Characterizations of Sprays of Modified Starch Solution at Elevated Temperature for Particle Coating Application

by

Mohd. Hazwan bin Mohd. Ariff

Dissertation submitted in partial fulfilment of

The requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2013

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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In partial fulfilment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

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(Ir. Dr. Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2013

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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MOHD. HAZWAN BIN MOHD. ARIFF

ABSTRACT

Spray is a liquid that is driven through the air in the form of tiny drops. In agriculture industry, this technology has been widely used to apply coating on fertilizer particles or granules. Through this application, plantation growth due to the supply of nutrients from urea granules could be controlled accordingly. In order to do that, it is very important to formulate and determine the most suitable thickness, composition and concentration of urea coating to control the nutrients release rate for any specific application. Hence, a study on characteristics of spray and particle coating is crucial and essential in order to achieve the best spray configurations. The present work focused on characterizations of spray for particle coating application. Modified starch solutions with varied compositions and concentrations of starch, urea and borate were studied as sprays throughout this project. Input parameters like temperature, pressure, density, flow rate, dynamic viscosity, surface tension and solution concentration were determined and varied during the experiments. Then, the corresponding spray characteristics including spray cone angle, spray width, spray tip penetration, nozzle discharge coefficient, Weber number and Reynolds number were measured by using high speed digital camera. It was found that spray cone angle will increase as the temperature and pressure increase. Due to that, spray width and spray tip penetration would increase as well. For nozzle discharge coefficient, the fluid flow rate increased with the rise in fluid supply pressure due to the increasing in fluid velocity which influences the value of nozzle discharge coefficient. Last but not least, high Weber number and Reynolds number were found to result in finest atomization of the modified starch solution.

ACKNOWLEDGEMENT

Here, I would like to express my greatest gratitude to God the Almighty for his blessing that allows me to complete my Final Year Project. My deepest appreciation goes to my supervisor, Associate Professor Ir. Dr. Shaharin Anwar Sulaiman. He gave me a great deal of help and guidance throughout the project. Besides that, he was also very understanding and supportive despite of major delays while the execution phase of the project. Thanks to Mr. Muhammad Yasin Naz for his ideas, guidance and technical assistance throughout the course of the conducted research work. Not to forget, Dr. Ku Zilati for her helps in providing commercial urea granules for this project. Last but not least, thank you so much to my parents and friends for giving me endless support both morally and financially.

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ABBREVIATIONS

T	Temperature
P	Pressure

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Spray is a dynamic collection of liquid drops dispersed in gas (Lefebvre, 1989). There are a few main functions of spray; distributing a liquid over an area, increasing liquid surface area and creating impact force on a solid surface. Spray nozzle is normally used to facilitate the dispersion of liquid into a spray. When a gas is injected under a certain pressure through a tube with a decreasing cross-section of area, it speeds up and generating a pressure drop at the narrowest point. The pressure difference formed between these two points will suck up liquid into the moving gas flow and projects it out as a fine spray of droplets. Normally, it is designed whether to have either one or more outlets, depending on the requirements of spray applications (Mohamad Yusoff, 2011).

There are thousands of application which spray allows materials to be used effectively (Ballester, 1994). In manufacturing industry, sprays are used extensively in cleaning components with sprays of hot water and detergent sprays for degreasing, diesel engine rebuilding, steel mill bearings and plant maintenance. For fire protection purpose, water tunnel systems are designed to ensure a safe cool corridor to allow people to escape in the event of fire. Apart from that, the technology also has been widely applied in agriculture sector to coat fertilizer particles or granules. By applying coating on urea particles, the performance of urea could be controlled accordingly, beneficial for plantation growth. The maximum benefit from coated fertilizer is only achieved when the duration of nutrients release is synchronized with the periods of plant nutrient uptake.

The coating of urea granules may control the rate of nutrients released to the soil. Normally, fertilizer particle contains a high percentage of nutrients importance for plant growth. When reacts with water, the chemical reaction that occurs will have the tendency to release a high amount of nutrients to the soil that may lead to waste of nutrients and improper watering to the underground water sources. With the use of coating, the nutrients release rate would be limited to a certain degree, only due to the reaction with heat of the soil that consumes a small amount at any given time. This method might be the most efficient way in making sure that only the required amount of nutrients are released to the soil without wasting the fertilizer used (Suherman and Anggoro, 2011). The thickness and evenness of coating also need to be carefully considered since there are main factors contributing to the life span of fertilizer and the rate of nutrient released. These two factors shall be dealt accordingly due to their huge impacts to the fertilizer particle used throughout the project.

1.2 Problem Statement

Jet breakup mechanism or atomization is a condition when the liquids mix with air as fine droplets achieved by using the venture effect. It is known that the performance of coating is depending on the physical conditions of coating (Wan Sohaimi, 2012). The main concern of atomization study is on how to control the thickness and evenness of the sprayed materials when applying coating. In agricultural industry, these two factors contribute a huge significant influence on the fertilizer performance. Instead of having an ideal sphere shape, normally the urea produced will come in an irregular shape. Due to that, it is very important to ensure that every area should be coated evenly when applying spray to the fertilizer granules. The main reason behind this is because the exposed area will permit the fertilizer to react with water or air producing nitrous oxide. The emission of this toxic gas should be avoided or minimized as it contributes to the greenhouse effect and depletion of ozone layer in stratosphere (Tucker, 2005). Coating thickness plays important role in controlling the rate of nutrients released to the soil. But dealing with sprays of modified starch solution at high temperature into ambient air may be quite complicated since there is a high tendency for sudden temperature drop during atomization, which can affect structure of the coating layer. In order to achieve the desired life span and nutrients release rate from fertilizer, the thickness of the solution coating must be monitored accordingly (Mohamad Yusoff, 2011). The coating applied must be not too thin that consequently may not meet the initial purpose of having coating, which is to control the nutrients release rate and must be not too thick which can lead to inefficiency of the fertilizer granules in providing the required nutrients to the plant accordingly. Due to these contributing factors, a study of spray characteristics of the modified starch solution is vital. Besides, it is worth to note that the losses of fertilizer granules are mainly caused by leaching, decomposition and ammonium volatilization in soil, handling and storage (Shaviv and Mikkelsen, 1993).

1.3 Objectives and Scope of Study

The main objective of this project was to study the characteristics of sprays of a modified starch solution as a result of a few input parameters. The input parameters of interest were temperatures of 60, 80 and 100°C at pressures of 2 and 4 bar. The characteristics of spray with different compositions and concentrations were determined and measured in term of spray cone angle, spray width, spray tip penetration, nozzle discharge coefficient, Weber number and Reynolds number. Related studies like granule diameter, microscopic analysis, dissolution rate and crushing strength were also conducted in order to study the effects of weight ratios and concentrations on the coated urea particles.

The scope of study for this project consisted of preparation of the modified starch solution and study on the characteristics of spray and particle coating by using high speed digital camera. For this project, the research work did not involve modelling or simulation. The project was done with the assumption that the urea granules used were approximately homogeneous in size with an average diameter of 3 mm. The results gathered from this project would be used in future work to determine the best spraying configuration in order to obtain the most suitable fertilizer coating characteristics.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Non-Newtonian Fluid

Rheology is referring to the study of the deformation of flowing fluids. Non-Newtonian fluids can be best defined as fluids for which the shear stress not linearly related and dependent on shear rate as shown in Figure 2.1. Cake butter, paste, sauce and polymer solutions are a few examples of Non-Newtonian fluids. The special feature of Non-Newtonian fluid is its exhibits a "memory" where the shear stress depends not only on the local strain rate, but also highly depending on its viscosity. Due to this, it will completely recover back to its initial state after the applied stress is released (Cengel, 2010). This ability to return to its original state is called viscoelastic.

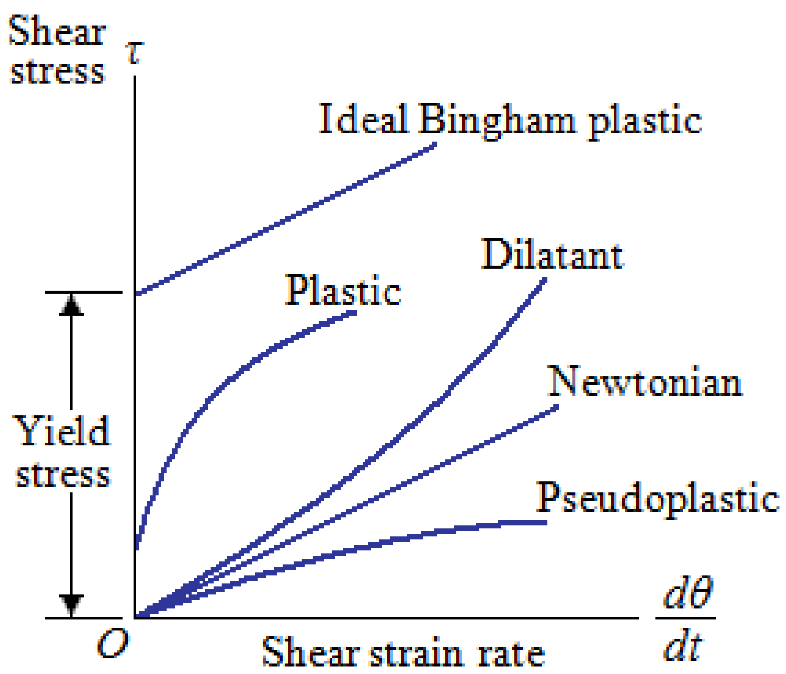

Figure 2.1: Rheological behaviour of fluid shear stress as a function of shear strain rate (Engineering Archives, 2012)

Shampoo is classified as a pseudo-plastic or shear thinning fluid because when the fluid is sheared to a certain degree, the viscosity will decrease (Cengel, 2010). Since the shear rate of shampoo is small, the high viscosity makes it easy to pick up by hand. But when applied to the body, the smooth layer that forms between hand and the body is subjected to a large shear rate; hence it will become less viscous. Plastic fluids are those in which the shear thinning effect is extreme. The best example to show this phenomenon is tooth paste. When the tube is held upside down, the paste will not flow even though there is a non-zero stress due to the gravity. However, when the tube is squeezed, the paste flows like a viscous fluid.

Other fluids that behave in the opposite manner are referred as dilatant or shear thickening fluids; the more the fluid is sheared, the more viscous it will become (Cengel, 2010). Quicksand, a thick mixture of water and sand behaves in such a way. Moving slowly through quicksand is easy as compared to move quickly due to the increasing of viscous resistance.

2.2 Modified Starch Solution

Modified starch solution that was used throughout this project consisted of various compositions of starch, urea and borate. Starch or also known as amylum is a naturally nutrient carbohydrate, $(C_6H_{10}0_5)_n$ forming polysaccharide that is produced by all green plants as an energy store (Gait, 2012). Natural starch is a mixture consists of two types of molecules; branched amylopectin and helical amylose. The cereal grains like rice, wheat, barley, oats and corn as well as tubers such as potatoes are rich in starch. Starch modification, through the use of nano composite such as nanoclay alters the physical and chemical characteristics of pure starch (Nik Omar, 2011). Due to its versatility and low price, starch could be modified to be used broadly as water binder, gelling agent, emulsion stabilizer and thickener.

2.3 Fertilizer Granules Coating

The main purpose of applying urea granules coating is to control the release rate of nutrients to the plantation soil. The control is enabled by properties of the coating; porosity, heat resistance and low solubility rate in water (Nik Omar, 2011). Uncoated fertilizer particle releases a high amount of nutrients to the soil when reacts with heat from the soil and dissolving in water due to the rain and watering system. With the coating application, the nutrients release rate could be formulated as desired during manufacturing. Hence, the amount of nutrients supplied could be controlled according to the plant needs and waste of nutrients could be extremely reduced. As the result, the life span of fertilizer particles could be extended. In addition, this technique might be the most efficient way in making sure that only the required amount of nutrients are released to the soil without wasting the fertilizer (Suherman and Anggoro, 2011).

Currently, modified starch solution has become the best alternative to replace synthetic polymer which was conventionally used to coat fertilizer granules (Nik Omar, 2011). This is mainly contributed due to the increasing of society's concerns for environmental issues such as biodegradable and non-toxicity (Tudorachi et al., 2000). On top of that, starch is favourable since its cost of manufacturing is much cheaper as compared to conventional synthesis polymer like polyethylene. However, pure starch polymer is poor in term of mechanical properties needed to coat urea granules such as water solubility resistance. Hence, modified starch solution needs to be carefully formulated to serve its function for coating purposes.

In order for the coating to serve its function properly, the coating has to encapsulate the fertilizer granules (Nik Omar, 2011). The spraying system should be able to produce a high area of coverage to coat hundreds of fertilizer granule simultaneously. Hence, it is important to have a large spray cone angle and width. Apart from that, the thickness and evenness of coating on the urea particles have to be monitored accordingly as they determine the performance of fertilizer. The thicker the coating, the slower nutrients release rate will become (Mohamad Yusoff, 2011).

The microscopic analysis that was done by using Scanning Electron Microscopy showed that the formation of a thin layer on the surface of coated product has a different morphology, more compact and any irregularities of the crystal (Suherman and Anggoro, 2011). They added that the dissolution rate of fertilizer granules decreases with the increasing concentration of starch and decreasing fluidized bed temperature. The drawback of slow-released fertilizer may be in term of cost which is slightly higher, but their benefits outweigh the disadvantages (Vashishtha et al., 2010).

2.4 Spraying Mechanism

Sprays are the result of high pressure-driven liquid jets injected through injector nozzle orifice into surrounding mechanism. Liquid droplets need sufficient momentum to penetrate the surrounding mechanism to produce spray break up. The characteristics of spray are summarized by its spray cone angle, spray width, spray tip penetration, nozzle discharge coefficient, Weber number and Reynolds number. The main components acting on the liquid during spray break-up are dynamic viscosity and surface tension. Their relative important is indicated by the values of Weber number and Reynolds number where high values indicate fine atomization.

For spraying mechanism, a few options of spraying mechanisms should be thoroughly considered and studied before applying coating to the fertilizer granules or particles. There are two ways to apply coating to the urea particles, either by top spray or bottom spray methods. Top spray method as shown in Figure 2.2 is very popular in pharmaceutical industry for active layering and coating to modify or control drug release because it produces a superior film as compared to other coating techniques (Saurabh and Garima, 2010).

