UNIVERSITI
TEKNOLOGI
PETRONAS

DISSERTATION REPORT

Spray Characteristics of Non-Newtonian Fluids

Prepared By,

Muhammad Kamil bin KamarulBahrin

10843

Bachelor of Mechanical Engineering (Hons)

(Mechanical Engineering)

SEPT 2011

UniversitiTeknologi PETRONAS,

Bandar Seri Iskandar,

31750, Tronoh,

Perak DarulRidzuan

CERTIFICATION OF APPROVAL

Spray Characteristics of Non-Newtonian Fluids

By

Muhammad Kamil bin KamarulBahrin

A Dissertation submitted to the

Mechanical Engineering Programme

UniversitiTeknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

(Dr. AzuraienbintiJapper @ Jaafar)

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.

MUHAMMAD KAMIL BIN KAMARUL BAHRIN

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report is about fundamental study of non-Newtonian fluid sprays. The concept of non-Newtonian fluid sprays is not well understood and research on this topic needs to be done in order to gain more information and to make this information useful. This concept is usually applied in the painting industry. The material that we used as non-Newtonian fluid is Xanthan gum. Xanthan gum is an extracellular polysaccharide produced by the micro-organism Xanthomonascampestris (Phillips, 2000).

The purpose of this dissertation report is to represent all the flow and result of the study starting from introduction until conclusion. The first chapter makes brief introduction to the project. The report continues with the second chapter, which is literature review. Then it is followed by methodology and discussion which is discuss about how the process of study will carry and the obtain result. Conclusion part summarizes the result. The objective of the present research is to study characteristics of different concentration of non-Newtonian fluid sprays which are mean velocities, droplet sizes, and spray angle by using different pressure and same penetration range.

Spray characteristics of 4Xanthan gum solution with different concentration (0.1% concentration of Xanthan gum solution, 0.5% concentration of Xanthan gum solution, 1.0% concentration of Xanthan Gum solution, 2.0% concentration of Xanthan gum solution and water) are analyzed by Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA). Laser Doppler Anemometry (LDA) systems were used to measure droplet velocities of fluid sprays. Phase Doppler Anemometry (PDA) systems were used to measure the droplet sizes of fluid sprays. These results were compared with each other and relate it to spraying efficiency. All the results are analyzed to further understand the characteristics of non-Newtonian fluid sprays with different concentration. High speed digital camera was used in order to observe the structure of fluids and to measure the spray angles at nozzle exit.

ACKNOWLEDGEMENT

Here, I would like to express my greatest gratitude to The God Almighty for His blessing that allows me to complete my Final Year Project (FYP). My deepest appreciation goes to my FYP supervisor, Dr. AzuraienbtJapper @ Jaafar. She gave me a great deal of help and guidance throughout the project. Besides that, she also was very understanding and supportive to me entire time despite of major delays while the execution phase of the project. In addition, I would like to thank Scomi Group Bhd who supports Xanthan gum powder as material in this project. Without them, this study cannot run smoothly. Not to forget, Mr. Khairul Anwar Sulaiman who gave me help on commissioning the pump to the spray system and also taught me on the LDA/PDA software system. Last but not least, thank you so much to my parents and friends for giving me endless support both moral and financial.

Thank You.

CHAPTER 1

INTRODUCTION

1.1 Background Study

The main idea was to study the spray characteristics of non-Newtonian fluids which are mostly related to painting, polish, and cleaning industry. A lot of study was dedicated for this spray research but most of them focused on Newtonian fluids. As the best of my knowledge, the previous study on non-Newtonian fluids was about capillary break-up of this fluid. To make this study different from any other papers, the Non-Newtonian fluids were used in this spraying study instead of Newtonian fluids. This study was developed not only to study the spraying characteristic of these fluids but also to find out the relationship between droplet size and quality of spraying. Furthermore, the study of degradation of non-Newtonian fluids was carry on to find the suitable additive that can stabilize the viscosity of specimen within experiment time.

Xanthan gum solution is the chosen non-Newtonian fluids because of its properties most stable compared to other non-Newtonian fluids. This solution will be prepared using dispersion method in ambient temperature. 0.1%, 0.5%, 1%, and 2% of concentration of solution will be prepared and the experiment will be carried to achieve the objective of study. Moreover, water also was using as specimen to study the characteristics different between non-Newtonian and Newtonian fluids.

Both fluids will be evaluated using Phase Doppler Anemometry (PDA) and Laser Doppler Anemometry (LDA) to obtain droplet size and mean velocity and the result will be compared. Furthermore, the angle of spray break up will be analyzed by high speed digital camera. The reason for comparing result is to analyze the feasibility of both fluids in spraying industry.

1.2 Problem Statement

The characteristic of non-Newtonian fluid are not well understood and well-known although many research was done. However, there is no specific study conducted on these types of fluids. The spray concept is usually applied in painting theory. In painting industry, the angle of spray and droplet size is important parameter need to consider to improving the painting quality while economically feasible. In addition, Xanthan gum will degrade over time because of the bacteria. Suitable additive is important to maintain the viscosity of solution within time of the experiment.

1.3 Objective

1. To study the characteristics of non-Newtonian fluid sprays which are droplet size, mean velocity, spray angle and break out structure when the pressure and concentration of non-Newtonian fluid is varied.
2. To study the different of Newtonian fluid and non-Newtonian fluid in spray angle, droplet size and velocity.
3. To study the degradation of non-Newtonian fluids and the suitable additive to last long its viscosity.

1.4 Scope of Work

The work covers the study of characteristics which are spray velocity, droplet size, and break up structure of same solution with different concentration of Xanthan gum as non-Newtonian fluid under variety pressure. Spray characteristics play an important role in painting quality, cosmetic spray, and cost of painting. The results and data of different concentration non-Newtonian fluid sprays are compared to each other and discussed accordingly.The characteristics of sprays are analyzed by using Laser Doppler Anemometry (LDA) for velocity measurements and Phase Doppler Anemometry (PDA) for droplet size measurements. These systems assist to analyze characteristics of sprays in greater detail.Clorox and Formaldehyde was used as additive in degradation experiment for 14 days. Degradation experiment is to study either Clorox or Formaldehyde has ability to prevent bacteria action on solution at certain time in order to maintain the viscosity solution.

1.5 Relevancy of the Study

This study is relevant for me because I'm taking mechanical engineering. As a mechanical engineering student, I study about Introduction to Materials Science and Engineering and Fluid Mechanics which have much used in this study. Other than that, I also refresh my memory and knowledge regarding flow of fluid, viscosity and many other engineering term and phenomenon.

1.6 Feasibility of the Project

This study was feasible to do according to scope and given time but the author need to spend more time on LDA/PDA experiment because low data rate taken by author. This experiment also needs vary its penetration and radial distance to understand more about the characteristics of non-Newtonian fluids at different point.

CHAPTER 2

LITERATURE REVIEW AND THEORY

3.1 Non-Newtonian Fluid

The study of the deformation of flowing fluids is called rheology. In this study, the author will concentrate on Non-Newtonian Fluids, defined as fluids for which the shear stress not linearly related and dependent on shear rate (Figure 1).Examples include slurries and colloidal suspensions, polymer solutions, blood, sauce, paste, and cake butter. Some non-Newtonian fluids exhibit a "memory" means that the shear stress depends not only on the local strain rate, but also its viscosity will recover completely back to initial state after the applied stress is released (Cengel, 2010). This unique behavior of this fluid was called viscoelastic.

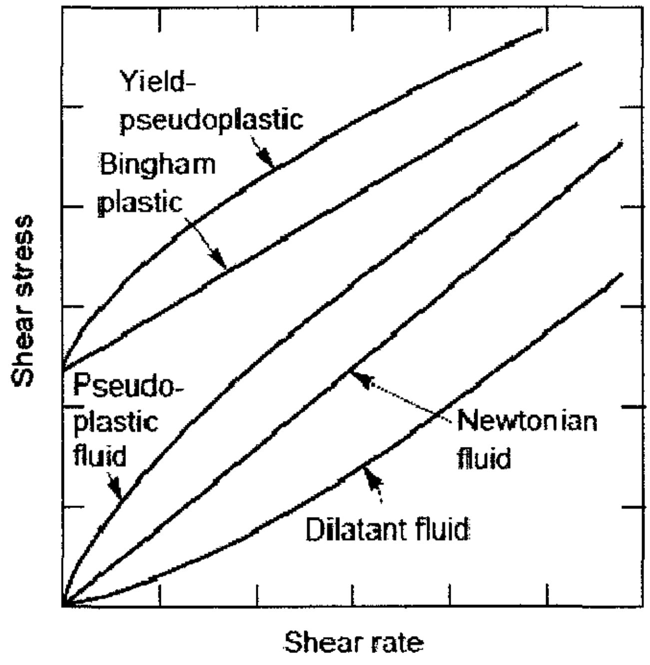


Figure 1: Rheological behavior of fluids- shear stress as a function of shear strain rate (Chhabra, 2001).

Some non-Newtonian fluids are called shear thinning fluids or pseudo-plastic fluids, because the more the fluid is sheared, the viscous will be decrease(Cengel, 2010). A good example is shampoo. Shampoo is very viscous when picked up by the hand, since the shear rate is small. However, as the shampoowas applied to the body, the smooth layer of shampoo between hand and the body is subjected to a large shear rate, it becomes much less viscous. We can easily smooth onto our body. Plastic fluids are those in which the shear thinning effect is extreme. In some fluids a finite stress called the yield stress is required before the fluid begins to flow at all such as Bingham plastic fluids. Certain paste such as tooth paste is examples of Bingham plastic fluids. If you hold the tube upside down, the paste does not flow, even though there is a nonzero stress due to gravity. However, if you squeeze the tube (increasing the stress), the paste flows like a very viscous fluid.

Other fluids show the opposite effect are called shear thickening fluids or dilatants fluids means that the more the fluid is sheared, the more viscous it becomes (Cengel, 2010). The best example is quicksand, a thick mixture of sand and water. It is easy to move slowly through quicksand, since viscosity is low but if you panic and try to move quickly, the viscous resistance increases considerably and you cannot move.

3.2 Xanthan gum

Xanthan gum is a natural polysaccharide. In late 15^{th}, US Department of Agriculture discovered it during research work into the industrial applications of microbial biopolymers (Jungbunzlauer AG, 2006). Later on, this high molecular weight polysaccharide was found on cabbage plant produced by bacterium Xanthomonascampestris using a natural, aerobic fermentation process. The process is conducted in a sterile environment where the pH, oxygen content and temperature are strictly controlled. After fermentation completed, the soap is uncontaminated and the gum is recovered by precipitation with isopropyl alcohol, then dried, milled and packaged under aseptic conditions (Glyn O. Phillips, 2000). Xanthan gum widely used as a rheology control agent in aqueous systems and as a stabilizer for emulsion. It increase viscosity of substance and prevents the settling of solids in wide industrial applications.

The main properties of Xanthan gum are its ability to significantly increase the viscosity of fluids. This effect is visible at concentrations of Xanthan gum as low as 1%.Glyn O. Phillips (2000)statedthat solution of Xanthan gum at 1% or higher concentration appears almost gel-like at rest yet these same solutions pour readily and have low resistance of pumping and mixing. The viscosity of Xanthan gum solutions is variable. Indeed, it is highly pseudoplastic solution not thixotropic (Jungbunzlauer AG, 2006).

The rheology of Xanthan gum solutions isoutstandingly stable over temperature range as shown in Table 1. They have ability to maintain their viscosity until a definite "melting temperature" is reached. In other word, Xanthan gum solution provides the same thinning or thickening, and stabilizing properties as it does at ambient conditions at elevated temperature during long-term period of time. However, if the temperature exceeds the melting temperature, the viscosity drops sharply due to a reversible molecular conformation change (Glyn O. Phillips, 2000). But, this high viscosity loss will be recovered upon cooling.

