure and more power in the expansion stroke.
e. Alcohol has high latent heat of vaporization, which results in a cooler intake process. This raises the volumetric efficiency of the engine and reduces the required work input in the compression stroke.
f. Alcohol fuels have low sulphur content.

There are two types of alcohols that have been commercially used as fuels. The fuels are ethanol and methanol. In this project, the physical characteristics of the alcohols for the project are listed in Table 2.1.

Table 2.1: Table of physical properties of alcohols (Fisher Scientific 2009)

	Ethanol C_2H_5OH	Methanol CH_3OH	Propan-2-ol $(CH_3)_2CHOH$	Butanol $CH_3.(CH_2)_3OH$
Molecular Weight	46.07	32.04	60.10	74.12
Boiling Point	$78°C$	$64.6°C$	$82.5°C$	$116°C - 119°C$
Percentage	96%	99.8%	99.6%	99%

2.2.1 Ethanol

Ethanol is considered as a good spark-ignition engine fuel. There are three ways to use ethanol as a transportation fuel: (1) as blended of 10% of ethanol with 90% gasoline and known as "gasohol"; (2) as a reformulated gasoline's component both directly and/or transformed into a compound such as ethyl tertiary butyl ether (ETBE); or (3) used directly as fuel or with 15% gasoline known as "E85". There is no need for special configuration in using gasohol or transformed into ETBE for use in reformulated gasoline. Besides that, ethanol can also be used directly in diesel engines. In the USA, the price of E85 is much lower than gasoline as shown in Figure 1.1 (NEVC 2008). However, the diesel engines must be specially configured, and modification on fuel injection is required.

The usage of E85 will only eliminate some problems of pure alcohols such as cold starting and tank flammability. Conversely, the usage of E10 only reduces the amount of gasoline without modification to the automobile engine. Generally, ethanol produces less HC emissions than gasoline (Ganesan 2004).

2.2.2 Methanol

Besides ethanol, methanol is also used as an alternative fuel in transportation. Pure methanol and mixtures of methanol and gasoline in various percentages have been used in engines. The example of the mixtures fuels are M85 (85% methanol and 15% gasoline) and M10 (10% methanol and 90% gasoline) (Bechtold 2002).

Emissions from the engine using M10 fuel are about the same with gasoline. The advantage is only reduction of 10% usage of gasoline. However, with M85 fuel, there is a decrease in HC and CO exhaust emissions. Also, there is an increase in NO_x as well as formaldehyde formation. Some dual-fuel CI engines use methanol fuel. Due to high octane number, it is not a good for CI engines. Nevertheless, if a small amount of diesel oils is used for ignition, it will solve the cold-start and flame visibility of methanol (Ganesan 2004).

2.2.3 Butanol

According to Wikipedia (2008), butanol is less toxic and less volatile compared to methanol. With the characteristics of high flash point, it is good for fire safety. However, it is difficult to start the engine especially during cold season. This is because it requires a very high temperature (several hundred degrees Celsius) for the ignition to take place. For butanol, it contains much higher energy density compared to ethanol. Besides that, fiber left over from sugar crops used to make alcohol could be used to produce butanol. Thus, there will not be waste of the crops.

2.2.4 Propanol

According to Wikipedia (2008), propanol also shares characteristics with butanol because propanol contains less volatile. 2-propanol is generally used as fuel additive (gasoline additives). In fuel tanks, water is quite a problem as it separates from gasoline and is able to freeze in the supply lines at low temperature (cold). With the help of 2-propanol, it solubilizes water in the gasoline. Thus, it will not accumulate in supply line and freeze.

2.3 Sprays

Sprays happen when a liquid disperse into a stream of droplets and a spray nozzle helps facilitate in achieving it. Spray nozzle has two main functions which are to increase liquid surface area to enhance evaporation, or to distribute a liquid over an area. (Wikipedia 2009). When energy is imparted to the liquid, it forms large specific surface area as a result of small droplet size. The mechanism of atomization includes jet break up, sheet break up and droplet break up.

In jet break up surface tension, inertia, liquid viscosity and gas motion are important to be considered. It is observed that the surface energy of a uniform circular cylindrical jet is not the minimum attainable for a given jet volume (Azzopardi 1983). By neglecting the effects of gravity and ambient gas, Rayleigh (1878) showed that the mechanism of the jet breakup is the hydrodynamic instability caused by the surface tension. Weber and Chandrasekhar discovered that the viscosity has only a stabilizing effect that reduces the breakup rate and increases the drop size.

When jets wave grow on thin sheets produced by some atomizers, they grow and drops precursors. The process starts from sheet to ligament and then finally to drops. Gebhard (1996) shows how bubbles can grow, burst and form holes, then to ligaments and finally become drops.

The Weber (We) number is a dimensionless value useful for analyzing fluid flows where there is an interface between two different fluids (The Engineering ToolBox 2005). Drops are subjected to aerodynamic forces are unstable if $We > We_{critical}$. According to Lane (1951), $We_{critical}$ is usually taken as 12. This is also called as secondary atomization.

Researches have proposed different boundaries at different Weber number which is shown below:

Table 2.2: Table of Weber number proposed

We	Sarjeant	Krzecz	Pilch Erdman	Hsiang Faeth
Bag	12-25	12-20	12-50	14-32
Umbrella	25-50	20-30	50-100	32-72
Transition	-	30-65	-	32-72
Shear/ligament	>50	>65	100-350	>72

2.4 Droplet Break up

The main objective of the liquid fuel atomization is to produce small drops. When energy is imparted to liquid, it will produce smaller drops. With smaller drops, there will be large specific area. The characteristics of droplet break up depend on non dimensional parameters such as Weber (We) and Reynolds (Re). Discussion on droplet break up is explained below (Tan, Papadakis and Sampath 2005)

According to Lane (1951, 1949, 1952), a single drop subjected to a steady stream of air would initially flatten into a disk. At the critical air velocity, it would be blown out into the form of a hollow bag attached to a circular rim. Fine shower droplets are produced from the bursting of this bag. However, the rim (70% of the mass of the original drop) broke up into much larger drops, which is known as the bag break up mode (Figure 2.2). Besides that, he discovered droplets that were subjected to transient gas flows exhibited a different break up mode known as stripping or shear break up. The droplet is deformed in the opposite direction to that of the bag break up and formed a convex surface to the flow. The edges of the saucer shape were drawn out into a thin sheet and then into fine elements. These will turn into droplets.

For Hinze (1949), he showed that the increase of droplet viscosity could delay the onset of break up. In highly viscous fluids, incomplete break up was observed. He proposed the critical Weber number for break up was approximately 13 for shock flows. For falling droplets, the proposed critical Weber number was approximately 22. He also discovered that the break up process consisted of several stages, including extreme droplet flattening, formation of a torus with an attached hollow bag-shaped film, and bursting of the film.

Krzeczkowski (1980) studied break up by using an open-jet horizontal wind tunnel. This was done by releasing droplets at the nozzle exit of the tunnel. He also effects of fluid viscosity on the break up modes and times by using methanol, butanol, water, water-glycerin and glycerin solutions. Based on the experimental data, he suggested four distinct modes of break up:

- For bag break up type, it is characterized by a hollow bag-shaped film and a ring torus.
- Bag-jet break up is characterized by the additional stamen in the middle of the bag.
- For transition type, it is characterized by an initial bag type break up but transformed into disintegration of the bag film.
- Shear or stripping type is characterized by stripping of the surface layer.

Figure 2.2 shows the illustration of different possible transition modes of droplet break up. Figure 2.3 shows the break up times corresponding to two different modes of break up for water droplets.

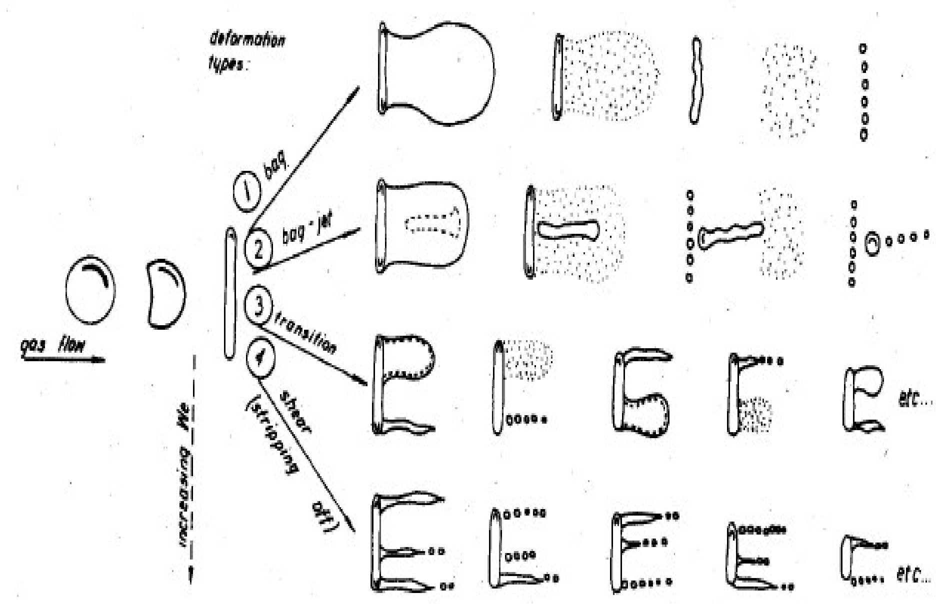
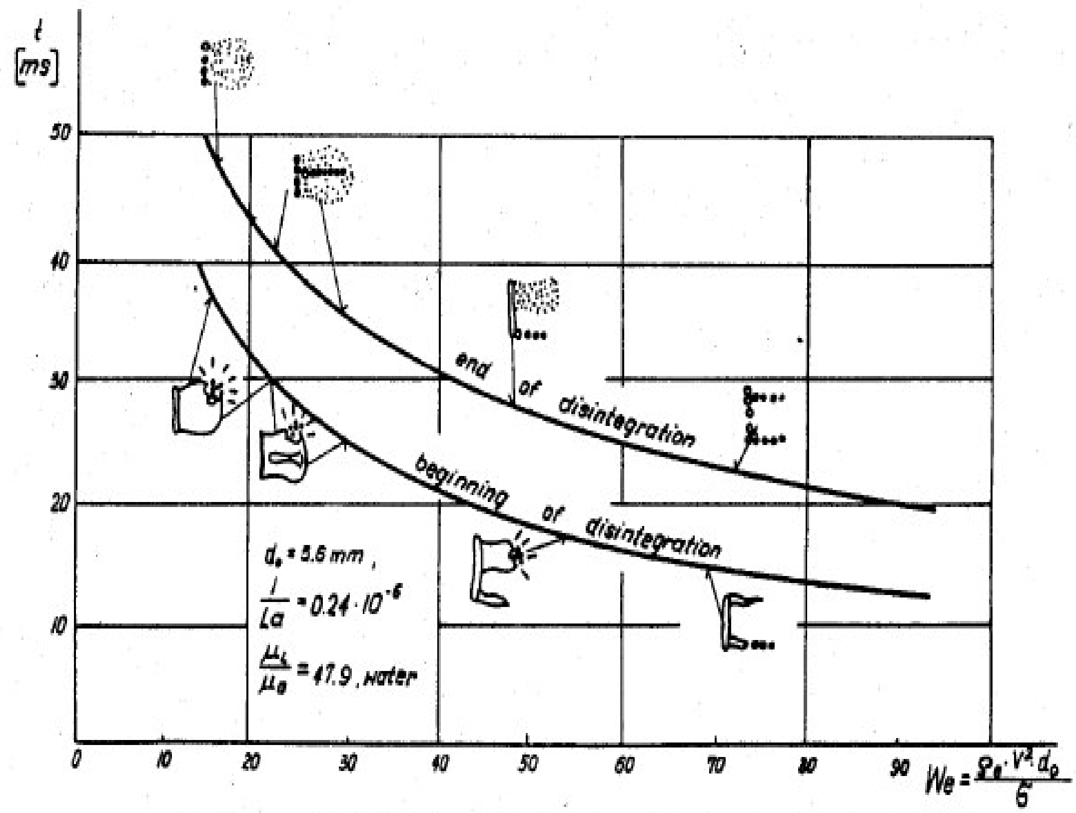


Figure 2.2: Illustration of different possible transition modes of droplet break up (Krzeczkowski 1980)



Break-up duration vs the Weber Number for water droplets (beginning and the end of disintegration).

Figure 2.3: Graph of break up duration versus Weber number for water droplets (Krzeczkowski 1980)

Based from the findings in the literature review, studies have been done by Krzeczkowski to investigate on the effect of fluid viscosity on the alcohols only. Most of the studies are mostly on water. As a result, study on microscopic characteristics has never been done yet. Although a study on alcohols has been done, it is only focusing on one main variable which is the fluid viscosity. Thus, a break up study in this project will have different variables such as pressure for evaluation.

2.5 Droplet Size Terminology

The drop size is an important parameter as it is normally used for the correlation of the combustion behaviour. However, all drops are not the same size in alcohol sprays. Thus, there is a need for averaging in order to determine a suitable mean size that corresponds to necessary droplet properties (Lefebvre 1989). Sauter Mean Diameter (SMD) or D_{32} is commonly used, which is given by:

$$\text{SMD}= D_{32} = \frac{\sum_{i=1}^{k} n_i D_i^3}{\sum_{i=1}^{k} n_i D_i^2} \tag{2.1}$$

where

n_i = the number of droplets within a range of is centred on diameter D_i

K=is the number of ranges.

SMD is an indicator of the degree of atomization produced by injector. Besides that, surface mean diameter or D_{20} is also used to represent an average diameter with a surface area equal to the mean surface area of all droplets. This is given by:

$$D_{20} = \sqrt{\frac{\sum_{i=1}^{k} n_i D_i^2}{\sum n_i}} \tag{2.2}$$

CHAPTER 3
METHODOLOGY

3.1 Project Scheduling

According to Gantt chart, as shown in Appendix A-1, all the activities are planned thoroughly. Although some activities are delayed, experiments are able to finish within the expected time limit.