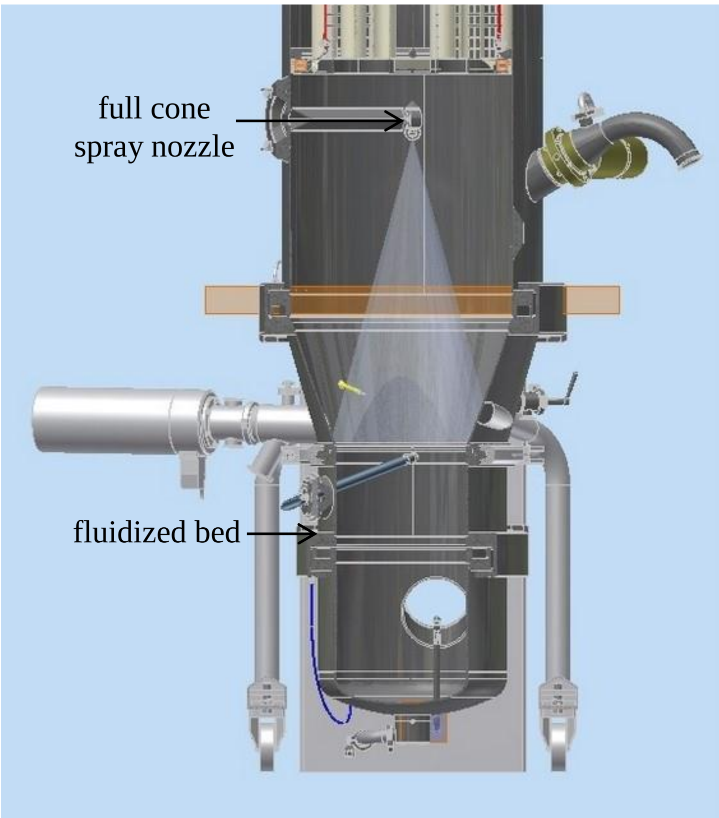

Figure 2.2: Top spray granulation (Smith et al., 2005)

In this system, atomizer was mounted at the top part of the container and a short distance of 6 cm was kept between the injector tip and fluidized bed during coating process. A full cone spray nozzle having orifice diameter of 1.5 mm was used to atomize the solution at elevated temperatures and pressures.

It was designed to be in such arrangement in order to minimize the spray drying effects and enhance the coating uniformity and efficiency. It will also ensure that the coating applied will cover the urea granules evenly with the desired thickness. One of the distinguish advantages of using top sprayed fluidized coater is its self-controlling system (Alavi and Mirmomen, 2007). As compared to bottom spray mechanism, top spray granulation has a greater effect on granulation and lesser attrition due to its higher spray rate. Hence, it will ensure the consistency of batch-to-batch produced which will be resulting in improving quality of the coating.

2.5 Dynamic Viscosity

In simple words, dynamic viscosity is the fluid resistance to shear or flow and is a measure of the frictional fluid property. This resistance is due to the intermolecular friction exerted when layers of fluid attempts to slide by one another. Figure 2.3 is velocity profile of a fluid flows between moving and fixed plates of the tangential force per unit area when maintained at a unit distance.

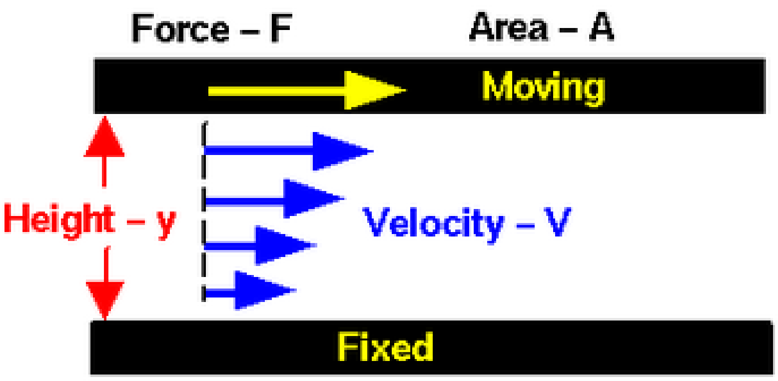

Figure 2.3 Dynamic viscosity (National Aeronautics and Space Administration, 2010)

By referring to Figure 2.3, F represents the force applied, A is area, *y* is the distance between moving and fixed plates while v indicates the velocity profile of fluid moving between both plates. Dynamic viscosity in this case can be best expressed as:

$$\tau = \mu \frac{dv}{dy} \tag{2.1}$$

where τ is the shearing stress and μ is the dynamic viscosity. An increase in dynamic viscosity not only leads to decrease in flow rates and creating heavy edges, but also will increase the capacity and drop size of the sprayed modified starch solution.

2.6 Surface Tension

Conceptually, surface tension is the tendency of the surface of a liquid that allows it to resist an external force. The phenomenon is normally caused by the cohesive forces between molecules. The cohesive forces between liquid molecules are shared with neighbouring atoms in all directions, resulting in a net force of zero. Those molecules on the surface which do not have any neighbouring atoms above will have the tendency to exhibit stronger attractive forces upon their nearest neighbours on the surface. The droplets of liquid tend to be into a spherical shape by the cohesive forces of the surface layer. As the temperature increases, the surface tension will decrease significantly due to the polar nature of the liquid molecules. In daily life, the application of surface tension concept could be clearly observed when hot water is more preferable as cleaning agent. The lower surface tension allows hot water to get into pores and fissures rather than bridging them with surface tension. By increasing the surface tension, the droplet size and minimum operating pressure will increase with the decreasing in spray cone angle.

2.7 Density

Density can be best defined as mass per unit volume of a substance under specified conditions of pressure and temperature. The relationship between density, mass and volume is shown as:

$$\rho = \frac{m}{V} \tag{2.2}$$

where ρ is the density, m is the mass and V represents the volume. Density of a material varies with pressure and temperature, hence, any changes either to the pressure or temperature will have a huge significant impact to the density of any substance. At the pressure of 1 atm and temperature of 100°C, the density of water is given by 958.4 kg/m^3 while at the same pressure and temperature of 25°C, the density of water is given by 997.8 kg/m^3. This shows clearly the relationship between the temperature and density of water. At a constant pressure, the increasing of temperature will lead to the decreasing of density while by increasing the pressure will increase the density.

2.8 Spray Cone Angle and Width

Figure 2.4 portrays the fine spray of droplets coming out from a nozzle that form spray cone angle and width. Spray cone angle refers to the angle forms when the fluid is sprayed from the spray nozzle while spray width represents the width to which the sprayed fluid has fanned out at a predetermined distance from the orifice. When the fluid is sprayed downward like is shown in Figure 2.4, the spray width tends to shape like a candle flame as the distance from the orifice increases. Hence, the actual spray width that may be obtained is slightly different as compared to the theoretical spray width for any given spray cone angle. High speed digital camera was used to capture the images before comparing the gathered data.

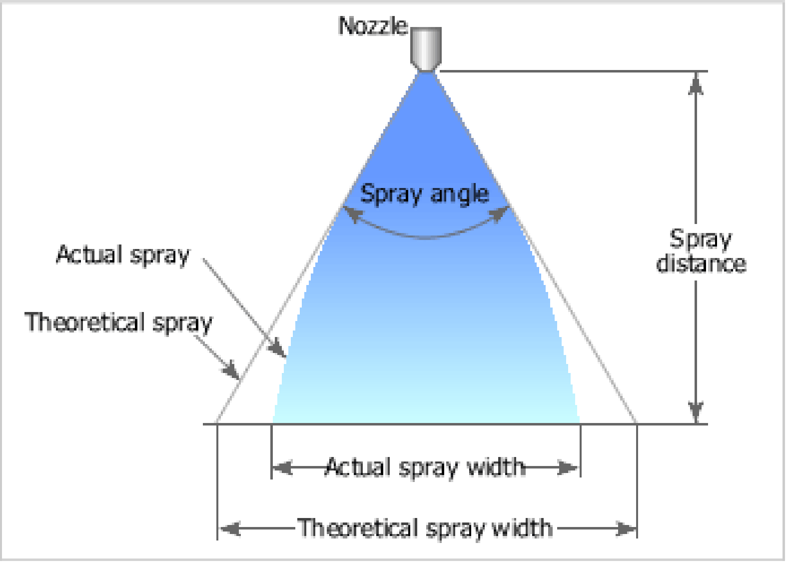

Figure 2.4: Spray cone angle and width (Nozzle Network, 2013)

2.9 Spray Tip Penetration

Spray tip penetration is defined as the maximum distance from the nozzle tip of the size view spray image (Abd Majid, 2011). Figure 2.5 portrays the radial distance covered, Θ and the penetration distance, L_{tip} for a given spray. By varying radial distance covered, Θ and penetration distance, L_{tip}, velocity and size of the spray droplet were taken. In order to capture the images of spray tip penetration, high speed digital camera was used.

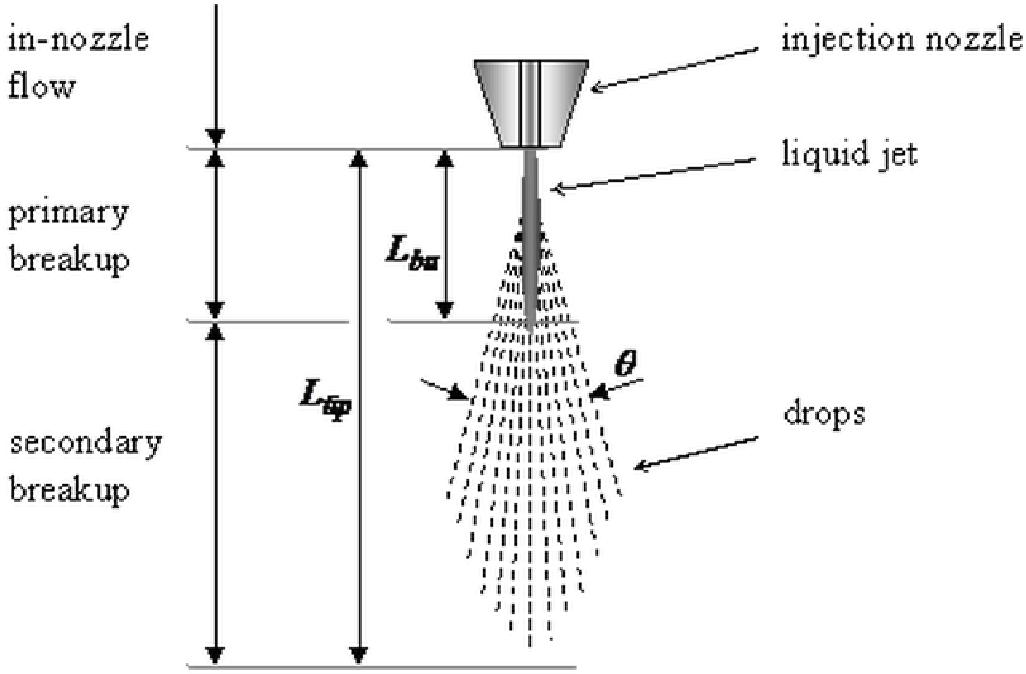

Figure 2.5: Spray distance from nozzle tip (SHRL, 2013)

2.10 Nozzle Discharge Coefficient

Nozzle discharge coefficient is the ratio of the actual discharge to the theoretical discharge. In other words, it is the ratio of mass flow rate at the discharge end of the nozzle to that of an ideal nozzle which expands an identical working fluid from the same initial conditions to the same exit pressure. The equation for nozzle discharge coefficient is given by:

$$C_d = \frac{Q}{A_0\sqrt{2gH}} \quad (2.3)$$

where Q is the flow rate of the fluid, A_0 is the orifice area, g is the gravitational constant and H is the centre line head (H).

2.11 Weber Number

Weber number (We) is a dimensionless value useful for analysing fluid flow relates the force from surrounding air pressure to the surface tension force around the droplet perimeter (Luxford, 2005). Equation (2.4) represents the ratio between the inertia forces to the surface tension forces which can be expressed as:

$$We = \frac{\rho V^2 L}{\sigma} \tag{2.4}$$

where ρ is density of the fluid, V is velocity of the fluid, L is the characteristic length (droplet diameter) and σ is the surface tension. Normally, Weber number is applied to analyse the formation of droplets and thin film flows. It was found that higher value of Weber number will cause finer atomization (Kamarul Bahrin, 2011).

2.12 Reynolds Number

Reynolds number (Re) can be simply defined as the ratio inertia forces to viscous forces. Commonly found in fluid mechanics application, Reynolds number relates the relative importance of these two types of forces for any specific given flow conditions. The equation is given by:

$$Re = \frac{inertial\ forces}{viscous\ forces} = \frac{\rho VL}{\mu} \tag{2.5}$$

where ρ is density of the fluid, V is mean velocity of object relative to the fluid, L is the characteristic linear dimension and μ is dynamic viscosity of the fluid.

Reynolds number is important to measure and indicate whether the flow is laminar, transition or turbulent. Reynolds number that gives value less than about 2300 is generally considered as laminar flow while turbulent flow occurs when the value is greater than 4000. If the Reynolds number lies between the ranges of 2300 to 4000, the fluid flow is considered as transition. Normally, in the low number of

Reynolds number, the viscous forces which are inversely proportional to the Reynolds number are dominant where the fluid tends to flow in a constant motion. The characteristics of laminar flow tends to produce chaotic eddies and vortices. It is worth to note that the higher value of Reynolds number indicates finer atomization (Kamarul Bahrin, 2011).

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Shown in Figure 3.1 is process flow of the project. The project commenced with background study on the characteristics of spray for urea granule coating application. The compositions of modified starch solution to be tested were thoroughly studied. In order to characterize and fully optimize the sprays of tested solution, input parameters like temperature, pressure, density, flow rate, dynamic viscosity, surface tension and solution concentration were carefully studied.

Then the familiarization of high speed digital camera equipment and other related procedures took into place. By referring to journals and papers related to the project, all possible improvements were identified to be implemented in this research work. The next step was preparing the modified starch solution by varying the composition of materials used; namely starch, urea and borate in 300 mL solution of distilled water. After the preparation of modified starch solution, parameters such as dynamic viscosity, surface tension and density were determined.

