CFD Modeling of Droplet Spreading Behavior on Tablet Edge Using Fluent 14.0

by

Mohamad Ariff Bin Mohamed

A project dissertation submitted to the Chemical Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfilment of the requirement for the BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

VERIFIED BY:

DR KU ZILATI BINTI KU SHAARI

CHEMICAL ENGINEERING

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MAY 2012

CERTIFICATION OF APPROVAL

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May 2012

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.

MOHAMAD ARIFF BIN MOHAMED
11132

ABSTRACT

In this paper, a numerical model was developed for direct simulation of droplet spreading behavior on the tablet edge since the coating uniformity become the most critical problem nowadays in pharmaceutical industry. Owing to that problem, a simulation of droplet spreading behavior on the tablet edge has been developed to study the effect of tablet surface to the droplet spreading behavior. This modeling will be conducted by using integrated software, Computational Fluid Dynamics which is Fluent 14.0. Only water will be used in this modeling over to the different velocity of droplet. As addition, the surface roughness and contact angle also will be varying due to study the behavior of the spreading in certain condition. This project actually is the continuality of the previous laboratory experiment which is the study of the droplet impact behavior on the edge of a tablet to predict the coating variation, conducted by Ku Zilati Ku Shaari and Richard Turton from Department of Chemical Engineering, West Virginia University, Morgantown. The result of the simulation will be compared to this experiment result in order to have the clear understanding of spreading behavior on the tablet edge. As the result, there is not much different of the droplet spreading behavior between geometry 1, geometry 2 and geometry 3 due to the very small change in the surface roughness applied to the wall. Theoretically, the smoothest surface will give the largest spreading factor, D_i/D_0. Thus, further development and study on the model will be taken for the future work.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamic
CCD	Charged- couple Device
CFX	Commercial Computational Fluid Dynamic
2D	Two- dimensional space
3D	Three- dimensional space
FYP	Final year project

CHAPTER 1: INTRODUCTION

1.1 Project Background

The phenomenon of wetting and spreading has been widely applied in the numerous engineering applications. This phenomenon is the essential parameters of the good process control in industrial applications such as spray coating, herbicide spraying, and ink-jet printing. For additional, the trickle bed reactor and structured reactor are also applying the wetting and spreading principle. In these reactors, the spreading impact of liquid droplets on solid surfaces plays an essential role. For example, a fraction of the external catalyst area wetted by flowing the droplets governs the catalyst efficiency and therefore process performance (Lunkad, Buwa, & Nigam, 2007). In recent times, the pharmaceutical industry has become one of the field that is crucial in requiring the wetting and spreading principle, such as film coating. The uniformity of coating is very important on the pharmaceutical tablet when the coating provides functional purpose. In the development of coating technology, the study of possible droplet impact behaviors will be carried out to forecast the impingement behavior of the liquid drop.

The surface thermodynamic and drop spreading are the fundamental of the wetting theory (Krishnakumar, 2010). Basically, the spreading phase is preliminary of the wetting stage. With follows the free falling body movement, the droplet fall down onto the surface and the liquid evolves horizontally to form a thin film; this is generally termed as spreading phase. Owing to the accretion of mass at the edge of droplet, the liquid may form a donut- like shape at the initial spreading and will be end after the droplet achieves the maximum diameter as the completion of wetting stage (Wang, Hung, Lin, & Lin, 2009). According to Roux and Copper- White (2004), the spreading can be divided into two types of behaviors which are low and high impact velocity. This experiment was conducted using a high speed camera, CCD camera. Based on the experiment, the condition of droplet spreading behavior can be explained by low and high impact velocity.

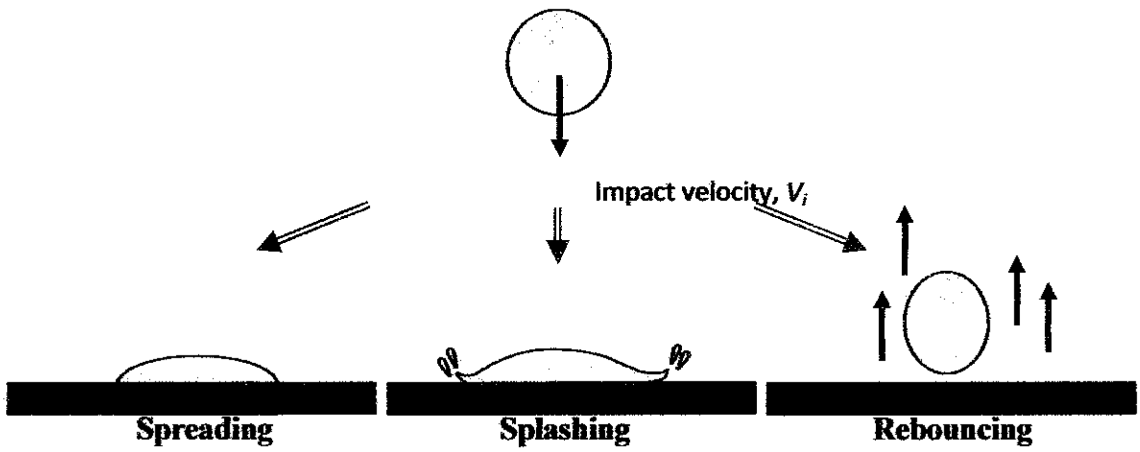


Figure 1: Three major scenario in droplet impact behavior

Spreading, splashing and the rebouncing are three major droplet impacts that may occur after a drop of liquid detaches from a thin film. These stages of liquid drop are generally influenced by liquid and solid properties such as the viscosity and the roughness of the substrate. This modeling is conducted on the spreading behavior due to know the principle of the coating uniformity occurs on the edge of tablet.

1.2 Problem Statement

For many years, the nonengineering field such as pharmaceutical industry has acknowledged a lot of problems due to the droplet impact behavior of spreading in coating technology. Various parameters such as droplet velocity, droplet diameter, liquid viscosity, surface tension and roughness have been investigated to correlate the droplet impact with the spreading process. Owing to the important of droplet spreading process in the various applications, the phenomena of the droplet spreading behavior over the surface roughness received a substantial attention in the literature. Consequently, the roughness of coating surface for the pharmaceutical tablet is even more complex and already extensively studied by researchers. However, a large number of the researches done were mostly concentrated on the droplet spreading behavior on the flat surface. As the improvement, this study is conducted by using the integrated software, Computational Fluid Dynamic (CFD).