Xanthan gum solution, wt.%	Temperature, °C	Viscosity, MPa.s
0.5	20	550
0.5	40	500
0.5	60	450
1.0	20	1550
1.0	40	1550
1.0	60	1500

Table 1: Effect of Temperature on Viscosity Solution (R. T. Vanderbilt Company. Inc., 2002)

Even though Xanthan gum is highly stable polysaccharide and not easily degraded by most microorganisms but at room temp, it tends to be attack by bacteria over time. Because of that, this study includes the degradation of Xanthan gum which is examining the suitable additive to prevent bacterial degradation or attack on solution. These bacteria will attack the molecule of Xanthan gum and do rapid degradation on polymer over time.

3.3 Fundamentals of Sprays

Sprays are the results of high pressure-driven liquid jets injected through injector nozzle orifices into surrounding medium. Liquid droplets need sufficient momentum to penetrate the surrounding medium to produce spray break up. Normally nozzle was used as a spray producing device or called as atomizer. Process utilizing droplets require enough momentum to transport the droplets to gaseous surrounding and mixing with the gas. The characteristics of a spray are summarized by its velocity droplet, break up pattern and the measurement of droplet sizes. Nowadays, the technology of spray was applied in many industry fields such as pharmaceutical manufacturing, sprays in pulp and paper manufacturing, food processing, painting, and industrial diesel engines.

Basically there are two types of atomization in spray that is primary atomization, near the nozzle and secondary atomization, which is the break-up of drops further downstream. The main components acting on the liquid during spray break-up are; inertia, viscous and surface tension. Their relative important is indicated by the Reynolds number and the Weber number. High value of both Re and We will cause more finer atomization. In other word, when the viscosity of the liquid high, the bigger droplet will produce. (BendigL, 2002). According to Luxford (2005), the Weber (*We*) number is a dimensionless value useful for analyzing fluid flows relates the force from surrounding air pressure to the surface tension force around the droplet perimeter and the Reynolds (Re) numberrelates the force on the droplet from the dynamic pressure of surrounding fluid, due to its velocity relative to the droplet acting over projected area of the droplet.

2.4 Droplet Size

The drop size is an important parameter as it is normally used for the determination of the painting quality. According to Bendig L (2002), the number distribution of droplets is the Probability Density Function n(D) of droplet diameters at the measurement position,

$$\int_{Do}^{Dm} n(D)dD = 1$$

Where,

D_m = Maximum droplet diameter

D_o = Minimum droplet diameter

As shown in Figure 2, n(D) is usually a smooth continuous function and it has units $(\text{length})^{-1}$.

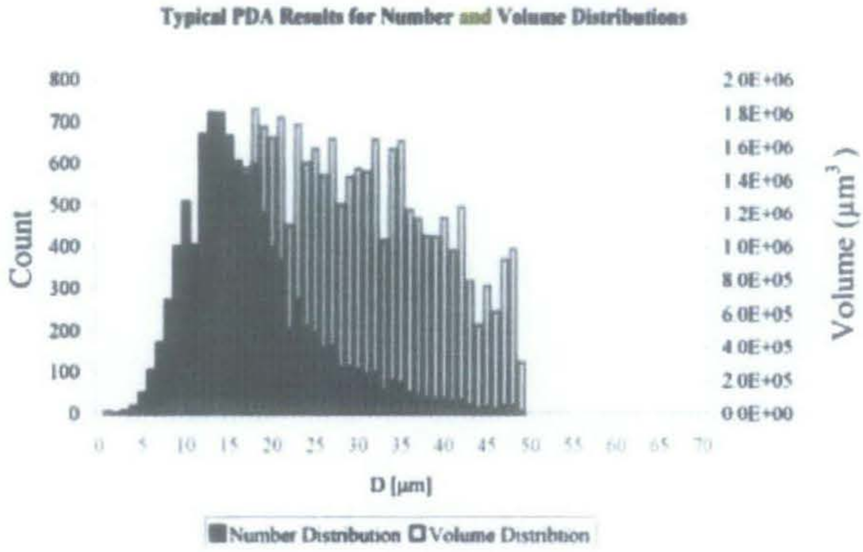


Figure 2: PDA result for number and volume distribution (Bendig L, 2002)

Figure above also shown that each droplet has different sizes even its come from same fluid.Therefore, there need to averaging the diameter of droplet to get the suitable mean diameter. A general mean diameter that commonly used is,

$$\overline{D}_{pq} \equiv \left\{ \int_{D_o}^{D_m} D^p\, n(D)\, dD \Big/ \int_{D_o}^{D_m} D^q\, n(D)\, dD \right\}^{1/(p-q)}$$

$\overline{D_{pq}}$ is based upon two functions of droplet diameter with orders p and q. There are different mean diameters for different purpose of application as shown Figure 3.In this study, Sauter Mean Diameter (or volume/surface mean diameter) was used because this studies more relevant into transferring the mass of fluid to surrounding.Chin and Lefebvre (1985) also suggest that it is the best measure of the fineness of sprays.

Mean diameter	Name	Field of application
D_{10}	Arithmetic or linear	Evaporation
D_{20}	Surface	Surface area controlling (e.g., absorption)
D_{30}	Volume	Volume controlling (e.g., hydrology)
D_{21}	Surface diameter	Adsorption
D_{31}	Volume diameter	Evaporation, molecular diffusion
D_{32}	Sauter	Efficiency studies, mass transfer, reaction
D_{43}	De Brouke	Combustion equilibrium

Figure 3: The different mean diameter for different purposes (Barry J, 2010)

This equation have p=3 and q=2 and $\overline{D_{32}}$ is a measure of the ratio of the total volume of droplets in a spray and the total surface area of droplets.

$$d_{32} = \frac{\sum_{i=0}^{n} n_i d_i^3}{\sum_{i=0}^{0} n_i d_i^2}$$

Where,

d_i = diameter of measured droplet

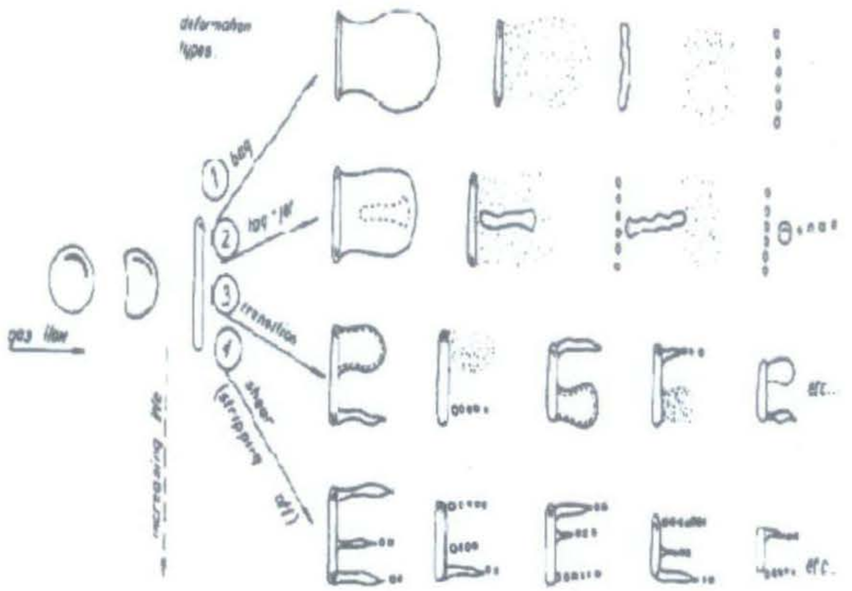
n_i= the number of droplet within a range of centered on diameter D_i

k = the number of ranges

2.5 Droplet Break up

Liquid atomization or the production of drops is common phenomenon in a variety of scientific and engineering application. When the spherical drop encounters asurrounding flow field moving at a relative velocity to it, aerodynamic forces cause the droplet to deform and may break apart into fragments. This process referred to as secondary atomization (Guildenbecher, Lopez-Rivera, &Sojka, 2009). Secondary atomization isdifference to primary atomization where bulk fluid in the form of a sheet or jet, breaks up for the first time and form drops. In spray formation, primary atomization occurs at or near the nozzle exit while the secondary atomization occurred further downstream.

Figure 4 below shown 4 type of droplet break up suggested by Krzeczkowski (1980) result from the study of break up using an open-jet horizontal wind tunnel. This was done by releasing droplets with different viscosity fluid at the nozzle exit of the tunnel.



:

Figure 4: Different possible modes of droplet break up suggested by Krzeczkowski (1980)

	Type of Droplet Break up	Characteristics
1.	Bag	Hollow bag-shaped film and a ring torus
2.	Bag-Jet	Additional stamen in the middle
3.	Transition	Initial bag type break up then transform to disintergration of the bag film
4.	Shear or Stripping	Stripping of the surface layer

Table 2: Characteristics of each droplet break up

Based from the research, the studies have been done by Krzeczkowskionly focused on the effect of fluid viscosity on the alcohols only. Most of the studies about droplet are mostly on Newtonian fluids. For this project, the study will carried differently by using non-Newtonian fluids as specimen. Furthermore, a break up study in this project will have different variables such as pressure and concentration of Xanthan gum for evaluation.

3.4 Laser Doppler Anemometry and Phase Doppler Anemometry

The equipment used to measure velocities of flows is known as Laser Doppler Anemometry (LDA) invented by Yeh and Cummins in 1964 (Dantec Dynamics, 2010). The principles of Laser Doppler Anemometry are to take measurement of laser light scattered by particles that pass through series of interference fringes (Figure 5). Velocity of particles is measured by converting the oscillation of scattered laser light with specific frequency. This scattered light was detected by a photomultiplier tube (PMT), an instrument that generates a current in proportion to absorbed photon energy, and then amplified that current. The need for physical contact with the flow is eliminated in LDA, thus producing no disturbances (Durst, 1981).

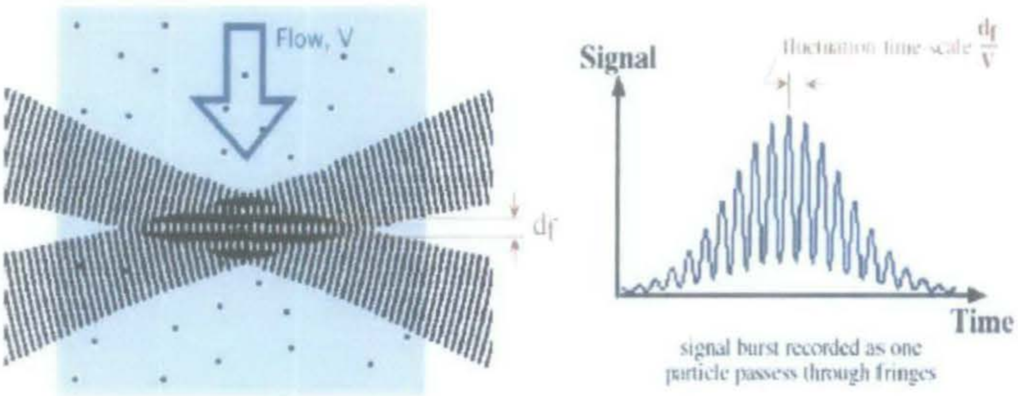


Figure 5: A fringe pattern is created as measurement volume at the intersection of two incident beams (Dantec Dynamics, 2010)

A Phase Doppler Anemometry (PDA)system is extension of the LDA principle (Dantec Dynamics, 2010). It can measure the velocityand size of spherical particles as well as mass flux and concentration. The principle behind PDA is to take measure size of droplet that pass through volume measurement created by intersection of two incident beam. This particle will scatter light from two incident laser beams. Then, both scattered waves will interfere in space and create a beat signal with a frequency which is proportional to the velocity of the particle. Lastly, two detectors will receive this signal with different phases and the phase shift between these two signals is proportional to the diameter of the particle.The position of each detector shown in Figure 6.