The other relevant preparations of experiment consisted of deciding on the spraying system setup and selecting the spray nozzle type. Next, the images of spray were captured by using high speed digital camera. A set of pressures and temperatures were varied to see the effects on the characterizations of spray. A few relevant studies like granule diameter, microscopic analysis, dissolution rate and crushing strength were also conducted to see the effects of weight ratios and concentrations on the coated fertilizer particles.

All the data acquired throughout the project were thoroughly analysed and discussed in Chapter 4. Figure 3.2 shows the key milestone and Gantt chart for the whole research work.

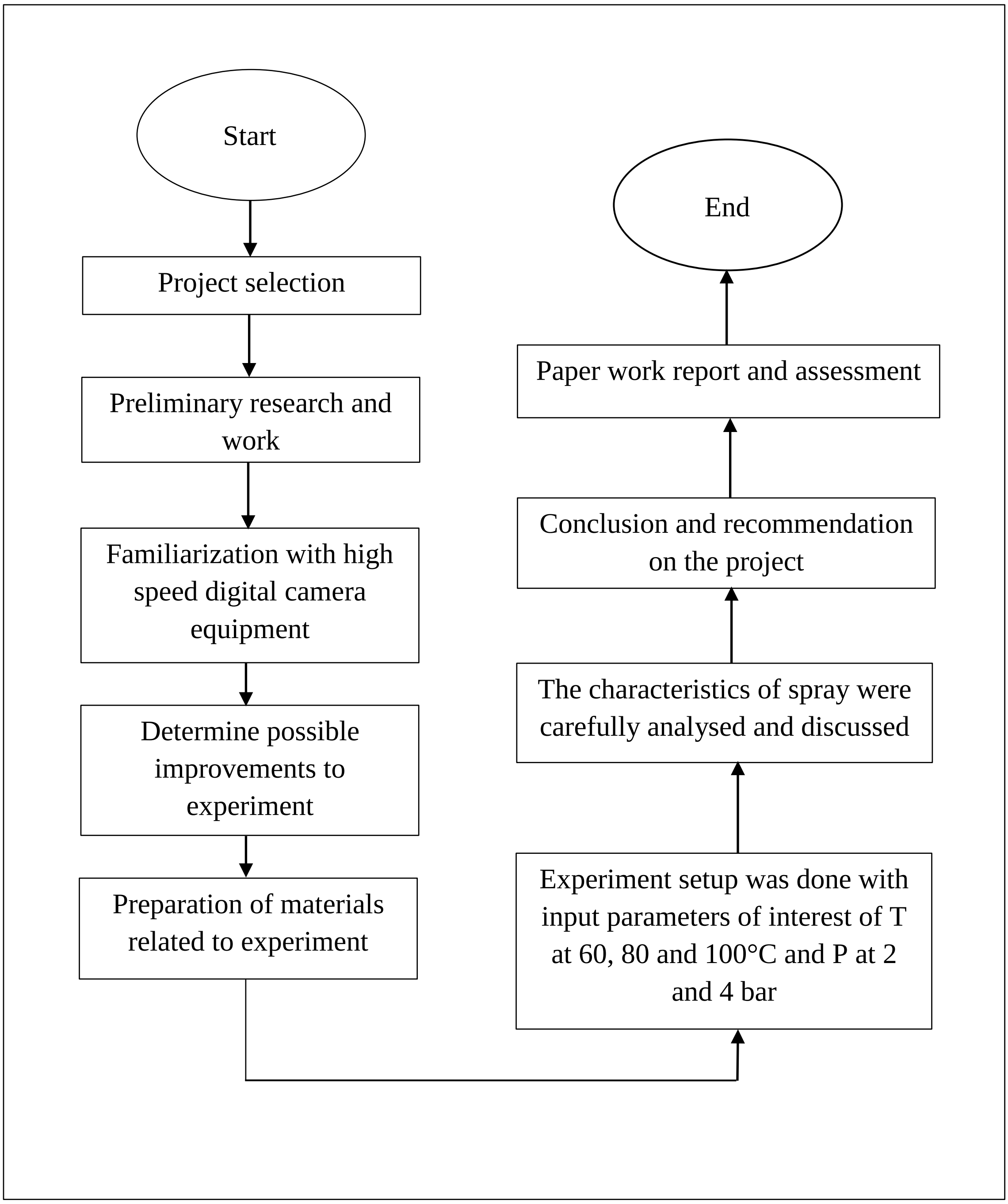

Figure 3.1: Process flow of the project

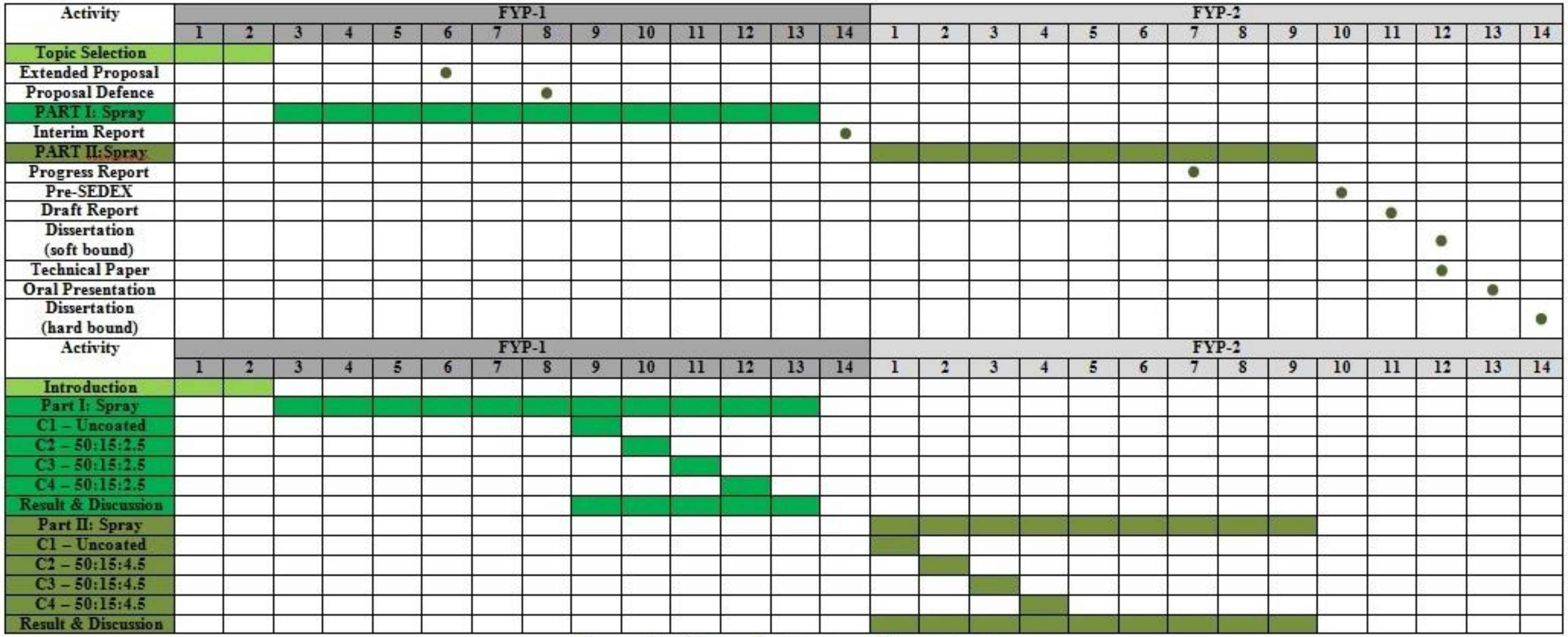

Figure 3.2: Key milestone and Gantt chart

3.2 Experimental Setup

3.2.1 Spraying System Setup

Figure 3.3 shows the experimental setup for the project. The system consisted of a full cone spray nozzle, valves, a fluidized bed, an air compressor, a pressure gauge meter and a high speed digital camera. For this project, single spray mechanism was used to coat the urea granules evenly. This property would ensure that the coating process would be as efficient as possible. By situating the nozzle at the centre, the wetting process would become more uniform. The urea granules were placed in the fluidized bed and were fluidized at a higher pressure than their minimum fluidization. The modified starch solution was atomized through 1.5 mm injector at a set of temperatures (60, 80 and 100°C) and pressures (2 and 4 bar) by using an air compressor. The injection system dispersed the modified starch solution onto the fluidized bed for 30 seconds at room temperature. The images of spray were captured by using high speed digital camera. After 30 seconds, the solution supply was stopped by keeping on the fluidization until dryness. The urea samples were coated with different compositions and concentrations; 30 g of urea with starch-urea-borate weight ratios of 50:15:2.5 and 50:15:4.5, and concentrations of 1.0, 1.5 and 2.0 mL.

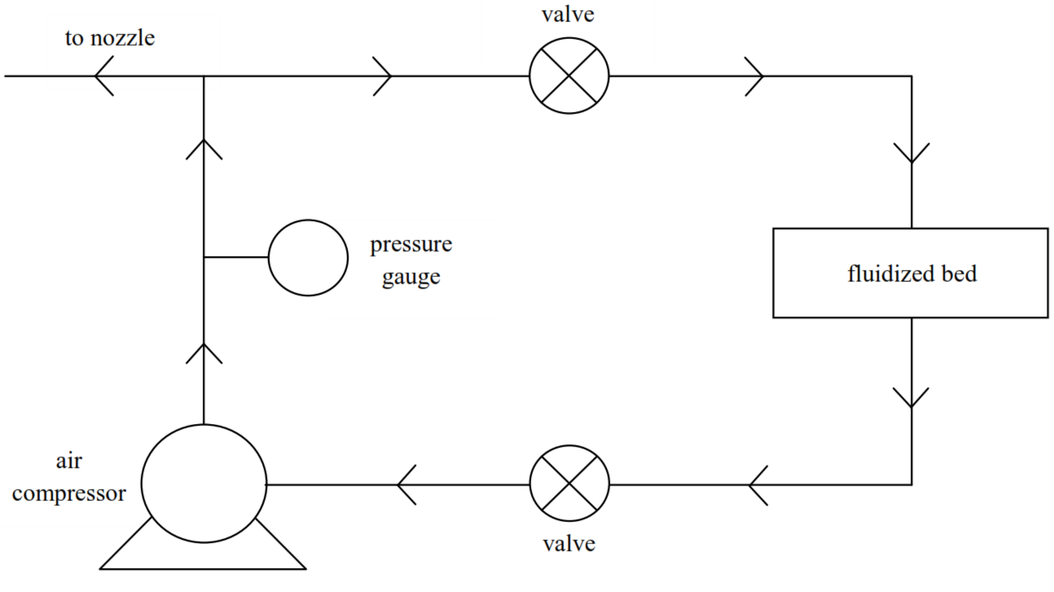

Figure 3.3: Experimental setup

3.2.2 Spray Nozzle

The spray nozzle that has been used throughout this project was high pressure nozzle F-75s manufactured by Akoka. The specifications of the spray nozzle are full cone spray nozzle, operating pressure, P_{op} of 300 – 500 kPa, nozzle outlet diameter of 1.5 mm with flow rate of 0.0013 m^3/s.

3.2.3 Air Compressor

Air compressor was used throughout the project to supply pressure in studying the characteristics of spray. The input parameters of interest for pressure were 60, 80 and 100°C. The air compressor was also needed to fluidize the urea granules in the fluidized bed during coating process.

3.2.4 High Speed Imaging

High speed digital camera was used to record and capture the fast-moving photographic images of the spray under high exposure and high resolution. The settings were set as such in order to acquire good images for better analysis. The images that are captured earlier can be played back in slow-motion. High speed digital camera comes together with Phantom Camera Control software where the settings like light exposure, resolution and shutter speed could be controlled manually.

By carefully analysing the images captured, spray cone angle, spray width and spray tip penetration could be measured. It could be done by drawing two lines to mark the spreading of the spray which later were measured by using Phantom v675.2 software. Specifications of Phantom Camera Control are; full frame 4:3 aspect ratio CMOS sensor composed of 1632 x 1200 pixels, 14-bit image depth, 1000 frames per second full resolution to 153846 fps maximum, 2400 ISO/ASA monochrome, 600 ISO/ASA colour sensitivity equivalency, 24 Gigabytes DRAM, 24 Gigabytes non-volatile flash memory and extreme dynamic range exposure control.

3.3 Scanning Electron Microscopy

Scanning Electron Microscopy as shown in Figure 3.4 was used to study the morphology of particle surface. In this project, morphology of the uncoated and coated urea granules were analysed and studied. For Scanning Electron Microscopy, minimum preparations were needed before examining the samples. By conducting this scanning process, the detailed three-dimensional and topography could be collected and examined. The specifications of equipment are shown in Table 3.1.

Figure 3.4: Scanning Electron Microscopy (Swapp, 2006)

Table 3.1: Specification of Scanning Electron Microscopy

Item	**Specification**
Resolution SE	3.0 nm at 30 kV (High Vacuum Mode)
Resolution BSE	4.0 nm at 30 kV (Variable Pressure Mode)
Magnification	5 - 300,000 X
Accelerating Voltage	0.3 – 30 kV
Maximum Specimen Size	153 mm in diameter

3.4 Dissolution Rate

Modified starch solution serves as a physical barrier to control the nutrients release rate of fertilizer into the soil for plantation growth as desired. The main reason of having this dissolution rate test was to study the relationship between the weight mass and concentration of modified starch solution with the time required for complete dissolution of uncoated and coated urea granules. The test was done by placing 5 g of urea particles into a beaker containing 100 mL of distilled water maintained at room temperature. Stirrer was used at a constant speed of 200 rpm.

3.5 Crushing Strength

Coated urea fertilizer should be designed to have a sufficient mechanical strength to withstand normal handling and storage without fracture. There are a few parameters influence the mechanical strength of a material; chemical composition, porosity, shape, surface crystal and moisture content (Tudorachi et al., 2000). Crushing strength test can be defined as the minimum force required to crushing the individual particle. Crushing strength is measured by applying pressure onto the individual granule, usually of a specified range and noting the pressure required to fracture each granule. For this test, 5 urea granules with approximately homogeneous in size from each sample were randomly selected and the crushing strength readings were taken and averaged by using Erweka equipment.

