Development of an Effective Drying System to Improve the Fuel Quality of Poultry Waste Material Using FLUENT Simulation

by

MUHAMMAD LUQMAN BIN MOHD NASIR

Dissertation submitted to the Mechanical Engineering Programme
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons.)
(Mechanical Engineering)

SEPTEMBER 2012

UniversitiTeknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak DarulRidzuan

CERTIFICATION OF APPROVAL

Development of an Effective Drying System to Improve the Fuel Quality of Poultry Waste Material Using FLUENT Simulation

By

MUHAMMAD LUQMAN MOHD NASIR

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons.)
(Mechanical Engineering)

Approved by,

____

MS. CHIN YEE SING
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JULY 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.

MUHAMMAD LUQMAN BIN MOHD NASIR

ABSTRACT

Indubitably, the world today is in a state of dependent towards energy for developments. It is no riddle today that world is heavily reliant on oil as the primary source of fuel for energy and oil is known to be a finite source of fuel, thus with the increasing need and usage, the source itself is depleting. Scientists and developers are ever in desperation to seek a new source of energy to prepare for the inevitable day when oil is completely depleted. Biomass provides an ample alternative for a renewable energy source. Nevertheless, extracting energy from poultry waste is not as simple as combusting fuel oil. Poultry waste is far more distinguished compare to oil. Although the step of recovering energy is somewhat similar to oil, that is by combusting the poultry waste, it is not as simple as throwing the poultry waste into a combustor and hope for the best. Poultry waste is known to have a high moist content, thus recovering energy using Fluidized Bed Combustor is a problem as it is not as efficient. Moreover, the high content of water in poultry waste will lead to a waste of energy as it is being use to dry up the moisture.A drying technique is required to ensure the moist content of poultry waste is lowered and possibly purge completely. A spraying technique is developed as one of the technique to be used for drying up the poultry waste. Simulation using FLUENT 6.3 will be conducted to analyze the effectiveness of droplets in drying mechanism. Success in developing this spraying technique will ensure the optimum energy recovery from poultry waste and reduction of cost.

ACKNOWLEDGMENT

I would like to express my deepest, humblest gratitude towards Allah s.w.t for His blessing in my undertaking to complete this Final Year Project. Truly without His blessing, this would never have been accomplished.

My greatest appreciation goes to my supervisor, Ms. Chin Yee Sing for her relentless support in helping me complete my final year project. Her supervision and moral support push me to go the length require for me to complete this project. Thank you, Ms. Chin, for your assistance from the beginning of this project until the end.

Not to mention, my utmost thankfulness to a Universiti Teknologi PETRONAS Master Student, Mr. Hilmee Bin Ibrahim, for sharing his experience and insightful knowledge to get me around tight corners in completing my project. Without his full assistance and guidance, this project would have never been able to be completed.

Also, a great recognition and appreciativeness to Universiti Teknologi PETRONAS especially Mechanical Engineering Department for giving me the opportunity to gain valuable experience in research, experimental and simulation works.

Last but not least, special thanks to my family and friends for their never ending support in completing the project. Likewise, thanks to everyone that was involve during the passage of this project. It has been a pleasure.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

2D - Two Dimensional
3D - Three Dimensional
dp - Double precision
CFD - Computational Fluid Dynamic
FBC - Fluidized Bed Combustor
FLUENT - Commercial Fluid Simulation Software
GAMBIT - Design Modeler Software
ICEM - Pre-processing Meshing Tool
lam - Laminar flow
pbns - Pressure based navier stoke

CHAPTER 1

INTRODUCTION

1.1 Background Study

Indubitably, the world today is in a state of dependent towards energy. Energy plays a really important role in the developments around the globe and an essential vital for every organism walking the earth, especially mankind. It is no riddle today that world is heavily dependent on oil as the primary source of fuel for energy and with the increasing populations, more energy is required. Oil is known to be a finite source of fuel, thus with the increasing need and usage, the source itself is depleting. Scientists and developers are ever in desperation to seek a new source of energy to prepare for the inevitable day when oil is completely depleted.

One key element in researching for a new potential source of energy is the energy recovery. Energy recovery, in its essence, is the application of technique to curtail the amount of energy absorbed into the system to produce output energy. Biomass poses as the promising option for sustainable renewable energy. Research indicates that waste produce from agriculture sector, for example, emits high deposition of gas compound such as nitrogen that affect the environment negatively. This poultry waste, as it is known, mostly use as fertilizers, nevertheless, as the volume increase over the years, the traditional recycle as fertilizers has come down to environmental problems. Using biomass, turning poultry waste to usable energy, provide adequate solutions to overcome the problems. Essentially, it is a process of extracting energy through the combustion of poultry waste.

1.1.1 Energy Recovery

One key element in researching for a new potential source of energy is the energy recovery. Energy recovery, in its essence, is the application of technique to curtail the amount of energy absorbed into the system to produce output energy [1].