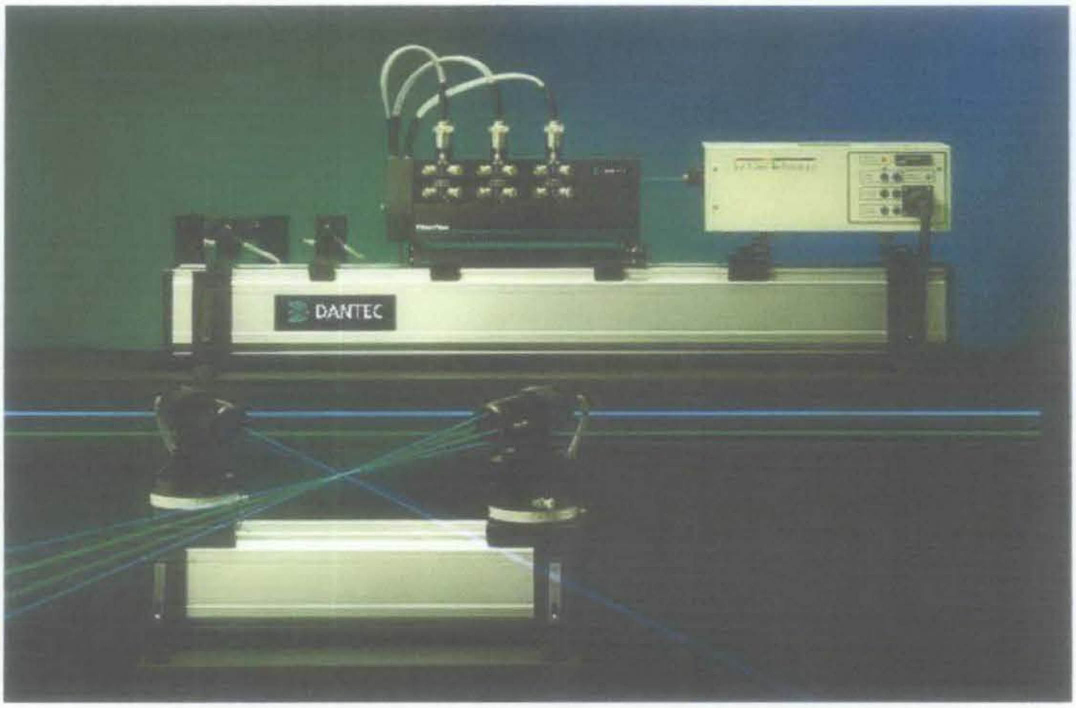


Figure6: Setup of a PDA/LDA (Dantec Dynamics, 2010)

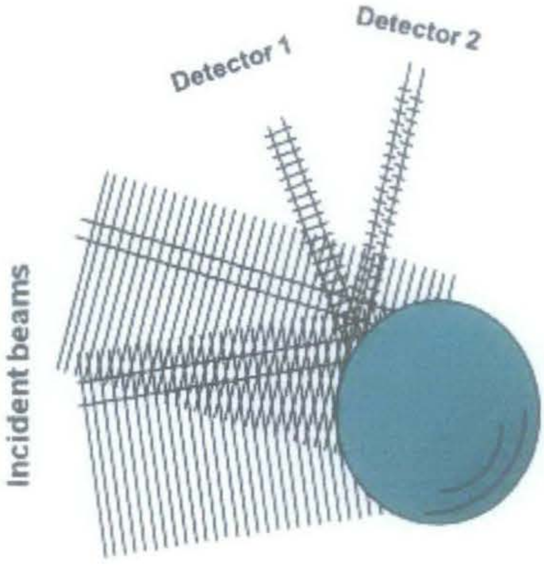


Figure 7: Graphical illustration of PDA principle

CHAPTER 3

METHOLOGY/ PROJECT WORK

3.1 Research Methodology

Thestudy started with background research on the topic of Spray characteristic of non-Newtonian fluids. In this project, Xanthan gum solution was chosen as non-Newtonian fluids that will study by vary the pressure of spray and concentration of Xanthan gum solution. With background study, it will give the rough idea about Xanthan gum and helping in extended report completion. Every finding or research must be recorded in my logbook as reference in further doing my project. Before start the experiment, the Xanthan gum solution need prepare first one week before carrying the experiment with different concentration. Four different concentration of Xanthan gum solution need to produce and used in this study. Experiments have been planned and scheduled to study and make comparison between different concentration fluid sprays. Diameter and velocity of spray were study by using Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA). The breakup angle of spray were taken by high speed camera and analyzed by picture software. The results experiments are discussed and analyzed. The health and safety environmental (HSE) matters and experiment procedure has been discussed with technician. Any problems that may occur regarding the experiments in the future can be avoid and discussed in this stage. If there is any problem, steps taken should be revised again.

3.2 Project Activities

The project was started off withdegradation of Xanthan gum solution testing (Phase 1) which is the study of degradation Xanthan gum versus time on FYP 1. This study to observed the changing of Xanthan gum viscosity after certain time. This is to ensure that when the PDA/PDA experiment started, the same solution with the same value of viscosity will used to get the accurate result. It is because the viscosity plays the important roles in the size of droplet and droplets break up. In this experiment, the additive such formaldehyde or Clorox was used as viscosity stabilizer in Xanthan solution. Formaldehyde is a chemical compound which is widely used in embalming preservative (Wisegeek, 2011). Experiment was held for 14 days for each additive and the viscosity recorded every day using digital viscometer unit by using 0.1% wt. Xanthan gum solution. Then, the result will compared to each other and determine which additive will stabilize the viscosity of Xanthan gum in certain period of time.

In Phase 2, Xanthan gum solution were produced by mixing Xanthan gum powder with water at concentrations of 0.1%, 0.5%, 1.0%, and 2.0% Xanthan gum by mass. Total of 4.5L were created for all run whether using LDA/PDA equipment or high speed camera. The solution of Xanthan gum was prepared 10 days before carrying this experiment. It is because the sediment of Xanthan gum will completely dissolve around that time. Moving toPhase 3, the spray characteristic study was carried on by using PDA/LDA system for droplet size and velocity measurement. The PDA/LDA equipment must be calibrated first with constant distance to the measurement volume. The pressure and concentration will be varied but penetration distance and radial distance of spray will be constant. After conducting the PDA/LDA experiment, the picture of break up structure must be taken by high speed camera at certain distance (Phase 4). For the final phase, all result then evaluated. The experiment varies pressures (60kPa, 80kPa and 100kPa) and liquid types in order to understand spray characteristics. By taking pictures, the spray angle can be observed. Figure 8 show the flow chart of project activities.

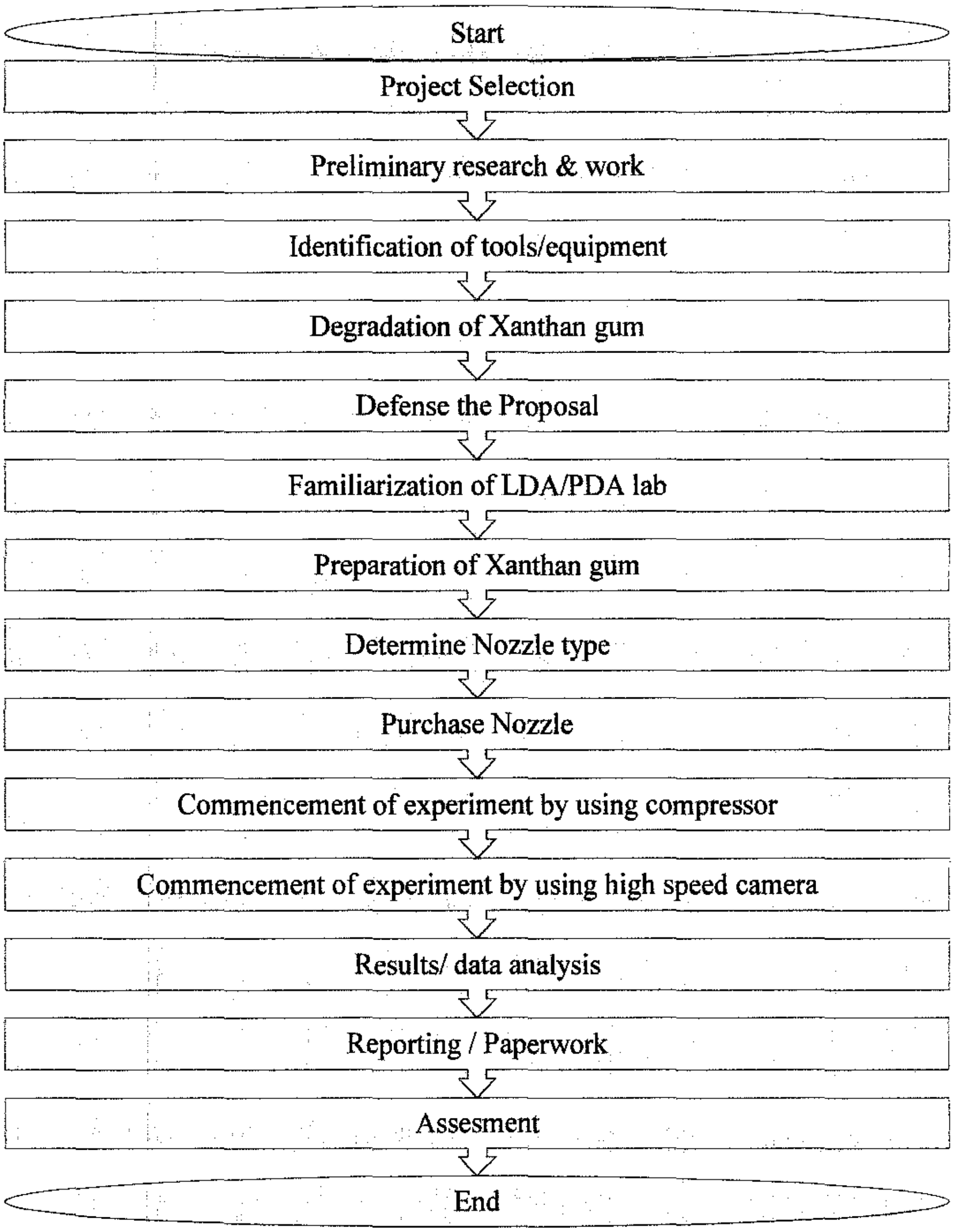


Figure 8: Flow of project activities

3.3 Project Scheduling

In the Gantt charts shown in Table 3 & 4, all the activities are planned carefully.