3.6 Modified Starch Solution Preparation

Composition of the modified starch solution consisted of starch, urea and borate. Generally, modified starch solution serves as a physical barrier to control the nutrients release rate of fertilizer into the soil for plantation growth as desired. Starch was used as one of the components since it could be modified to be used broadly as water binder, gelling agent, emulsion stabilizer and thickener. In agriculture industry, borate is favoured due to it is low solubility and remains longer in soil as compared to other materials. For this project, two compositions with different weight ratios were used to study the characteristics of spray at elevated temperature. The compositions for both modified starch solutions are shown in Table 3.2.

Table 3.2: Composition of the modified starch solution

Material	**Weight Ratio (g)**	
	50 : 15 : 2.5	**50: 15: 4.5**
Starch	50	50
Urea	15	15
Borate	2.5	4.5

The preparation of modified starch solution commenced by measuring 300 mL of distilled water in a beaker. Heat was supplied until the temperature of distilled water reached 80°C. Magnetic stirrer was used to distribute heat evenly to the distilled water. Starch was then weighed with the desired mass into a round bottom flask before added into the distilled water. The solution was left for 30 minutes for complete dissolution. The desired mass of urea and borate were then added into solution and left for one hour with constant stirring at the temperature of 80°C. The solution was left to cool to room temperature for 5 hours.

3.7 Urea Sample Preparation

Figure 3.5 (a) shows the uncoated urea while Figure 3.5 (b) portrays the urea that has been coated with the compositions of starch, urea and borate with green dye. The purpose of applying green dye to the samples was to distinguish between the uncoated urea with coated urea. The uncoated urea and coated urea samples were characterized and analysed in term of urea granule diameter, microscopic analysis, dissolution rate and crushing strength. Before all experiments were conducted, the samples were prepared at the lab with different weight ratios and concentrations. 30 g of urea with the weight ratio of 50:15:2.5 (starch-urea-borate) and 50:15:4.5 (starch-urea-borate) with the concentrations of 1.0 mL, 1.5 mL and and 2.0 mL were prepared and labelled as shown in Table 3.3.

Figure 3.5 (a): Uncoated urea

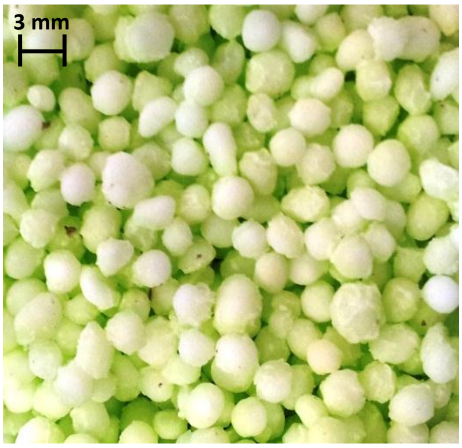

Figure 3.5 (b): Coated urea

Table 3.3: Composition and concentration of the sample

Sample	Composition	Concentration (mL)
1	Uncoated	0.0
2	50 : 15 : 2.5	1.0
3	50 : 15 : 2.5	1.5
4	50 : 15 : 2.5	2.0
5	50 : 15 : 4.5	1.0
6	50 : 15 : 4.5	1.5
7	50 : 15 : 4.5	2.0

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Spray Cone Angle and Width

In order to measure spray cone angle and width, images were captured by using high speed digital camera. To acquire good images for analysis, settings of the equipment were set at high exposure and high resolution. Both of modified starch solutions with the weight ratios of starch-urea-borate of 50:15:2.5 and 50:15:4.5 were heated up at a set of temperatures of 60, 80 and 100°C. Then pressures were supplied from the air compressor at 2 and 4 bar. Phantom v675.2 software was utilised to determine the spray cone angle for each composition. By using the same application, the spray width for both compositions was measured by drawing two lines to mark the spreading of spray. Figure 4.1 portrays the example of the measurement of spray cone angle.

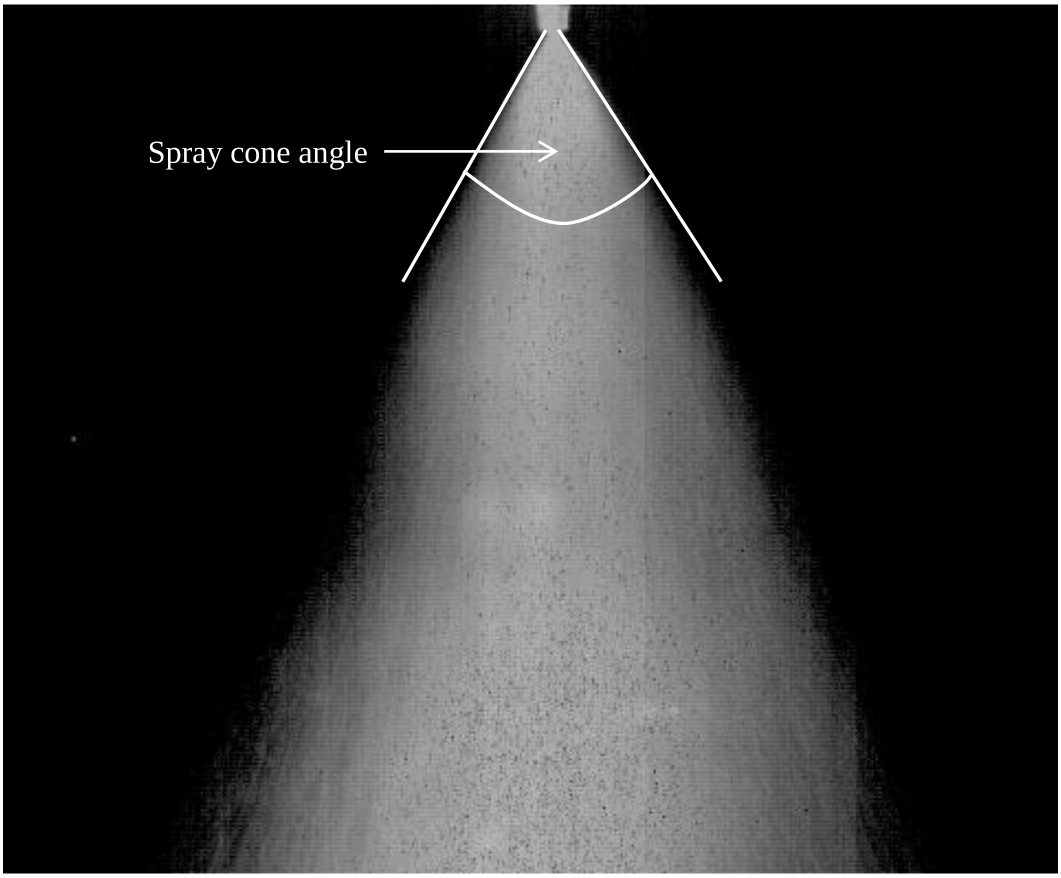

Figure 4.1: Spray cone angle measurement

Figures 4.2 (a), (b), (c) and (d) show the images of modified starch solution with the weight ratio of 50:15:2.5 captured by using high speed digital camera. The images of spray cone angle for the solution were taken at a set of temperatures of 60, 80 and 100°C. For each elevated temperature, the images of spray cone angle set at the pressures of 2 and 4 bar were captured to see the relationship between temperature and pressure on the spray cone angle and width produced.

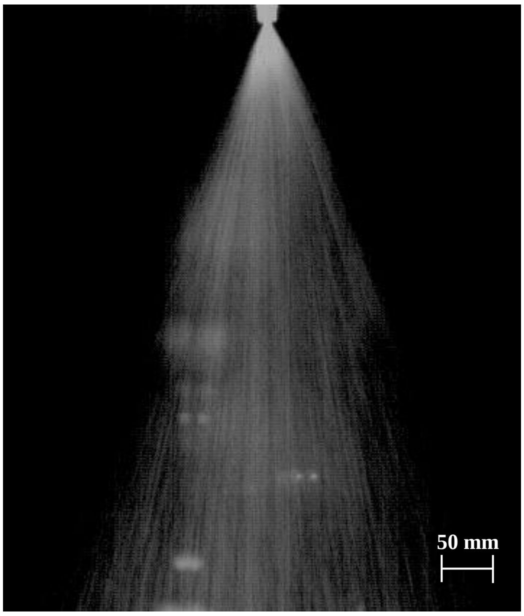

Figure 4.2 (a): Spray cone angle for the liquid at 60°C and 2 bar for weight ratio of 50:15:2.5

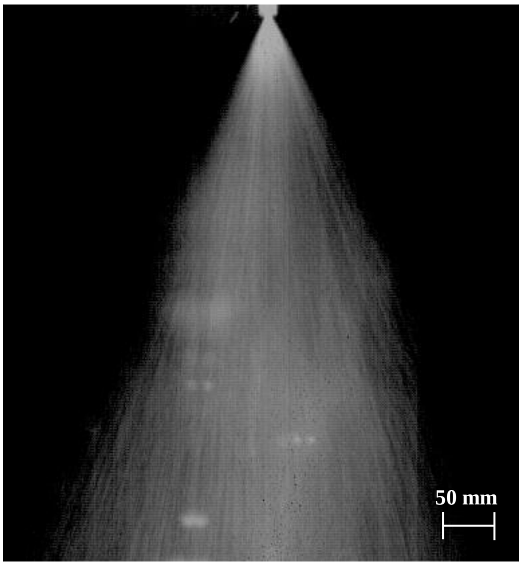

Figure 4.2 (b): Spray cone angle for the liquid at 60°C and 4 bar for weight ratio of 50:15:2.5

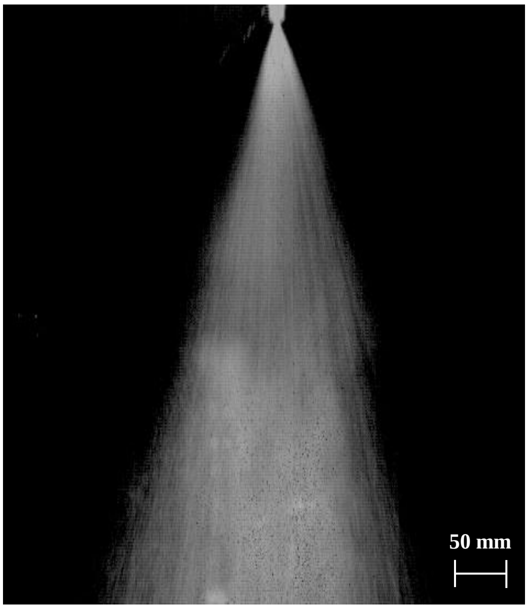

Figure 4.2 (c): Spray cone angle for the liquid at 100°C and 2 bar for weight ratio of 50:15:2.5

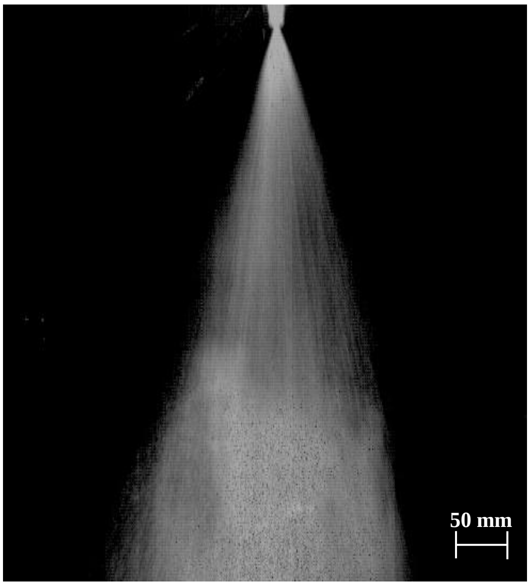

Figure 4.2 (d): Spray cone angle for the liquid at 100°C and 4 bar for weight ratio of 50:15:2.5

Figures 4.3 (a) and (b) portray the images of spray cone angle of modified starch solution with the weight ratio of 50:15:4.5 that were set at a temperature of 60°C with variations in pressures of 2 and 4 bar. Figures 4.3 (c) and (d) were the images of the same weight ratio taken by using high speed digital camera set at a temperature of 100 °C with pressures of 2 and 4 bar.