1.1.2 Biomass

Biomass poses as the promising option for sustainable renewable energy. Research indicates that waste produce from agriculture sector emits high deposition of gas compound such as nitrogen that affect the environment negatively [2]. Using biomass, turning poultry waste to usable energy, provide adequate solutions to overcome the problems. Essentially, it is a process of extracting energy through the combustion of poultry waste in a Fluidized Bed Combustor.

1.2 Problem Statement

While the ideas of using poultry waste as potential source of energy stands out as anapplicable initiative, there are a few issues regarding the combustion of poultry waste. One definitive issue is the unavailability of a system to convert the poultry waste, in its original form, to energy [1]. In its novel form, poultry waste has a high content of moisture and it is a problem when it comes to combustion. Poultry wastes are required to undergo a drying process in order to purge the moisture content before it is subjected to direct combustion. For the drying process, a spraying technique is instigated to keep the poultry waste in its original, slurry form for energy conversion.

1.2.1. Problem Identification

This research focuses on the atomization of the liquid through a nozzle. Atomization is the break ups of liquid into smaller droplets [3]. The problem in this research is to reduce the droplets size and increase the surface area exposed for combustion that will enable a high energy recovery. Commercial simulation software FLUENT 6.3 is used in this research to determine the best configurations of the nozzle to produce the optimum droplets size for the energy recovery.

The atomization of the liquid is affected by the fluid properties (viscosity, density and surface tension) and pressure as well as velocity of the fluid inside the nozzle [3]. Fluid properties affecting the droplets break ups mainly are surface tension, viscosity and density of the fluid.

1.3 Objectives

The objectives of this project are:

1. To analyze and characterize the basic properties of atomization of poultry waste (slurry) through computer simulation using FLUENT 6.3 software
2. To conduct computer modeling of the nozzle that uses spraying technique for drying of the poultry waste
3. To develop the effective nozzle configurations for drying process

1.4 Scope of the Project

This project covers the drying process of the poultry waste prior to combustion. It includes analysis of nozzle configuration effects on the atomization of the poultry waste into droplets. The characteristic of the droplets exiting the nozzle will be observed, in this case, numerically through computer simulation, considering variation such as surface area, flow rate, momentum and heat recovery [1]. Suffice to say, the droplet will be experimented to acquired highest heat recovery when injected into Fluidized Bed Combustor. The output of this study is in hope to achieve the optimum dry poultry waste to ensure the maximum heat recovery that can be extracted from the poultry waste.

1.5 Significance

This project carries out study to improve the efficiency of the poultry waste inside the combustor for production of optimum energy output. Upon successful development of the drying-spraying system will help utilize poultry waste as new fuel source for usable energy. This will become advantageous as the world currently requires a renewable energy source for the ever growing developments. If this project is not done, the opportunity to discover a new potential renewable energy will be lost.

CHAPTER 2

LITERATURE REVIEW

2.1 Fluidized Bed Combustor

Fluidized Bed Combustor (FBC) is known as one of the most effective methods for energy recovery. FBC is the best existing technology since the mid-1960s for combusting atypical solid fuel such as poultry waste to recover energy [4]. Basically, FBC consist a blower at the bottom of the chamber where air is blown to suspend and circulate the sand and poultry waste particle while combustion process takes place [1]. The sand helps provide more effective reaction by colliding with poultry waste particles to expose the carbon element inside [1].

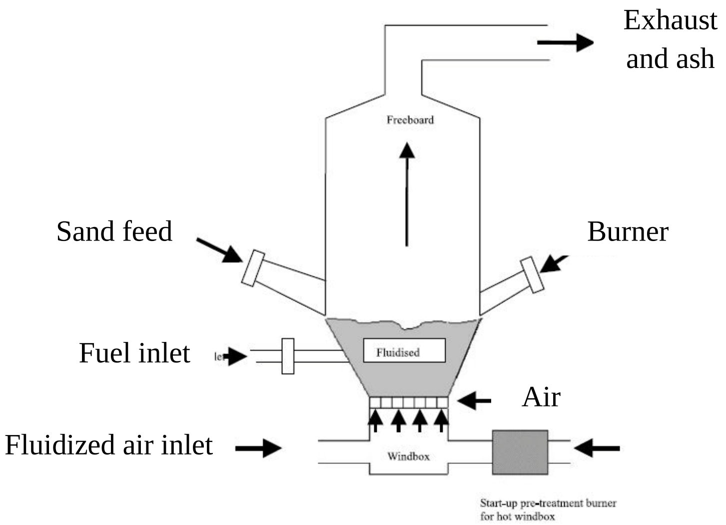


Figure 2.0: Simple mechanics of Fluidized Bed Combustor [1]

A typical problem with a FBC is its inability to efficiently combust fuel, such as poultry waste, that contains a high moisture level (above 25%) [1]. In order to overcome the problem, the poultry waste, in this context to be used as fuel, must be dry and purge of moisture content. A drying technique is to be developed to dry the poultry waste before it can be used as fuel to be combusted inside FBC.