3.2 Research Methodology

The first step is to do background research on the topic of alcohol sprays. The background information is the base for the research. Preliminary report mainly is about the findings of the research as this is important in determining the experiments that are to be done. Then, experiments are planned accordingly to study alcohols sprays. Identification of equipments and chemicals are done for the experiments. Then, familiarization with the LDA/PDA equipments is done before the actual experiments are performed. This is important because during this stage, problems can be detected before starting the actual performance. If there is any problem, steps taken should be revised again from identifying of equipments and chemicals. For the successful experiments, the results are analyzed. Successful experiments mean that the complete results are able to be obtained while conducting the experiment. However, for the fail experiments, they need to be identified the roots for the failure and then to be corrected and repeated. The results of the experiments are then analyzed. The results and discussions are included in Chapter 4.

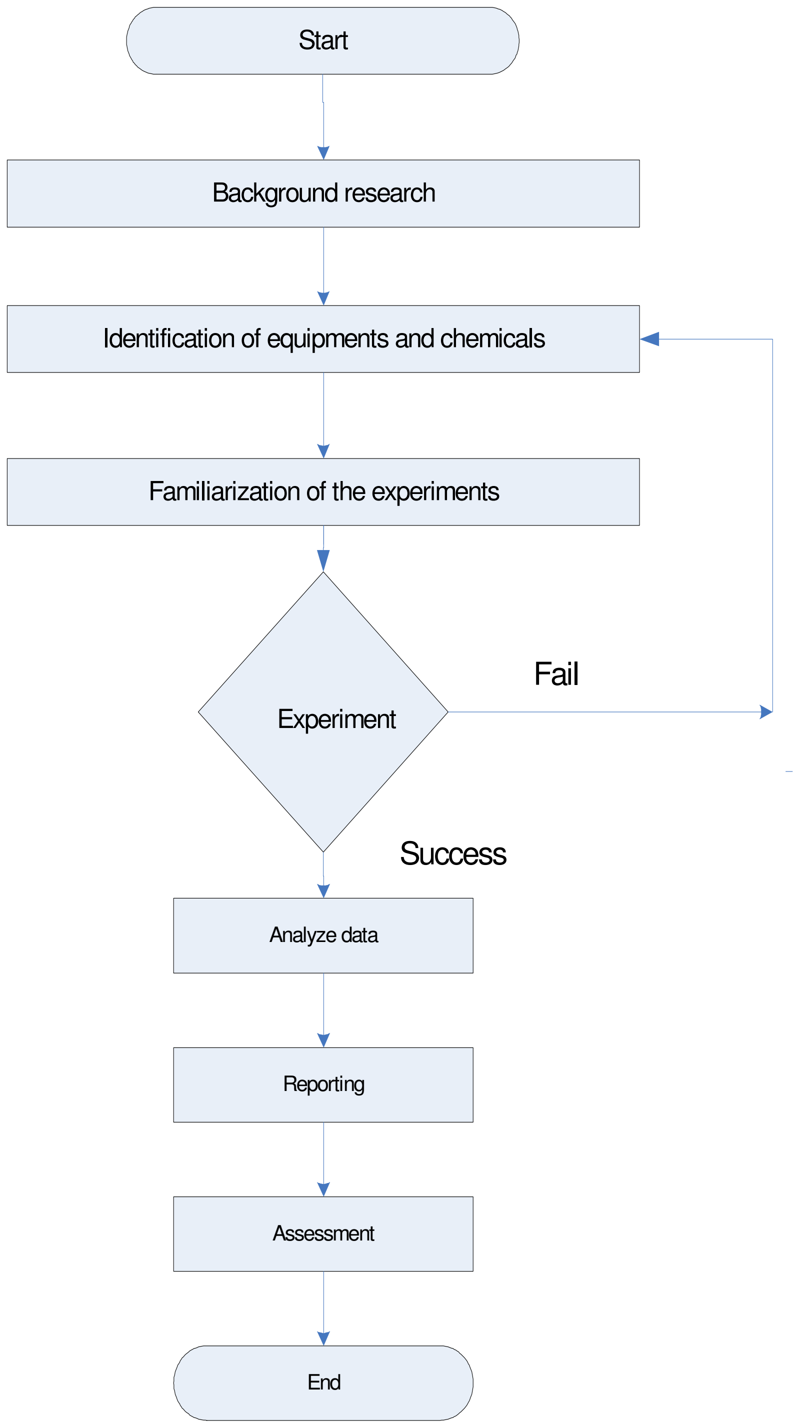


Figure 3.1: Flow of project activities

3.3 Tools

For this project, experiments have been planned to study the characteristics of alcohol sprays. To study microscopic characteristics, Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA) shall be used. LDA is used to measure mean velocity of the droplets and direction while PDA is used to measure droplets size. High speed camera is used to take pictures of droplet break up of alcohol sprays. Other tools include spray nozzle and lighting.

3.3.1 LDA/PDA Systems

To study microscopic characteristics, Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA) shall be used. LDA is used to measure mean velocity of the droplets and direction while PDA is used to measure droplets size. In LDA, the laser crosses two beams of collimated, monochromatic, and coherent laser light in the flow of the fluid being measured, where these two beams are usually obtained by splitting a single beam. This will result coherency between them. Then the two beams are made to intersect at the focal point of a laser beam. This is where they interfere and then generate straight fringes. The sensor is aligned so that the fringes will be perpendicular to the flow of direction. With the information of fringe spacing, d, velocity can be obtained (Wikipedia 2008).

PDA is a non-intrusive method in the research of two phase flows. Basically, PDA consists of a laser, fibre optics, frequency shifter, transmitting and receiving optics, signal processor, traversing system and a computer to control the measurement and save the data. In PDA, laser beams from the transmitting optics cross at the focal point of the front lens while the receiving optics looks to the same focal point at certain angle. The size is measured based on phase difference between the signals received by the two detectors.

The LDA/PDA is manufactured by Dantec Dynamics consists of following components which are:

(a) A 300mW argon-ion laser source, LaserPhysics Reliant 500m;
(b) A laser splitter and manipulator, Dantec 60 × 26;
(c) A signal processor, Dantec 58N80-MultiPDA;

(d) Optical-fiber cables, to convey the beams to the transmitter;

(e) A transmitter with a convergent lens, $f = 600$ mm;

(f) A receiver with a convergent lens, $f = 300$ mm;

(g) A traverse system Dantec 57G15; and

(h) Operating software, Sizeware 2.3, installed into a desktop computer.

3.3.2 High Speed Camera and Lighting

Besides that, high speed camera is used to capture picture of the spray development near the nozzle exit. The high speed camera is manufactured by Photron USA. The model used is photron fastcam x 1280pci and it has the following specifications:

(a) The framing rate is available for 60, 125, 250, 500, 1000, 2000, 4000, 8000 and 16000 fps.

(b) The sensor resolution is 1280 x 1024 pixels.

(c) The framing rate used for the project is 2000 fps

(d) The interval is 0.0005 seconds

The lighting used together with the high speed camera model is LX901GZ, which is manufactured by Unomat International, Germany. Its specifications are listed as below:

(a) Security net video light with zooming system. Noiseless cooling blower. Inclusive equipment safety device.

(b) Multi power circuit 1000W.

(c) Light head and handle around 90° tiltable.

(d) Colour temperature 3200 K

3.3.3 Spray Nozzle

The project uses high pressure spray nozzle F-75s, which is manufactured by Akoka and the characteristics are listed below:

(a) Operating pressure between 3 to 5 bar

(b) Air inlet is 6.35 mm diameter

(c) Nozzle outlet is 1.3 mm diameter

(d) Full cone spray nozzle

3.4 Project Activities

Two experiments are done in order to study the spray characteristics. The experiments are:

a. Experiment to determine microscopic characteristics
b. Experiment to observe break up zone.

3.4.1 Experiment to Determine Microscopic Characteristics

For experiment a, the diagram is shown in Figure 3.2 and Figure 3.3. According to these figures, the alcohols are poured into the filter funnel, and it will be delivered to nozzle via a hose. The pressure is controlled by adjusting the compressor. Then, the alcohols are collected in the tray and are used again in the experiments.

The first experiment is conducted to study the alcohols characteristics at different pressure which are 0.5 bar, 1 bar and 1.5 bar. The experiments are repeated three times for each alcohol. Figure 3.3 shows the arrangement of the equipments in the lab.

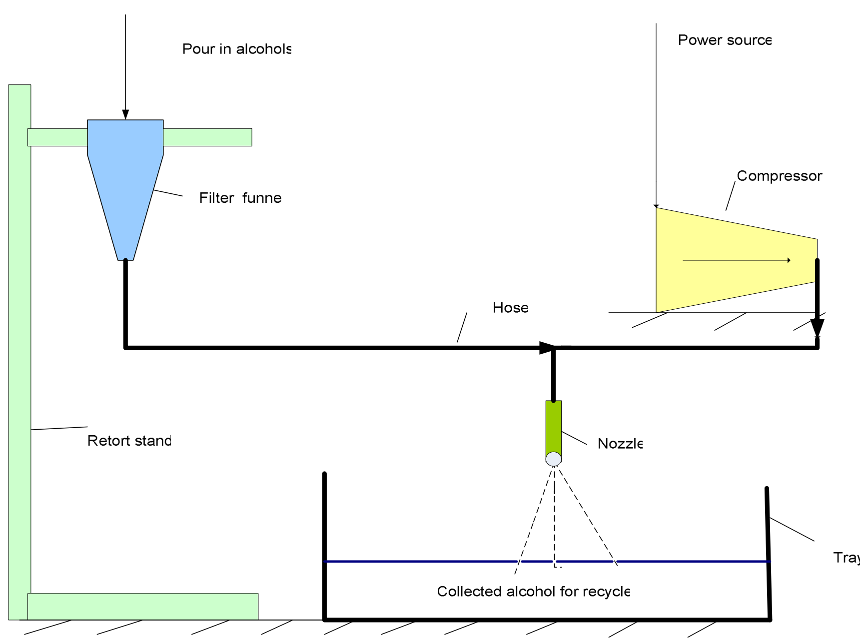


Figure 3.2: Diagram for the experiment

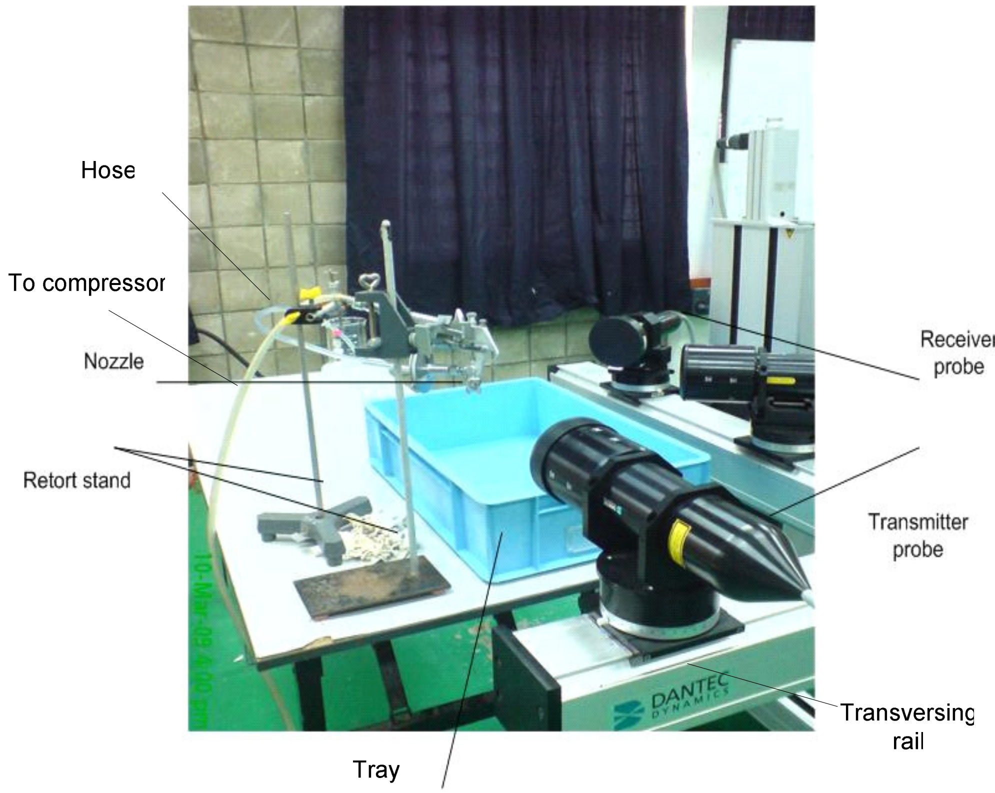


Figure 3.3: Arrangement of LDA/PDA Systems in the lab.

The purpose of this experiment is to determine droplet size and its mean velocity. LDA is used to determine the mean velocity while PDA is used to determine the droplet size. The experiment will vary pressure, location, and liquid types in order to understand alcohols' characteristics. Figure 3.4 is the LDA/PDA Systems diagram.

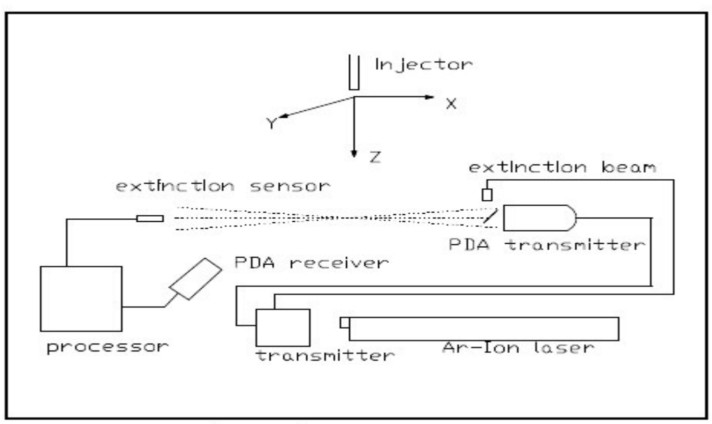


Figure 3.4: Experimental set-up (Palacios, Lecuona, Vega & Rodrigues, 2002)

Based on Figure 3.4, 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 3.5. This is when the diameter and mean velocity of the particle is measured.