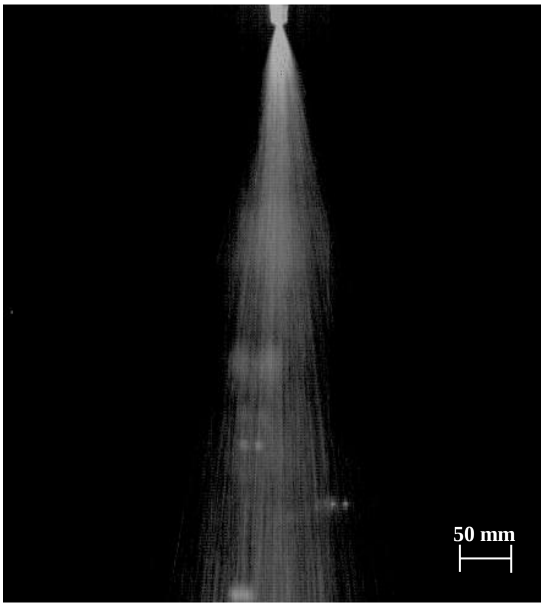

Figure 4.3 (a): Spray cone angle for the liquid at 60°C and 2 bar for weight ratio of 50:15:4.5

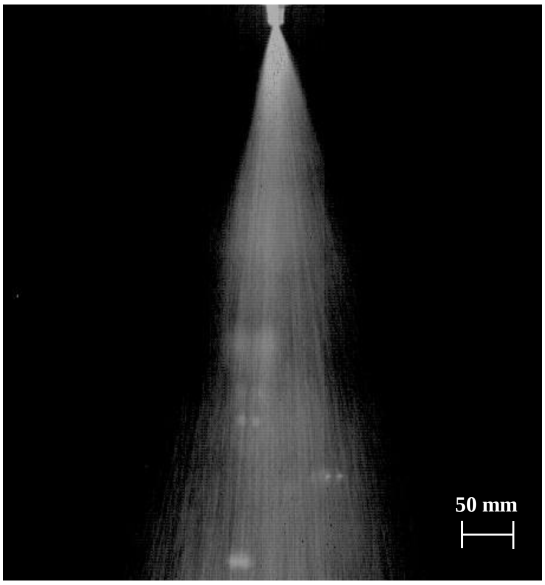

Figure 4.3 (b): Spray cone angle for the liquid at 60°C and 4 bar for weight ratio of 50:15:4.5

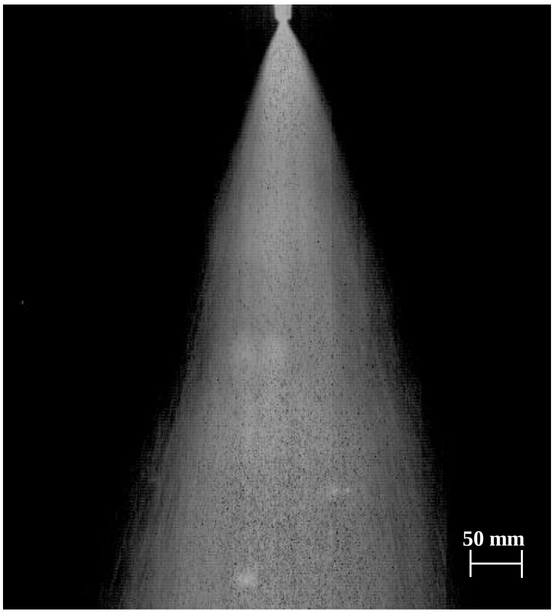

Figure 4.3 (c): Spray cone angle for the liquid at 100°C and 2 bar for weight ratio of 50:15:4.5

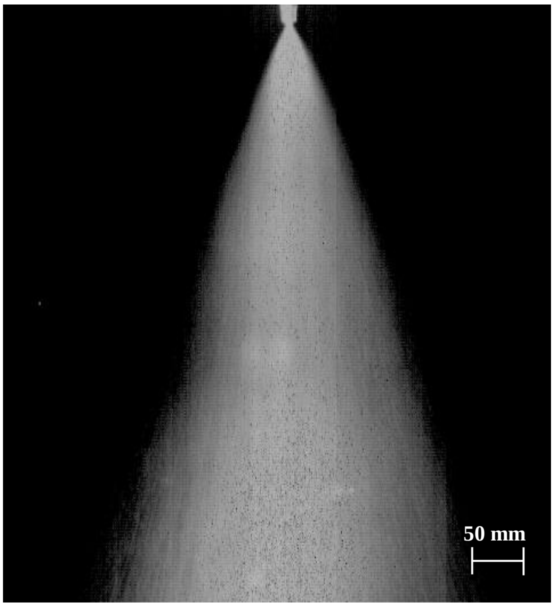

Figure 4.3 (d): Spray cone angle for the liquid at 100°C and 4 bar for weight ratio of 50:15:4.5

From the images captured by using high speed digital camera and analysed by using Phantom v675.2 software, it was noticed that spray cone angle will increase as the temperature and pressure increase. As the result, spray width will increase as well. In addition, as the temperature and pressure increase, it was found that a large amount of droplets dispersed from the nozzle. This phenomenon was indicated by the increasing contrast as clearly can be observed in the images of 4 bar compared to 2 bar for each case. By referring to Table 4.1, it was known that modified starch solution with the weight ratio of 50:15:4.5 gave bigger spray cone angle and width as compared to the weight ratio of 50:15:2.5 for respective temperatures and pressures.

Table 4.1: Measurement of spray cone angle and width

Weight Ratio (g)	**Temperature (°C)**	**Pressure (bar)**	**Spray Cone Angle (°)**	**Spray Width (mm)**
50 : 15 : 2.5	60	2	69.4	253.7
		4	69.7	269.3
	80	2	70.4	278.3
		4	71.1	294.3
	100	2	72.2	286.0
		4	73.0	296.2
50 : 15 : 4.5	60	2	69.9	268.2
		4	70.1	281.8
	80	2	71.6	314.6
		4	72.7	348.0
	100	2	73.5	385.7
		4	75.7	386.9

4.2 Spray Tip Penetration

Spray tip penetration is defined as the maximum distance from the nozzle tip of the size view spray image (Abd Majid, 2011). The images were captured by using high speed digital camera. Phantom v675.2 software was used to measure the spray tip penetration of each weigh ratio at various temperatures and pressures. The images were taken exactly at 10 ms to study on the spray tip penetration for each weight ratio with respect to various temperatures and pressures. The results are tabulated as shown in Table 4.2.

By referring to Table 4.2, it was found that higher pressure supplied from the air compressor would give higher spray tip penetration. In addition to that, with the increasing in temperature, the spray tip penetration for both weight ratios with 2.5 and 4.5 g borate mass respectively will increase as well. This clearly shows a close relationship between temperature and pressure with spray tip penetration. Higher pressure will force a high amount of modified starch solution atomized at a given time that can be clearly observed for pressure of 4 bar as compared to 2 bar for each temperature and pressure for both compositions. Modified starch solution with weigh ratio of 50:15:4.5 set at 100°C and 4 bar gave the highest spray tip penetration of 304.5 mm.

Table 4.2: Measurement of spray tip penetration

Weight Ratio (g)	Temperature (°C)	Pressure (bar)	Spray Tip Penetration (mm)
50 : 15 : 2.5	60	2	210.3
		4	250.3
	80	2	232.1
		4	270.8
	100	2	257.0
		4	292.5
50 : 15 : 4.5	60	2	219.8
		4	262.7
	80	2	240.8
		4	289.3
	100	2	260.7
		4	304.5

4.3 Nozzle Discharge Coefficient

Nozzle discharge coefficient is the ratio of mass flow rate at the discharge end of the nozzle to that of an ideal nozzle which expands an identical working fluid from the same initial conditions to the same exit pressure. By using Equation (2.3), the nozzle discharge coefficient for both weight ratios of modified starch solution at 60, 80 and 100°C with 2 and 4 bars could be easily determined. The values of nozzle discharge coefficient were tabulated in Table 4.3.

By referring to Table 4.3, it was known that the nozzle discharge coefficient for the modified starch solution with the weight ratio of 50:15:4.5 at temperatures of

60, 80 and 100°C and pressures of 2 and 4 bar was higher as compared to the weight ratio of 50:15:2.5. The fluid flow rate increased with the rise in fluid supply pressure due to the increasing in fluid velocity which influences the nozzle discharge coefficient. The phenomenon was clarified when the nozzle discharge coefficient of 4 bar was slightly higher as compared to 2 bar at the temperatures of 60, 80 and 100°C for both modified starch solution weight ratios. The reason behind this phenomenon was contributed by the reduction on relative head losses as the velocity increases.

Table 4.3: Measurement of nozzle discharge coefficient

Weight Ratio (g)	**Temperature (°C)**	**Pressure (bar)**	**Nozzle Discharge Coefficient**
50 : 15 : 2.5	60	2	0.7687
		4	0.8962
	80	2	0.8962
		4	0.8962
	100	2	0.8599
		4	0.9480
50 : 15 : 4.5	60	2	1.1502
		4	1.3339
	80	2	1.1517
		4	1.3639
	100	2	1.1459
		4	1.3728

4.4 Weber Number

Weber number (We) is a dimensionless value useful for analysing fluid flow relates the force from surrounding air pressure to the surface tension force around the droplet perimeter (Luxford, 2005). Normally, Weber number is determined to analyse the formation of droplets and thin film flows. By using Equation (2.4), Weber number for the modified starch solution at both compositions, 50:15:2.5 and 50:15:4.5 at a set of temperatures (60, 80 and 100°C) and pressures (2 and 4 bar) could be determined and the result was tabulated in Table 4.4.

Table 4.4: Measurement of Weber number

Weight Ratio (g)	Temperature (°C)	Pressure (bar)	Weber Number
50 : 15 : 2.5	60	2	4755.16
		4	6509.55
	80	2	5043.28
		4	6868.02
	100	2	5256.63
		4	7210.83
50 : 15 : 4.5	60	2	4351.89
		4	6092.15
	80	2	4571.34
		4	6421.20
	100	2	4823.24
		4	6685.64

From Table 4.4, Weber number for modified starch solution of the weight ratio of 50:15:4.5 were slightly lower as compared to the weight ratio of 50:15:2.5. Generally, with the increasing pressure and temperature, the value of Weber number increases as well. By referring to Equation (2.4), Weber number is directly proportional to density of the fluid, velocity of the fluid and characteristic length of the droplet diameter while inversely proportional to the surface tension. The density of modified starch solution with the weight ratio of 50:15:4.5 was slightly higher as compared to the weight ratio of 50:15:2.5 contributed by the 4.5 g borate mass. As the pressure supplied from the air compressor increases, the velocity of dispersed fluid coming out from the nozzle will increase as well. Besides, the data gathered for the surface tension showed an inversely proportional relationship with the Weber number that consistent with the formula using in Equation (2.4). In his paper, Kamarul Bahrin (2011) claimed that higher value of Weber number will cause finer atomization. It can be concluded that, modified starch solution with 2.5 g borate at 100°C and 4 bar will give the finest atomization as compared to the other set of composition, temperatures and pressures.

4.5 Reynolds Number

Reynolds number can be simply defined as the ratio inertia forces to viscous forces. Reynolds number is important to measure and indicate whether the flow is laminar, transition or turbulent. Reynolds number that gives value less than about 2300 is generally considered as laminar flow while turbulent flow occurs when the value is greater than 4000. If the Reynolds number lies between the ranges of 2300 to 4000, the fluid flow is considered as transition. Normally, in the low number of Reynolds number, the viscous forces which are inversely proportional to the Reynolds number are dominant where the fluid tends to flow in a constant motion. The characteristics of the laminar flow tends to produce chaotic eddies and vortices.

Table 4.5: Measurement of Reynolds number

Weight Ratio (g)	Temperature (°C)	Pressure (bar)	Reynolds Number
50 : 15 : 2.5	60	2	45443.38
		4	53767.17
	80	2	59233.55
		4	70202.72
	100	2	73718.12
		4	86791.31
50 : 15 : 4.5	60	2	41095.04
		4	48081.97
	80	2	53824.17
		4	53824.17
	100	2	53824.17
		4	77978.04

By referring to Equation (2.5), Reynolds number is directly proportional to density of the fluid, velocity of the fluid, characteristic linear dimension and inversely proportional to the dynamic viscosity. From Table 4.5, it can be clearly observed that modified starch solution with 2.5 g borate mass respectively at the temperature and pressure of 100°C and 4 bar gave a higher value as compared to 4.5 g borate mass. The results were consistent with the inversely proportional relationship between Reynolds number and dynamic viscosity where the value is the lowest as compared to other dynamic viscosity values.

It is crucial to note that higher value of Reynolds number indicates finer atomization. From all the values obtained throughout the experiment, modified starch solution with weight ratio of 2.5 g at 100°C and 4 bar was said to have the finest atomization as compared to others. Since all the values of Reynolds number were greater than 4000, the atomization of modified starch solution for both weight ratios was considered turbulent.

4.6 Granule Diameter

The thickness of coating applied was determined by comparing the coated urea diameter with the uncoated urea diameter. 10 urea granules with approximately homogeneous in size from each sample were randomly selected and the diameters were carefully measured by using digital vernier calliper. The measurements for each sample were averaged and tabulated as shown in Table 4.6.

Table 4.6: Measurement of urea granule diameter

Sample	**Diameter (mm)**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1	3.73	3.37	3.04	3.47	3.46	3.60	3.16	3.07	3.79	3.82	3.45
2	3.67	3.54	3.38	3.49	3.53	3.61	3.33	3.36	3.45	3.46	3.48
3	3.52	3.52	3.62	3.33	3.83	3.71	3.42	3.28	3.42	3.67	3.53
4	3.53	3.94	3.43	3.44	3.45	3.52	3.41	3.97	3.56	3.50	3.58
5	3.44	3.36	3.88	3.45	3.43	3.14	3.60	3.72	3.56	3.39	3.49
6	3.14	4.18	3.36	3.55	3.65	3.32	3.32	4.26	3.32	3.28	3.54
7	3.56	3.47	4.12	3.82	3.20	3.97	3.57	3.52	3.29	3.40	3.59

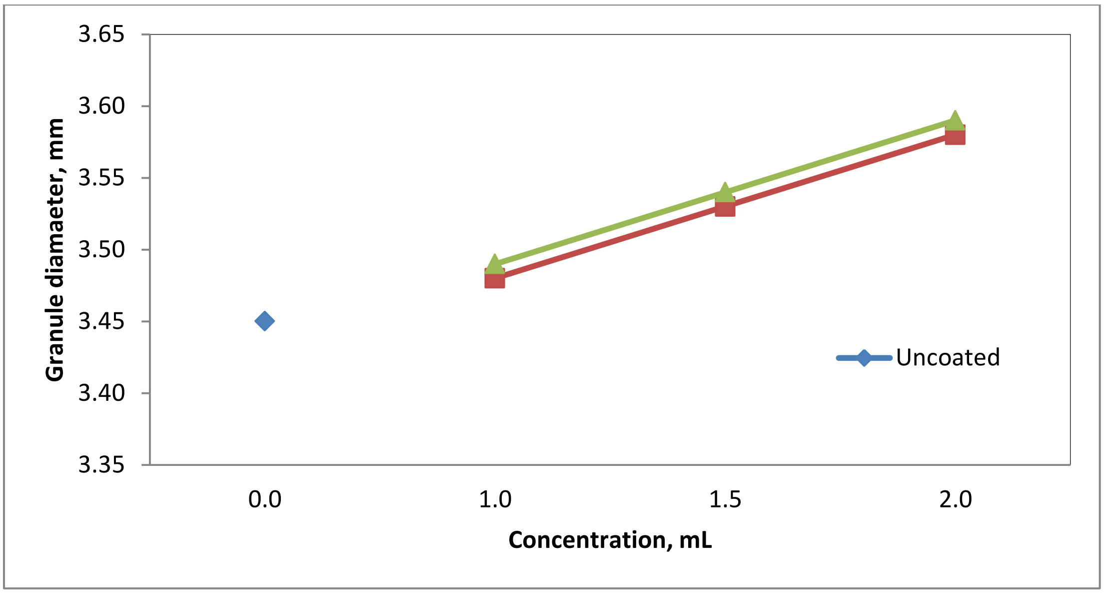

Figure 4.4: Graph of granule diameter versus concentration

From the data gained that have been portrayed in Figure 4.4, it can be clearly observed that the diameter of uncoated urea granule sample was the lowest as compared to the other samples. Besides, it was noticed that Samples 4 and 7 with the concentration of 2.0 mL gave the highest readings as compared to the other samples with the concentrations of 1.0 mL and 1.5 mL. The diameters for Samples 5, 6 and 7 with the weight ratio of 50:15:4.5 (starch-urea-borate) were found a slightly higher as compared to the uncoated urea and other samples with weight ratio of 2.5 g borate mass.