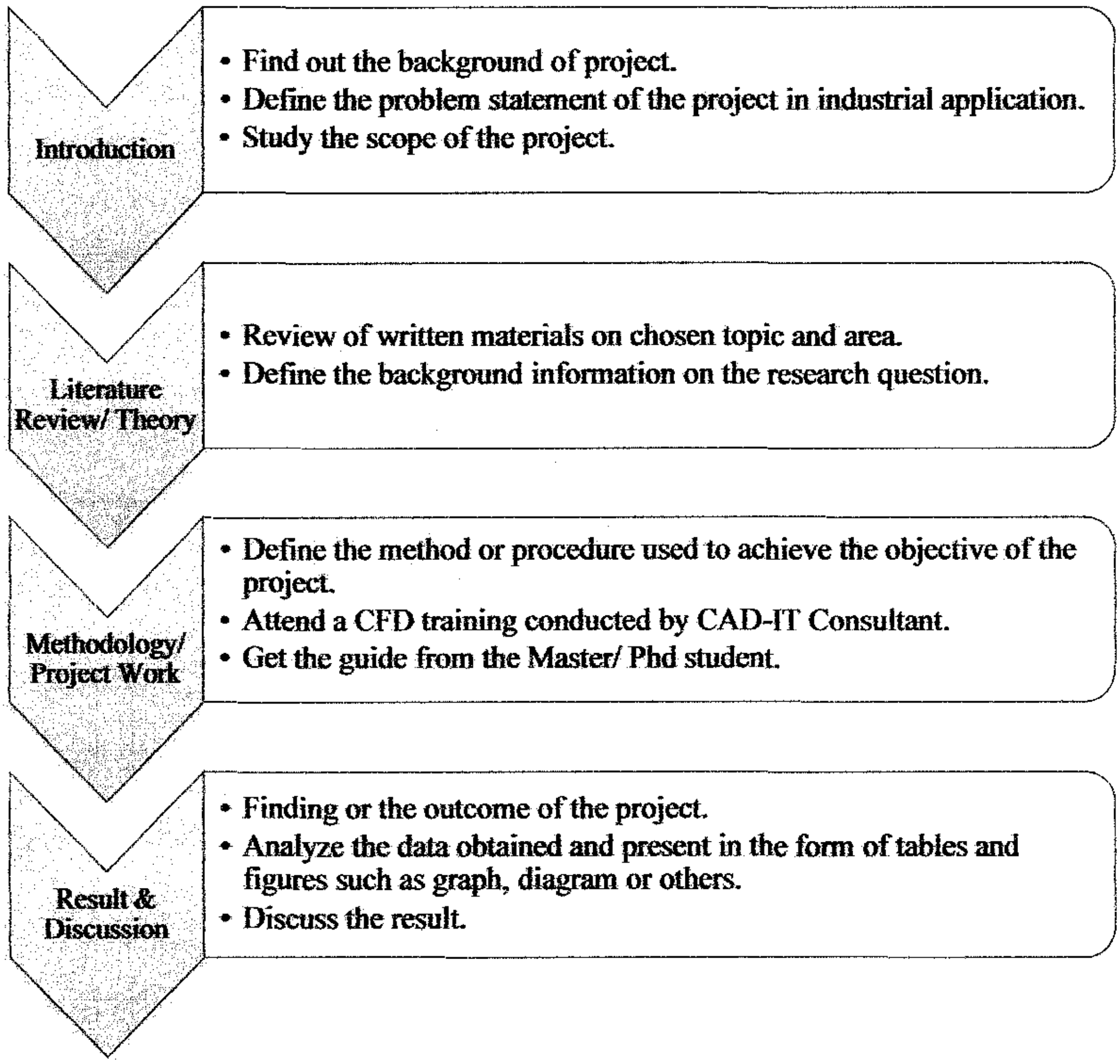
Computational Fluid Dynamic will be applied in the present study to simulate the process of wetting and spreading. This is the initial attempt to formulate concept of the fluid mechanics and develop an understanding of complex process. CFD is one of the branches of liquid mechanics that uses numerical methods and algorithms to solve and analyze the problems that involve fluid flow. Computers are used to perform the millions of calculation required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. The fundamental basis of the CFD problems is the Navier- Stokes equations which defined any single phase fluid flow.

Through this simulation, ANSYS 14.0 was used to model the problem of droplet spreading behavior in order to have a complete understanding of the droplet impact of spreading process on the tablet edge. It is very important in coating technology. The model that is related to this problem is Volume of Fluid (VOF). Instead of to mask the unpleasant taste and smell, the coating technology also have demonstrated several other purposes such as controlling the release of the drug from the tablet, facilitating handling and protecting the drug from the its surrounding environment to improve its stability (Shaari, 2003).

1.3 Objective of the Project

- To simulate the droplet impact of spreading behavior on the tablet edge using FLUENT 14.0.
- To study the impact behavior of water droplet on tablets with different roughness of tablet surface.
- To validate the model with experimental result.

1.4 Scope of Study



CHAPTER 2: LITERATURE REVIEW &THEORY

2.1 Literature Review

The impact without the production of any secondary droplets is termed as spreading or deposition while the term splash indicates the formation of secondary droplets. In an experiment conducted by Sikalo & Ganic (2006), distilled water, isopropanol and glycerin were selected to study the effect of liquid surface tension and viscosity. In addition, they vary the surface of glass by using one smooth (with roughness of Ra= 0.003μm amplitude) and one rough (with roughness of Ra= 3.6 μm amplitude), and one surface of smooth wax (Ra= 0.3μm). The spread factor (d/D) and apex height (y/D) of droplets of different liquids are compared, as a function of non- dimensional time after impact (tu/D), to examine the effect of the droplet viscosity. As conclusion, an increase of viscosity will decrease the spread factor (d/D).

Related to the droplet impact issue, S. Sikalo et al (2001) carried out an experimental investigation of droplets impacting on horizontal surfaces. In this experiment, they have studied the effect of impact parameters on the droplet impingement. The results are presented for different droplet Weber numbers, ranging from 50 to 1080 and for three liquids with different densities which are water, isopropanol and glycerin. Besides, smooth glass, PVC wax and rough glass have been used to study the wettability characteristics in term of contact angle. A charge- coupled device (CCD) camera has been employed to visualize the process of the spreading. The result presented that the wettability have a strong influence on the spreading of droplet in the later stages of the process.

In the contrast, a numerical simulation of dynamics of droplet impact and spreading on horizontal and inclined surfaces was conducted using the volume of fluid (VOF). With static contact angle (SCA) and dynamic contact angle (DCA), the influence of wetting characteristics was investigated. From this simulation, it was found that SCA model can predict the spreading behavior in quantitative agreement with the experiments for less wettable surfaces (SCA>90°) and for more wettable surfaces (SCA<90°), the DCA at initial contact times were magnitude higher than SCA values. As the result, DCA model is needed for the accurate prediction of spreading behavior (Lunkad, Buwa, & Nigam, 2007).

2.2 Theory

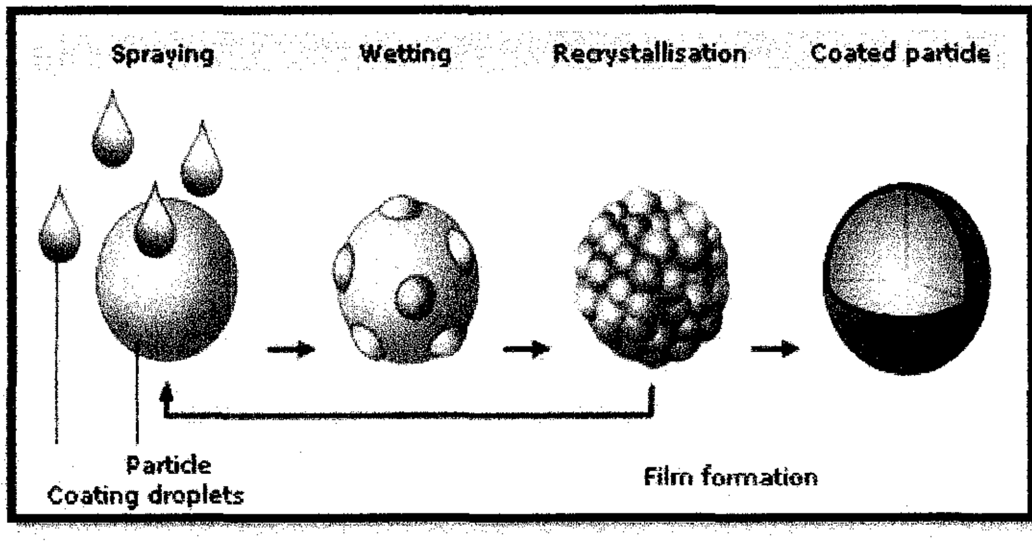
2.2.1 Coating Uniformity Process

There are many ways to coat tablet. One of them is spray technique. It is the most widely used in tablet coating. As shown in figure 1, there have four stages of coating. Initiated with spraying which is to apply force to the droplet and followed by wetting. The wetting stage will be emphasized in the present work. The droplet impact behavior is observed in this state where the diameter of the droplet spreading becomes to maximum to form the wetting stage. Then, the recrystallization stage will be involved. In this state, the moisture from the material coat evaporates to dry up the coating. It is called as the completion stage of the coating and the tablet is considered as coated.