2.2 Effective Dry Spraying Technique Using High Speed Camera

One of the techniques developed to help dry the poultry waste before it can be used as combustion fuel is the spraying technique. It is essentially a technique where the poultry waste is pumped through the nozzle and sprayed into droplets. This atomization process, as it is known, increases the surface area of the poultry waste so it can be effectively dried. This study was performed by Muhammad Nadhir Othman Hasbi in 2011 using a high speed camera to analyze the atomization droplets produce. In his research, he found that spraying technique is an effective drying technique as the droplets of poultry waste (slurry) is much less compared to water [1]. He also believed that by employing this drying spraying-technique, the efficiency of poultry waste as combustion fuel in FBC could also be optimized [1].

In his experiment, he studied the different angles the spray produce with different level of openings on the nozzle.

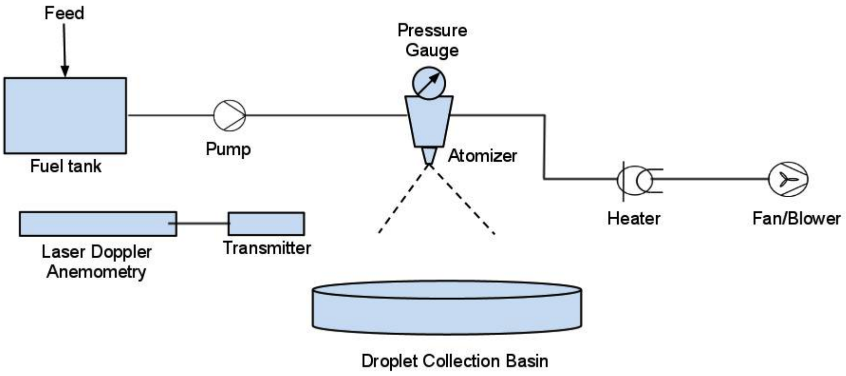


Figure 2.1: Spraying system setup used by Muhammad Nadhir in his experiment [1]

2.3 Computer Simulation Using FLUENT 6.3

FLUENT 6.3 is a computer simulation tool use to study gas-liquid flows [5]. The software generate analysis of a model constructed based on numerical methods. In a research paper about a study for spray characteristic of an internal mixing air atomizing nozzle written by Liuqing Xiu and Yuming Xing in 2011 [5], they utilized FLUENT 6.3 software in their research to investigate the spray characteristic of internal-mixing atomizing nozzle with 8 jet orifices. In their paper, they compared the result obtained from the simulation to that of the experiment.

Simulation software, FLUENT 6.3, will be used in this particular project to investigate the characteristic of poultry waste droplets exiting the nozzle. The numerical result obtain from the simulation will be compared and analyze with the experimental value.

2.4 Meshing

Mesh, in its general term, is defined as connected strands that are similar to web or net. Before a computer simulation could be done, the model must be mesh into smaller domains [6]. Meshing is vital in computer simulation to analyze the fluid flows. The flow domain is riven into smaller subdomains allowing governing equation to discretize and solved within each subdomain [6]. The approximate solutions inside each subdomains are put together to give the full picture of the fluid flow.

In the research paper about study for spray characteristic of an internal-mixing air atomizing nozzle written by Liuqing Xu and Yuming Xing in 2011 [5], prior to computer simulations the model of the field model is mesh into subdomains for the equations to be solved in each subdomain. They sliced the geometric model into 670, 956 grids using pre-processing software ICEM [5].

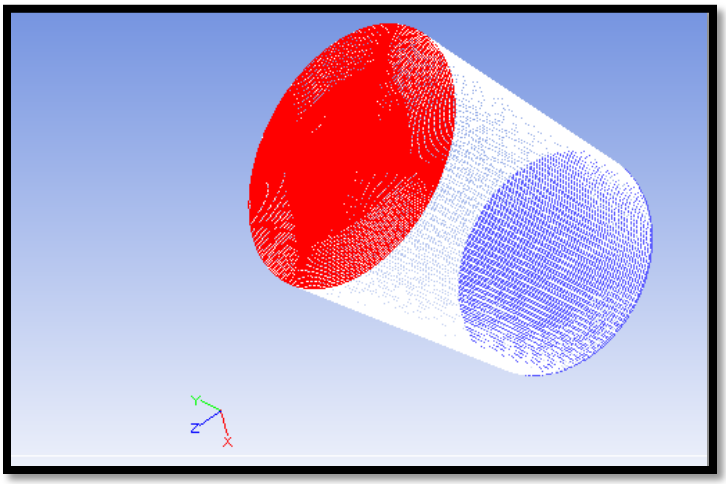


Figure 2.2: 3D flow field model with mesh [5]

Similarly in a research project on mathematical modeling of droplet atomization using the population balance equation by Hosaam S. Ally et al. in 2009, a grid of 35188 volume cells was constructed to solve the discrete population balance model [7]. This is to simulate a plain jet air blast using Computational Fluid Dynamic (CFD) code FLUENT 6.3.