4.7 Microscopic Analysis

The aim of having the spectroscopy analysis of urea particle by using Scanning Electron Microscopy was to get the microscopic images of particle surface. The existence of layers was expected in the coating process. Several particles were randomly selected and carefully observed under Scanning Electron Microscopy at the magnifications of 50, 100 and 200 X. Images were taken at these magnifications and analysis of these images for changes in surface properties was done. Several sample images were shown for the uncoated and coated granules with different surface morphology.

Figure 4.5 (a) shows the surfaces of the uncoated urea with magnification of 50 X. The other two figures; Figures 4.5 (b) and (c) portray clearer images of the surface with the magnifications of 100 and 200 X respectively. From these three figures, surface of the uncoated urea appeared to be less dense and rough. The degree of porosity on the surface of uncoated urea was found quite high due to the absence of coating. The images of uncoated urea were compared with coated urea in term of density, degree of porosity and surface roughness for both modified starch solution with 2.5 and 4.5 g borate.

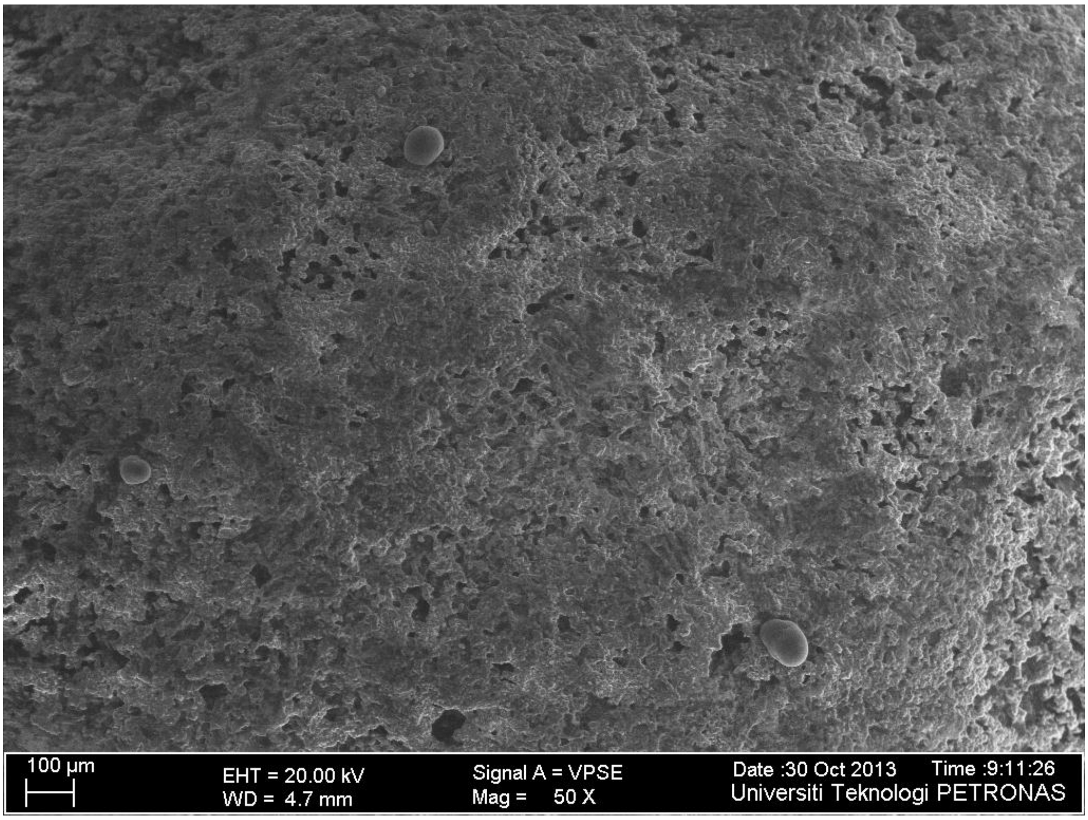

Figure 4.5 (a): Surface of the uncoated urea with magnification of 50 X

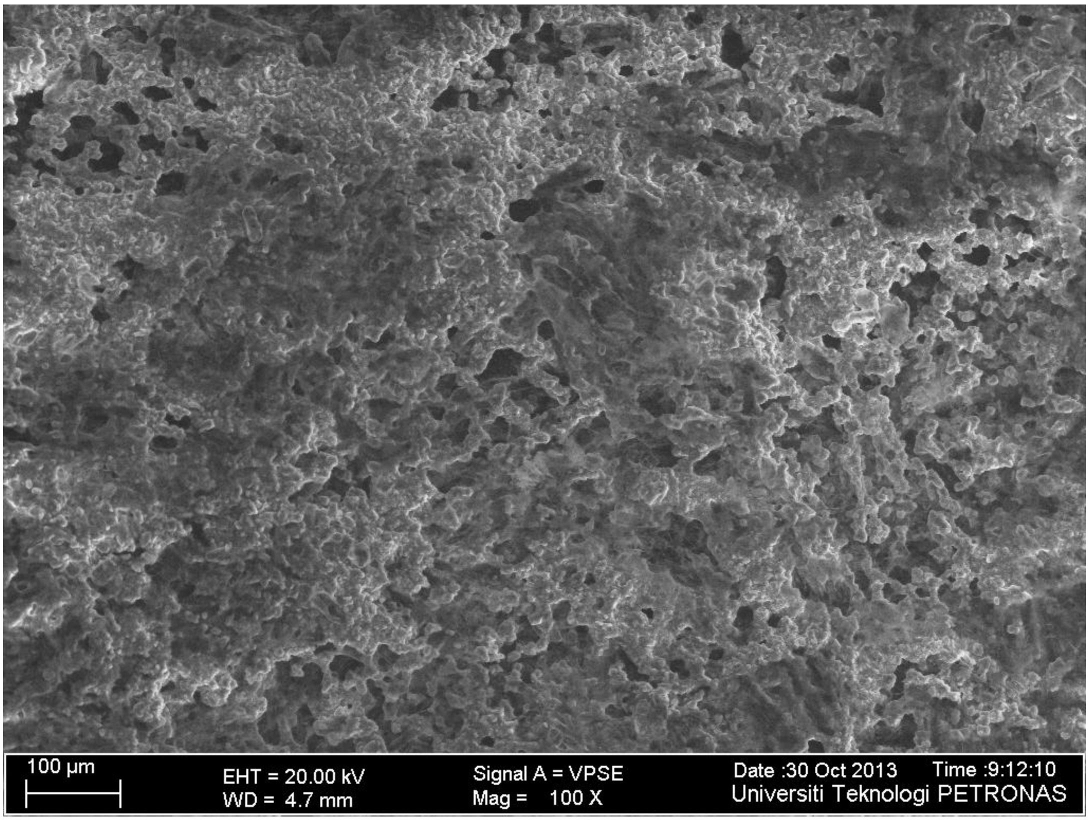

Figure 4.5 (b): Surface of the uncoated urea with magnification of 100 X

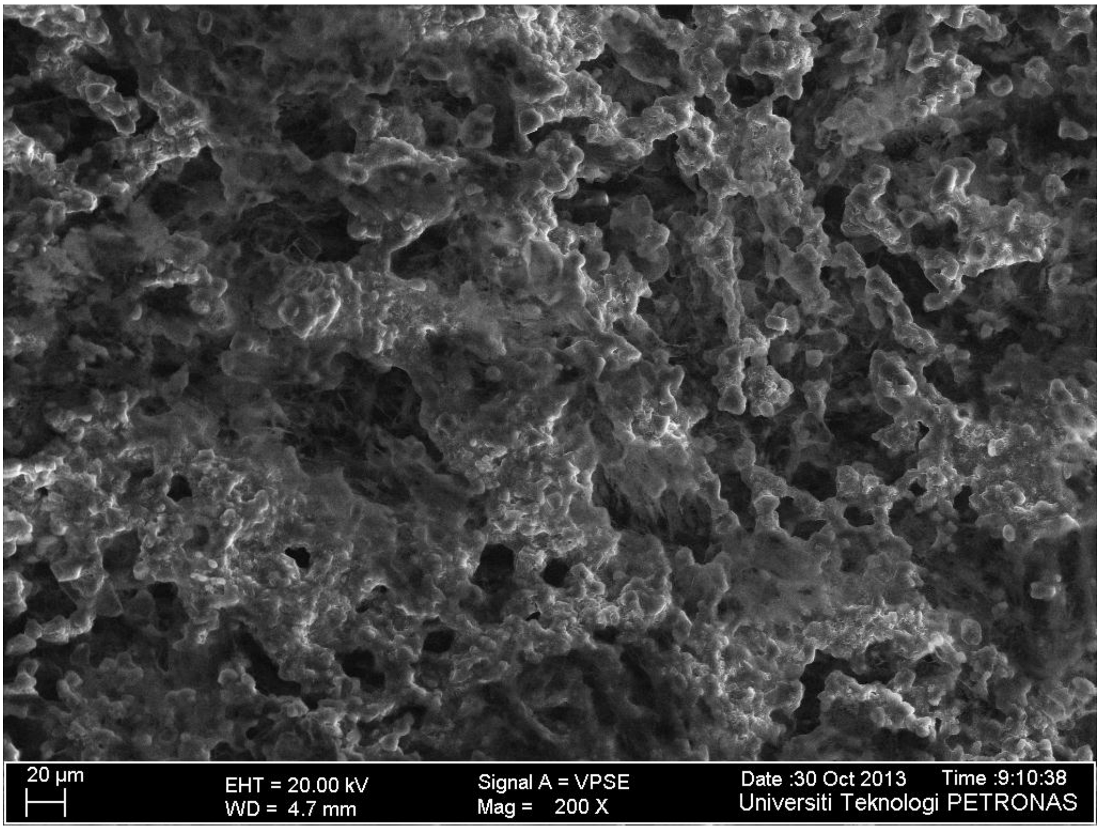

Figure 4.5 (c): Surface of the uncoated urea with magnification of 200 X

Figures 4.6 (a), (b) and (c) portray the surface of Sample 2, coated urea with the weight ratio of 50:15:2.5 (starch-urea-borate) and concentration of 1.0 mL. The image of Figure 4.6 (a) was captured with magnification of 50 X, 100 X for Figure 4.6 (b) and (c) with magnification of 200 X. From Figure 4.6 (c), it can be clearly observed that the surface of this sample was smoother and denser as compared to Sample 1 (uncoated urea). Since this sample was coated with the compositions of starch, urea and borate, the degree of porosity appeared to be lesser as compared to the previous sample. Normally, there will be a lot of voids scattered on the surface of particle. By applying coating on the urea granules, the voids could be reduced at a significant amount. Due to the modified starch solution that has filled the voids; the density of the urea particle will slightly increase. The surface of the urea granule will become finer as well, since the coating has formed a thin layer on the rough surface of the granule. The thicker coating applied to the fertilizer particles, the finer the surface roughness will become.

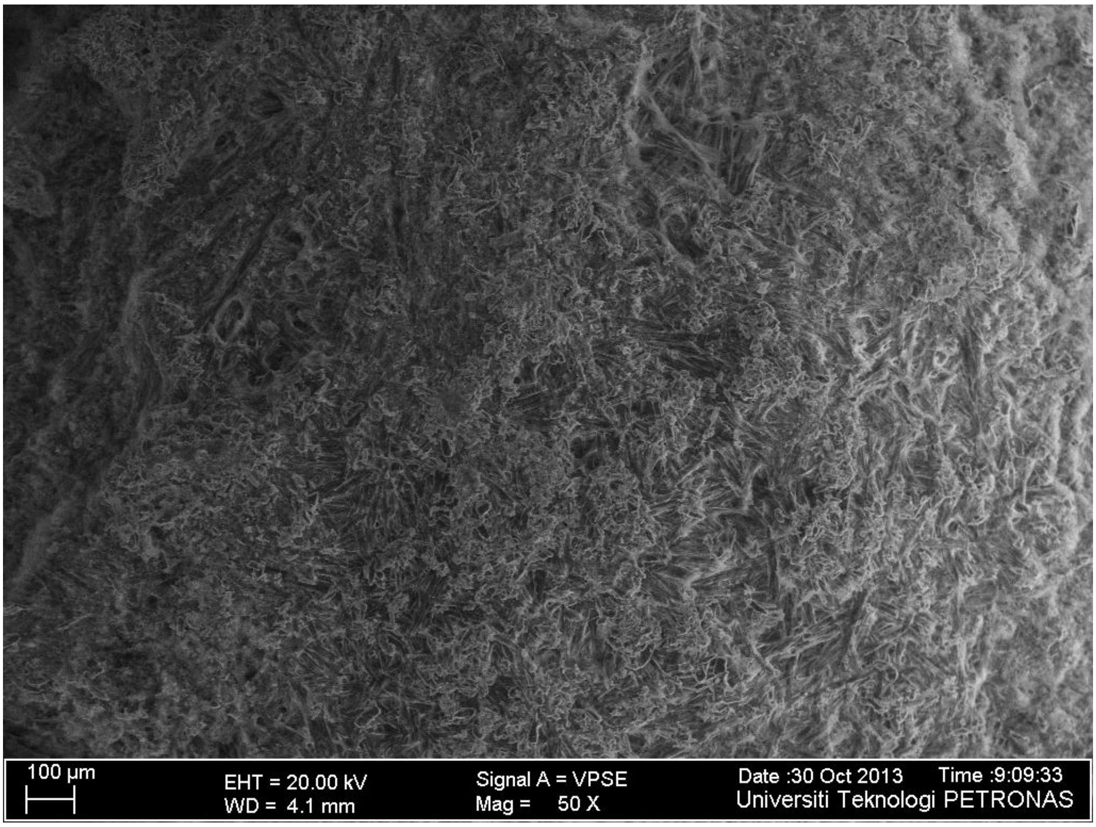

Figure 4.6 (a): Surface of Sample 2 (50:15:2.5 and 1.0 mL) with magnification of 50 X