Coating can be considered a good one when the film has higher consistency at overall part of the tablet. It is important to have a good coating due to some reasons which are:

1. Strengthen the tablet
2. Control its release
3. Improve the taste and color
4. Make it easy to handle and package
5. Protect from the moisture

Figure 2: Coating Process



2.2.2 The Navier- Stokes Equation

The Navier-Stokes equations are the basic governing equations for a viscous, heat conducting fluid. It is a vector equation obtained by applying Newton's Law of Motion to a fluid element and is also called the momentum equation. It is supplemented by the mass conservation equation, also called continuity equation and the energy equation. In an inertial frame of reference, the general form of the equations of fluid motion:

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) = -\nabla p + \nabla \cdot \mathbb{T} + \mathbf{f},$$

Where v is the flow velocity, ρ is the fluid density, p is the pressure, T is the (deviatoric) stress tensor, and f represents body forces (per unit volume) acting on the fluid and ∇ is the del operator.

The conservation of mass equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0$$

The conservation of momentum equation is

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho(\vec{V} \cdot \nabla)\vec{V} = -\nabla p + \rho \vec{g} + \nabla \cdot \tau_{ij}$$

These equations are essential in the CFD modeling for the project.

2.2.3 Volume of Fluid (VOF)

2.2.3.1 Overview of VOF

The VOF model can model two or more immiscible fluids by solving a single set of momentum equations and tracking the volume of each of the fluids throughout the domain. Typical applications include the prediction of jet breakup, the motion of large bubbles in a liquid, the motion of liquid after a dam break and steady or transient tracking of any liquid-gas interface.

The VOF method is known for its ability to conserve the "mass" of the traced fluid, also, when fluid interface changes its topology, this change is traced easily, so the interfaces can for example join, or break apart. The method is based on the idea of so called fraction function *C*. It is defined as the integral of fluid's characteristic function in the control volume. Then the substantial derivative of fraction function *C* needs to be equal to zero:

$$\frac{\partial C}{\partial t} + \mathbf{V} \cdot \nabla C = 0.$$

This is actually the same equation that has to be fulfilled by the level set distance function φ.

2.2.3.2 Limitation of VOF

The following restrictions apply to the VOF models in ANSYS FLUENT:

- Must use the pressure-based solver. The vof model is not available with the density-based solver.
- All control volumes must be filled with either a single fluid phase or a combination of phases. The VOF does not allow for void regions where no fluid of any type is present.
- Only one of the phases can be defined as a compressible ideal gas. There is no limitation on using compressible liquids using user-defined functions.
- Stream wise periodic flow cannot be modeled when the VOF model is used.
- The second-order implicit time-stepping formulation cannot be used with VOF explicit scheme.

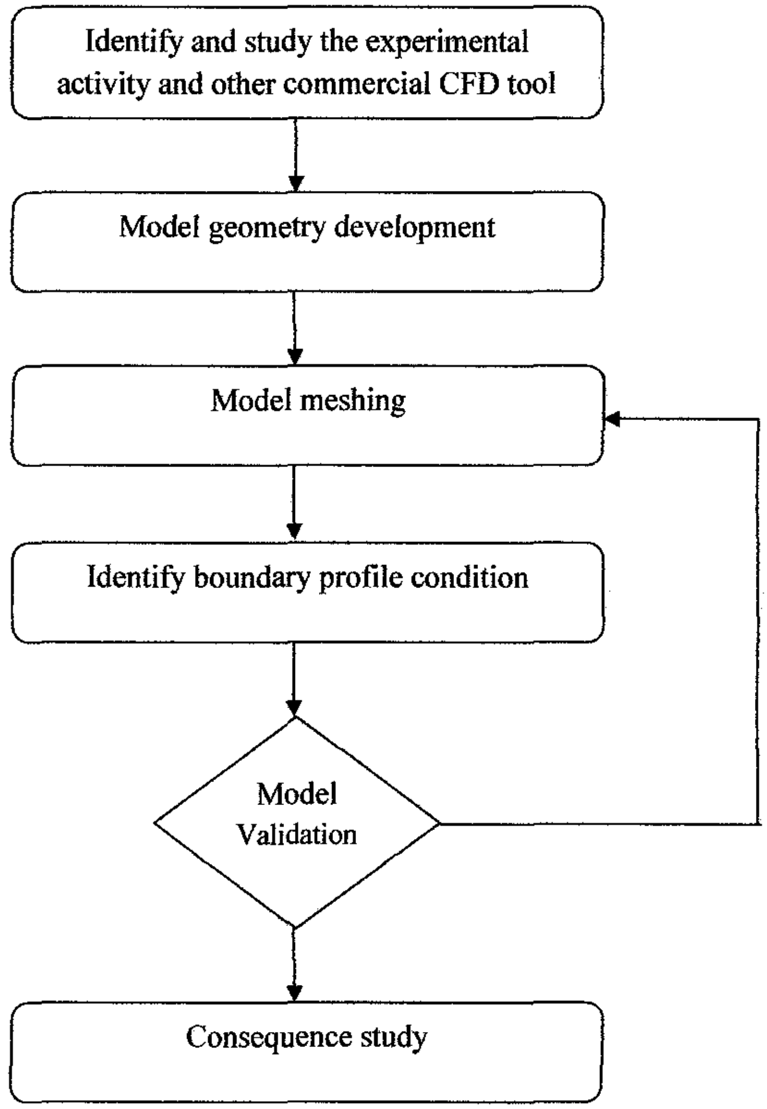
CHAPTER 3: METHODOLOGY

3.1 Research Methodology

ANSYS is engineering simulation software and is considered as the most powerful tool nowadays in term of modeling the fluids dynamic problem. ANSYS offers a comprehensive range of engineering simulation solution sets providing access to virtually any field of engineering simulation that a design process requires. Companies in a wide variety of industries use ANSYS software. The tools put a virtual product through a rigorous testing procedure.

This work was applied ANSYS software to do the simulation. ANSYS software has three main workflow which are pre- processing, solver execution and post processing. Pre-processing process consist of model geometry development, model meshing and boundary set-up condition. All equations used for the computation process will be considered in solving process. Finally, post-processing process concern more on the analysis work on the result generated. It is important to analyze the result in order for us to retrieve more accurate result by do checking and repair on the model meshing or boundary identification.

Figure below shows the flowchart of the CFD modeling.



3.2 The Study of Experimental Activity

Basically, this study is to look the spreading behavior of water droplet on the tablet edge in term of the spreading factor. D_i is the diameter of the droplet water after impacting the wall and D_o is the initial diameter of the droplet water before impacting the wall. Thus, the spreading factor is the ratio of droplet diameter before and after impacting the wall. It is significant to the pharmaceutical industry nowadays since the high quality of pharmaceutical tablet required a uniformity of coating.

$$\text{Spreading Factor} = \frac{D_i}{D_o} = \frac{\textit{Droplet diameter after impacting the wall}}{\textit{Droplet diameter before impacting the wall}}$$

Previously, an experiment was conducted to study the spreading behavior of the water droplet on the three types of different surface. Below are the details of the experimental data:

No.	Parameter	Value
1	The water droplet size (radius)	0.7- 1.0mm
2	Velocity applied to the water droplet	0.5m/s
3	Tablet edge angle	106^o
4	Tablet surface characteristics	1) Non-coated rough 2) Coated rough 3) Non- coated smooth.