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
	Timelines for FYP 1																
1	Selection of Project Topic	■	■														
2	Preliminary Research Work		■	■	■	■											
2.1	Finding journal about non-Newtonian Fluids		■	■													
2.2	Extract important fact			■	■												
2.3	Discussion with Supervisor(SV)					■											
3	Submission of Extended Proposal Defence						◆										
3.1	Discussion about Proposal Defence with SV							■									
4	Proposal Defence									■	■						
5	Project work continues											■	■	■			
5.1	Appointment with Lab Technician											■					
5.2	Finding more detail about xanthan gum											■					
5.3	Familiarize with PDA/LDA												■				
5.4	Familiarize with preparation xanthan gum solution experiment												■				
5.5	Schedule/Plan the Experiment for FYP 2												■				
5.6	Focus doing Interim Draft Report													■			
6	Submission of Interim Draft Report														◆		
6.1	Correction on Interim Draft Report														■		
7	Submission of Interim Report															◆	

Table 3: Timelines for FYP 1

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
	Timelines for FYP 2																
1	Project Work Continues	■	■	■	■	■	■	■									
1.1	Prepare xanthan gum solution	■	■														
1.2	Experiment for Water & 0.1% concentration		■	■													
1.3	Experiment for 0.5% concentration				■												
1.4	Experiment for 1% concentration					■											
1.5	Experiment for 2% concentration						■										
2	Submission of Progress report							■		◆							
3	Project Work Continues									■	■	■	■	■			
3.1	Experiment for Methanol+xanthan gum solution (if needed)									■	■						
3.2	Repeat the failure experiment (if needed)										■	■					
4	Pre-EDX												◆				
5	Submission of Draft Report													◆			
6	Submission of Dissertation (soft bound)														◆		
7	Submission of Technical Paper														◆		
8	Oral Presentation															◆	
9	Submission of Project Dissertation (Hard Bound)																◆

■ Process
◆ Suggested Milestone

Table 4: Timelines for FYP 2

3.4 Key Milestone

Activity	FYP 1				FYP 2				Remark
	May	June	July	Aug	Sept	Oct	Nov	Dec	
Degradation of Xanthan Gum Test									Done
Preparing Xanthan Gum Solution									Done
Completing PDA/LDA experiment									Done
High Speed Camera experiment									Done
Result and Conclude the analyze									Done

Table 5: Key Milestone of FYP

3.5 Tools and Equipments

3.5.1 LDA/PDA System

In this project, the main equipment used is Laser Doppler Anemometry (LDA) and Phase Anemometry (PDA) to get the data of spray characteristics. LDA has been used to measure mean velocity of the droplets and direction while PDA has been used to measure droplets size. This LDA/PDA was manufactured by Dantec Dynamics. This machine was located in Block N. Here the specifications of the machine:

Dantec Dynamics (manufacturer)

1. A 300mW argon-ion laser source, Laser Physics Reliant 500m;
2. A signal processor, Dantec 58N80-MultiPDA;
3. A laser splitter and manipulator, dantec 60 x 26;
4. A transmitter with a convergent lens, f= 600mm;
5. A receiver with a convergent lens, f = 300mm;
6. A traverse system Dantec 57G15
7. Optical-fiber cables, to convey the beams to the transmitter

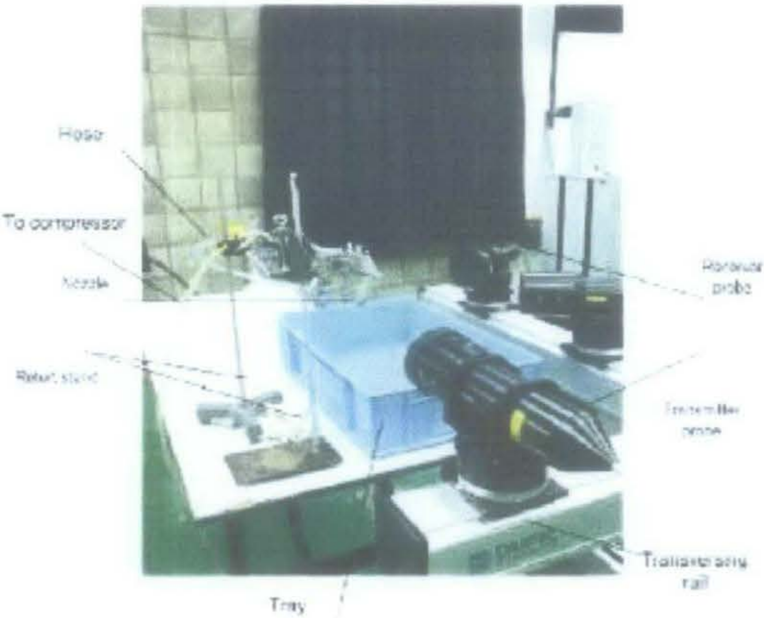


Figure 9: Arrangement of LDA/PDA Systems in the lab (Rejep, 2010)

3.5.2 Spray Nozzle

In this study, high pressure spray nozzle F-75s manufactured by Akoka will be used. The same spray nozzle will be used for each trial and the characteristics are listed below:

(a) Full cone spray nozzle

(b) Operating Pressure, P_{op} = 300-500kPa

(c) Diameter nozzle outlet = 1.3 mm

(d) Diameter air inlet = 6.35 mm

3.5.3 Compressor

The compressor will used to vary the pressure of the spray (60kPa, 80kPa and 100kPa) for the LDA/PDA experiment. Meanwhile for high speed camera experiment, 20kPa, 40kPa, and 60kPa pressure were used in this experiment. The angle of spray and droplet size will change when the pressure varied.

3.5.4 High Speed Digital Camera

This experiment uses high speed digital camera manufactured by Vision Research Inc. in order to take the picture of spray break up structure. In one trial, the pictures taken must be plenty and the best quality picture will be chosen. Then, the pictures will be analyzed. The spray angle will be measure using picture software considering all the pictures were taken at constant distance. The data will be recorded and discussed.

3.5.5 Digital Viscometer Unit

The viscometer unit was used to measure viscosity of Xanthan gum for each concentration before held the PDA/LDA procedure. The viscosity of each concentration will be recorded. The measurement of viscosity needed after preparing the solution and before using the solution for experiment (10 days later) to ensure the degradation of Xanthan gum will not happen.

Figure 10: Digital Viscometer Unit

3.5.6 High Shear Mixer Machine

In this study, preparation of solution plays the important part to determine the accuracy of the result. In order to mix the Xanthan gum powder and water according to procedure, the high shear stress needed to ensure all powder or sediment completely dissolve in the water.

Figure 11: High Shear Mixer Machine.

3.6 Preparation of Xanthan gum solution

To obtain optimum functionality, Xanthan gum must be properly hydrated before use. Hydration highly depends on four factors; dispersion, agitation rate of the solvent, composition of solvent, and particle size. The gum particles must be well dispersing to make sure the Xanthan gum was properly hydrated. If not, this will result to the formation of swollen lumps. Severe lumping prevents complete hydration and reduced functionally. The ideal way to prepare Xanthan Gum solution that is dispersion method through the use of a dispersion funnel and mixing educator. This ideal method is; the tap water will fill in container through educator while Xanthan gum is being added, and until it is completely dissolved. Meanwhile, the liquid will be stirred continuously and water pressure into container was kept low. If the flow too fast, the particle will lump because of its 'pseudoplastic' properties (Glyn O. Phillips, 2000). This method usually was to produce high volume of solution (usually 100L).

In this study, approximately 500mL of water were used to make Xanthan gum solution for each concentration (wt.0.1%, wt.0.5%, wt. 1.0%, and wt. 2.0%). For this little amount of solution, the normal dispersion method was enough. Below was the procedure of the preparation;

Preparation of 0.1% Xanthan gum solution

1. Prepare the 500mL of tap water in 1000mL beaker.
2. Setup the beaker below the grinder of motor stirrer.
3. Switch ON the motor stirrer.
4. Stir the tap water using the motor stirrer.
5. Setup the speed of motor stirrer to 300rpm.
6. Dissolve 0.5g of Xanthan gum powder gradually in the 500mL of tap water.
7. After Xanthan gum powder completely dissolve, make sure no lump exist in the solution. (REMINDER: If the lump exist, repeat step 3 until the lump disappear)
8. Put 2 drops of Formaldehyde in beaker.
9. Switch OFF the motor stirrer.
10. Close the beaker with plastic wrapper as pre-caution step of the reaction Xanthan gum solution to surrounding.

11. Label the beaker as '0.1% Xanthan gum Solution'.
12. Repeat step 1 until step 9 using 2.5g, 5g, and 10g of Xanthan gum powder in order to make 0.5%, 1.0%, and 2.0% Xanthan gum solution respectively.

This preparation will carry out 10 days before the experiment of fluids behavior analysis in the lab.

3.7 Experiments to Measure Spray Angle

This experiment useshigh speed camera type Phantom ir300 manufactured by Vision Research Inc. to capture the pictures of breakup spray. Then, these pictures are evaluated by Adobe Photoshop. The experiment varies pressure as 60kPa, 80kPa, and 100kPa for each liquid with different concentration in order to understand more spray characteristics other than diameter and velocity. To achieve the clear picture, the lighting around camera focus must be adjusted. The blur picture will cause the difficulty in evaluating the angle of spray. In some cases such the viscosity of solution too high will cause the difficulty of liquid flow into spray gun. Then, ratio of liquid and air of spray gun will be low. So, the atomization will be difficult to developed and the picture of spray taken was kind of blur. Figure below is the example of clear picture and blur picture.

Figure 12: Blur picture.

Figure 13: Clear picture.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Experiment on Degradation of Xanthan gum solution

The experiment on degradation of Xanthan gum was conducted to determine the suitable of formaldehyde or Clorox as viscosity stabilizer in the Xanthan gum. Each of additives was added into 2 different beakers that contain 500mL 0.1% wt. Xanthan gum solution. Preparation on 500mL 0.1% wt. Xanthan gum solution needed as reference to both solutions with additive. Shown in Table 7 is viscosity of each solution recorded daily for 14 days.

Time (day)	without additive(Cp)	with Clorox (Cp)	with Formaldehyde (Cp)
1	3.90	6.12	3.24
2	4.50	6.95	4.32
3	5.28	7.44	6.32
4	6.18	8.46	7.08
5	6.48	6.18	7.32
6	7.02	4.80	7.88
7	8.22	4.02	8.04
8	8.46	4.50	8.46
9	8.96	4.38	8.96
10	9.56	4.28	9.56
11	10.10	4.02	10.00
12	9.36	4.12	10.10
13	8.96	4.28	10.05
14	8.50	3.96	10.15

Table 7: The viscosity of threesame solutions with different additive each day

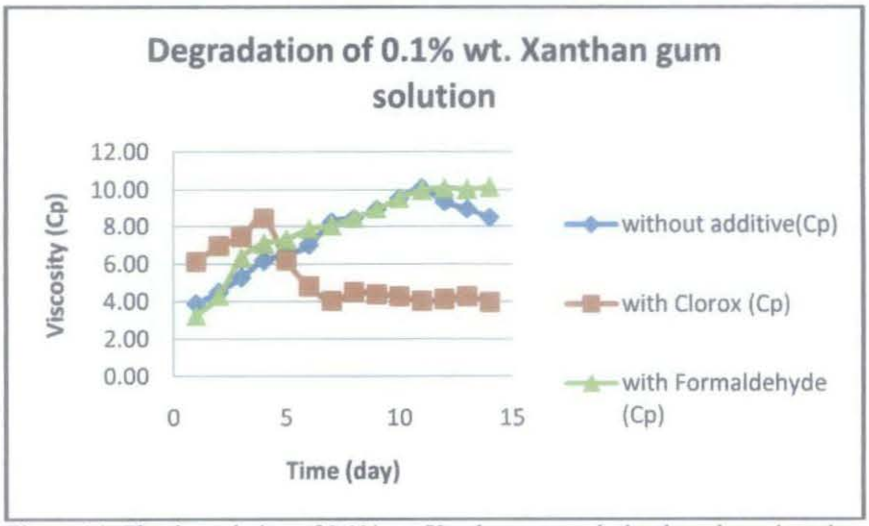


Figure 14: The degradation of 0.1% wt. Xanthan gum solution based on viscosity.