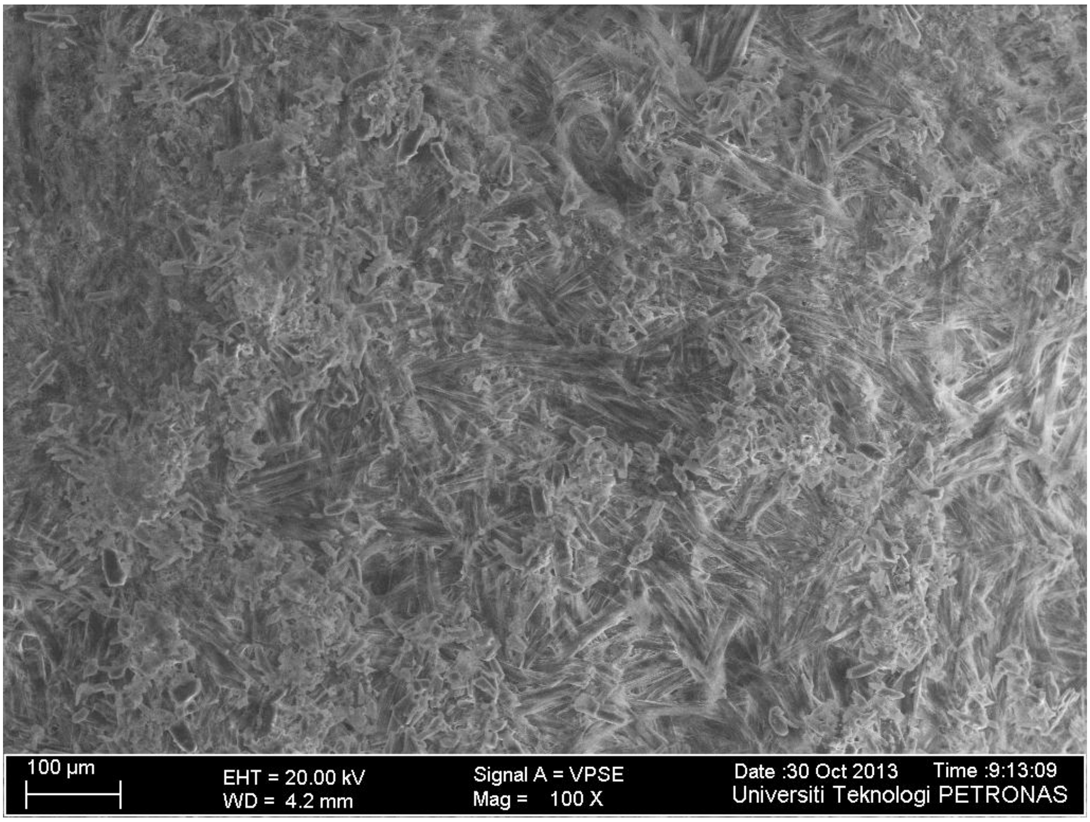

Figure 4.6 (b): Surface of Sample 2 (50:15:2.5 and 1.0 mL) with magnification of 100 X

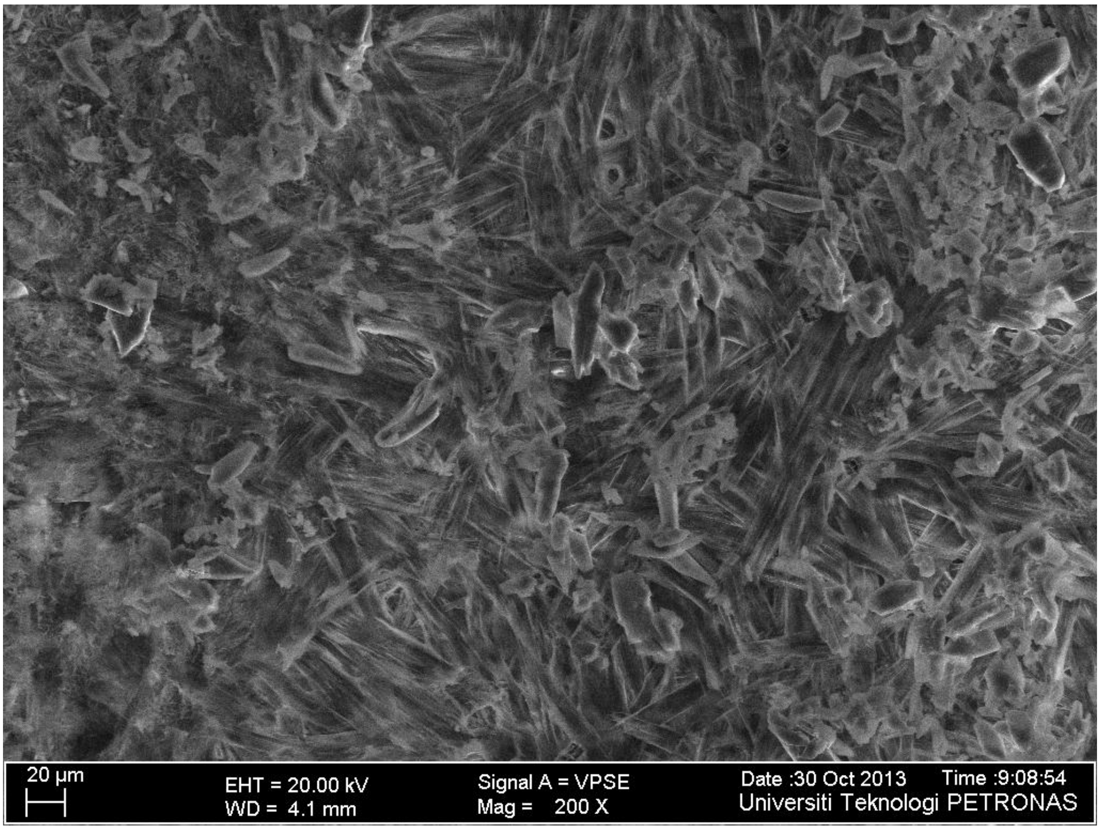

Figure 4.6 (c): Surface of Sample 2 (50:15:2.5 and 1.0 mL) with magnification of 200 X

Figures 4.7 (a), (b) and (c) show the surface of Sample 4, coated urea with the composition of 50:15:2.5 and concentration of 2.0 mL. The image of Figure 4.7 (a) was captured with magnification of 50 X, 100 X for Figure 4.7 (b) and (c) with magnification of 200 X. By referring to Figure 4.7 (c), the surface of this sample appeared to be denser and smoother as compared to Sample 1 (uncoated urea) and Sample 2 (coated urea with weight ratio of 50:15:2.5 and concentration of 1 mL). Since this sample was coated with a higher concentration of modified starch solution and higher borate mass, the degree of porosity appeared to be lesser as compared to the other two samples. Compared to Sample 2 (50:15:2.5 and 1.0 mL), more voids on the granule surface were filled due the higher concentration of modified starch solution applied. As a result, the density of this sample was found to be a slightly higher as compared to Sample 2. Higher concentration also means that better layering on the surface particle that leads to a much better surface roughness.

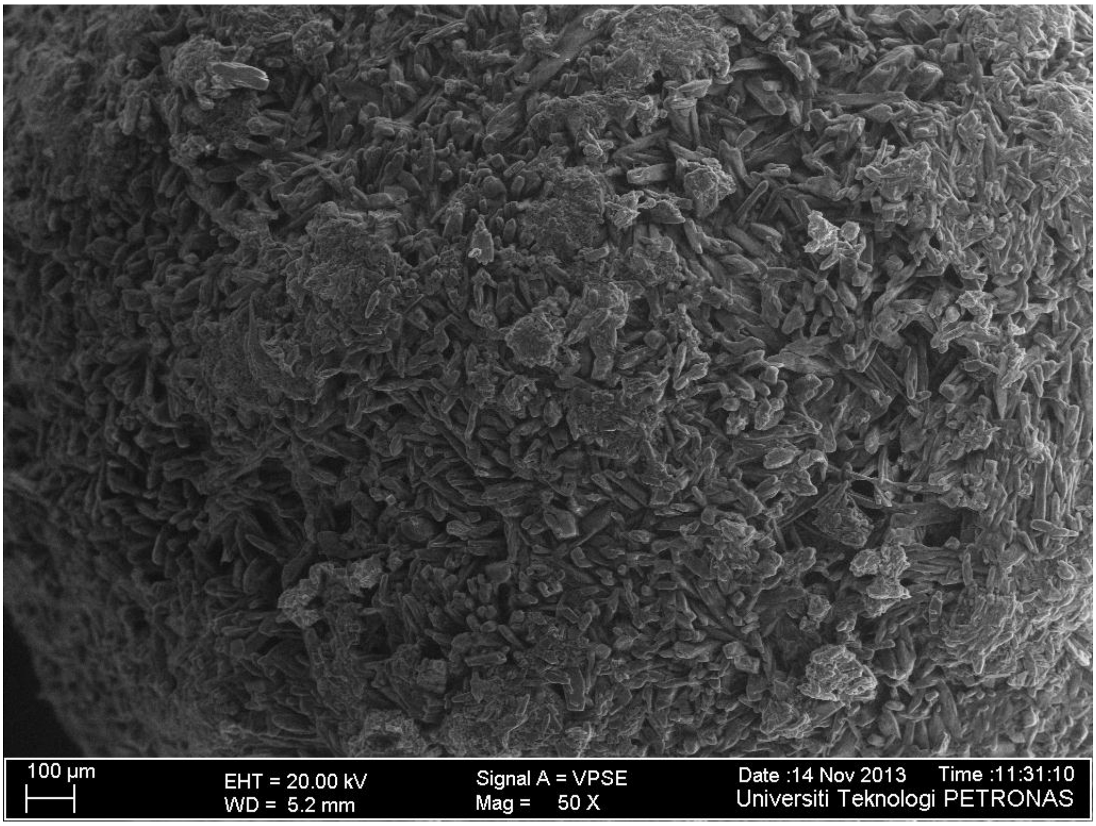

Figure 4.7 (a): Surface of Sample 4 (50:15:2.5 and 2.0 mL) with magnification of 50 X

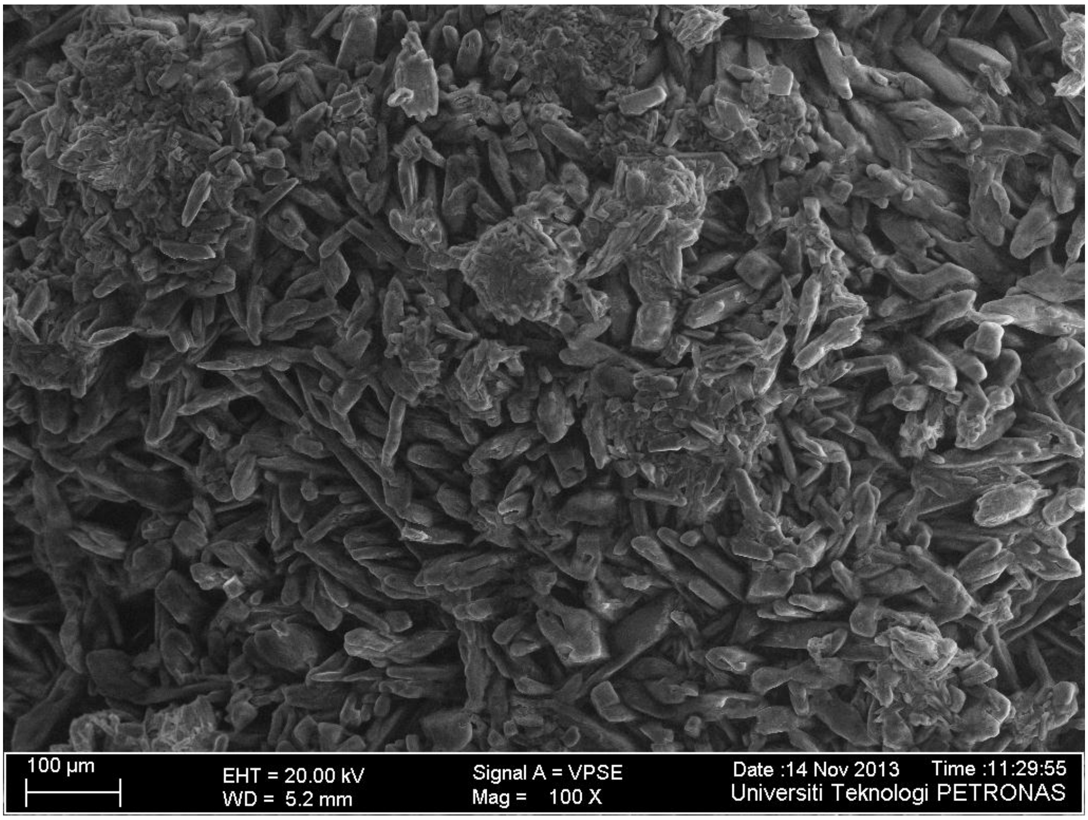

Figure 4.7 (b): Surface of Sample 4 (50:15:2.5 and 2.0 mL) with magnification of 100 X