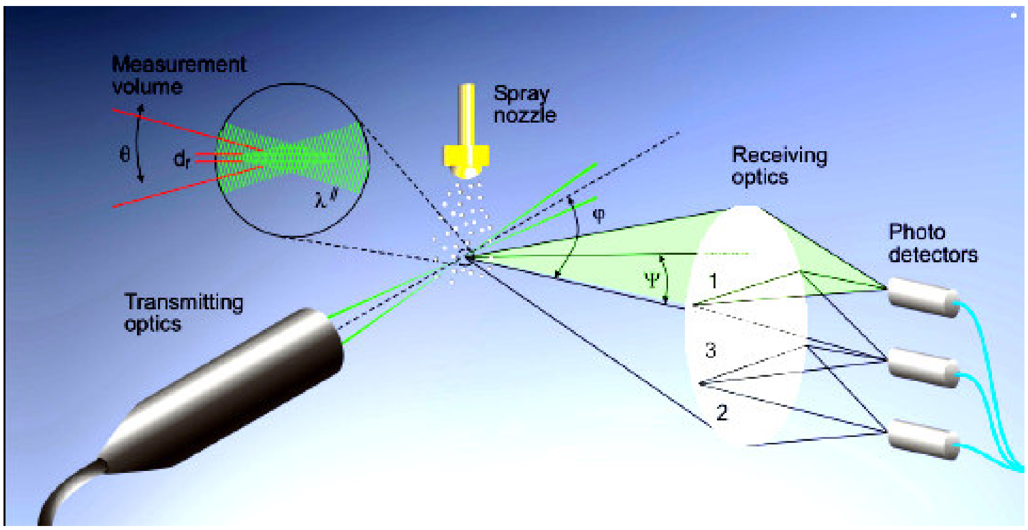


Figure 3.5: Picture showing intersection point for volume measurement

For the experiments, pressure, penetration distance, radial distance, and alcohol types are varied. The characteristics of alcohol are attached in Appendix A-2 for further information. The penetration distance and radial distance are varied as shown in Figure 3.6

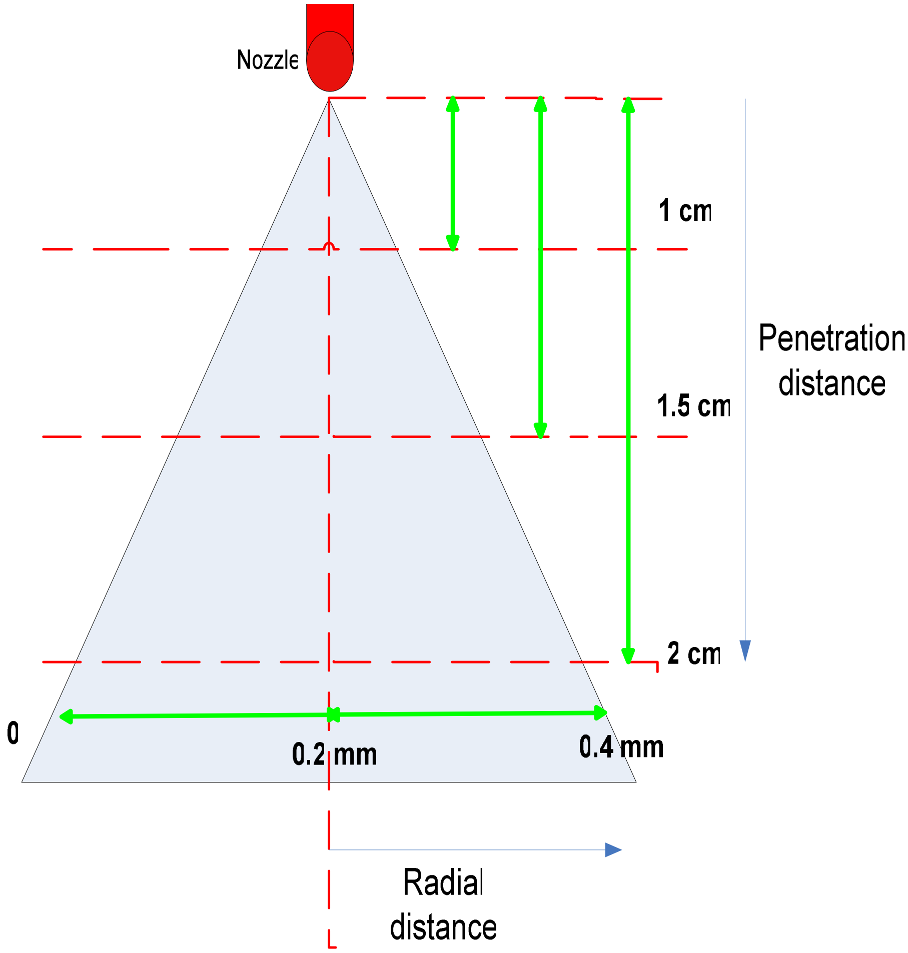


Figure 3.6: Diagram showing penetration distance and radial distance of spray area

3.4.2 Experiment to Observe Break up Zone

This experiment will be using high speed camera in order to capture the picture of the spray development. The picture is then evaluated. The experiment will vary pressure and liquid types in order to understand alcohols' characteristics. By taking pictures, the structure of the break up zone can be further understood. Figure 3.7 shows the experiment setup diagram:

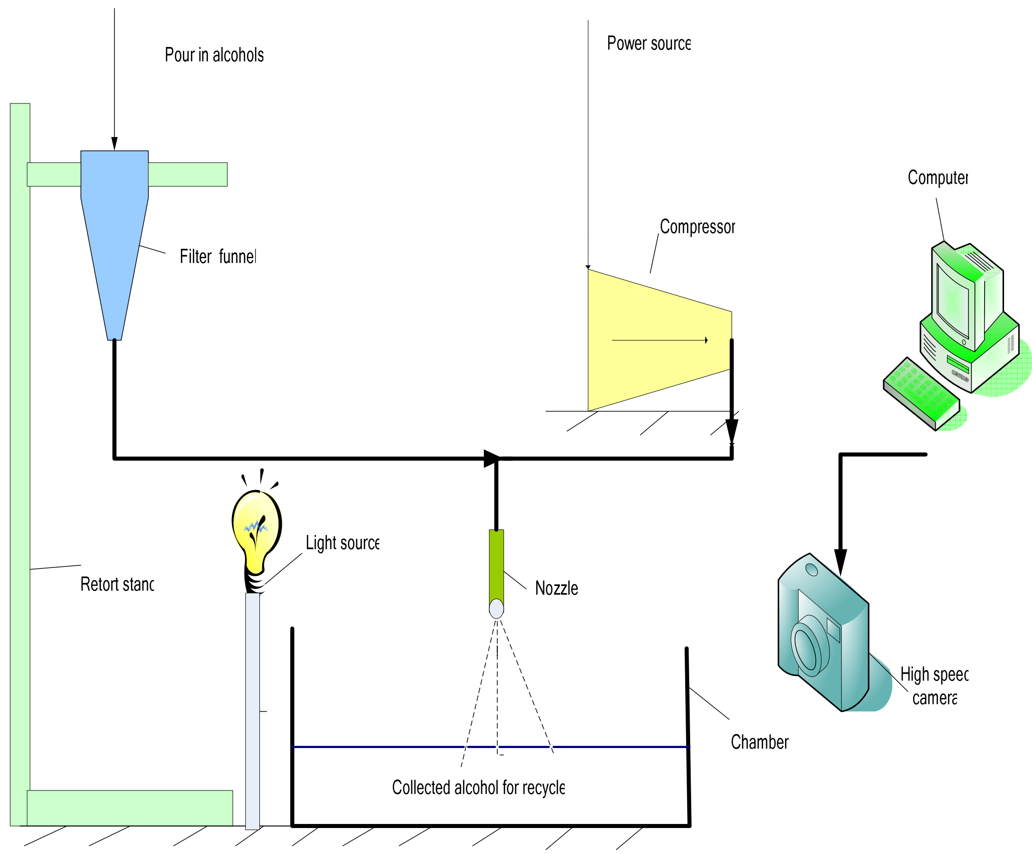


Figure 3.7: Experiment set up diagram to observe structure of break up zone

For this part, pictures are taken in order to see the break up structure of the alcohols. Pressure is varied at 0.5 bar, 1 bar and 1.5 bar. Figure 3.8 shows the arrangement of equipments in the lab:

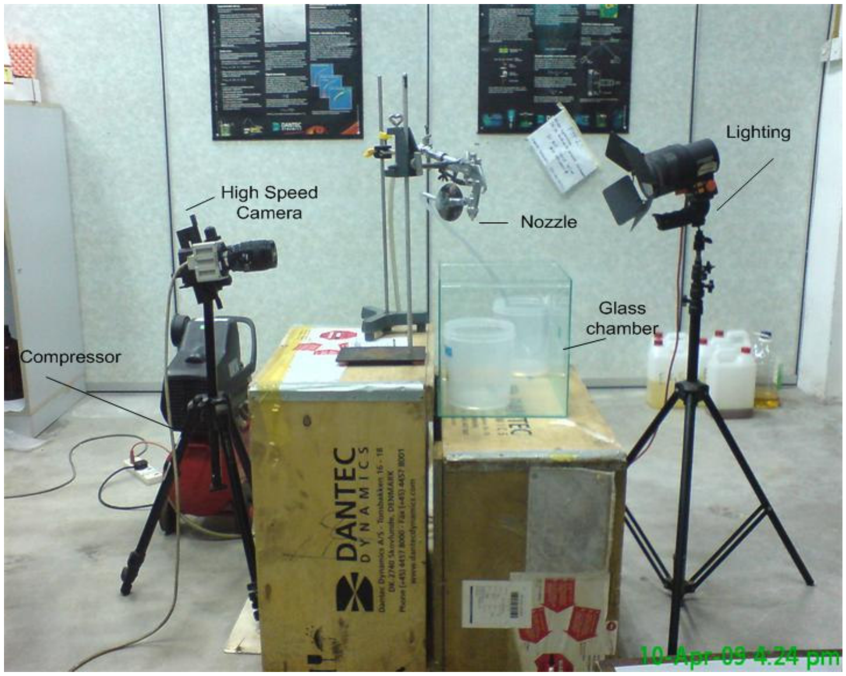


Figure 3.8: Arrangement of equipments to observe the break up zone structure.

3.4.3 Experiment Plan

Three experiments are planned for LDA/PDA. Pressure, penetration distance and radial distance are varied. For each experiment, the experiments are repeated three times for each fuel. This is illustrated in Table 3.1. However, experiments to observe the break up zone is planned by varying pressure to be 0.5 bar, 1.0 bar and 1.5 bar and it is illustrated in Table 3.2. The experiment at pressure 2.0 bar is excluded in this work because it is very difficult to capture the droplets. At high pressure the alcohols might evaporate, thus it is difficult to get the data for velocity and mean size of the droplets.

From the experiment plan, there are some experiments that have not been conducted due to insufficient of time and alcohols. The shaded blue columns and rows in Table 3.1 and Table 3.2 are the experiments which could not be done.

Table 3.1: Table of experiment plan for LDA/PDA Systems (Shaded rows and columns are the experiments which cannot be done).

Fuel	Trial	Pressure			Penetration Distance			Radial Distance			Radial Distance
					At 0.5 bar	At 1.0 bar	At 1.5 bar	At 0.5 bar	At 1.0 bar	At 1.5 bar	At 0.5 bar
		0.5 bar	1.0 bar	1.5 bar	1.0 cm 1.5 cm 2.0 cm	1.0 cm 1.5 cm 2.0 cm	1.0 cm 1.5 cm 2.0 cm	0 mm 0.2 mm 0.4 mm	0 mm 0.2 mm 0.4 mm	0 mm 0.2 mm 0.4 mm	By trial to find the spray boundary
Ethanol	R1										
	R2										
	R3										
Methanol	R1										
	R2										
	R3										
Propanol	R1										
	R2										
	R3										
Butanol	R1										
	R2										
	R3										

Table 3.2: Table of experiment plan to observe the break up structure

Fuel	Trial	Pressure		
		0.5 bar	1.0 bar	1.5 bar
Ethanol	R1			
Methanol	R1			
Propanol	R1			
Butanol	R1			

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Experiment To Determine Microscopic Characteristics

Three experiments are conducted to determine microscopic characteristics using LDA/PDA. One set of result of ethanol at 1.5 bar, obtained from LDA/PDA is shown in Figure 4.1. The results generated from LDA/PDA provide information on data count, downward velocity, horizontal velocity, and diameter of droplets. For interpretation, data count has to be multiplied by 2000. Average value of downward velocity and horizontal velocity are calculated. However, by using the information of diameter of droplets, the SMD is then calculated.

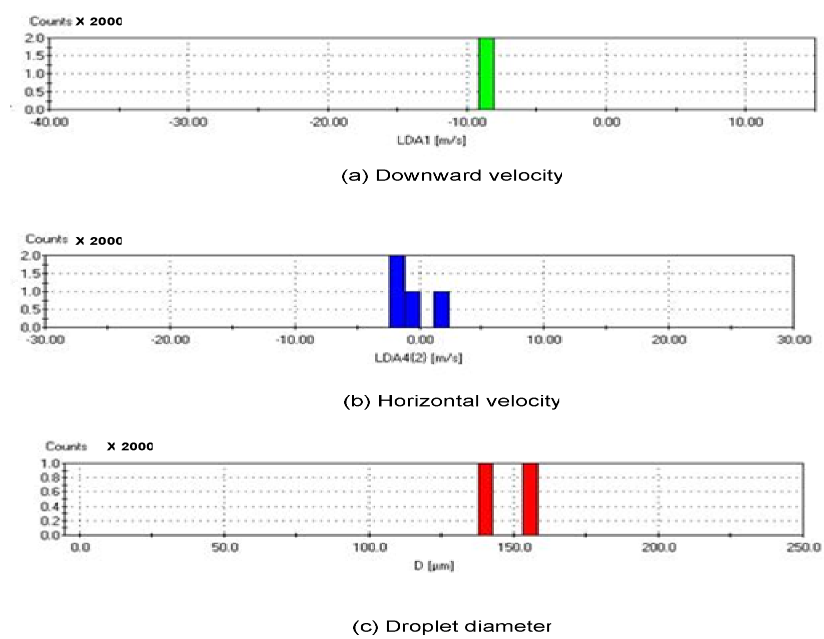


Figure 4.1: Graph generated from LDA/PDA Systems for ethanol at 1.5 bar.