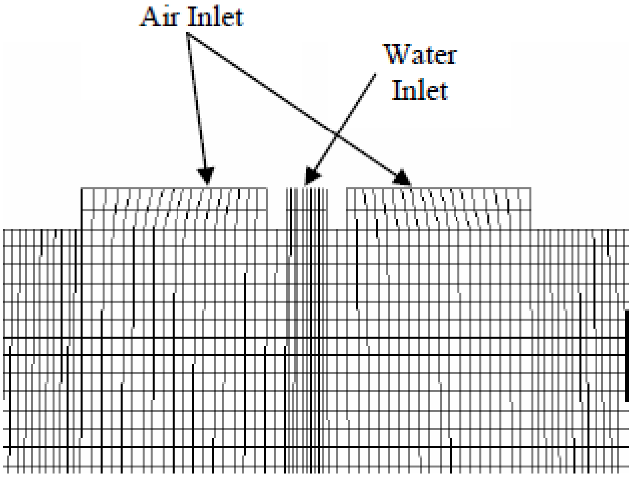


Figure 2.3: Grid and inlet boundaries [7]

2.5 Fundamental of Atomization

Atomization is basically a definition for a process of liquid break ups into droplets [3]. A stream liquid poured out from certain height will eventually breaks up into droplets prior to hitting the ground. This is an example of an atomization process [3]. An atomization of liquid through a nozzle resulted in the droplets moving in a well-ordered fashion [3]. This movements of droplets is known as spray.

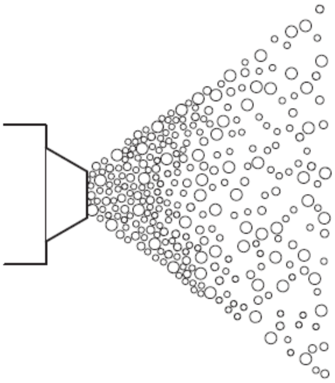


Figure 2.4: Spray through a nozzle [3]

2.5.5 Fluid Properties

The break ups of droplets in a spray is affected by various factors. One of which is the properties of the fluid itself. This property affected the dropet size, velocity and the tendency of the fluid atomizes [3]. Surface tension, density and viscosity are the fluid properties that have direct effect on the atomization of the fluid.

Surface Tension

Surface tension of the fluid helps to pull the fluid into a more or less spehrical shape after an atomization. However, a high surface tension will prevent the liquid from breaking up into small droplets thus will result into an atomization of bigger droplets [3]. Table 1 shows some common fluids with their respective surface tension.

Table 2.0: Common liquid surface tensions [3]

Liquid	Surface Tension (N/m) @ 20°C
Ethyl alcohol	0.022
Benzene	0.029
Lubricant	0.037
Glycerine	0.063
Water	0.073
Mercury	0.465

Density

A high density liquid tends to resist acceleration place upon the fluid [3]. It is easier to accelerate a low density liquid compare to a high density one. An accelerated liquid will break up into droplets upon atomization, thus a high density liquid will surely atomize to a bigger average droplets size.

Viscosity

Viscosity, similar to surface tension, prevents the breakup of liquid resulting in bigger droplet size. Viscosity of a fluid acts to resist agitation and holds the liquid together preventing it from breaking up [3]. Needless to say, the higher the viscosity of a liquid, the bigger the diameter of the droplets.

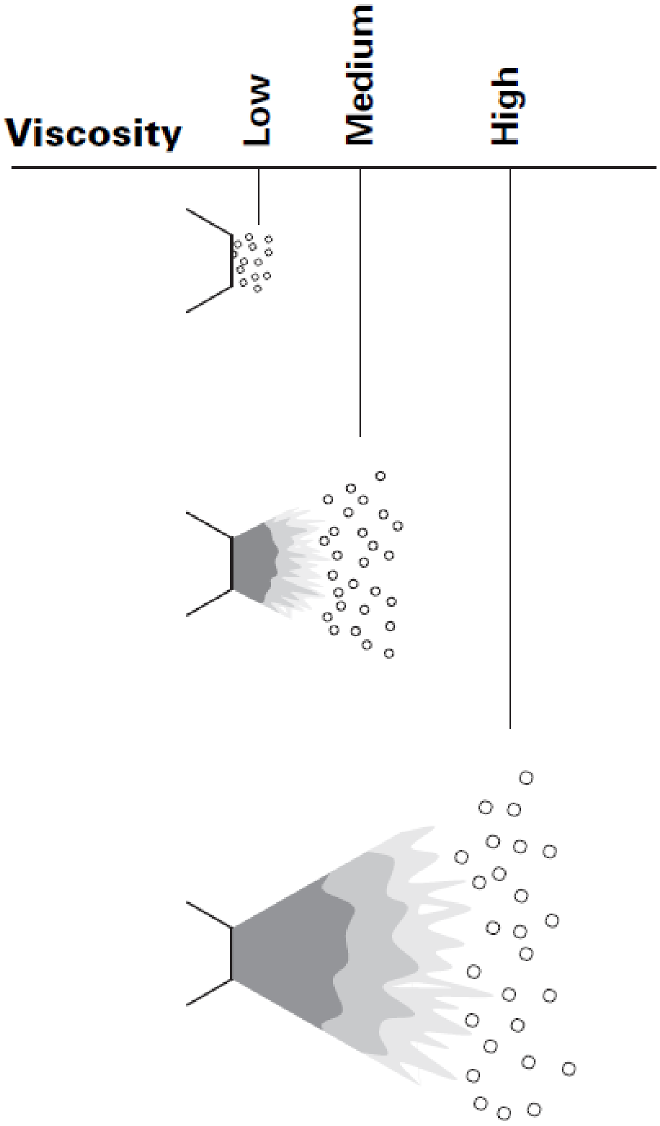


Figure 2.5: Relationship of droplet size and viscosity of the fluid [3]