Table 1: Experimental Specification

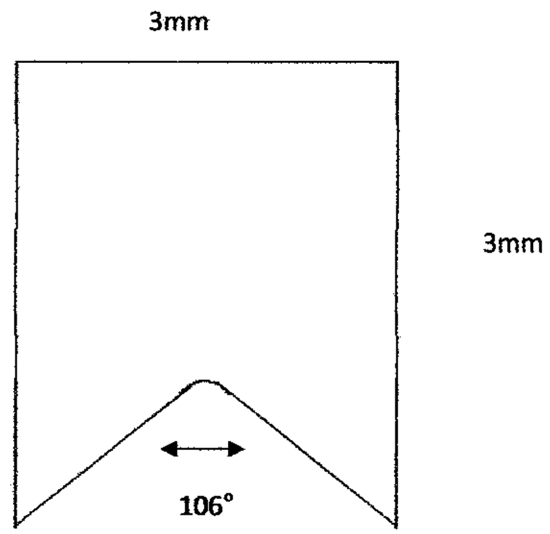


Figure 3: Sketch of model geometry

In order to study the spreading behavior, D_i/D_o *had been analyzed. As the* hypothesis, the highest spreading factor will represent the best of the uniformity. Theoretically, the wetting stage is formed when the diameter of the spreading become to the maximum.

3.3 Area of Study

Figure 4: Area of Study

Throughout the coating process, there are two parts that are required to coat which are flat and non- flat area (edge). In this case, the one that is critical to have a consistent covered is the edge part. The edge is the most difficult part to have a good uniformity of coating. Therefore, the area of interest for project is at the edge of the tablet.

3.4 Model Development

3.4.1 Model Geometry

Geometric modeling is a branch of applied mathematics and computational geometry that studies methods and algorithms for the mathematical description of shapes. The shapes studied in geometric modeling are mostly two- or three-dimensional, although many of its tools and principles can be applied to sets of any finite dimension. Thus, two- dimensional geometry had been created for this simulation. The model geometry is the most important part to ensure the simulation model is conducted as real case scenario as the experiment. This simulation model was developed by using Design Modeller as the primary step. There are two domains that need to be focused in constructing the model geometry which are the fluid domain and the wall domain. The fluid domain is represented as the atmosphere area while the wall domain refers to the surface of the tablet. The model geometry was constructed in two- dimensional as below.

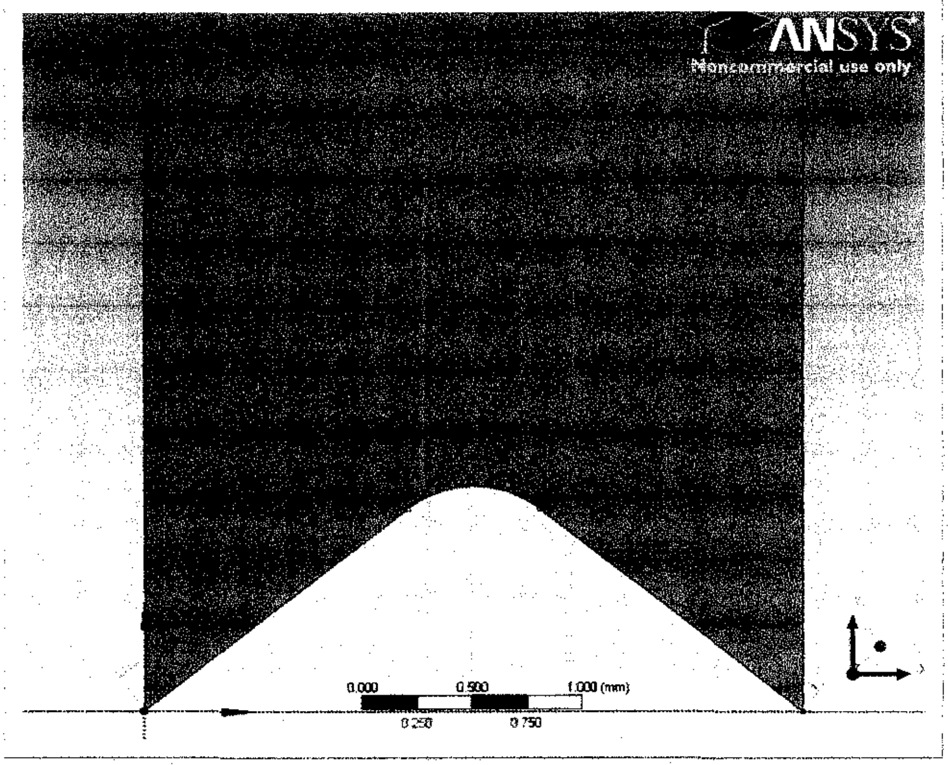


Figure 5: Geometry 1

Since the parameter that needs to be varied is the roughness surface of the tablet, two more model geometries had been constructed as the figures below. Figure 6 represents the smooth surface tablet while the figure 7 and 8 represent the rough surface tablets.