The information from the above figure is tabulated into Table 4.1.

Table 4.1: Table of information of results generated from LDA/PDA

Vertical velocity(m/s)	Counts	Horizontal velocity	Counts	Diameter μm	Counts
-8.0	4000	-1.9232	4000	140.625	2000
		-0.7692	2000	154.6875	2000
		1.923	2000		

Sample calculation:

Average vertical velocity= -8 m/s (shows downward velocity)

Average Horizontal velocity= $\dfrac{\Sigma V}{n}$

$$= \frac{(-1.9232)(4000) + (-0.7692)(2000) + (1.923)(2000)}{(4000 + 2000 + 2000)}$$

$= -0.67315$ m/s (moving to the right)

$$\text{SMD} = D_{32} = \frac{\sum_{i=1}^{k} n_i D_i^3}{\sum_{i=1}^{k} n_i D_i^2}$$

$$= \frac{(2000)(140.625)^3 + (2000)(154.6875)^3}{(2000)(140.625)^2 + (2000)(154.6875)^2}$$

$= 148\mu m$

4.1.1 Pressure Variation

According to Figure 4.2, downward velocity with standard deviation is plotted for each alcohol at 0.5 bar, 1 bar and 1.5 bar. There is no specific pattern can be obtained from this graph. It is observed that at pressure 0.5 bar, the standard deviation is the largest compared to standard deviation at pressure at 1.0 bar and 1.5 bar. Standard deviation at pressure 1.5 bar is moderate and standard deviation at pressure 1.0 bar is the smallest. This shows that the experiments at 0.5 bar should be repeated to reduce errors. As a conclusion, pressure at 1 bar is reliable to run the experiment compared to pressure at 0.5 bar and 1.5 bar.

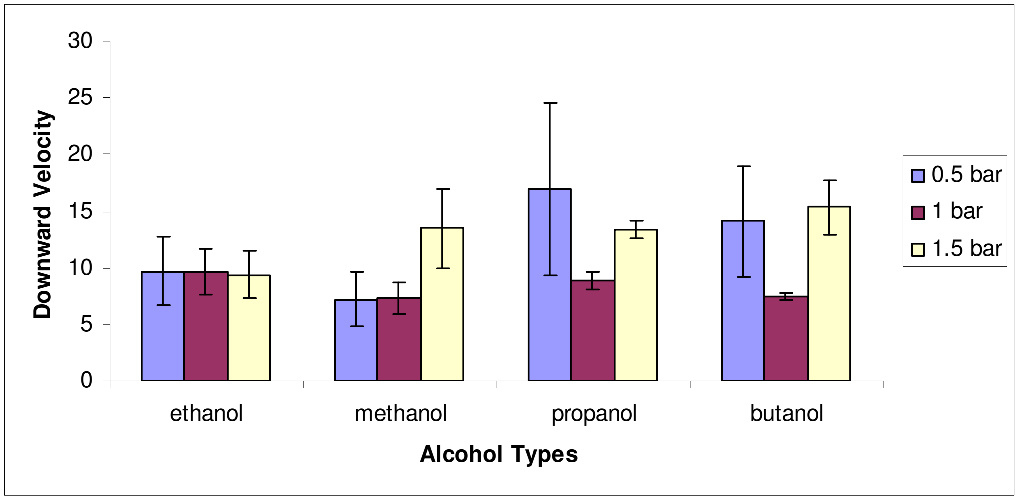


Figure 4.2: Graph of downward velocity versus alcohol types at various pressures

Referring to Figure 4.3, the horizontal velocity of methanol and propanol increases as the pressure increases. However, this does not apply to ethanol and butanol as the horizontal velocity decreases at 1.5 bar. It is affected by positive and negative value of horizontal velocity. Unlike downward velocity, horizontal velocity possesses both directions. Positive value means that the velocity is moving towards the left while negative velocity is moving towards the right. As a result, there is reduction in average horizontal velocity. According to the figure below, large standard deviation occur at pressure 0.5 bar and 1.5 bar. It shows that the horizontal velocity is spread apart at pressure 0.5 bar and 1.5 bar. In this case, direction of the movement causes this. Smallest standard deviation occurs at pressure 1 bar, thus the result is reliable.

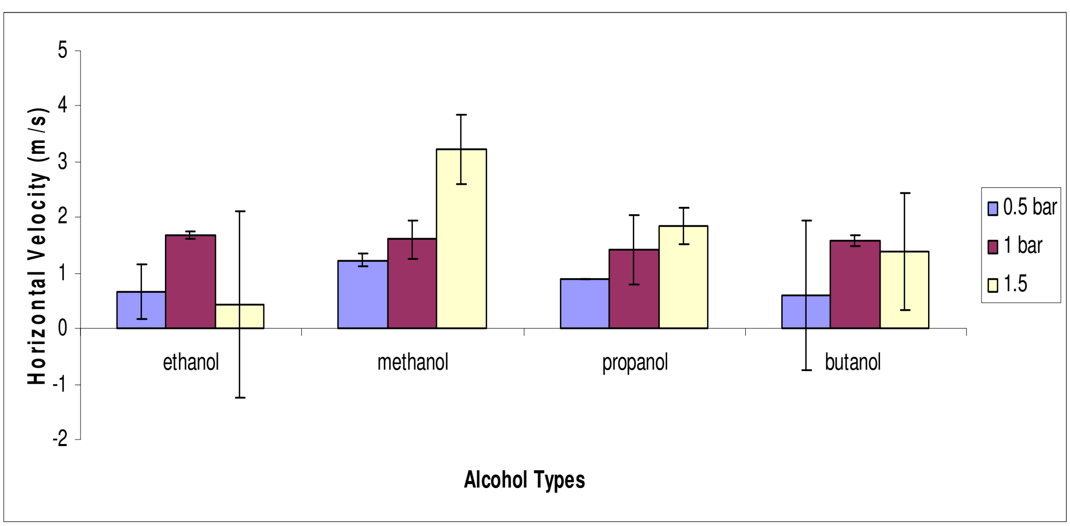


Figure 4.3: Graph of horizontal velocity versus alcohol types at various pressures

According to Figure 4.4 below, the SMD for ethanol, methanol and butanol decreases as pressure is increased from 1 bar to 1.5 bar. However, there is no special pattern for the SMD. This error could happen due to limited number of experiment trials. The error could happen due to difference in number of counts for each droplet which will result in accuracy of the SMD.

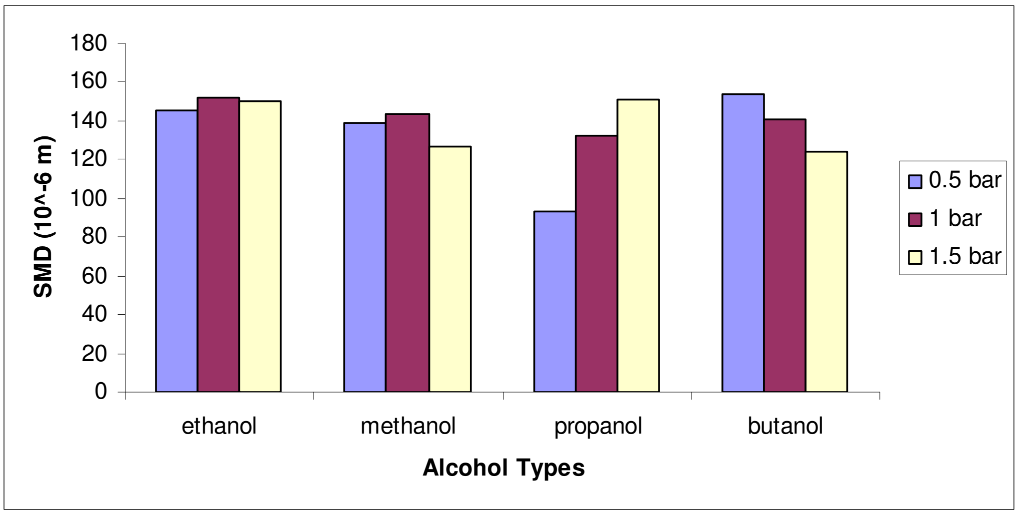


Figure 4.4: Graph of the SMD versus alcohol types at various pressures

4.1.2 Penetration Distance

Referring to Figure 4.5, penetration is varied at location 1 cm, 1.5 cm and 2.0 cm. The outcomes are explained below.

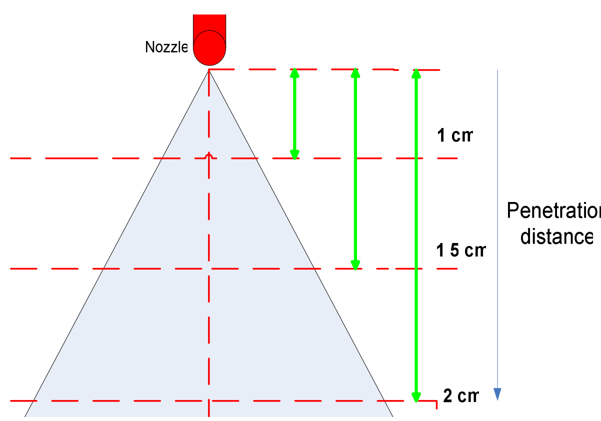


Figure 4.5: Diagram showing penetration distance of spray area at 0.5 bar

In Figure 4.6, downward velocity of ethanol and methanol increases as the pressure increases. However, propanol and butanol show the same pattern. Downward velocity of ethanol and methanol increases as the penetration changes from 1 cm to 2.0 cm. However, the downward velocity of propanol and butanol decreases as the penetration changes from 1 cm to 1.5 cm. Then, the velocity increases as the penetration moves from 1.5 cm to 2.0 cm. From the figure below, the pattern for standard deviation for propanol and butanol are about the same. Thus, it can be concluded that the results obtained for propanol and butanol are more reliable than the results obtained for ethanol and methanol.

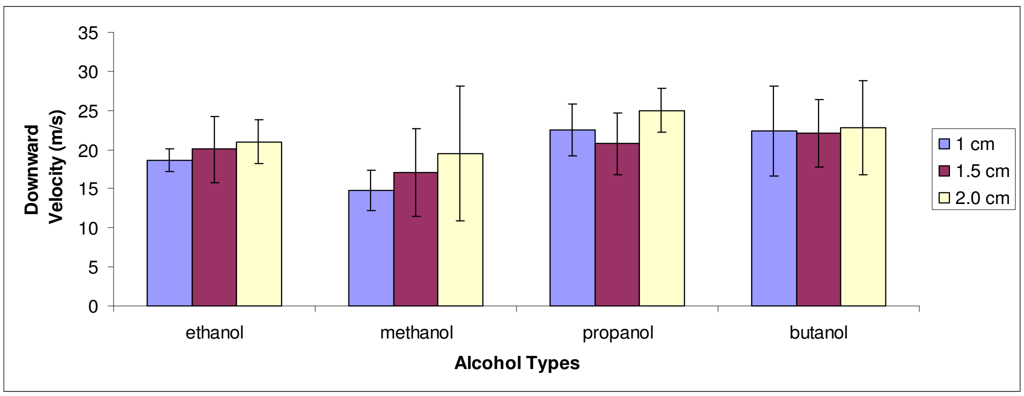


Figure 4.6: Graph of downward velocity versus alcohol types at various penetration distances.

According to Figure 4.7, the pattern for horizontal velocity ranges for location at 1 cm, 1.5 cm and 2.0 cm. The standard deviations for ethanol, methanol and butanol at all locations are quite large. Only propanol possesses small standard deviation among other alcohols. It is affected by positive and negative value of horizontal velocity. Unlike downward velocity, horizontal velocity possesses both directions. Positive value means that the velocity is moving towards the left while negative velocity is moving towards the right. When the standard deviation is large, the values are spread apart. In this case, direction of the movement causes this.

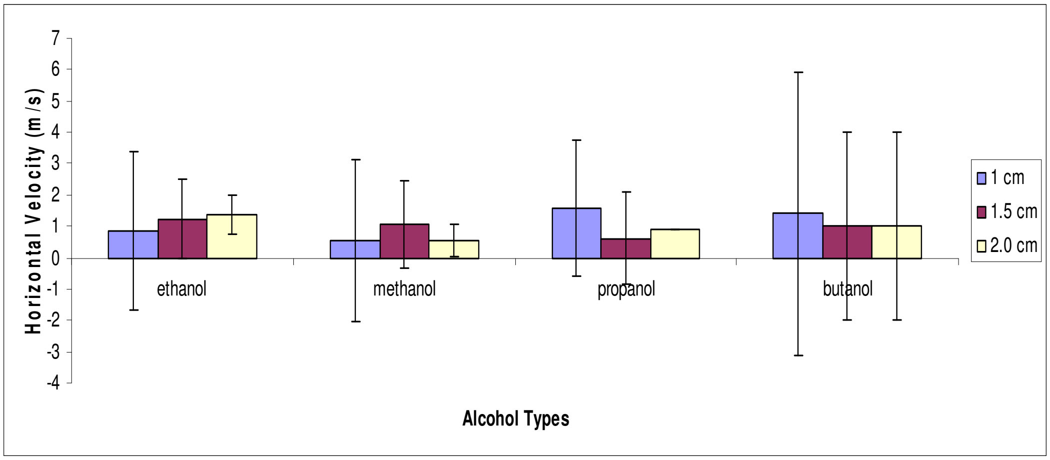


Figure 4.7: Graph of horizontal velocity versus alcohol types at various penetration distances.

Figure 4.8 shows that ethanol, propanol and butanol have the same pattern. The SMD increases as the penetration changes from location 1.0 cm to 1.5 cm. Then, the SMD decreases as penetration changes from location 1.5 cm to 2.0 cm. However, the SMD for methanol keeps increasing as the location changes from 1.0 cm to 2.0 cm.