2.5.6 Process of Atomization

For this research, a pressure atomization type nozzle is used. The pressure atomization involves a process of fluid forces by a high pressure through a small nozzle opening [3]. Fluid discharged from the nozzle as high speed stream and the drag that exists between the fluid and air disturbs the stream leading to break ups of fluid into droplets [3]. The fluid pressure acted as energy source for this type of atomization and the energy is converted to momentum as the fluid is discharged from the nozzle [3].

There are factors that contribute to the formation of droplets in this process. These factors are the nozzle diameter, the atmospheric pressure and relative velocity of air and the fluid. For the nozzle diameter, the larger the diameter of the nozzle, the bigger the size of the droplets discharged from it [3].

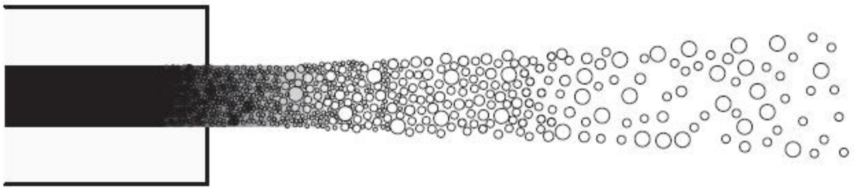


Figure 2.6: Fluid atomization through a nozzle with certain diameter [3]

The resistant from atmosphere tends to disrupt the fluid stream and overcome the fluid properties such as viscosity, surface tension and density [3]. Moreover, temperature may also play a part in the structure of atomization process [3]. Theoretically, a pump pumping fluids through a nozzle will create a high pressure and as the fluid flow through the opening, the stream will disperse into droplets due to the resistant from the atmosphere and the pressure put on the fluid.

In the nutshell, a general rule can be applied to the atomization process of the fluid. According to the Graco Inc. learning module, “as the fluid pressure increases, velocity increases and the average droplet size decreases” [3].

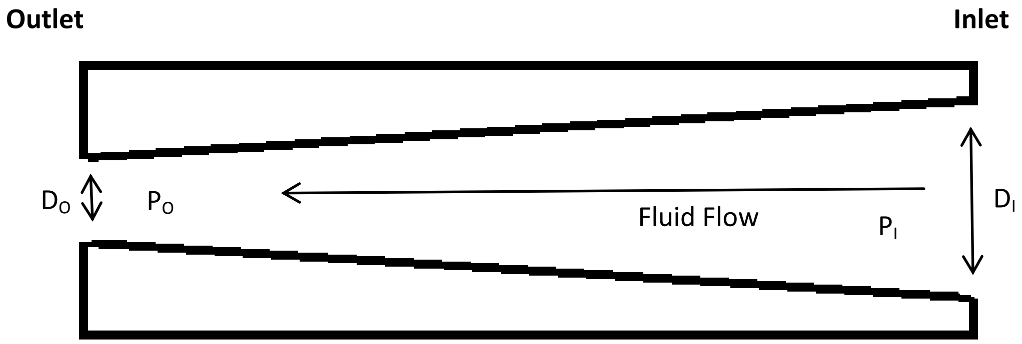


Figure 2.7: Cross section plane of the nozzle

Figure 2.7 shows a section plane of a nozzle. D_o and P_o represent the outlet diameter and pressure respectively while D_I and P_I represent inlet diameter and pressure respectively. The velocity of the fluid is gained from the pressure in the nozzle [3]. The inlet cross sectional are is greater than outlet cross sectional area and this will cause the pressure to increase as the fluid travels from inlet to outlet. The increase in pressure is then converted into velocity procuring a high velocity fluid at the inlet. As the general rule apply, the break ups of the fluid will occur in smaller size. This can be represented in the relation shown as follow:

$$Po \ \propto 1/(diameter\ of\ the\ droplets)$$

In conclusion, the smaller droplet size of the atomization process of liquid can be gain by increasing the outlet pressure of the nozzle.

CHAPTER 3

METHODOLOGY

3. Preface

The duration of this project stretch across two semesters, namely Final Year Project I (FYP I) and Final Year Project II (FYP II). In the course of this project, the preliminary research work and tutorial of the software this project requires will be done in the first semester. The second semester includes the construction of the FLUENT 6.3 software modeling of the nozzle use in this study. The computer simulation analysis of the atomization of the droplets of poultry waste will also be done in FYP II, as well as the comparison of the experimental results.