Based on Figure 14, the viscosity of pure Xanthan gum solution increased until the day of eleventh. At the day of twelve, the viscosity drop had shown the impact of degradation of Xanthan gum. For Xanthan gum solution with Clorox additive, the solution seem increase from the first day to the day of fourth compare to other solution. Unfortunately, on the day of fifth, the viscosity drop rapidly until the day of seventh then the solution has constant viscosity approximately about 4.20 Cp till the last day of experiment.Its seem Xanthan gum incompatible with strong oxidizing agents such as NaOCl (bleach or Clorox) which can cause rapid and severe degradation of the solution. For the solution with formaldehyde additive, it have same pattern of viscosity increasing as pure solution till on the day of eleventh. After that, the viscosity seems constant till the last day. It's seem that the formaldehyde successfully maintain the viscosity of the solution at certain period of time. The increasing of viscosity pattern may result by there is some sediment in solution after mixing even it use the high shear mixer machine. This sediment will dissolve in time. As shown in figure, the optimum viscosity of solution is on the day of eleventh as the sediment of Xanthan power completely dissolved.

4.2 Experiment onspray characteristics of Non-Newtonian Fluids

The experiment on spray characteristics was conducted by using water first to analyze the point where many droplets will go through the volume measurement of laser intersection. After many set of test run for 20kPa, 40kPa, 60kPa, 80kPa, and 100kPa, only a little of result was achieved. The table below shows the tabulate data of spray characteristics for 20kPa and 40kPa. Above 50kPa of compressor pressure, LDA/PDA has difficulties in measuring the droplet size and velocity. According some research, the atomization of two fluids spray not very consistence going through the measurement volume of laser intersection. It will result to low data reading of LDA/PDA device. Figure 15, 16, and 17 shows the water spray data look like after LDA/PDA Flow software detecting some samples going through the measurement region. Same goes to other liquid which is Xanthan gum with variety concentration. After choose the best data, all these data will compile into tabulate form and final graph will be produced (Table 8 & 9). But, this result still considered as low data rate. Thus, more samples for a set of result should be obtained by adjusting the LDA/PDA laser intersection to spray region with more samples.

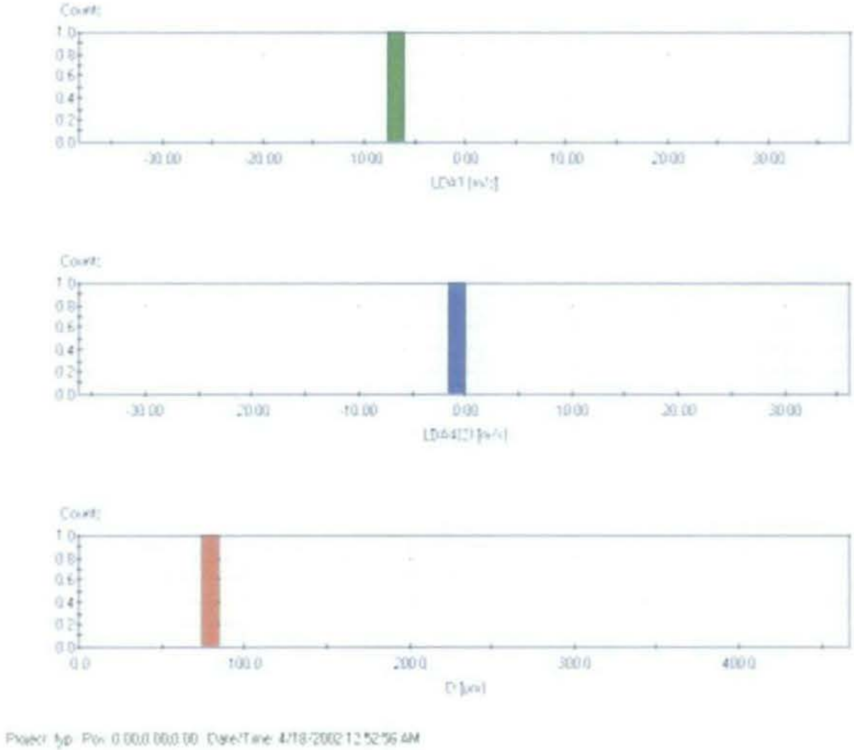


Figure 15: Water spray result 1st run – 20kPa pressure

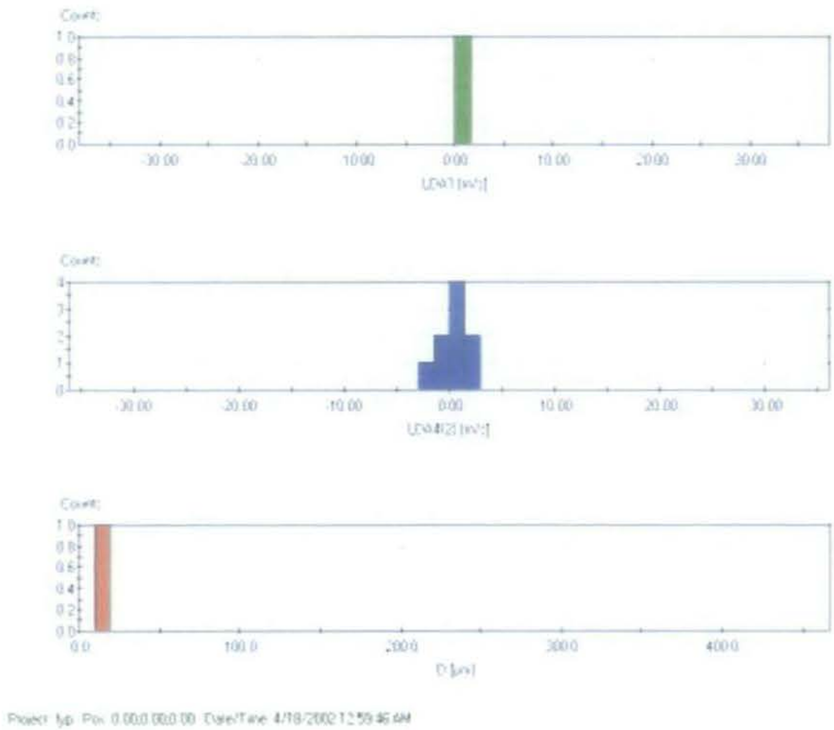


Figure 16: Water spray result 2nd run – 20kPa pressure

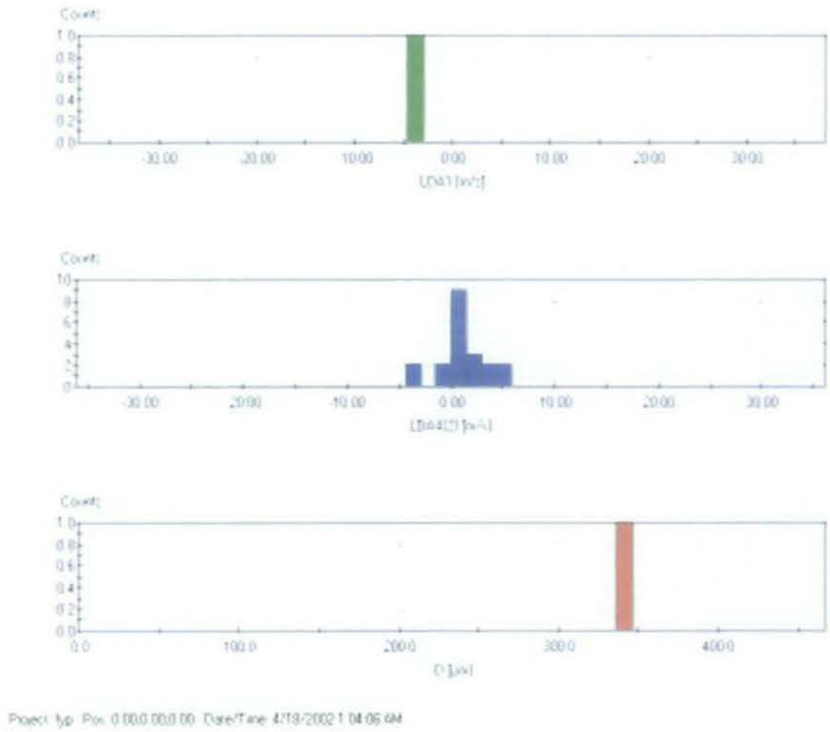


Figure 17: Water spray result 1st run – 40kPa pressure

20kPa		vertical velocity(m/s)	horizontal velocity(m/s)	SMD (microns)
	water	3.11	2.5	20
	xanthan gum 0.1%	2.9	1.8	80
	xanthan gum 0.5%	2.2	-1.3	134
	xanthan gum 1.0%	1.25	0.9	188
	xanthan gum 2.0%	0.7	-0.6	234

Table 8: Summary of LDA/PDA result (20kPa).

40kPa		vertical velocity(m/s)	horizontal velocity(m/s)	SMD (microns)
	water	5.9	5.3	15
	xanthan gum 0.1%	5.2	-4.2	64
	xanthan gum 0.5%	4.2	-2.6	93
	xanthan gum 1.0%	3.4	1.8	154
	xanthan gum 2.0%	2.1	-1.2	183

Table 9: Summary of LDA/PDA result (40kPa).

4.2.1 Vertical velocity result for 20kPa and 40kPa

The chart below shows that the vertical velocity of droplet for each concentration from 0% to 2.0% of concentration. In this experiment, water was considered as 0% concentration of Xanthan gum. Figure 18&19 concluded that Xanthan gum has lower vertical velocity compared to water. Furthermore, as concentration of Xanthan gum increase, the vertical velocity of spray decrease as pressure constant. This is related to viscosity, surface tension and density of fluid. As viscosity of spray liquid decrease, more droplets are affected by turbulent flow of air coming out of the nozzle. Thus, there are more droplets the fluid and the faster they travel vertically to deposition area. But vertical velocity of each fluid increase when the pressure is increase.

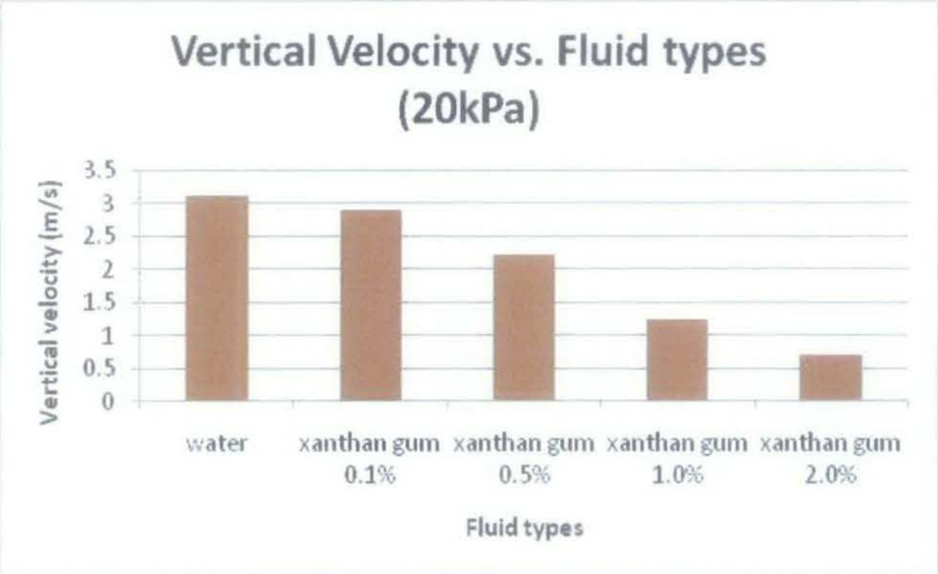


Figure 18: Vertical velocity versus Fluid types (20kPa).