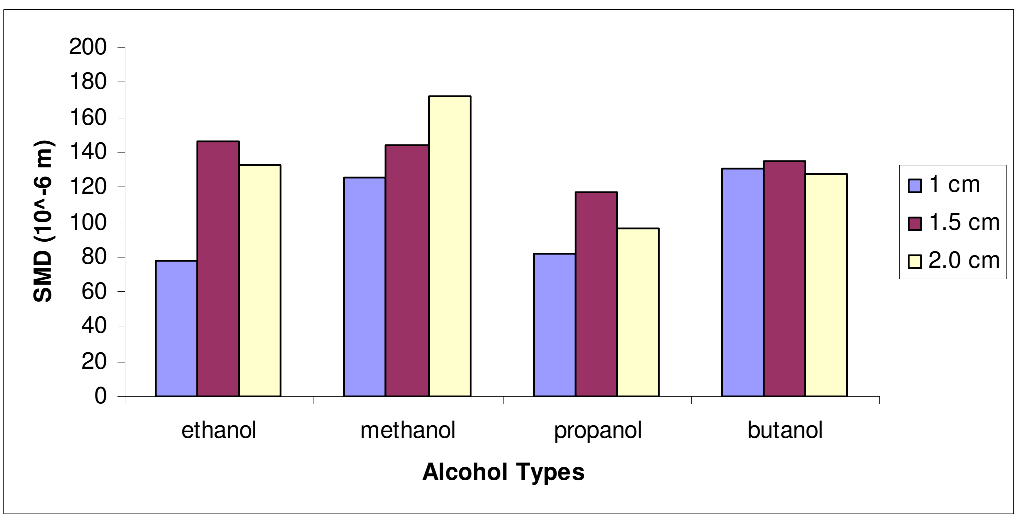


Figure 4.8: Graph of the SMD versus alcohol types at various penetration distances.

4.1.3 Radial Distance

For radial distance, three locations have been decided which are at 0 mm, 0.2 mm and 0.4 mm

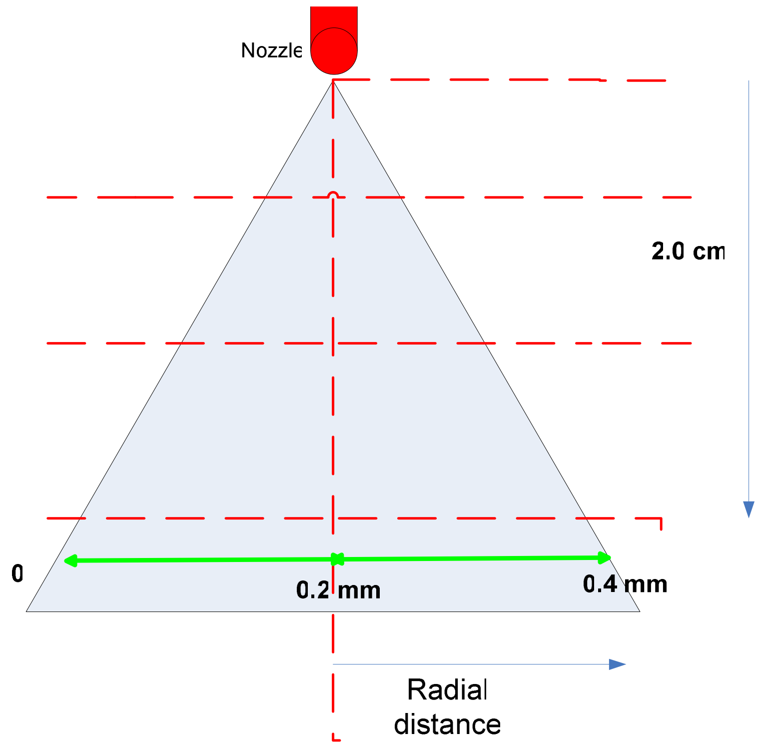


Figure 4.9: Diagram showing radial distance of spray area at pressure 0.5 bar

Based on Figure 4.10, ethanol and methanol show the same pattern when radial distance varies. However, downward velocity for propanol and butanol shows the same pattern. At location 0.2 mm, the standard deviation is the largest compared to standard deviation at location 0 mm and 0.4 mm. For overall, the downward velocities for the alcohols at various locations do not vary much. It ranges from 15 m/s to 27 m/s.

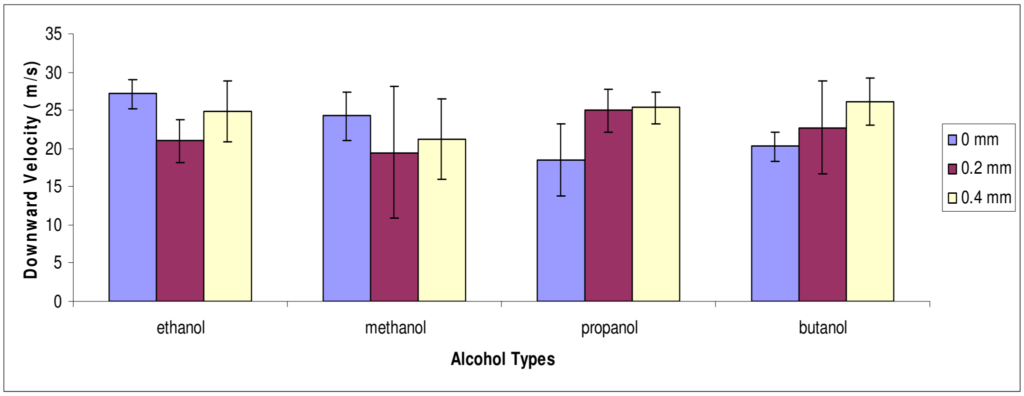


Figure 4.10: Graph of downward velocity versus alcohol types at various radial distances.

According to Figure 4.11, the pattern for horizontal velocity ranges for each location. It is obvious that the standard deviation is the largest for butanol at location 0 mm and 0.2 mm. Besides that, standard deviation for propanol is quite large at location 0 mm. The values are spread apart as horizontal velocity possesses both positive and negative velocity. Thus, it results in large standard deviation.

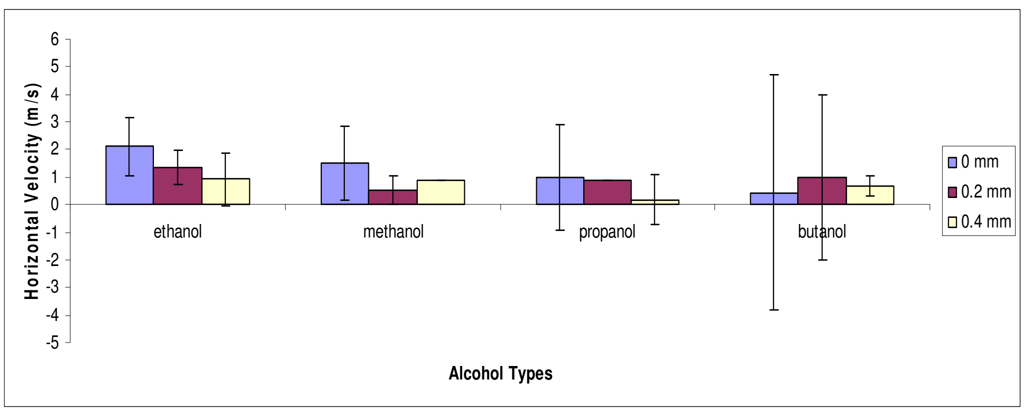


Figure 4.11: Graph of horizontal velocity versus alcohol types at various radial distances.

According to Figure 4.12, the pattern for the SMD ranges for all radial location. There is a pattern similarity between ethanol and methanol. However, there is no special pattern for generalization. This error could happen due to limited number of experiment trials. The error could happen due to difference in number of counts for each droplet which will result in accuracy of the SMD.

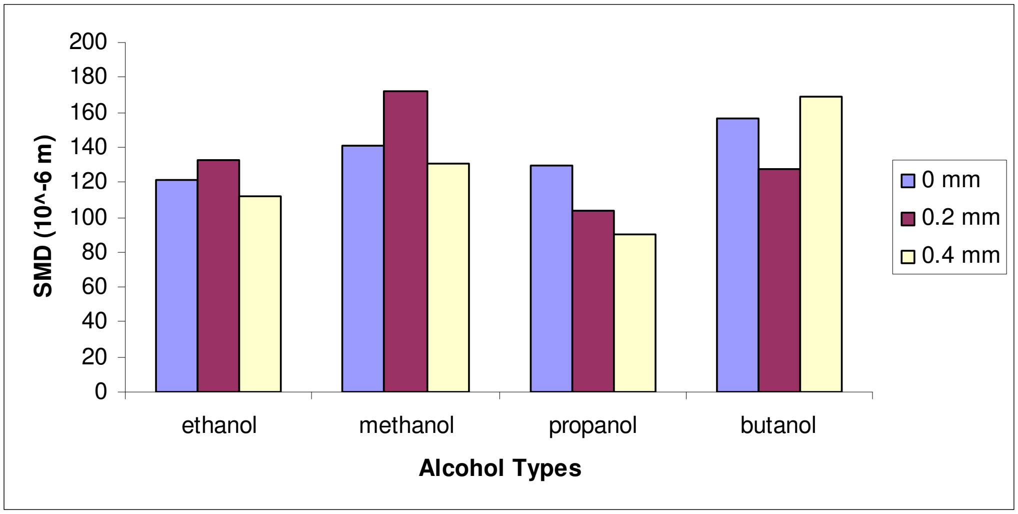


Figure 4.12: Graph of the SMD versus alcohol types at various radial distances

4.1.4 Radial Distance for Methanol

Methanol at 0.5 bar is the only alcohol that is used for detail radial distance. The offset radial distance is 0.8 mm. However, as it is approaching the spray boundary, it has smaller offset which is 0.6 mm and 0.4 mm. Thus, the distance of spray boundary is 7.4 mm.

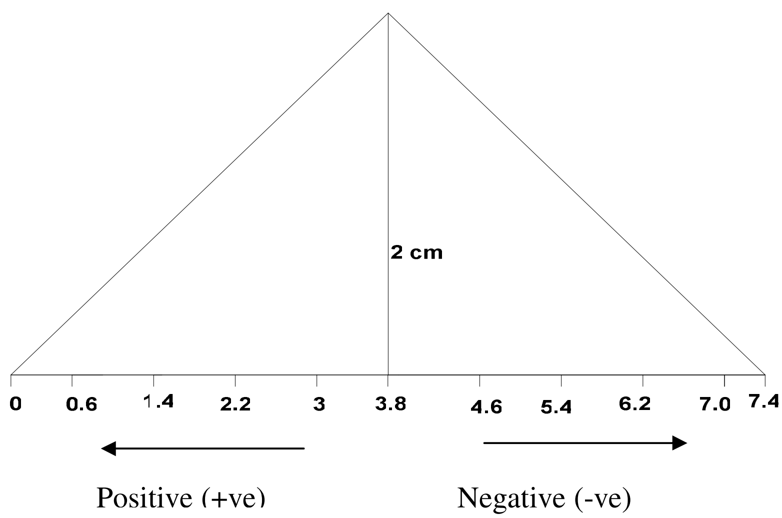


Figure 4.13: Diagram showing radial location of methanol spray area at 0.5 bar.

The downward velocity is almost the same at every radial location. The lowest velocity happens at 0.6 mm while the highest velocity occurs at 0 mm. The rest of the value ranges from 10 m/s to 20 m/s

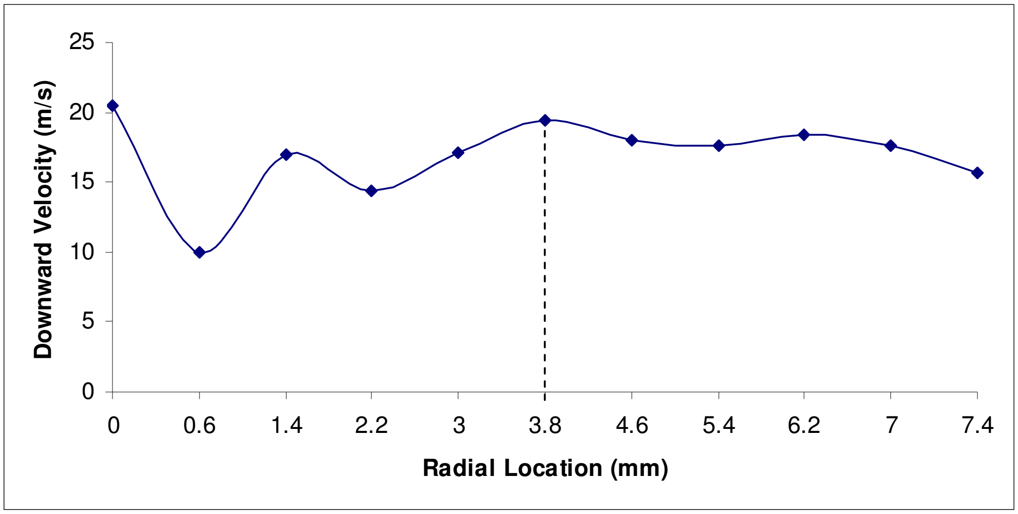


Figure 4.14: Graph of downward velocity versus radial location

In Figure 4.15, the horizontal velocity increases as it is approaching the spray boundary. The horizontal velocity is the lowest at location 6.2 mm. The positive horizontal velocity shows that it is moving to the left while negative value shows that the horizontal velocity is moving to the right.