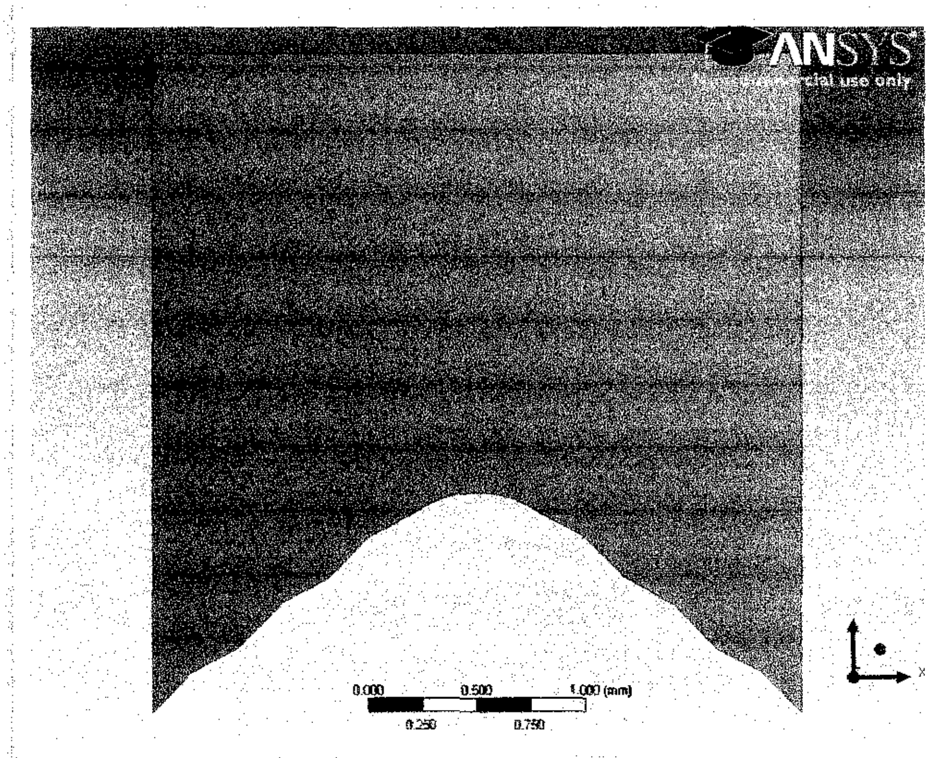


Figure 6: Geometry 2

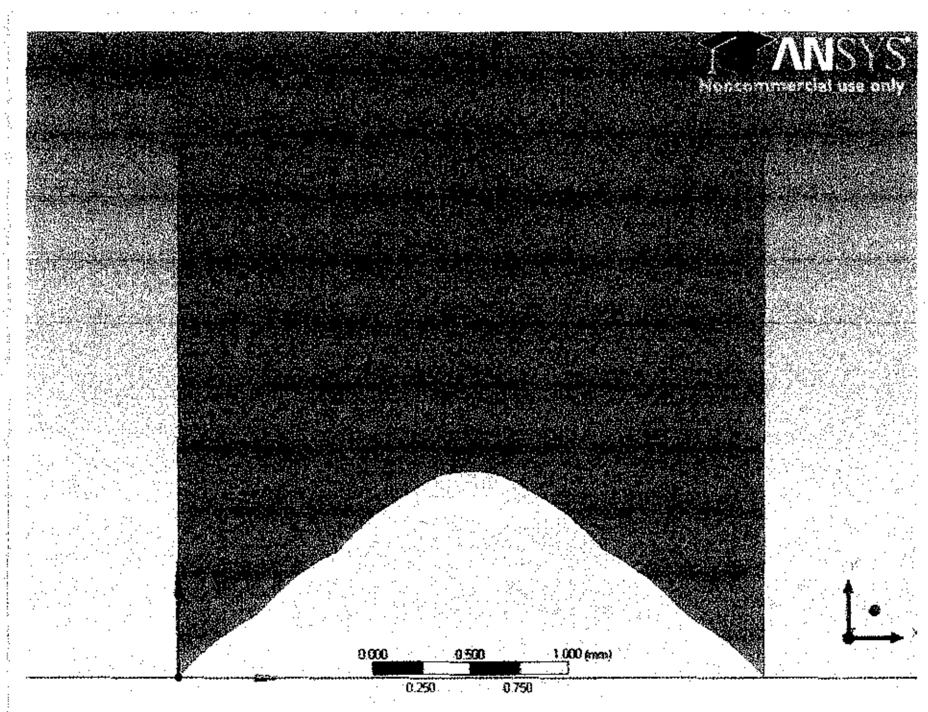


Figure 7: Geometry 3

3.4.2 Model Specification

The geometries for this project have been constructed follow the dimension below.

No.	Parameters	Dimension (mm)
1	Height	3.0
2	Width	3.0
3	Edge angle	106°
4	Distance of the water drop	0.2- 0.3

Table 2: Model specification

3.5 Mesh Preparation

Mesh generation is one of the most critical aspects of this simulation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. ANSYS meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible.

3.5.1 Mesh Specification

As mentioned in the geometry specification, 3mm x 3mm of a square was used to construct the model geometry. When the geometry is finally dimensioned, the mesh step will be applied. The domain was carefully meshed in a manner which maximized the detailing of the importance region. Fine mesh and huge number of cell elements was applied at the tablet wall. The refinement of mesh with the highest number; 3 was applied to the whole part of the domain due to get a high quality of mesh. Below are the specifications of the mesh for model geometry.

No.	Factor	Specification
1	Relevance center of sizing	Fine
2	Smoothing of sizing	High
3	Number of nodes	7911
4	Number of elements	7710
5	Mesh metric	Orthogonal quality
6	Minimum number of element metric	0.8317
7	Maximum number of element metric	1.0

Table 3: Mesh specification

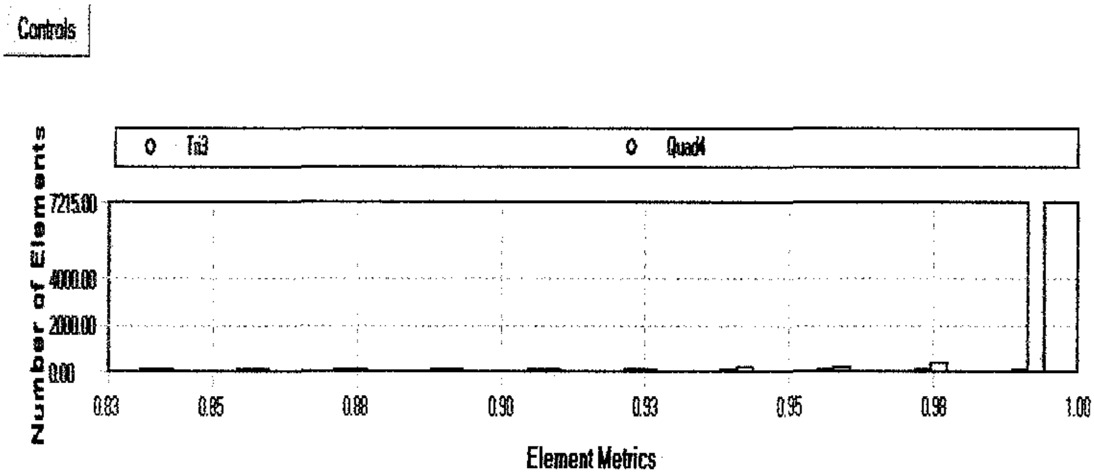


Figure 8: Meshing Quality Graph

Based on the details of mesh, quality of meshing can be studied and improved for better results. Orthogonal quality is the mesh statistics to show that the better quality for the generated mesh is when the average value is near to 1

3.5.2 Mesh Details

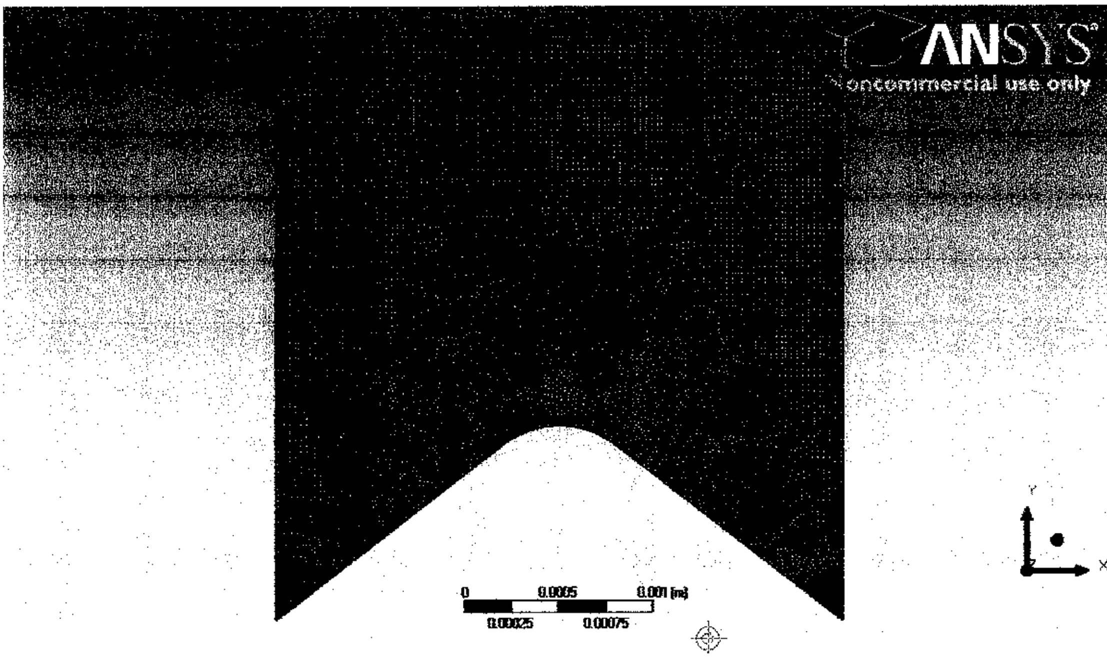


Figure 9: Mesh model

Details of "Mesh"	
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Fu...	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	High
Span Angle Center	Fine
Curvature Normal A...	Default (18.0 °)
Min Size	Default (6.1936e-007 m)
Max Face Size	Default (6.1936e-005 m)
Max Size	Default (1.2387e-004 m)
Growth Rate	Default (1.20)
Minimum Edge Length	6.4577e-004 m
Inflation	
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Advanced	
Defeaturing	
Statistics	
Nodes	31237
Elements	30836
Mesh Metric	Orthogonal Quality
Min	0.816160156207813
Max	1
Average	0.996942098249028
Standard Deviation	9.67942262513274E-03

Figure 10: Mesh Details

3.5.4 Boundary Named Selection

Basically, only two boundaries were defined in these projects which are outlet and wall. The outlet refers to the atmosphere condition where the droplet experiences the free fall with gravitational force, 9.81m/s2. Since the droplet falls down which is opposing the y- axis, the gravitational force was defined as negative value. Then, the wall is indicated as the surface of the tablet edge.