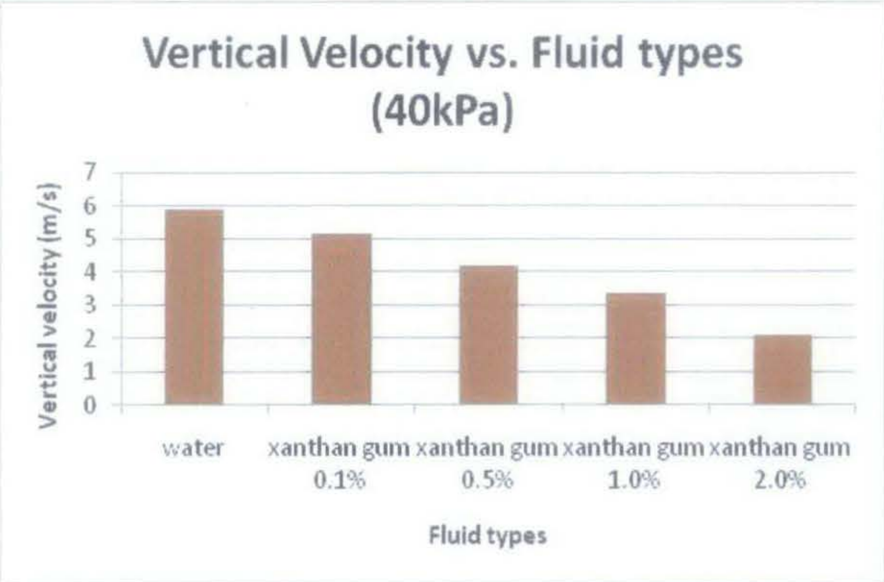


Figure 19: Vertical velocity versus Fluid types (40kPa).

4.2.2 Horizontal velocity result for 20kPa and 40kPa

The below chart shows that water has higher horizontal velocity than Xanthan gum but when concentration of Xanthan gum increase, the horizontal velocity will be decrease due to increase in density and viscosity. As density of spray liquid decrease, more droplets are affected by turbulent flow caused by the air coming out of the nozzle. Thus there are more droplets and the faster they travel horizontally to spray direction. Negative value means they travel at negative x-direction and vice versa.

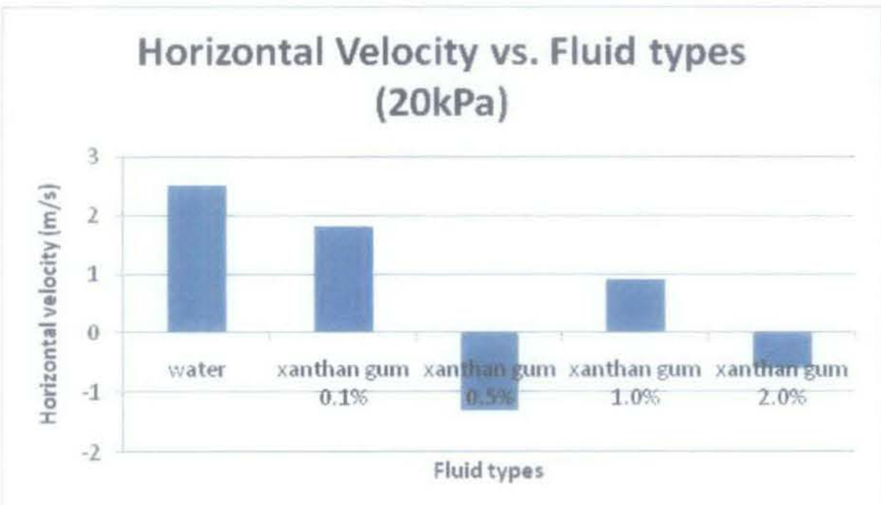


Figure 20: Horizontal velocity versus Fluid types (20kPa).

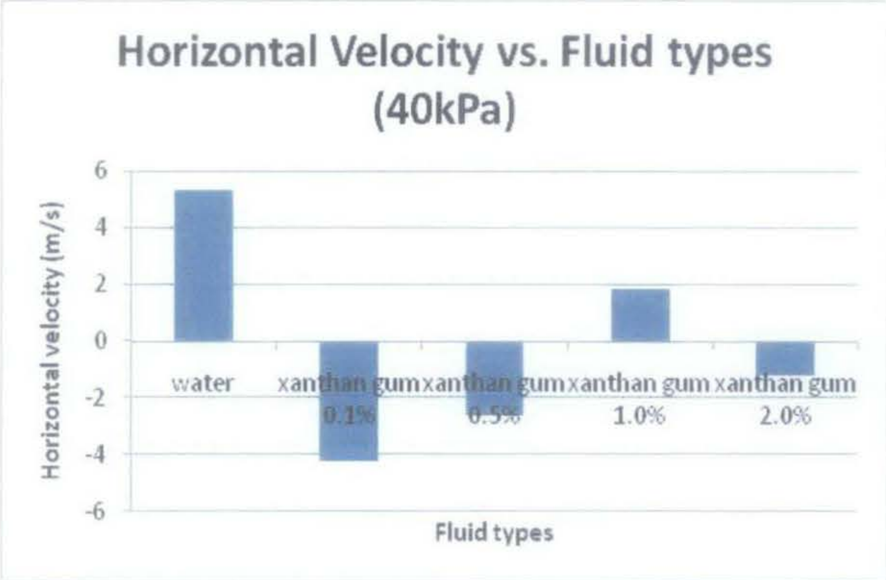


Figure 21: Horizontal velocity versus Fluid types (40kPa).

4.2.3 Sauter Mean Diameter result for 20kPa and 40kPa

The Figure 22& 23 shows the difference of spray droplet size in Sauter Mean Diameter (SMD) produced by the nozzle where Xanthan gum has higher SMD value than water. This proves that viscosity of spray liquid has direct relationship to spray droplet size produced by a full cone nozzle. Xanthan gum with high concentration has higher SMD compared to lower concentration due to increase in viscosity of liquid. While the pressure increases, the SMD value will be decreased due to pseudoplastic of Xanthan gum. More shear or pressure put onto this non-Newtonian fluid, less viscous the Xanthan solution behaves (pseudoplastic).

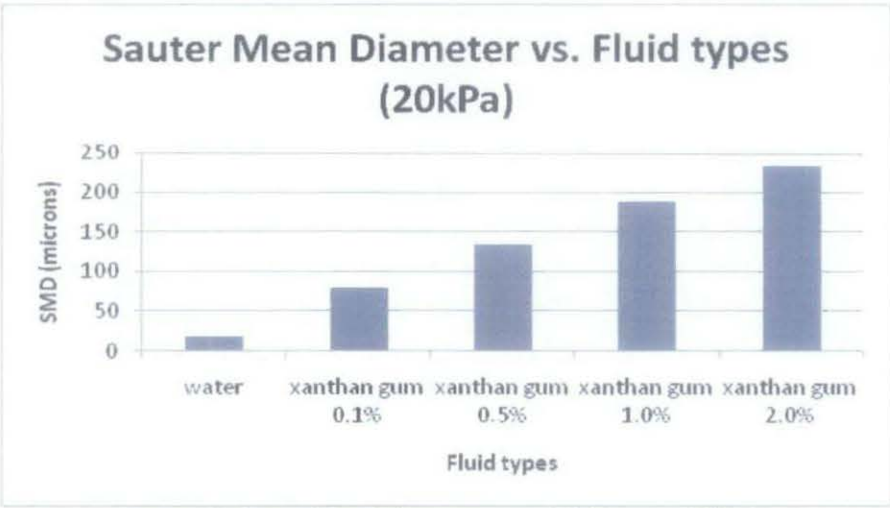


Figure 22: Sauter Mean Diameter versus Fluid types (20kPa).

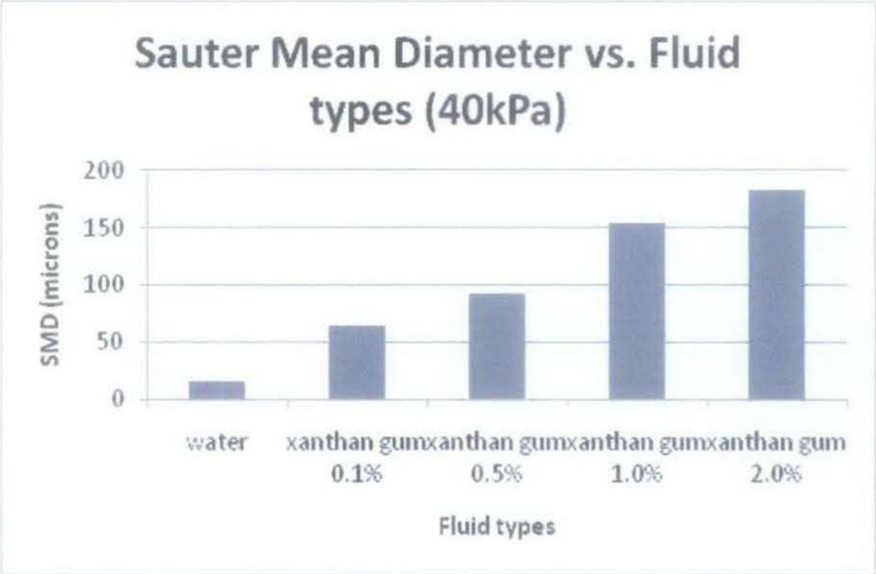


Figure 23: Sauter Mean Diameter versus Fluid types (40kPa).

4.3 Experiments on Spray Angles

This experiment was performed by using high speed camera. The pictures of spray were taken in a bulk volume. The high speed camera's position set up to static location in order to take pictures at the same distance for all type of liquids. The pressure of compressor varied as 60kPa, 80kPa, and 100kPa for each liquid. After take pictures all type of solutions, spray angle was calculated by drawing the line along the spray pattern. Two lines must be drawn and the angle between those lines as spray angle was measured by Adobe Photoshop 7.0 with angle tools. Spray angle measurement as shown by Figure below. A summary of the spray angle result for different concentrations and pressures shown in Table 10.

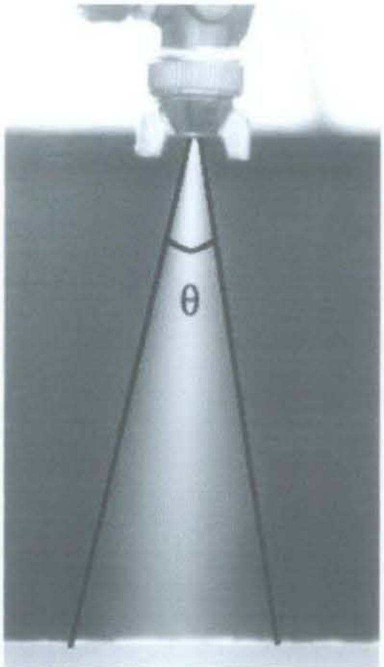


Figure 24: Spray angle measurement method.

	concentration (% wt.)	60kPa	80kPa	100kPa
water	0	18.5	20	22.5
xanthan gum 0.1%	0.1	22	23	24
xanthan gum 0.5%	0.5	21	21.5	22.5
xanthan gum 1.0%	1	20.1	21.1	22.2
xanthan gum 2.0%	2	16.1	16.6	17

Table 10: Spray angles result.