3.1 Research Methodology

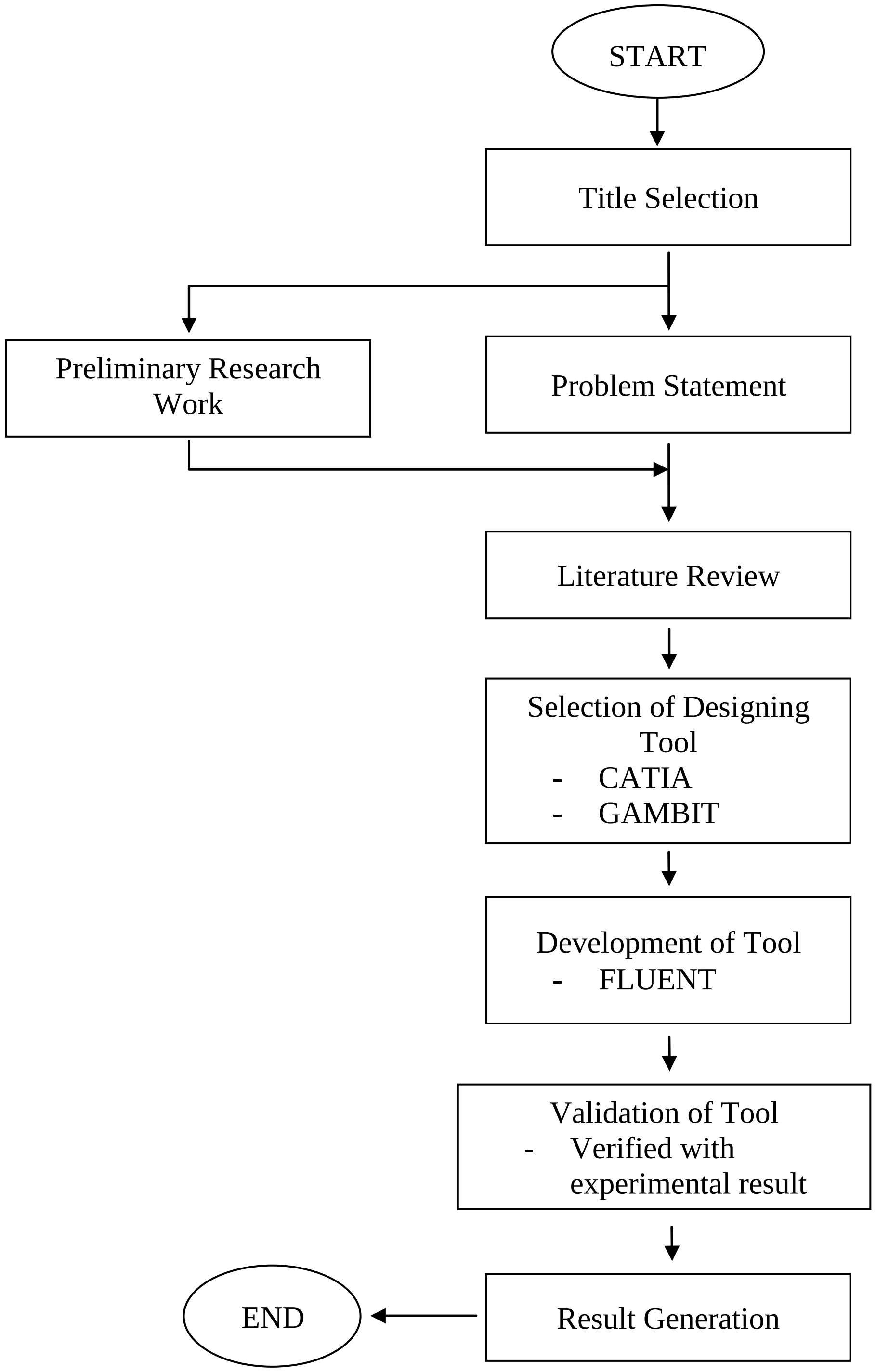
Preliminary research includes the collection and compilation of data from reading of journals, technical and research papers done by others that are closely related to the objective of this project. This preliminary research also is done to gain knowledge and understanding about biomass, drying-spraying system, fluid flow and properties of the poultry waste to be used in this study. During this, the understanding to use FLUENT 6.3 software to build computer model for analysis is acquired.

To achieve the objective of this project, the computer model of the spraying system must be constructed for analysis. Using the data collected from the research, the project will be then carried out. For the analysis to begin, few data such as the nozzle configuration, properties (density and viscosity) of poultry waste, boundary conditions (ambient pressure, air and water inlet velocity) and pressure must be known and set in the computer model. The results of the analysis are then observed and compared. In this project, poultry waste dispersion is analyzed using FLUENT 6.3 and water dispersion analysis is used as comparison. The air is used to observe the effect it has on the dispersion of the poultry waste.

3.2 Tools

Computer software, FLUENT 6.3, will be used in this project for modeling and computer analysis of the drying-spraying system. The analysis will be computed mathematically using mesh. The modeling of the nozzle will be done using CATIA. GAMBIT will be utilized for simulation modeling and meshing.