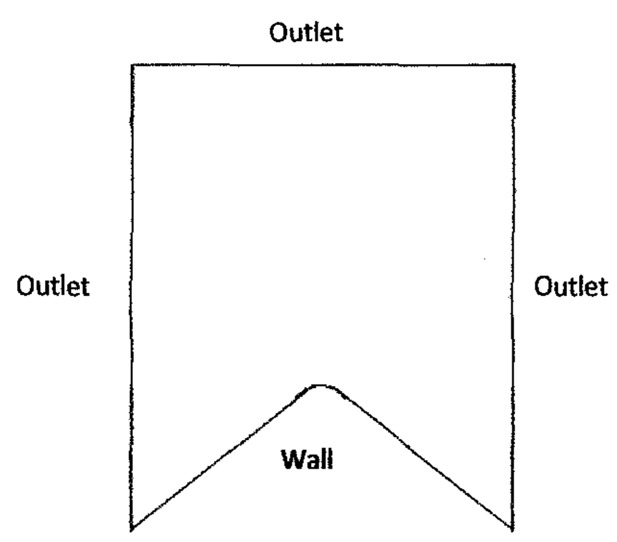


Figure 11: Named Selection

3.5.5 Grid Generation Study

Grid generation study is used to find the optimum or best mesh that can give the best solution for the model. In this case, six size of mesh have been chosen to study the relationship between the velocity of the droplet and the size of the elements. Big size of elements will take a long time of calculation. In order to avoid unnecessary calculation, the optimum size of mesh needs to be identified.

1. Relevance center: Fine

Parameter	Value
Refinement	3
Element	30836
Node	31327
Velocity	0.47m/s

2. Relevance center: Fine

Parameter	Value
Refinement	2
Element	17346
Node	17647
Velocity	0.48m/s

3. Relevance center: Fine

Parameter	Value
Refinement	1
Element	7710
Node	7911
Velocity	0.48m/s

4. Relevance center: Fine

Parameter	Value
Refinement	0
Element	1928
Node	2029
Velocity	0.481m/s

5. Relevance center: Medium

Parameter	Value
Refinement	0
Element	672
Node	732
Velocity	0.481m/s

6. Relevance center: Coarse

Parameter	Value
Refinement	0
Element	177
Node	209
Velocity	0.481m/s

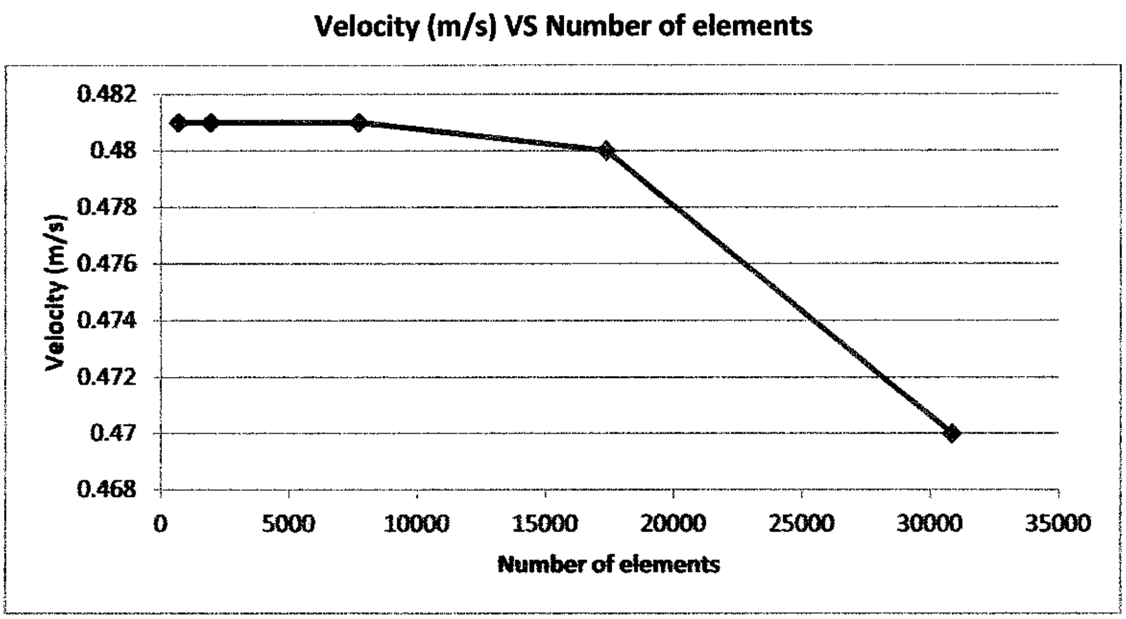


Figure 12: Grid generation study graph

Based on the figure 12, the velocity of the droplet is reducing when the number of element is 1 928. Thus, fine relevance center with no refinement is considered as the best mesh for this model since it takes optimum time to finish the calculation with the highest size of node.

3.6 Solution of Model

Setup can be divided into two parts which are CFX and FLUENT. Both software are slightly same in term of fluid dynamic purpose. Based on the literature, CFX cannot be applied in 2D problem. Since the present work is much related to both 2D and 3D, ANSYS FLUENT has been selected to conduct the simulation. In this part, there were several parameters that need to be defined as listed below:

- Define material properties
  - Fluid, solid, mixture
- Select appropriate physical models
  - Turbulence, combustion, multiphase, etc
- Prescribe operating conditions
- Prescribe boundary conditions at all boundary zones
- Provide initial values or a previous solution
- Set up solver controls
- Set up convergence monitors