4.3.1 Water

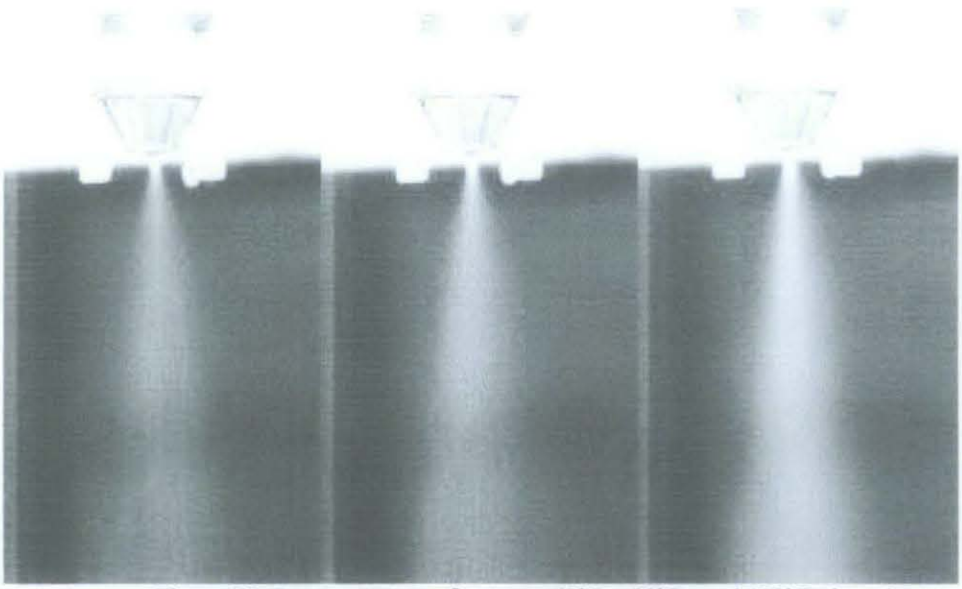


Figure 25: Spray structure of water at 60kPa, 80kPa and 100kPa in order.

It is observed from above figure, the spray angle of water increase as the pressure increases. The spray angle of water at 60kPa, 80kPa, and 100kPa was measured as 18.5□□, 20□, and 22.5□ respectively.

4.3.2 0.1% wt. Xanthan gum

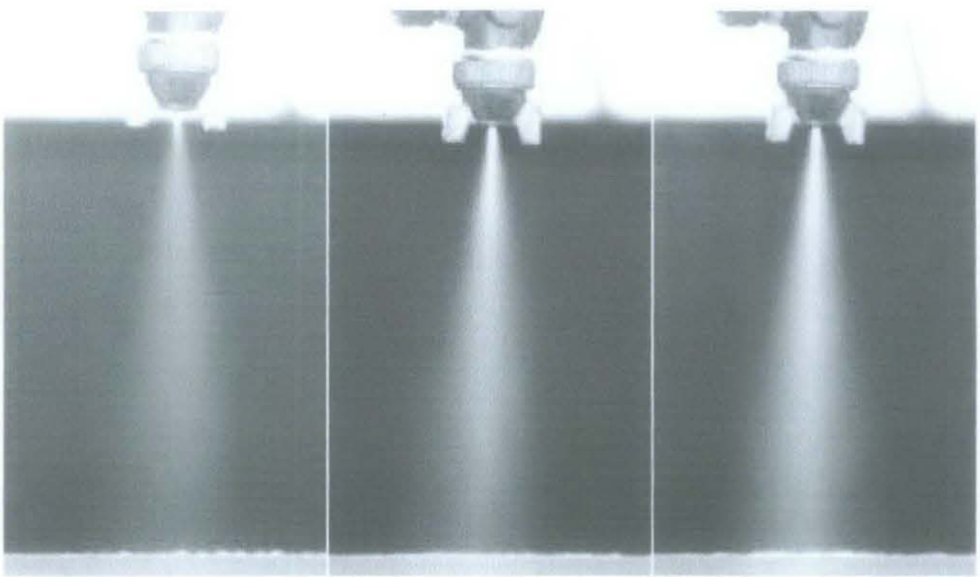


Figure26: Spray structure of 0.1% wt. Xanthan gum at 60kPa, 80kPa, and 100kPa in order.

In Figure 26, spray angle and spray break up structure of Xanthan gum can be seenmore clearly compared to water. At 60kPa, the spray angle of Xanthan gum was measured as 22□. When the pressure increases to 80kPa and 100kPa), the spray angle increases to 23□ and 24□ respectively. It shown that, the spray angle of non-Newtonian fluid will be increase when the pressure increases. But compared to water for each pressure, Xanthan gum produce more wide break up angle.

4.3.3 0.5% wt. Xanthan Gum

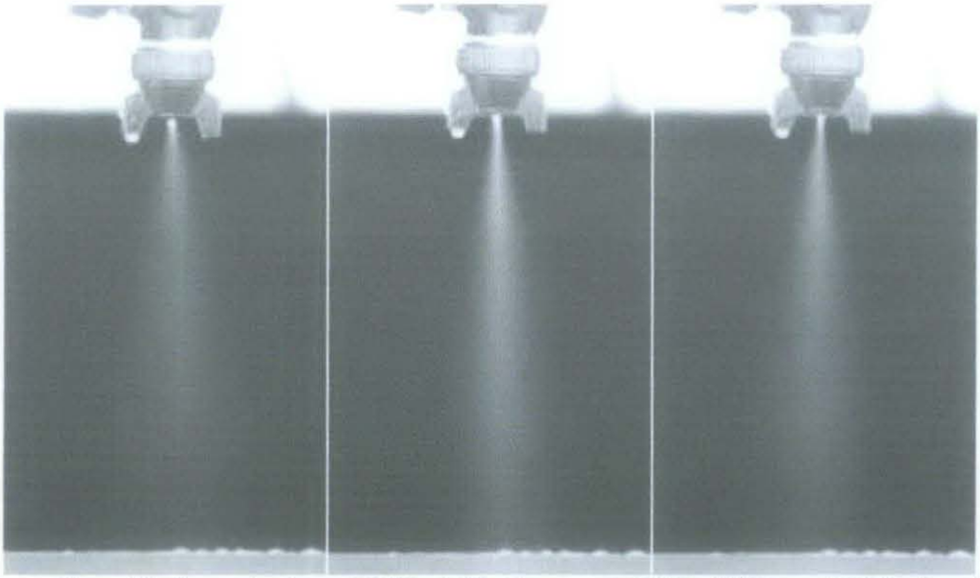


Figure 27: Spray structure of 0.5% wt. Xanthan gum at 60kPa, 80kPa, and 100kPa in order.

For 0.5% wt. Xanthan gum spray structure as shown above, the spray structure not as clear as 0.1% wt. It's because the viscosity of Xanthan gum increases when the concentration of solution increases. The pressure in vacuum area in spray gun will be reducing less than atmospheric pressure respect to the velocity of air flow in nozzle. The atmospheric pressure will push the solution to nozzle vacuum area. If the viscosity of liquid increases, less liquid will be push to vacuum zone. So, the less Xanthan gum will flow into the vacuum area in spray gun. At 60kPa, the spray angle was 21□. For 80kPa, the spray angle was 21.5□ and for 100kPa, the spray angle was observed as 22.5□. It can be observed that 0.5% wt. Xanthan gum spray angle increase with increase in pressure.

4.3.4 1.0% wt. Xanthan gum

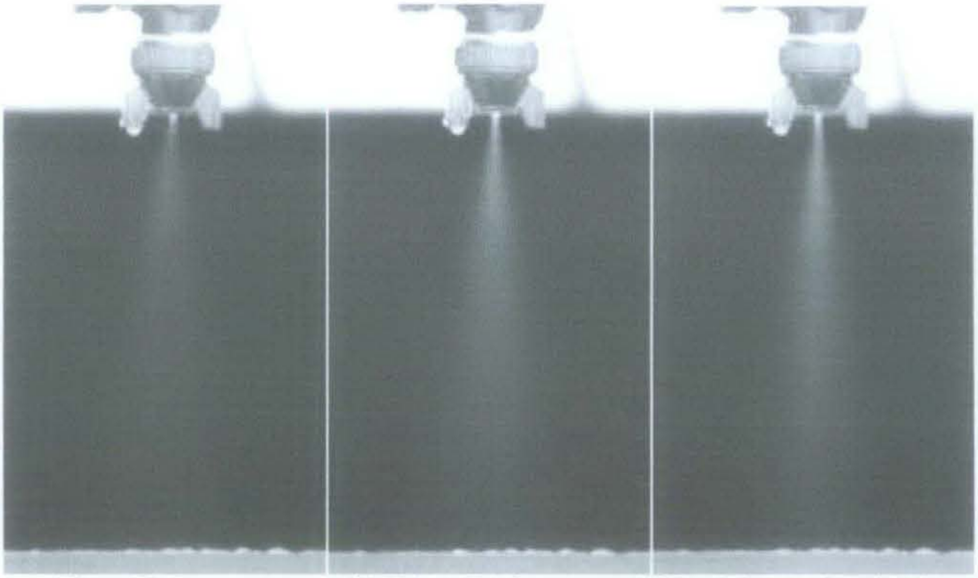


Figure 28: Spray structure of 1.0% wt. Xanthan gum at 60kPa, 80kPa, and 100kPa in order.

It is observed that from the Figure 28, the spray angle of 1.0% wt. Xanthan gum increase as the pressure increases. The spray angle at 60kPa, 80kPa, and 100kPa was measured as 20.1□, 21.1□, and 22.2□ respectively. In addition, spray break up become more blur than previous solution because of increase in viscosity.

4.3.5 2.0% wt. Xanthan gum

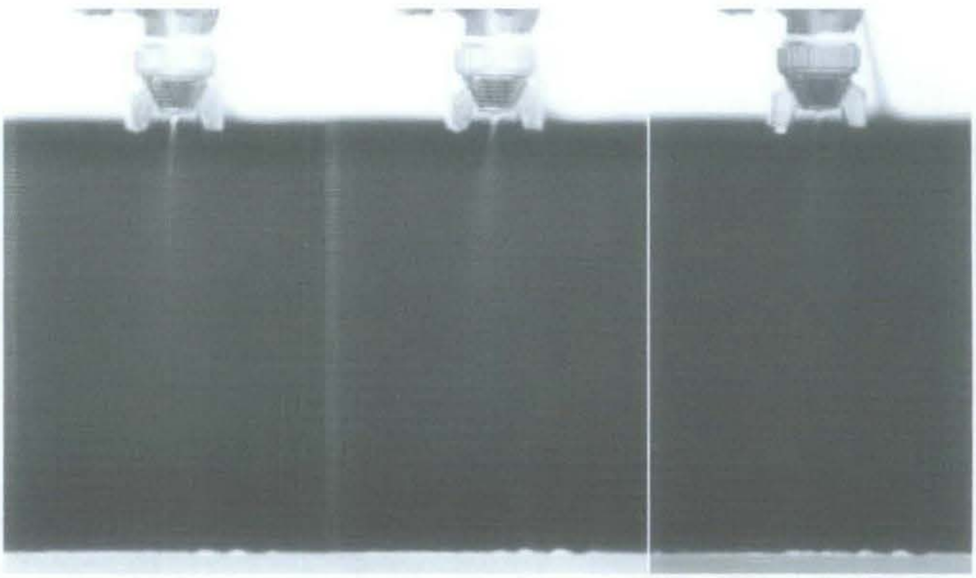


Figure29: Spray structure of 2.0% wt. Xanthan gum at 60kPa, 80kPa, and 100kPa in order.

Figure 29 shown that the spray break up structure of 2.0% wt. Xanthan gum. At 60kPa, the spray angle was measured as 16.1□. For 80kPa and 100kPa, the spray angle was 16.6□ and 17□ respectively. Same as previous concentration, the spray angle increase when the pressure increases. But the picture's view was very haze compared to all previous liquid. It is because the 2.0% wt. Xanthan gum was very viscous and need more pressure to push the solution flow into vacuum area in spray gun.