3.3 Project Flowchart



3.4 Gantt Chart

First Semester (FYP I)

Table 3.0: FYP I Gantt chart and key milestones

No	Detail/Week	1	2	3	4	5	6	
1	Selection of Project Topic: **Development of an Effective Drying System to Improve the Fuel Quality of Poultry Waste Material using FLUENT 6.3 Simulation**	■	■	■				
2	Preliminary Research Work: Research on literatures related to the topic		■	■	■			
3	Submission of Extended Proposal					■	28/02	**Mid Semester Break (7/02-11/02/2012)**
4	Project Activities • Familiarization with the experiment setup						■	
	• Collaborate with seniors in order to understand the experiment						■	
	• Familiarization and Tutorial of FLUENT 6.3 software						■	
5	Proposal Defend							
6	Project work continues: • Help calibrating the Laser Doppler Anemometry & setup experiment apparatus							
	• Development of the model of the nozzle							

Second Semester (FYP II)

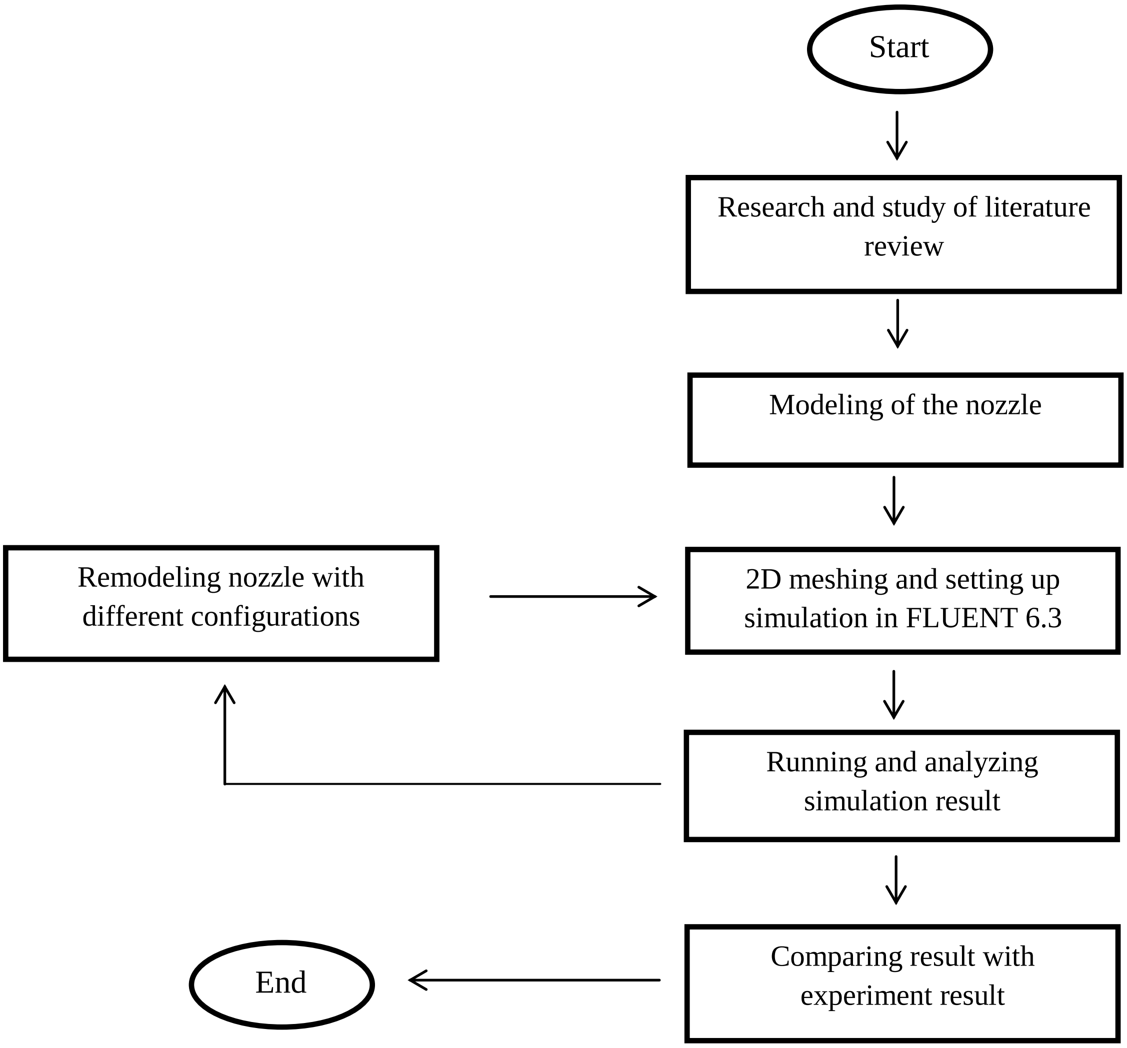
Table 3.1: FYP II Gantt chart and key milestones