3.6.1 Patch Input Coordinates

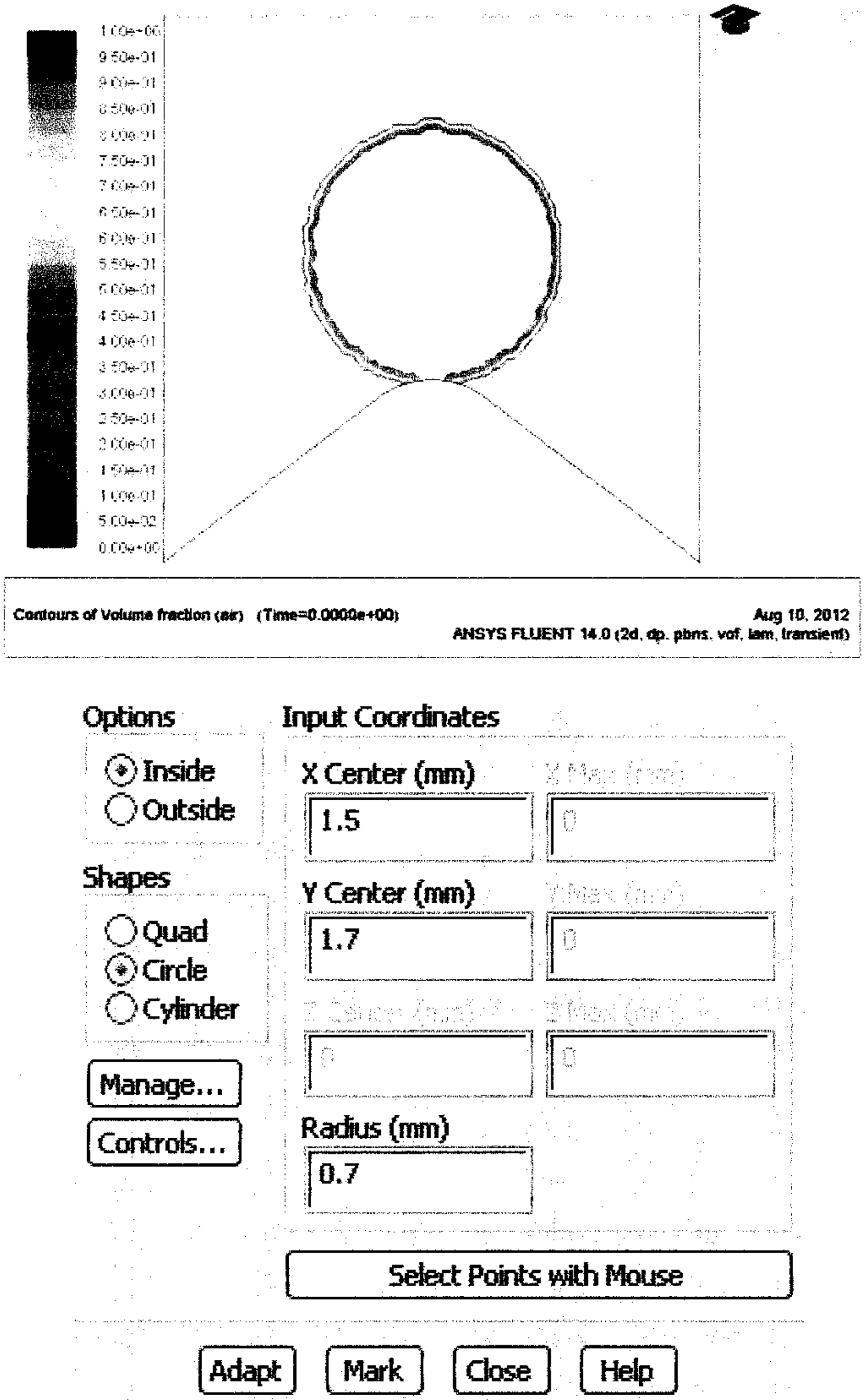


Figure 13: Patch Coordinates

3.6.2 Patch Specification

Patch is the most important part for this modeling. It is used to patch the water or secondary phase and apply the velocity of the droplet.

Phase	Variable	Value	Register to patch
Water- liquid	Volume fraction	1.0	Sphere-r0
Mixture	Y velocity	-0.5	Sphere-r0

Table 4: Patch specification

3.7 Post Processing

ANSYS provides a comprehensive set of post-processing tools to display results on models as contours or vector plots to provide summaries of the. Powerful and intuitive slicing techniques allow the user to get more detailed results over given parts of the geometries. All the results can be exported as text data or to a spreadsheet for further calculations. Animations are provided for static cases as well as for nonlinear or transient histories. Any result or boundary condition can be used to create customized charts. Post processing method will be applied to obtain the result in the next chapter such as the contours of the droplet spreading behavior on the tablet edge.

CHAPTER 4: RESULT AND DISSCUSSION

4.1 Effectiveness of using ANSYS 14.0

After using ANSYS 14.0 for the duration of this project, a better understanding of the program's benefits and shortcomings for the given problem was obtained. Overall, ANSYS 14.0 was deemed to be a less appropriate choice of CFD program for the given problem than other available CFD programs.

In this project, ANSYS 14.0 was fully utilized to simulate the free falling of droplet onto the tablet edge. Comparing to the last version of ANSYS, this version is more advance in term of function and also provides a Design Modeller in order to construct the model geometry.

ANSYS 14.0 was equipped with user guide and theoretical note inside the software. Thus, it can be considered as user friendly software and easy to learn.

4.2 Simulation Result

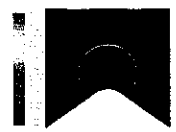
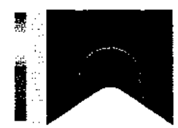
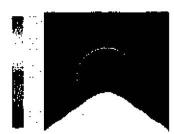
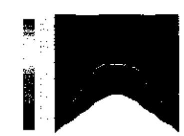
Time (ms)	T= 1.0	T= 3.0	T=5.0	T=8.0	T=10.0	T=150.0
Geometry 1						
Geometry 2						
Geometry 3						

Table 5: Contours of Droplet Spreading Behavior on Tablet Edge

4.3 Project Discussion

Time (ms)	1	3	5	8	10	150
Geometry 1	1	1.01	1.11	1.11	1	1.67
Geometry 2	0.98	0.99	1	1.11	0.9	1.44
Geometry 3	0.97	0.99	1	1.11	0.9	1.44

Table 6: Spreading factor

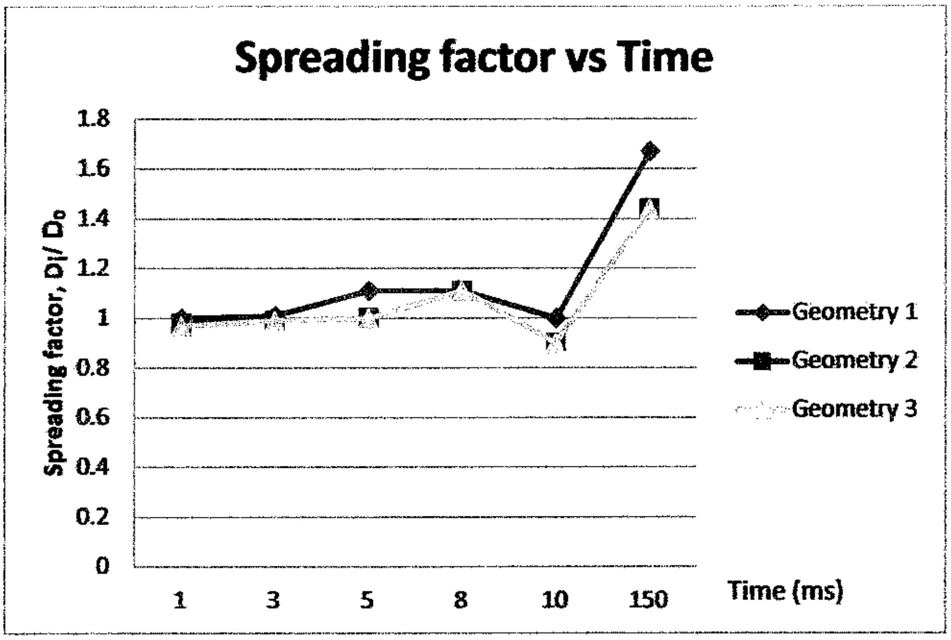


Figure 14: Spreading factor vs. time graph

Geometry 1 indicates the smooth surface of the tablet edge while geometry 2 and 3 refer to the rough surfaces of the tablet edge. The spreading factor was calculated by dividing the initial diameter of the droplet to the measured diameter of the droplet after a certain time.

Spreading factor is the ratio of the initial diameter and the measured diameter of the water droplet. Measured diameter, D_i can be defined as the maximum diameter of spreading state of the water droplet during the wetting process. Based on the graph as shown in figure 15, the smooth surface (geometry 1) of tablet edge got the highest number of the spreading factor. Thus, it proves that roughness of the surface can affect the dynamic of the water during the spreading process.

As shown in the table 6, the spreading factor is directly proportional with the time. But after the diameter of the droplet reaches the maximum dimension, the spreading factor will be reducing with time. Its means that the the wetting process is formed. As conclusion, there is not much different between the geometry 1, geometry 2 and geometry 3 for the droplet spreading behavior. This is due to the very small change in surface roughness applied to the wall.