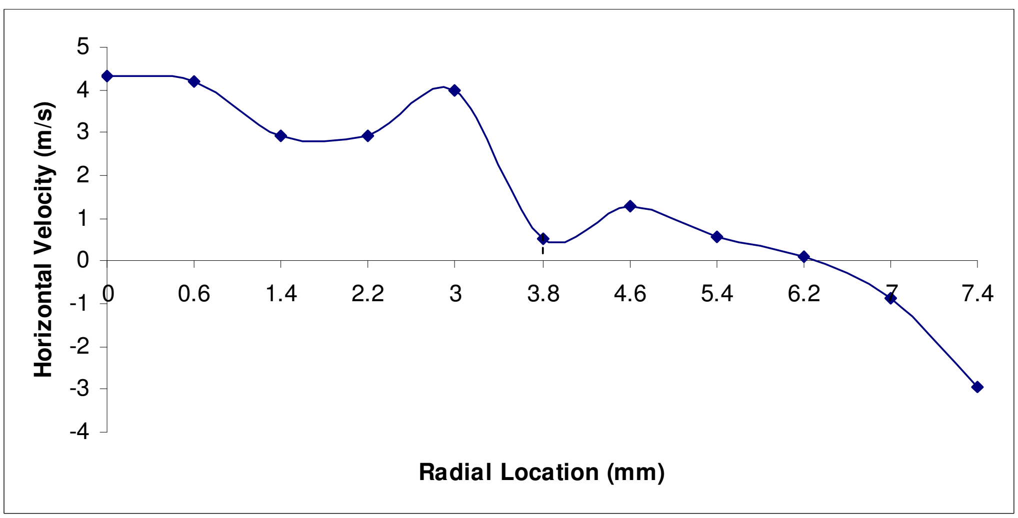


Figure 4.15: Graph of horizontal velocity versus radial location

Figure 4.16 is obtained by using the information of downward velocity and horizontal velocity. It is drawn graphically using Auto CAD in order to get the hypotenuse. The red lines in figure below shows the direction of the droplets.

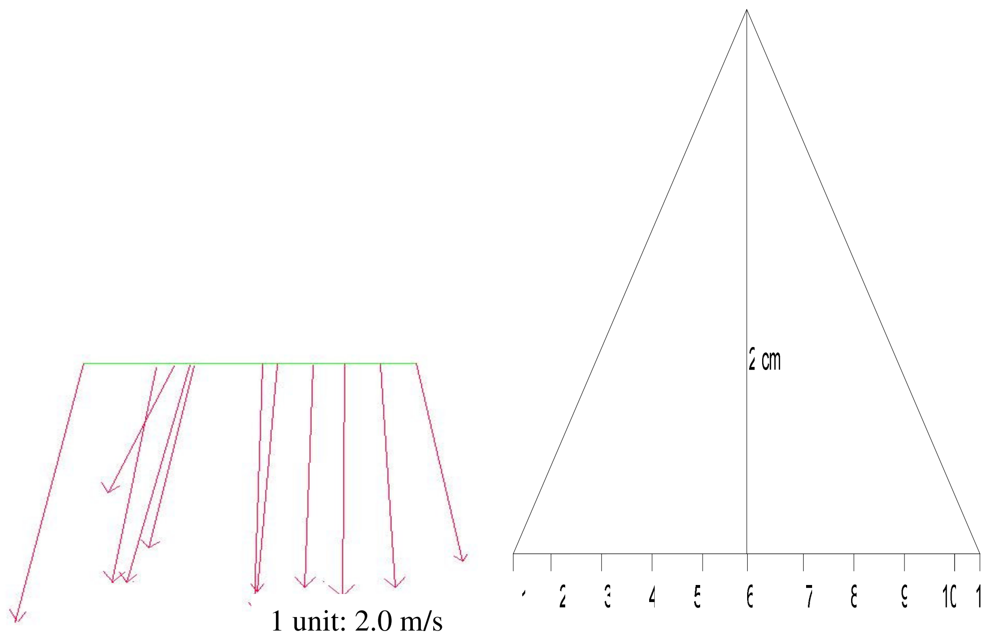


Figure 4.16: The direction of individual droplet

Then the SMD for location at 0.6 mm and at 7.4 mm are very low compared to the SMD at other locations. The SMD at the rest of the locations are about the same.

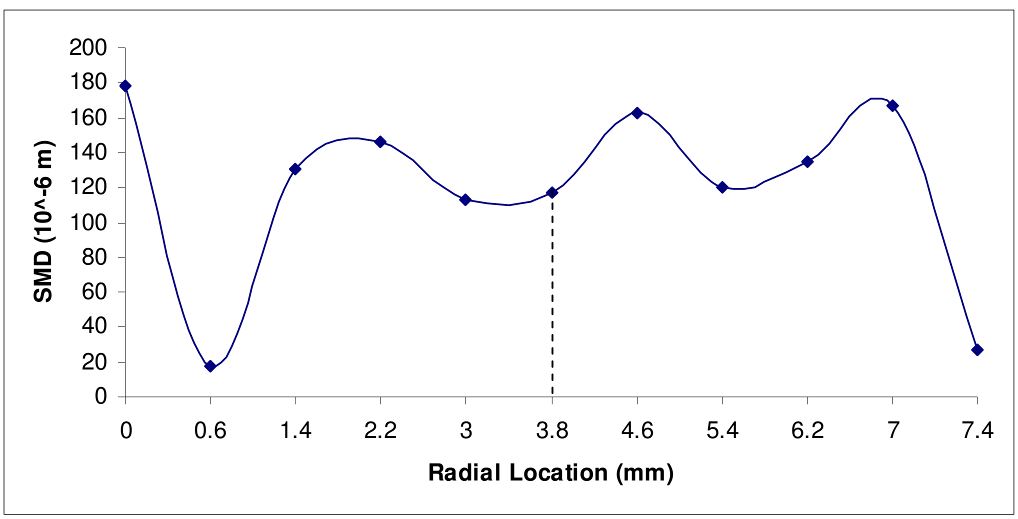


Figure 4.17: Graph of the SMD versus radial location

The experiments seem to be insufficient. The experiments cannot be repeated more than three times because there is short of alcohol stocks as it easily evaporates. From observation, about 76% percent of alcohol evaporates while the experiments are conducted. Thus, it is not feasible to repeat the experiments more than three times. Besides that, all the alcohols also experience temperature drop when experiments are being conducted

4.2 Experiment to study Break up structure

4.2.1 Ethanol

According to figure 4.18, the spray boundary is the largest and the droplets can be seen clearly. However, in Figure 4.19, the spray boundary is not as large as in Figure 4.20. The droplets are not as clear as in Figure 4.18. In Figure 4.20, the spray boundary distance is almost the same as in Figure 4.19. However, alcohol droplets cannot be seen as in Figure 4.19 and 4.20.

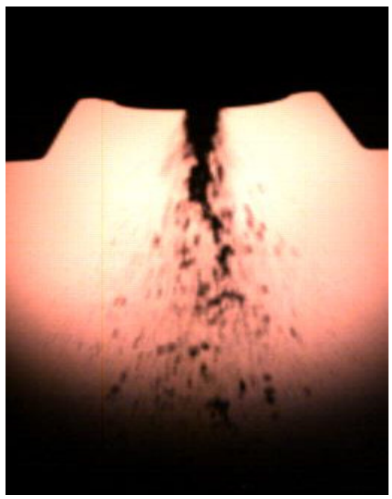


Figure 4.18: Break up structure of ethanol at 0.5 bar

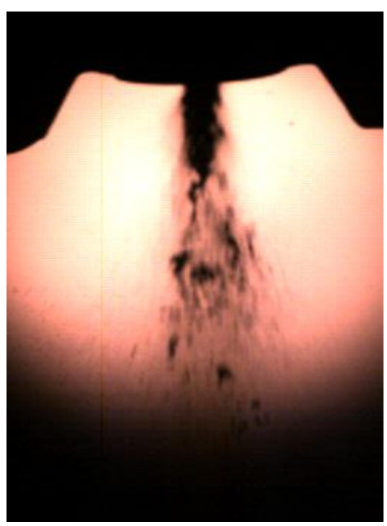


Figure 4.19: Break up structure of ethanol at 1.0 bar

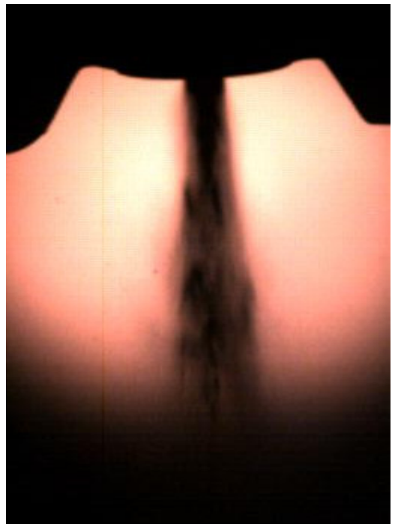


Figure 4.20: Break up structure of ethanol at1.5 bar

4.2.2 Methanol

In Figure 4.21, droplets of methanol spray can be seen quite clearly. However, in Figure 4.22, less of methanol droplets can be seen. Figure 4.21 and Figure 4.22 have rather similar spray boundary distance. In Figure 4.23, the alcohol droplets can not be seen as clearly as in previous two pictures. The spray boundary distance is the smallest among the three pictures.

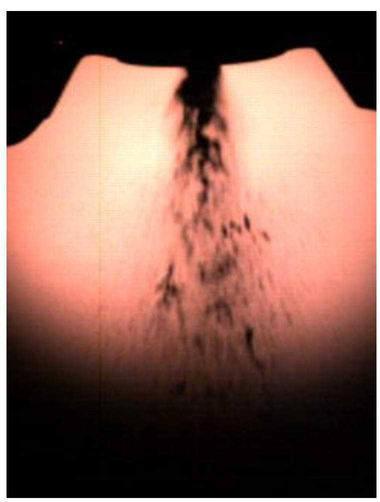


Figure 4.21: Break up structure of methanol at 0.5 bar

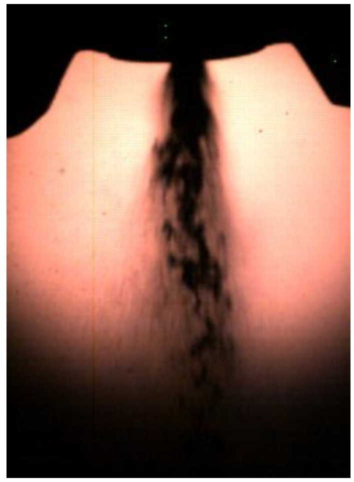


Figure 4.22: Break up structure of methanol at 1.0 bar

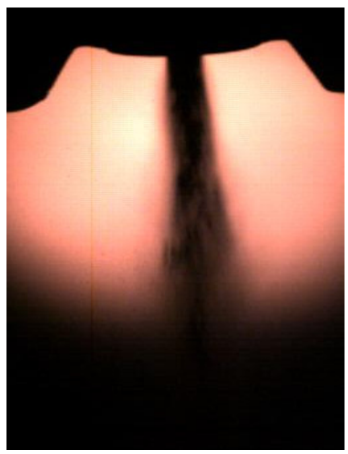


Figure 4.23: Break up structure of methanol at 1.5 bar

4.2.3 Propanol

According to figure 4.24, the spray boundary is the largest and the droplets can be seen clearly. However, in Figure 4.25, the spray boundary distance is smaller than the spray boundary distance in Figure 4.24. The droplets in Figure 4.25 are not as clear as in Figure 4.24. In Figure 4.26, the spray boundary distance is almost the same as in Figure 4.25. However, alcohol droplets cannot be seen as clear as in Figure 4.24 and 4.25.

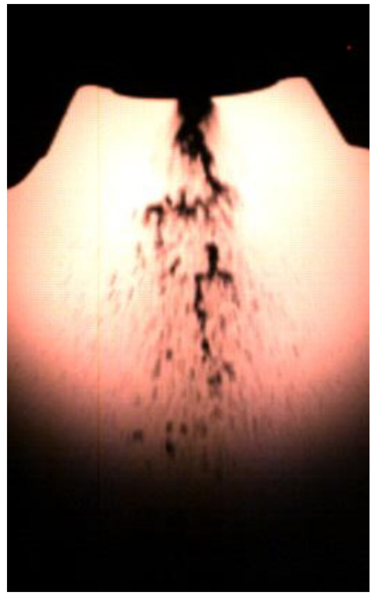


Figure 4.24: Break up structure of propanol at 0.5 bar

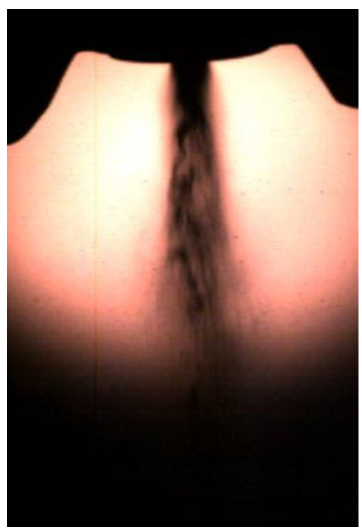


Figure 4.25: Break up structure of propanol at 1.0 bar

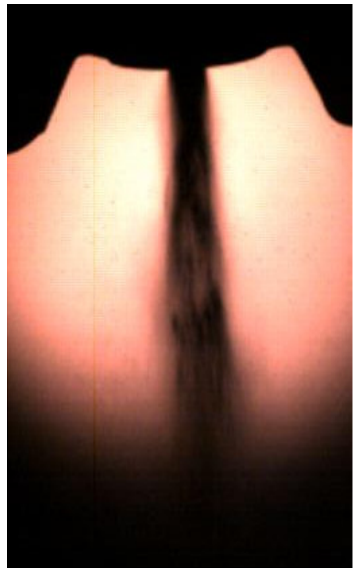


Figure 4.26: Break up structure of propanol at 1.5 bar

4.2.4 Butanol

In Figure 4.27, droplets of butanol spray can be seen quite clearly. However, in Figure 4.28, less of butanol droplets can be seen. Figure 4.27 and Figure 4.28 have rather similar spray boundary distance. In Figure 4.29, the alcohol droplets can not be seen as clearly as in previous two pictures. The spray boundary distance is the smallest among the three pictures.