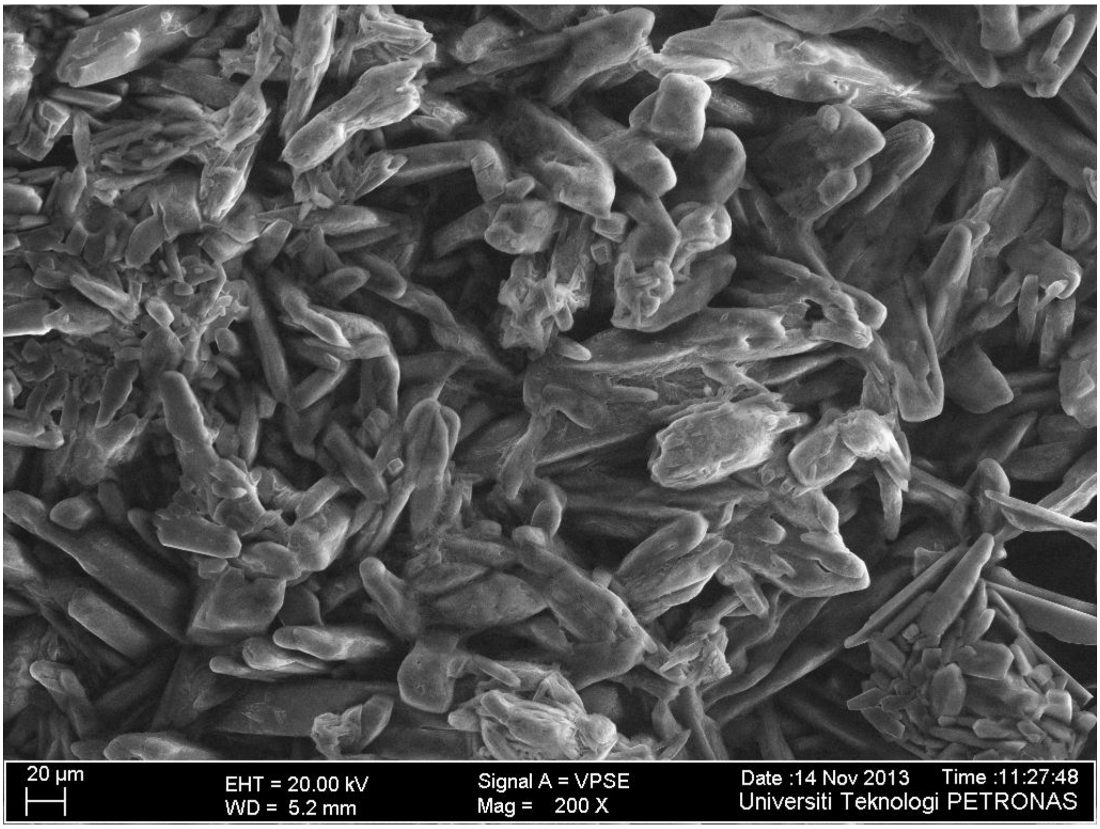

Figure 4.7 (c): Surface of Sample 4 (50:15:2.5 and 2.0 mL) with magnification of 200 X

From all these images that were taken by using Scanning Electron Microscopy, it was found that a close relationship existed between density, degree of porosity and surface roughness. By applying coating, modified starch solution would fill in all the voids that scatter on the surface of uncoated urea granules. The coated urea appeared to be denser as compared to the uncoated urea due to this factor. In addition, microscopic analysis by using Scanning Electron Microscopy also showed that the surface roughness of the coated urea granule was depending on the weight ratio and concentration of the modified starch solution applied during coating. From the images taken, it was noticed that higher concentration of modified starch solution and higher borate mass would lead to smoother and uniform coating. By applying high concentration of modified starch solution on the urea granules, fine thin layer will form that leads to a better surface roughness.

4.8 Dissolution Rate

Modified starch solution serves as a physical barrier to control the nutrients release rate of fertilizer into the soil for plantation growth as desired. The main reason of having this dissolution rate test was to study the relationship between the weight mass and concentration of modified starch solution with the time required for complete dissolution of the uncoated and coated urea granules. The test was done by placing 5 g of urea particles into a beaker containing 100 mL of distilled water maintained at room temperature. Stirrer was used at a constant speed of 200 rpm. The time required for complete dissolution of the uncoated urea and coated urea was taken and tabulated in Table 4.7.

Table 4.7: Time required for complete dissolution of coated urea

Coated Urea						
Composition (g)	**50:15:2.5**			**50:15:4.5**		
Concentration (mL)	**1.0**	**1.5**	**2.0**	**1.0**	**1.5**	**2.0**
Time taken (min)	1:21:27	1:42:91	2:05:62	1:30:07	2:01:39	2:27:21

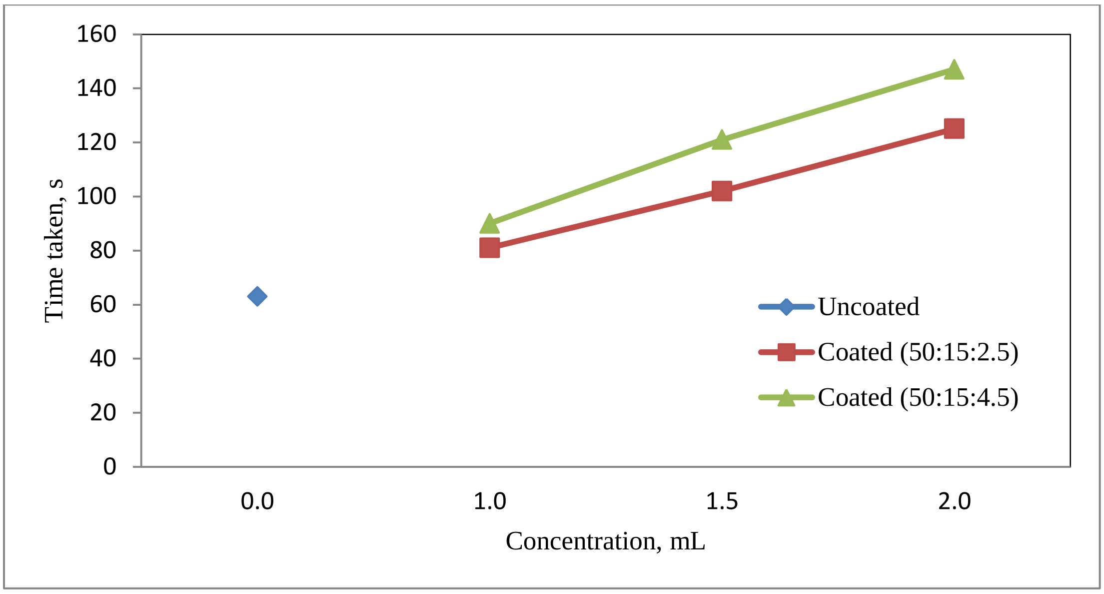

Figure 4.8: Graph of time taken versus concentration

From the experiment done, it was found that the uncoated urea granule required 1:03:33 min to completely dissolve in distilled water. By referring to Table 4.7 and Figure 4.8, it was noticed that the composition and concentration of modified starch solution influenced the dissolution rate of urea granules. The dissolution rate for uncoated urea gave the smallest reading as compared to other readings due to the absence of modified starch solution coating. For the composition of 50:15:4.5 (starch-urea-borate), the time required for complete dissolution of coated urea for concentration of 1.0 mL, 1.5 mL and 2.0 mL were slightly higher as compared to the composition of 50:15:2.5 (starch-urea-borate) for the same concentration. Besides affected by the composition and concentration of modified starch solution, the dissolution rate was also depending on the porosity of urea particle. Coated urea granules with higher concentration of coating applied would take longer time for complete dissolution as compared to the uncoated urea and coated urea granules with lower coating concentrations. The results were consistent with Vashishta, et al. (2010) claim, the greater the concentration of coating applied, the lower dissolution rate will become.

4.9 Crushing Strength

Coated urea fertilizer should be designed to have a sufficient mechanical strength to withstand normal handling and storage without fracture. There are a few parameters influence the mechanical strength of a material; chemical composition, porosity, shape, surface crystal and moisture content (Tudorachi et al., 2000). Crushing strength test can be best defined as the minimum force required to crushing the individual particle. Crushing strength is measured by applying pressure onto the individual granule, usually of a specified range and noting the pressure required to fracture each granule. For this test, 5 urea granules with approximately homogeneous in size from each sample were randomly selected and the crushing strength readings were taken and averaged by using Erweka equipment. Table 4.8 portrays the data obtained from the crushing strength test.

Table 4.8: Crushing strength for each sample

Sample	Composition	Concentration (mL)	Reading (N)					
			1	2	3	4	5	Average
1	Uncoated	0.0	29.0	15.0	21.0	25.0	32.0	24.4
2	50 : 15 : 2.5	1.0	28.0	30.0	24.0	19.0	29.0	26.0
3	50 : 15 : 2.5	1.5	34.0	25.0	22.0	21.0	37.0	27.8
4	50 : 15 : 2.5	2.0	20.0	18.0	23.0	17.0	21.0	19.8
5	50 : 15 : 4.5	1.0	28.0	36.0	32.0	31.0	21.0	29.6
6	50 : 15 : 4.5	1.5	22.0	29.0	32.0	38.0	29.0	30.0
7	50 : 15 : 4.5	2.0	16.0	22.0	27.0	28.0	33.0	25.2

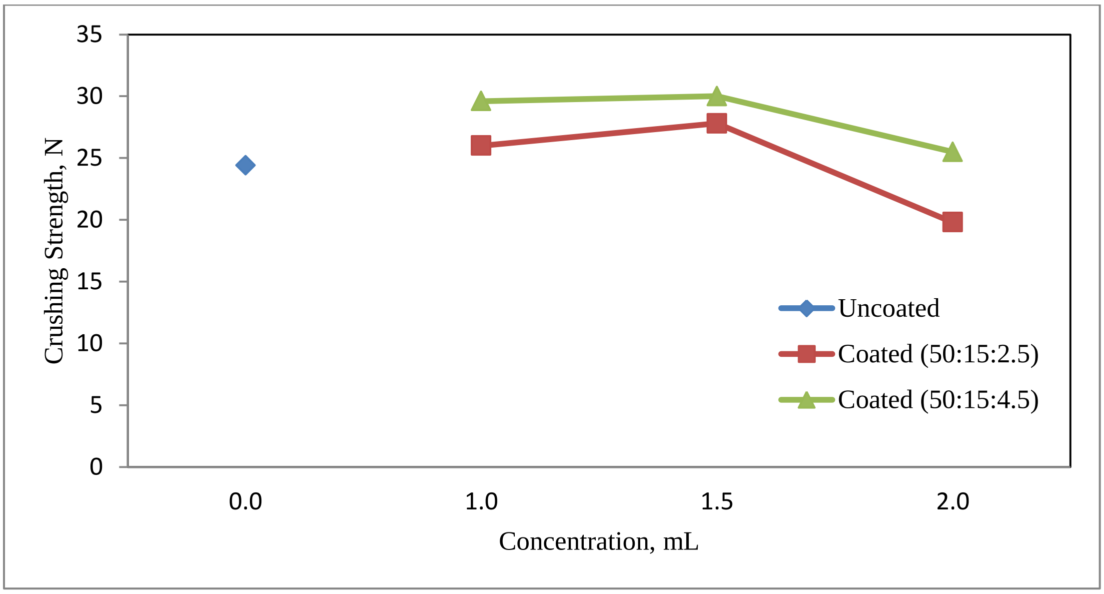

Figure 4.9: Graph of crushing strength versus concentration

From the result portrays in Table 4.8 and Figure 4.9, it can be clearly seen that the crushing strength was highly depending on the composition and concentration of the sample. As the weight mass and concentration of the modified starch solution increase, the crushing strength will directly increase as well. Urea granule that was coated with higher borate mass and concentration would have a smoother surface, denser and lower degree of porosity. Hence, the crushing strength will significantly increase due to these factors. However, it is worth to note that the excessive concentration of modified starch solution used will reduce the crushing strength of urea granules. By referring to Table Table 4.8 and Figure 4.7, it was found that the most suitable concentration for particle coating was 1.5 mL as compared to 1.0 mL and 2.0 mL.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

By getting the density, dynamic viscosity and surface tension of modified starch solution, spray characteristics such as spray cone angle, spray width, spray tip penetration, nozzle discharge coefficient, Weber number and Reynolds number could be measured and determined. From the images captured by using high speed digital camera and then analysed with Phantom v675.2 software, it was noticed that spray cone angle will increase as the temperature and pressure increase. Due to that, spray width and spray tip penetration would increase as well. For nozzle discharge coefficient, the fluid flow rate increased with the rise in fluid supply pressure due to the increasing in fluid velocity which influences the value of nozzle discharge coefficient.

Sprays of modified starch solution with 2.5 g borate at 100°C and 4 bar resulted in high Weber number and thus the finest atomization as compared to the other set of composition, temperatures and pressures. From all the Reynolds number values obtained throughout the experiment, modified starch solution with 2.5 g borate mass at 100°C and 4 bar resulted in the finest atomization as compared to others. Since all the values of Reynolds number were greater than 4000, the atomization of the modified starch solution for both weight ratios was considered turbulent.

By using digital vernier calliper, the diameters of uncoated and coated fertilizer granules were measured. It was found that the diameter was affected by the weight ratio and concentration of coating applied. Higher weight ratio of mass and concentration resulted in a better coating on the urea granules. From the Scanning Electron Microscopy images, it was noticed that a close relationship existed between density and degree of porosity. By applying coating, modified starch solution would fill in all the voids and refining the surface of particle. Higher concentration of modified starch solution and higher borate mass would lead to a smoother and uniform coating.

Dissolution rate test was done to study the time required for complete dissolution of the uncoated and coated urea granules with variations in weight ratios and concentrations. From this test, it could be concluded that coated urea granules with higher concentration of coating applied would take longer time for complete dissolution compared to the uncoated urea and coated urea granules with lower coating concentration. For the crushing strength test, it was found that as the weight mass and concentration of modified starch solution increase, the crushing strength will directly increase as well. However, it is worth to note that excessive concentration of modified starch solution used will reduce the crushing strength of urea granules.

5.2 Recommendations

For future work, the speed of stirrer used for dissolution rate test should be lowered so that it is possible to observe and note the time needed to dissolve the green dye used to coat urea granules. In order to get better images, one of the future recommendations is by using dark room for the purpose of using high speed digital camera. Better images of spray are possible to be taken as higher contract is achieved in the dark. In addition to that, higher quality nozzle should be used and suitable pump for the nozzle specification should also be taken into consideration. Comparison by using other software like MathLab should be considered in analysing spray cone angle, spray width, spray tip penetration and velocity profile. Measurements and analysis from both Phantom v675.2 and MathLab software should be compared to study the degree of accuracy of the results produced.

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