Below is the graph of the concentration of Xanthan gum versus Spray Angle at 60kPa, 80kPa, and 100kPa. As the concentration of Xanthan gum increases in the solutions, there is an initial increase in the spray atomization angle for all three type of pressure variable. This observation demonstrates that the addition of a small amount of polymer actually enhances the spray characteristics of the nozzle when compared to water, and produces a more dispersed spray. This result is in agreement with the experiment investigating the effect of polymer rigidity and concentration on spray atomization by Graham M. Harrison, Robert Mun, Graham Cooper, and David V. Boger (1998). The previous work showed that the very dilute polymer solutions actually tend to breakup more easily than Newtonian Fluids. This previous work's range of concentration was only between 0%wt. to 1%wt. Our experiment confirms this trend and these phenomenaare manifested in a wider spray angle than the Newtonian fluid.

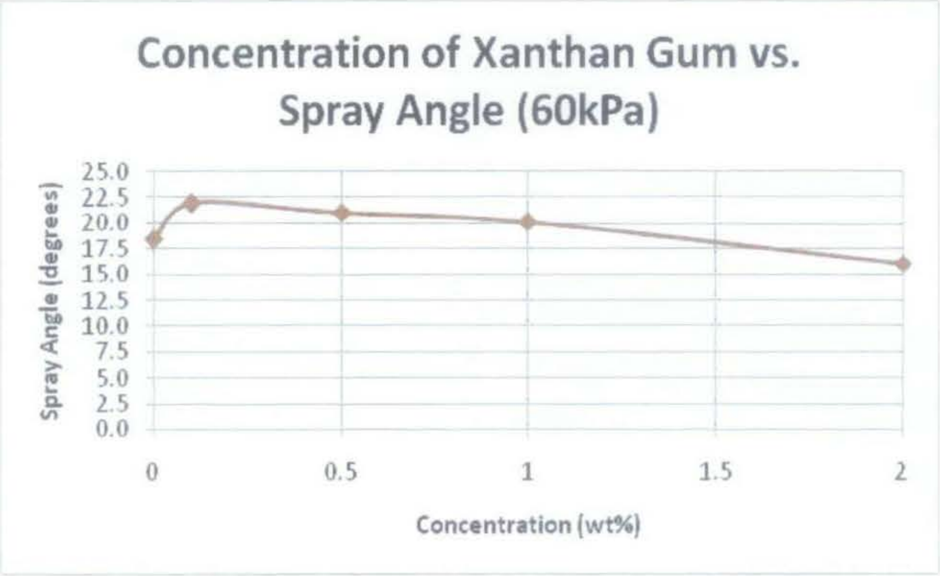


Figure 30: Concentration vs. spray angle of Xanthan gum (60kPa).

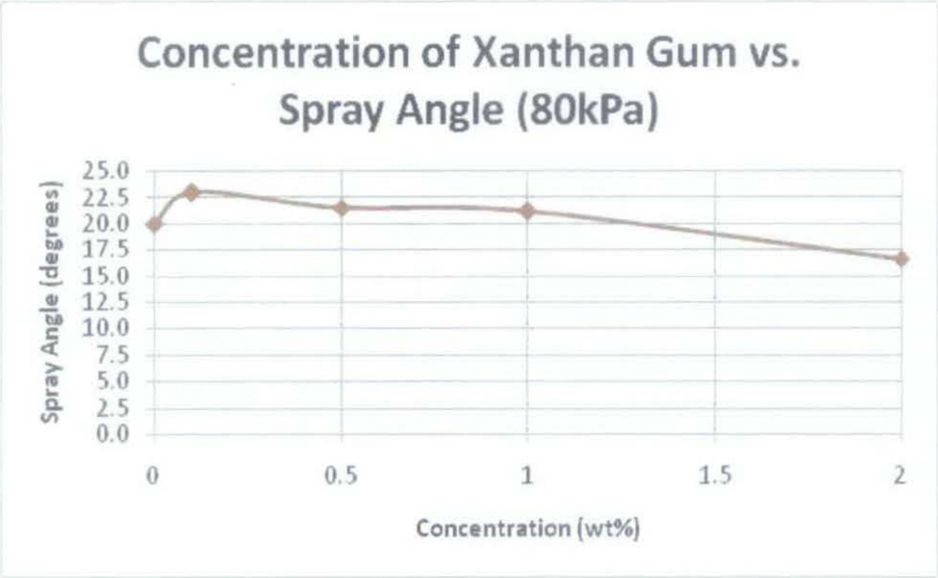


Figure 31: Concentration vs. spray angle of Xanthan gum (80kPa).

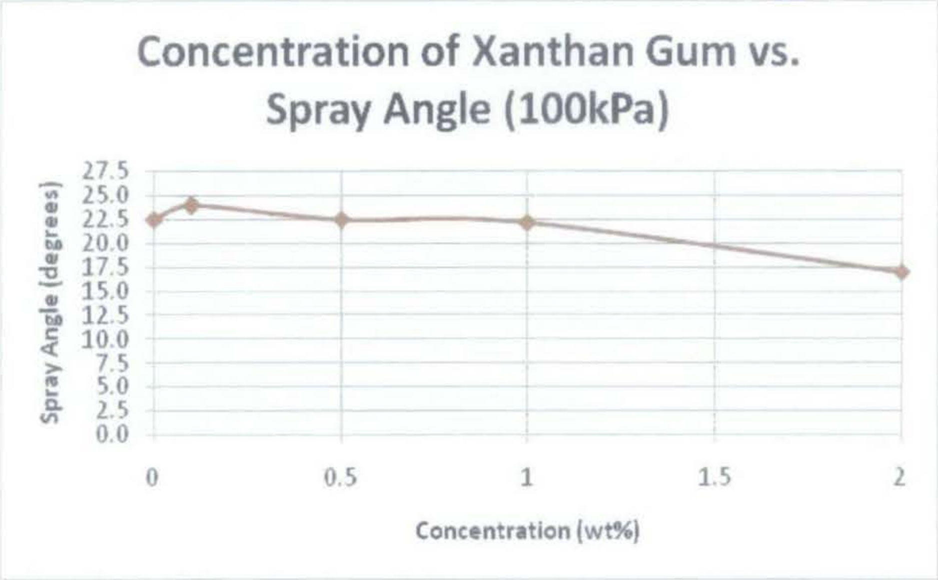


Figure 32: Concentration vs. spray angle of Xanthan gum (100kPa).

As seen in figure above, the trend of the graph was same for different pressure. The spray angle increase from 0% wt. to 0.1% wt. because of polymer influence but from 0.1% wt. concentration to 2.0% wt. concentration, the spray angle was decreased. It because the more viscous Xanthan gum become, the harder atomization breakup take place at tip of the nozzle.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The objectives have been achieved successfully. The project has two main objectives, which is; to study the characteristics of Xanthan gum with variety concentration and breakup structure of sprays. Water characteristics also determined in this study to compared the characteristics between Newtonian fluid which is water and non-Newtonian fluids which is Xanthan gum. LDA/PDA experiment was done to get the characteristics of fluid which are Sauter Mean Diameter and velocity of droplet coming out from the nozzle. Furthermore, the angle of spray breakup was determined by the picture captured by high speed camera. For LDA/PDA experiment, 2 value of pressure was used which is 20kPa and 40kPa for each fluid as the measurement difficult to take at higher pressure. Meanwhile for high speed camera experiment, 3 values of pressure was used which is 60kPa, 80kPa, and 100kPa.

As conclusion, the pressure and concentration of Xanthan gum is the factor that influence the characteristics of non-Newtonian fluids and breakup structure of spray. When the pressure increases, the velocity and spray angle will be increase but the SMD values of droplet will be decrease. Moreover, as concentration of Xanthan gum increase, the SMD values of droplet will be increase but the velocity and spray angle will be decrease.

4.2 Recommendations

Current spraying system available on the LDA/PDA lab should be upgraded or improved. This is important in order to produce better spray to get better reading on LDA/PDA system. In order to do so, higher quality nozzle should be used and suitable pump for the nozzle specification should also be taken into consideration. Besides that, the clamp used to hold spray nozzle should also be replaced with more stable and could be accurately positioned to get the lasers intersect on desired spray's penetration distance and radial distance. The current clamp used highly inaccurate as its adjusting joints move rotationally result to difficulty to control placement of nozzle with respect to the point where the lasers from LDA/PDA system intersect.

Furthermore, more detail study could be done by taking more measurement with vary the penetration distance, radial distance, pressure variable and different types of cone. Sometimes, high speed camera taking the blur picture and it should be upgraded its lens to more detail.

REFERENCES

1. Glyn O. Phillips, Peter A. William, 2000, "Handbook of Hydrocolloids", Cornwall, England, ISBN 1-85573-501-6.
2. Yunus A. Cengel, John M. Cimbala, 2010, "Fluid Mechanics; Fundamentals and Applications", Avenue of Americas, New York, ISBN 978-007-128421-9.
3. Krzeckowski, S.A., "Measurement of Liquid Droplet Disintegration Mechanism," Int. J. Multiphase Flow, Vol. 6, 1980, pp. 228-239.
4. Jungbunzlauer AG, 2006, "Xanthan Gun; A hydrocolloid with outstanding properties", http://www.jungbunzlauer.com/productsapplications/products/xanthan-gum/xanthan-gum/general-information.html, accessed – 21 June 2011.
5. Bendig L, Nasr G.G, Yule A.J, 2002, "Industrial Sprays and Atomization", Trowbridge, Wiltshire, ISBN 1-85233-460-6
6. D. R. Guildenbencher,C.Lopez-Rivera and P. E. Sojka, 2009, "Secondary Atomization", Exp. Fluid, Vol 46, Number 3, pp. 371-402.
7. Azzopardi, B.J, and Hutchinson, 1983, "The disintegration of liquid droplet", UKEA Report AERE R10929.
8. Rayleigh, Lord, 1873, "On the instability of jets", Proc. London Maths. Soc 10, pg 4 – 13.
9. Chin, J,S and Lefebvre, A. H., 1985, Some comments on the characterization of drop-size distribution in sprays, Proceedings of ICLASS-85, IV/A/1/1-12
10. Lane, W.R. and Dorman, R.G., 1951, "Further Experiments on the Shattering of Drops by a Supersonic Air Blast", Tech. Paper No., p.279, Porton, England.
11. Durst, F., A. Melling, and J. Whitelaw, 1981, "Principles and Practices of Laser-Doppler Anemometry", Academic Press.
12. G Luxford, 2005, "Experimental and Modelling Investigation of The Deformation, Drag and Break up of Drizzle Droplets subjected to strong Aerodynamic Forces in relation to SLD Aircraft Icing", PhD Thesis, Cranfield University 2005.
13. Graham M. Harrison, Robert Mun, Graham Cooper, David V. Boger, Sept. 1998, "A note on the effect of polymer rigidity and concentration on spray atomization", Journal Non-Newtonian Fluid Mechanic 85 (1999) 93-104.

14. DantecDynamics,2011,"http://www.dantecdynamics.com/Default.aspx?ID=1058 ", accessed – 20 June 2011.
15. Laser-Doppler Anemometry. Academic Press. Phase Doppler Anemometry, http://www.tut.fi/units/me/ener/laitteistot/EFD/PDA.html, accessed – 15 June 2011.
16. Azzopardi, Barry J, 2010, A-Z Guide to Thermodynamics, Heat & Mass Transfer, and Fluids Engineering, "http://www.thermopedia.com/content/1108/", accessed – 20 June 2011.
17. What is Formaldyhyde, wiseGEEK, 2011, "http://www.wisegeek.com/what-is-formaldehyde.htm" accessed – 01 August 2011