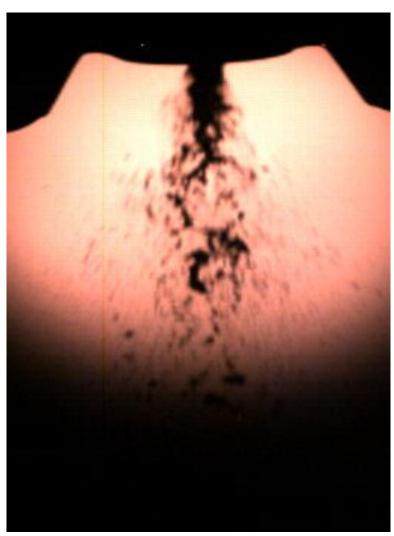


Figure 4.27: Break up structure of butanol at 0.5 bar

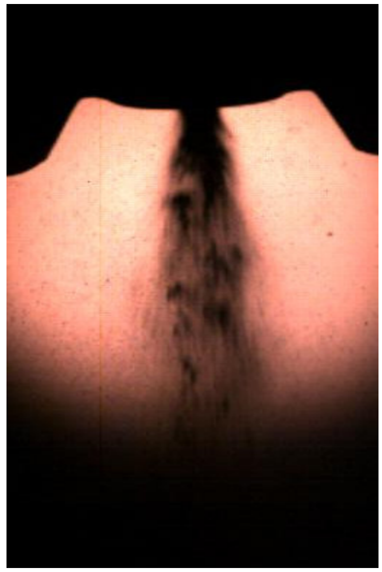


Figure 4.28: Break up structure of butanol at 1.0 bar

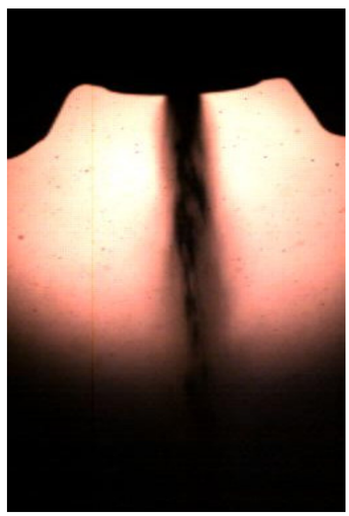


Figure 4.29: Break up structure of butanol at 1.5 bar

According to the previous figures, the pressure affects the distance of spray boundary. As the pressure increases, the distance of spray boundary lessens. Besides that, there will be less droplets of alcohol can be captured as it is moving at higher speeds when the pressure is increased.

To get a better result, the pictures should be taken from time 0, so that the spray development until it stabilizes can be seen clearly.

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CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objectives of this project are to study microscopic characteristics and break up structure of alcohol sprays. To understand microscopic characteristics, pressure, radial distance and penetration distance are varied in order to see the characteristics. The experiments are done using LDA/PDA.

Pressure variation

For downward velocity at pressure at 1 bar is reliable to run the experiment compared to pressure at 0.5 bar and 1.5 bar as it produces small standard deviation.

Penetration distance

The pattern for standard deviation for propanol and butanol are about the same. Thus, it can be concluded that the results obtained for propanaol and butanol are more reliable than the results obtained for ethanol and methanol.

Radial distance

For overall, the downward velocities for the alcohols at various locations do not vary much. It ranges from 15 m/s to 27 m/s.

Generally, analysis shows that the horizontal velocity always spread apart as the standard deviation is normally large. In this case, direction of the movement causes this. However, there is no special pattern for SMD. This error could happen due to limited number of experiment trials. The error could also happen due to differences in number of counts for each set experiment which will result in accuracy of the SMD.

The second experiment is done to observe the break up structure of alcohol sprays. Pressure is varied to be 0.5 bar, 1 bar and 1.5 bar. The pictures of spray structure are taken using high speed camera. As the pressure increases, less droplets can be captured due to high velocity of the droplets. Besides that, the spray boundary decreases as the pressure increases.

5.2 Recommendations

Generally, the experiments should be done more than three times in order to get more convincing results so that it would be much reliable.

Pressure variation

The experiments should be run more than three times for each set in order to get more accurate results and pressure should be varied more than 1.5 bar.

Penetration distance

The experiments should be done at more locations, at different pressures for better results.

Radial distance

The experiments should be done at more locations, at different pressures for better images.

For the experiments to observe the break up zone of alcohol sprays, the pictures should be taken from time 0, so that the spray development until it stabilizes can be seen clearly. Besides that, spray angle should be monitored in each set of experiment for accuracy.

REFERENCES

Azzopardi, B.J and Hutchinson, P. 1983, "*The disintegration of liquid droplet*", UKEA Report AERE R10929

Beam, J 2009, *What is E85?,* viewed 15 February 2009, < http://www.wisegeek.com/what-is-e85.htm>

Bechtold R.L.2002, *Alternative Fuels*, Warrandale, Global Mobility Database

Biofuels barometer 2007 - EurObserv'ER Systèmes solaires Le journal des énergies renouvelables n° 179, s. 63-75, 5/2007

Cook, J 2009, *California Gasoline Price Study,* viewed 23 March 2009, <http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2005/house050905/house050905.html>

Fisher Scientific, 2009, *Laboratory supplies ad chemicals manufacturing*, viewed 25 Match 2009,<www.fisher.co.uk>

Ganesan V. 2004, *International Combustion Engines*, North America, Mc Graw Hill

Hinze, J.O., "Critical Speeds and Sizes of Liquid Globules," *Applied Scientific Research*, A1, 1949, pp. 273-288

Hinze, J.O., "Fundamentals of the Hydrodynamic Mechanism of Splitting in Dispersion Processes," *A.I.Ch.E. Journal*, Vol. 1, No. 3, 1955, pp. 289-295.

Keenan, J.D 2008 *Alcohol as an Engine Fuel*, viewed 10 Sept 2008,<http://journeytoforever.org/biofuel_library/ethanol_motherearth/me1.html>

Kyoto protocol to the United Nations framework convention on climate change, 1997 (United Nations, New York)

Krzeczkowski, S.A., "Measurement of Liquid Droplet Disintegration Mechanism," *Int. J. Multiphase Flow*, Vol. 6, 1980, pp. 227-239.

Lane, W.R. and Dorman, R.G., "Further Experiments on the Shattering of Drops by a Supersonic Air Blast," Tech. Paper No., 279, Porton, England, 1952.

Lane, W.R., "Shatter of Drops in Stream of Air," *Ind. Eng. Chem.*, 43, No. 4, 1951, pp. 1312-1317.

Lane, W.R., Prewett, W.C., and Edwards, J., "Some Experiments on the Shatter of Drops by Transient Blast of Air," Tech. Paper No.115, Serial 15, Porton, England, 1949

Wikipedia, 2009, *Laser Doppler Anemometry*, viewed 25 April 2009,

<http://en.wikipedia.org/wiki/Laser_Doppler_velocimetry>

Lefebvre, A.H., Atomization and Sprays, Hemisphere Publishing, New York, 1989

Negrão, 2008 *Alcohol As An International Commodity*, viewed 12 December 2008, <http://ecen.com/eee47/eee47e/alcohol_as_commodity.htm>

NEVC, 2008, *E85 Prices*, viewed 29 December 2008,

<http://www.e85prices.com/>

Palacios, E., Lecuona, A., de Vega, M., and Rodriguez, P.*Sensitivity to optical of particle concentration and volume flux with a phase doppler anemometer in dilute sprays.* Avda. De la Universidad,Madrid, Spain.

Philadelphia, Hubbard bros, 1876, *infao5501.ag5.mpi-sb.mpg.de:8080/topx/archive?link=**Wikipedia**-Lip6-2/34725.xml&style*

Rayleigh, Lord (1873), " On the instability of jets", Proc. London Maths. Soc, 10, pp 4-13

The Engineering ToolBox 2005, *Weber Number,* viewed 1 June 2009, <http://www.engineeringtoolbox.com/weber-number-d_583.html>

Wikipedia, 2009, *Alcohol Fuel*, viewed 12 January 2009, < http://en.wikipedia.org/wiki/Alcohol_fuel>

Wikipedia, 2009, *Propanol*, viewed 10 January 2009, <http://en.wikipedia.org/wiki/Propanol>

Wikipedia, 2009,*Tert-Butanol*, viewed 13 March 2009, <http://en.wikipedia.org/wiki/Tert-Butanol>

Tan, J., Papadakis, M. and Samapath M.K. 2005.*Computational study of large droplet breakup in the vicinity of an airfoil.* Report Number DOT/FAA/AR-05/42, Wichita State University, Wichita,USA

APPENDICES

APPENDIX A-1: GANTT CHART

APPENDIX A-2 : PROPERTIES OF ALCOHOLS

Ethanol

Ethanol, 96% v/v — Specified

Application – Specified reagent for general laboratory work (SLR) 22

E/0551/17‡	2.5 L	GB
E/0551/PC17‡	2.5 L	PL
E/0551DF/17† Duty free	2.5 L	GB
E/0551DF/C17† Duty free	2.5 L	PL

† Duty free ethanol is supplied direct from our bonded warehouse in Loughborough to customers who have the necessary approval from H.M. Revenue and Customs.

‡ Excise Duty, at the current rate, will be added to the prices shown.

C_2H_5OH M.W. 46.07

Guaranteed analysis

Acidity/Alkalinity	<0.005 meq/g
Colour	<20 APHA
Residue after evaporation	<0.01%
Substances reducing $KMnO_4$	<0.001%
Calcium (Ca)	<5 ppm
Copper (Cu)	<1 ppm
Iron (Fe)	<2 ppm
Lead (Pb)	<1 ppm
Magnesium (Mg)	<2 ppm
Potassium (K)	<2 ppm
Sodium (Na)	<0.001%
Zinc (Zn)	<2 ppm
Total phosphorus (P)	<2 ppm
Total silicon (Si)	<1 ppm
Total sulfur (S)	<5 ppm

Chemical compatibilities

A table showing chemical compatibility can be found on page 609. Our Technical Information section can be found on page 600 onwards.

Ethanol, 96% v/v — Certified

Application – For analysis 22

Conforms to BP, EP and USP specifications

E/0555/17‡	2.5 L	GB
E/0555/PC17‡	2.5 L	PL
E/0555/25‡	25 L	MD
E/0555DF/17† Duty free	2.5 L	GB
E/0555DF/C17† Duty free	2.5 L	PL
E/0555DF/25† Duty free	25 L	MD

† Duty free ethanol is supplied direct from our bonded warehouse in Loughborough to customers who have the necessary approval from H.M. Revenue and Customs.

‡ Excise Duty, at the current rate, will be added to the prices shown.

C_2H_5OH M.W. 46.07

Physical Constant

Weight per mL at 20°C	0.811g

Guaranteed Analysis

Acidity/Alkalinity	<0.0005 meq/g
Colour	<10 APHA
Other impurities	<0.02%
Residue after evaporation	<0.001%
Substances darkened by H_2SO_4	<10 APHA
Substances reducing $KMnO_4$	<5 ppm
Calcium (Ca)	<1 ppm
Copper (Cu)	<0.05 ppm
Iron (Fe)	<0.2 ppm
Lead (Pb)	<0.05 ppm
Magnesium (Mg)	<0.2 ppm
Potassium (K)	<0.1 ppm
Sodium (Na)	<2 ppm
Zinc (Zn)	<0.2 ppm
Total phosphorus (P)	<0.02 ppm
Total silicon (Si)	<0.05 ppm
Total sulfur (S)	<2 ppm
Acetone	<0.002%
Furfuraldehyde	<0.001%
Methanol	<0.2%
Propan-2-ol	<0.02%

Typical Analysis

Aluminium (Al)	<0.1 ppm
Barium (Ba)	<0.02 ppm
Cadmium (Cd)	<0.05 ppm
Chromium (Cr)	<0.02 ppm
Cobalt (Co)	<0.02 ppm
Lithium (Li)	<0.02 ppm
Manganese (Mn)	<0.02 ppm
Molybdenum (Mo)	<0.02 ppm
Nickel (Ni)	<0.05 ppm
Strontium (Sr)	<0.02 ppm
Titanium (Ti)	<0.02 ppm
Vanadium (V)	<0.02 ppm

Figure 2: Properties of ethanol

Methanol

Methanol ≥99.9%

For analysis
This product meets ACS specifications 22

Certified Analytical Reagent

Assay (GC) ≥ 99.9 %

M/4000/PB08	500mL	PCG
M/4000/15	1L	GB
M/4000/17	2.5L	GB
M/4000/PB17	2.5L	PCG
M/4000/PC17	2.5L	PL
M/4000/21	5L	MC
M/4000/25	25L[1]	MD
M/4000/27	200L[1]	MD

CH_3OH M.W. 32.04

Guaranteed analysis

Assay (GC)	≥ 99.9 %
Acidity/alkalinity	≤ 0.0005 meq/g
Calcium (Ca)	≤ 0.2 ppm
Colour	≤ 5 APHA
Copper (Cu)	≤ 0.02 ppm
Ethanol	≤ 0.05 %
Iron (Fe)	≤ 0.1 ppm
Lead (Pb)	≤ 0.02 ppm
Magnesium (Mg)	≤ 0.05 ppm
Phosphorus, total (P)	≤ 0.05 ppm
Potassium (K)	≤ 0.5 ppm
Propan-2-ol	≤ 0.005 %
Residue after evaporation	≤ 10 ppm
Sodium (Na)	≤ 0.5 ppm
Substances darkened by H_2SO_4 (APHA)	≤ 5 APHA
Substances reducing $KMnO_4$	≤ 0.00025 %
Sulfur, total (S)	≤ 0.1 ppm
Water	≤ 0.05 %
Zinc (Zn)	≤ 0.05 ppm

Typical analysis

Aluminium (Al)	<0.05 ppm
Barium (Ba)	<0.01 ppm
Cadmium (Cd)	<0.02 ppm
Chromium (Cr)	<0.01 ppm
Cobalt (Co)	<0.01 ppm
Lithium (Li)	<0.01 ppm
Manganese (Mn)	<0.01 ppm
Molybdenum (Mo)	<0.01 ppm
Nickel (Ni)	<0.01 ppm
Selenium (Se)	<0.01 ppm
Silicon, total (Si)	≤ 0.05 ppm
Strontium (Sr)	<0.01 ppm
Titanium (Ti)	<0.01 ppm
Vanadium (V)	<0.01 ppm

Physical constant

Boiling point	64.6°C
Refractive index	1.3288
Wt/mL @ 20°C	0.7915 g

This product carries lot data on the pack label.

[1]See page 586 for suitable tap.