4.4 Model Validation

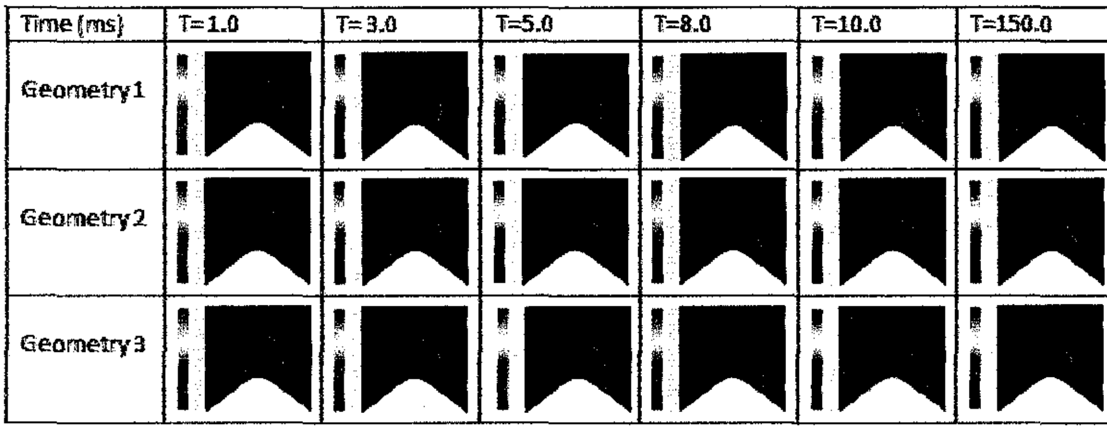


Figure 15: Modeling result

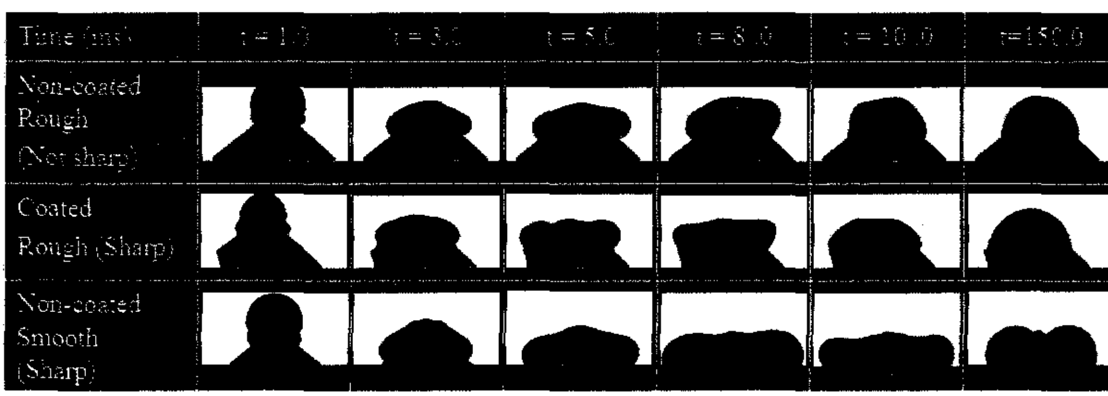


Figure 16: Experimental result

From the figure above, the contours of this simulation is quite comparable with literature outcome. All parameters have been set up exactly the same for both modeling and the experiment. However, the surface roughness of the edge is the one that not surely accurate because of some problem in identifying the factor of the roughness. In this modeling, the surface roughness has been generally set up without any factor.

CHAPTER 5: CONCLUSION & RECOMMENDATION

5.1 Conclusion

As the conclusion, all the objectives of this project have been completely achieved. The model of droplet spreading behavior has been developed using ANSYS 14.0. The model was developed to study the droplet spreading behavior on the tablet edge. The modeling result also was validated with the literature outcome.

Based on the result obtained, it is observed that the smooth surface of the tablet edge had the highest spreading factor and forms the thin film of the spreading which is promoted to uniform coating. Therefore, the smooth surface is preferable to coat the medicine.

However, the result obtained not really accurate because of the roughness of the surface is not exactly same as the experimental. Further development on the model should be done to get an accurate result.

5.2 Recommendation

For the recommendation, the further study of the ANSYS 14.0 needs to be done for the future work as the expansion such as develop a model to simulate droplet spreading behavior on the tablet edge which allows for different penetration edge and different edge geometries. Regarding the error in this modeling, the surface roughness of the tablet edge requires a standard specification in order to have a better result.

REFERENCES

ANSYS, Inc. (n.d.). Retrieved from ANSYS, Inc Web site: http://www.ansys.com/About+ANSYS

CJTech. (n.d.). Retrieved from CJTech Web site: http://www.cjtech.co.kr/Process%20Principles%20Film%20Coating.htm

Jr., N. C., Griffiths, R. F., & Santos, J. M. (2008). Parametric study of liquid droplets impinging on porous surfaces. *Applied Mathematical Modelling 32* , 341-361.

Krishnakumar, P. (2010). Wetting and spreading phenomena.

KuShaari, K., & Turton, R. (n.d.). Study of the droplet impact behavior on the edge of a tablet to predict coating variation using experimental and modeling methods.

Lunkad, S. F., Buwa, V. V., & Nigam, K. D. (2007). Numerical simulation of drop impact and spreading on horizontal and inclined surfaces. *Chemical Engineering Science 62* , 7214-7224.

Range, K., & Feuillebois, F. (1998). Influence of Surface Roughness on Liquid Drop Impact. *JOURNAL OF COLLOID AND INTERFACE SCIENCE 203,* , 16-30.

S.Sikalo, M.Marengo, C.Tropea, & E.N.Ganic. (2002). Anlysis of impact droplets on horizontal surfaces. *Experimental Thermal and Fluid Science* , 503-510.

Shaari, K. Z. (2003). *Modeling of Product Variability in Fluidized Bed Coating Equipment.* Morgantown, West Virgina.

Sikalo, S., & Ganic, E. N. (2006). Phenomena of droplet- surface interactions 31. *Experimental Thermal and Fluid Science* , 97-110.

Sikalo, S., M.Marengo, C.Tropea, & Ganic, E. N. (2001). Analysis of impact of droplets on horizontal surfaces. *Experimental Thermal and Fluid Science 25* , 503-510.

Wang, M.-J., Hung, Y.-L., Lin, F.-H., & Lin, S.-Y. (2009). Dynamic behaviors of droplet impact and spreading: A universal relationship study of dimensionless wetting diameter and droplet height. *Experimental Thermal and Fluid Science 33* , 1112–1118.

Yoon, S., Hewson, J., DesJardin, P., Glaze, D., Black, A., & Skaggs, R. (2004). Numerical modeling and experimental measurements of a high speed solid-cone water spray for use in fire suppression applications. *International Journal of Multiphase Flow 30* , 1369–1388.

Yoon, S., P.E.DesJardin, C.Presser, J.C.Hewson, & C.T.Avedisian. (2006). Numerical modeling and experimental measurements of water spray impact and transport over a cylinder. *International Journal of Multiphase Flow 32* , 132-157.

APPENDICES

FYP II Gant Chart

Table 7: Final year project 2 planning

NO.	ACTIVITY / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Define modelling goal															
2.	Perform the simulation															
3.	Discuss the outcome with supervisor															
4.	Reiterate the modelling															
5.	Examine & finalize the result															
6.	Consider revision to the model															
7.	Compiling all material for final report FYP 2															
8.	Submission of final report															

Key Milestone

Table 8: Key milestone

NO.	ACTIVITY / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Selection of Project Title		X													
2.	Preliminary Research Work					X										
3.	Submission of Extended Proposal						X									
4.	Preparation for Oral Proposal Defence							X								
5.	Oral Proposal Defence Presentation									X						
6.	Detailed Literature Review													X		
7.	Learn Modelling Software (FLUENT 14)															X
8.	Preparation of Interim Report															
9.	Submission of Interim Draft Report														X	
10.	Submission of Interim Final Report															X