Methanol >99.8%

For HPLC. 25

HPLC Certified

Assay >99.8%

M/4056/15	1L	GB
M/4056/PB17	2.5L	GB
M/4056/17	2.5L	PCG

CH_3OH M.W. 32.04

Guaranteed analysis

Assay	>99.8%
Acidity	<0.0002 meq/g
Alkalinity (meq/g)	<0.0002 meq/g
Residue after evaporation	<5 ppm
Water	<0.02 %

Max. absorbance (1 cm cell v HPLC water)

Absorbance @ 210nm	0.20 A.U./63%T
Absorbance @ 220nm	0.10 A.U./80%T
Absorbance @ 230nm	0.05 A.U./89%T
Absorbance @ 240nm	0.02 A.U./96%T
Absorbance @ 250nm	0.005 A.U./99%T
Absorbance @ 260nm	0.005 A.U./99%T

This product carries lot data on the pack label (except gradient analysis).

Filtered to 0.2µm.

Methanol >99.9%

For HPLC gradient analysis. 25

HPLC Certified

Assay >99.9%

M/4058/15	1L	
M/4058/17	2.5L	GB
M/4058/PB17	2.5L	PCG

CH_3OH M.W. 32.04

Guaranteed analysis

Assay	>99.9%
Acidity	<0.0002 meq/g
Alkalinity (meq/g)	<0.0002 meq/g
Residue after evaporation	<5 ppm
Water	<0.05 %

Max. absorbance (1 cm cell v HPLC water)

Absorbance @ 210nm	0.20 A.U./63%T
Absorbance @ 220nm	0.10 A.U./80%T
Absorbance @ 230nm	0.05 A.U./89%T
Absorbance @ 240nm	0.01 A.U./98%T
Absorbance @ 250nm	0.005 A.U./99%T
Absorbance @ 260nm	0.005 A.U./99%T

Conditions

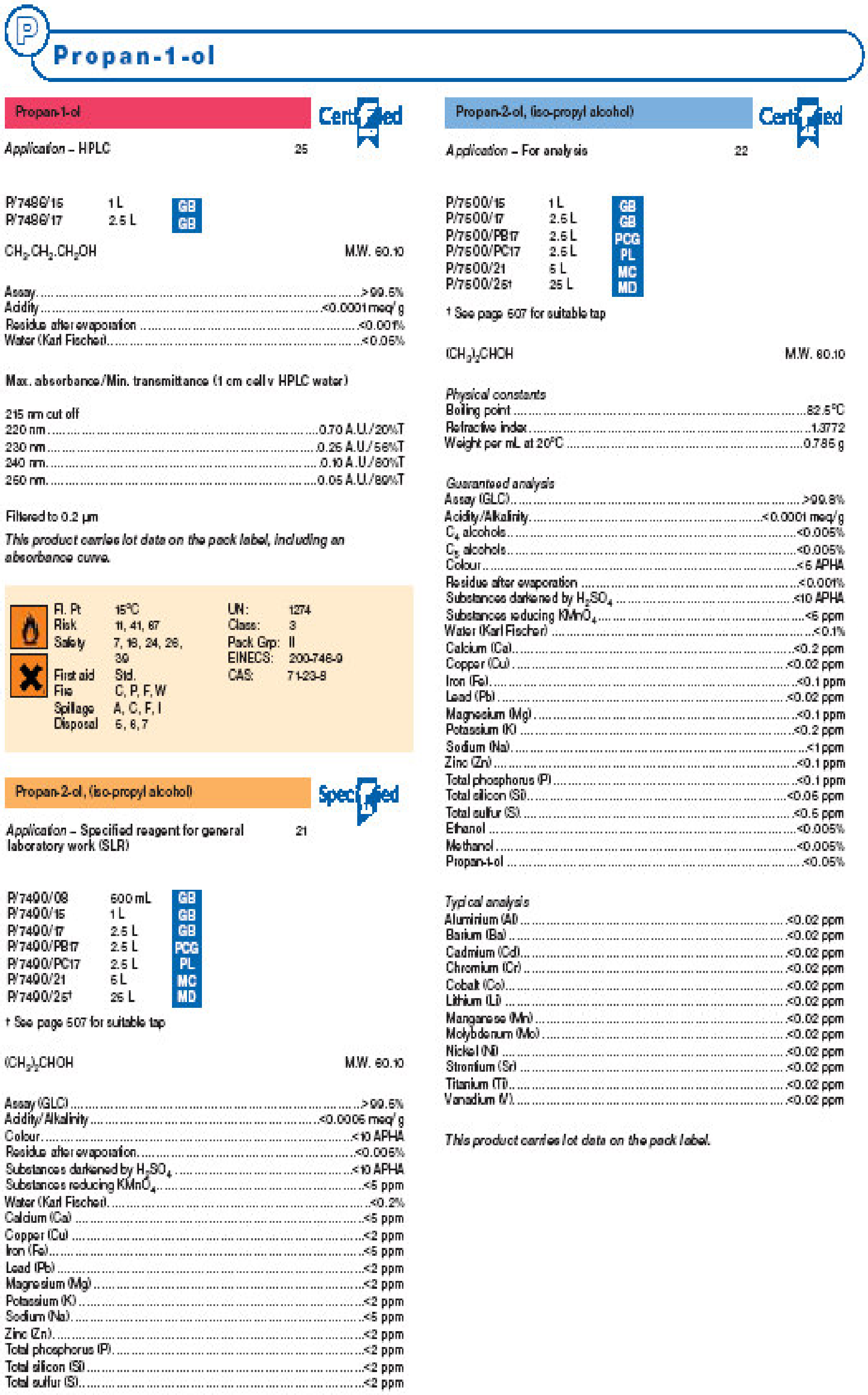
Column:	C18 Reverse phase
Flow rate:	2mL/min
Wavelength:	254nm
Absorbance scale:	0 to 0.8 A.U.F.S.
Solvent A:	Water
Solvent B:	Methanol
Gradient:	Linear from 95% A/5% B to 100% B over 20min

This product carries lot data on the pack label (except gradient analysis).

Filtered to 0.2µm.

380

Figure 3: Properties of methanol



Propan-1-ol

Propan-1-ol — Certified

Application – HPLC 25

P/7496/15	1 L	GB
P/7496/17	2.5 L	GB

$CH_3.CH_2.CH_2OH$ M.W. 60.10

Assay .... >99.5%
Acidity .... <0.0001 meq/g
Residue after evaporation .... <0.001%
Water (Karl Fischer) .... <0.05%

Max. absorbance/Min. transmittance (1 cm cell v HPLC water)

215 nm cut off
220 nm 0.70 A.U./20%T
230 nm 0.25 A.U./56%T
240 nm 0.10 A.U./80%T
250 nm 0.05 A.U./89%T

Filtered to 0.2 µm

This product carries lot data on the pack label, including an absorbance curve.

Fl. Pt	15°C	UN:	1274
Risk	11, 41, 67	Class:	3
Safety	7, 16, 24, 26, 39	Pack Grp:	II
		EINECS:	200-746-9
First aid	Std.	CAS:	71-23-8
Fire	C, P, F, W		
Spillage	A, C, F, I		
Disposal	5, 6, 7		

Propan-2-ol, (iso-propyl alcohol) — Specified

Application – Specified reagent for general laboratory work (SLR) 21

P/7490/08	500 mL	GB
P/7490/15	1 L	GB
P/7490/17	2.5 L	GB
P/7490/PB17	2.5 L	PCG
P/7490/PC17	2.5 L	PL
P/7490/21	5 L	MC
P/7490/25†	25 L	MD

† See page 507 for suitable tap

$(CH_3)_2CHOH$ M.W. 60.10

Assay (GLC) .... >99.5%
Acidity/Alkalinity .... <0.0005 meq/g
Colour .... <10 APHA
Residue after evaporation .... <0.005%
Substances darkened by H_2SO_4 .... <10 APHA
Substances reducing $KMnO_4$ .... <5 ppm
Water (Karl Fischer) .... <0.2%
Calcium (Ca) .... <5 ppm
Copper (Cu) .... <2 ppm
Iron (Fe) .... <5 ppm
Lead (Pb) .... <2 ppm
Magnesium (Mg) .... <2 ppm
Potassium (K) .... <2 ppm
Sodium (Na) .... <5 ppm
Zinc (Zn) .... <2 ppm
Total phosphorus (P) .... <2 ppm
Total silicon (Si) .... <2 ppm
Total sulfur (S) .... <2 ppm

Propan-2-ol, (iso-propyl alcohol) — Certified

Application – For analysis 22

P/7500/15	1 L	GB
P/7500/17	2.5 L	GB
P/7500/PB17	2.5 L	PCG
P/7500/PC17	2.5 L	PL
P/7500/21	5 L	MC
P/7500/25†	25 L	MD

† See page 507 for suitable tap

$(CH_3)_2CHOH$ M.W. 60.10

Physical constants
Boiling point .... 82.5°C
Refractive index 1.3772
Weight per mL at 20°C .... 0.785 g

Guaranteed analysis
Assay (GLC) .... >99.8%
Acidity/Alkalinity .... <0.0001 meq/g
C_4 alcohols .... <0.005%
C_5 alcohols .... <0.005%
Colour .... <5 APHA
Residue after evaporation .... <0.001%
Substances darkened by H_2SO_4 .... <10 APHA
Substances reducing $KMnO_4$ .... <5 ppm
Water (Karl Fischer) .... <0.1%
Calcium (Ca) .... <0.2 ppm
Copper (Cu) .... <0.02 ppm
Iron (Fe) .... <0.1 ppm
Lead (Pb) .... <0.02 ppm
Magnesium (Mg) .... <0.1 ppm
Potassium (K) .... <0.2 ppm
Sodium (Na) .... <1 ppm
Zinc (Zn) .... <0.1 ppm
Total phosphorus (P) .... <0.1 ppm
Total silicon (Si) .... <0.05 ppm
Total sulfur (S) .... <0.5 ppm
Ethanol .... <0.005%
Methanol .... <0.005%
Propan-1-ol .... <0.05%

Typical analysis
Aluminium (Al) .... <0.02 ppm
Barium (Ba) .... <0.02 ppm
Cadmium (Cd) .... <0.02 ppm
Chromium (Cr) .... <0.02 ppm
Cobalt (Co) .... <0.02 ppm
Lithium (Li) .... <0.02 ppm
Manganese (Mn) .... <0.02 ppm
Molybdenum (Mo) .... <0.02 ppm
Nickel (Ni) .... <0.02 ppm
Strontium (Sr) .... <0.02 ppm
Titanium (Ti) .... <0.02 ppm
Vanadium (V) .... <0.02 ppm

This product carries lot data on the pack label.

Figure 4: Properties of propanol

Butan-1-ol

Specified

Application – Specified reagent for general laboratory work (SLR) 21

B/4900/08	500 mL	GB
B/4900/15	1L	GB
B/4900/17	2.5 L	GB
B/4900/PB17	2.5 L	PCG
B/4900/21	5 L	MC
B/4900/25†	25 L	MD

† See page 507 for suitable tap

$CH_3.(CH_2)_3.OH$ M.W. 74.12

Assay (GLC)	>99%
Acidity/Alkalinity	<0.005 meq/g
Colour	<20 APHA
Residue after evaporation	<0.005%
Water (Karl Fischer)	<0.5%
Calcium (Ca)	<5 ppm
Copper (Cu)	<2 ppm
Iron (Fe)	<5 ppm
Lead (Pb)	<5 ppm
Magnesium (Mg)	<2 ppm
Potassium (K)	<2 ppm
Sodium (Na)	<5 ppm
Zinc (Zn)	<2 ppm
Total phosphorus (P)	<2 ppm
Total silicon (Si)	<2 ppm
Total sulfur (S)	<2 ppm

Butan-1-ol bioreagent

Application – Analytical reagent and solvent 32

BPE505-500	500 mL
BPE505-25	25 mL

$CH_3CH_2CH_2CH_2OH$ M.W. 74.07

Product Specifications

Assay	≥99.8%
Colour	≤5 APHA
Isobutanol	≤0.1%
Water	≤0.1%

Risk	10, 22, 37/38, 41, 67	UN:	1120
Safety	7/9, 13, 26, 37/39, 46	Class:	3
		Pack Grp:	III
		EINECS:	200-751-6
Fl. Pt	29°C	CAS:	71-36-3
First aid	Std.		
Spillage	A, C, F, I		
Disposal	5, 6, 7		

Butan-1-ol

Certified

Application – For analysis 22

B/4850/08	500 mL	GB
B/4850/15	1 L	GB
B/4850/17	2.5 L	GB
B/4850/PB17	2.5 L	PCG
B/4850/25†	25 L	MD

† see page 507 for suitable tap

$CH_3.(CH_2)_3.OH$ M.W. 74.12

Physical constants

Boiling point	116-119°C
Refractive index	1.3993
Weight per mL at 20°C	0.810 g

Guaranteed analysis

Assay (GLC)	>99.5%
Acidity	<0.0005 meq/g
Colour	<10 APHA
Residue after evaporation	<0.001%
Water (Karl Fischer)	<0.1%
Calcium (Ca)	<0.5 ppm
Copper (Cu)	<0.02 ppm
Iron (Fe)	<0.1 ppm
Lead (Pb)	<0.05 ppm
Magnesium (Mg)	<0.1 ppm
Potassium (K)	<0.1 ppm
Sodium (Na)	<1 ppm
Zinc (Zn)	<0.2 ppm
Total phosphorus (P)	<0.2 ppm
Total silicon (Si)	<0.05 ppm
Total sulfur (S)	<0.5 ppm
Butan-2-ol	<0.05%
2-Butanone	<0.1%

Typical analysis

Aluminium (Al)	<0.2 ppm
Barium (Ba)	<0.1 ppm
Cadmium (Cd)	<0.05 ppm
Chromium (Cr)	<0.02 ppm
Cobalt (Co)	<0.02 ppm
Lithium (Li)	<0.02 ppm
Manganese (Mn)	<0.02 ppm
Molybdenum (Mo)	<0.02 ppm
Nickel (Ni)	<0.02 ppm
Strontium (Sr)	<0.05 ppm
Titanium (Ti)	<0.02 ppm
Vanadium (V)	<0.02 ppm

This product carries lot data on the pack label.

Figure 5: Properties of butanol