No	Detail/Week	1	2	3	4	5	6	
1	Research work. **Fundamental of Atomization**	■	■	■				**Mid Semester Break**
2	Modeling of the nozzle		■	■	■			
3	Meshing and setting up simulations			■	■	■	■	
4	Submission of Progress Report							
5	Project work continues: • Meshing and running simulations							
6	• Analysis of the simulation and comparison to the experiment							
7	Submission of poster							
8	Submission of Final Report draft and technical paper							
9	Oral Presentation							

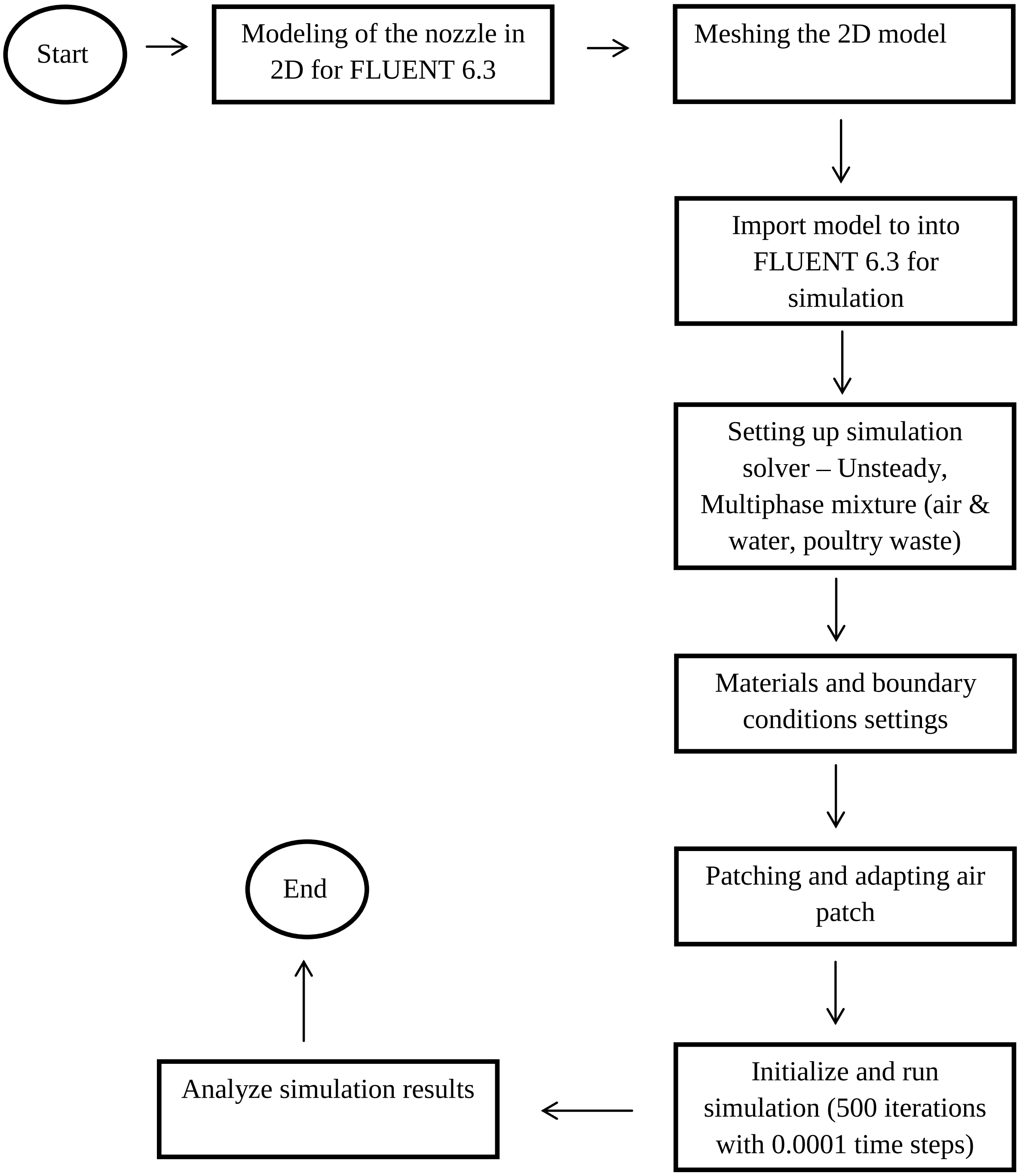
3.5 Project Activities

As far as the project has progressed, it is right on schedule. After the completion of the preliminary research work, the project progresses to the next stage which is familiarizing with the experiment setup by collaborating with post-graduate student who are using the same equipment (Laser Doppler Anemometry) and disseminating with the FLUENT 6.3 software. However, more time is required for the tutorial of FLUENT 6.3 as to fully understand the nature of the software. Ultimately, the computer model of the nozzle has been completed using the modeling software CATIA.

3.6 Project Activities Flowchart



3.7 Simulation Flowchart



CHAPTER 4

RESULT AND DISCUSSION

4.1 Computer Modeling

This project focused on the modeling configurations of the nozzle for the spray drying technique. The models of the nozzle will then be run in FLUENT 6.3 software for simulation to analyze the characteristics of atomization. Figure 4.0 shows the isometric view of the nozzle model. The modeling was done using the CATIA software.

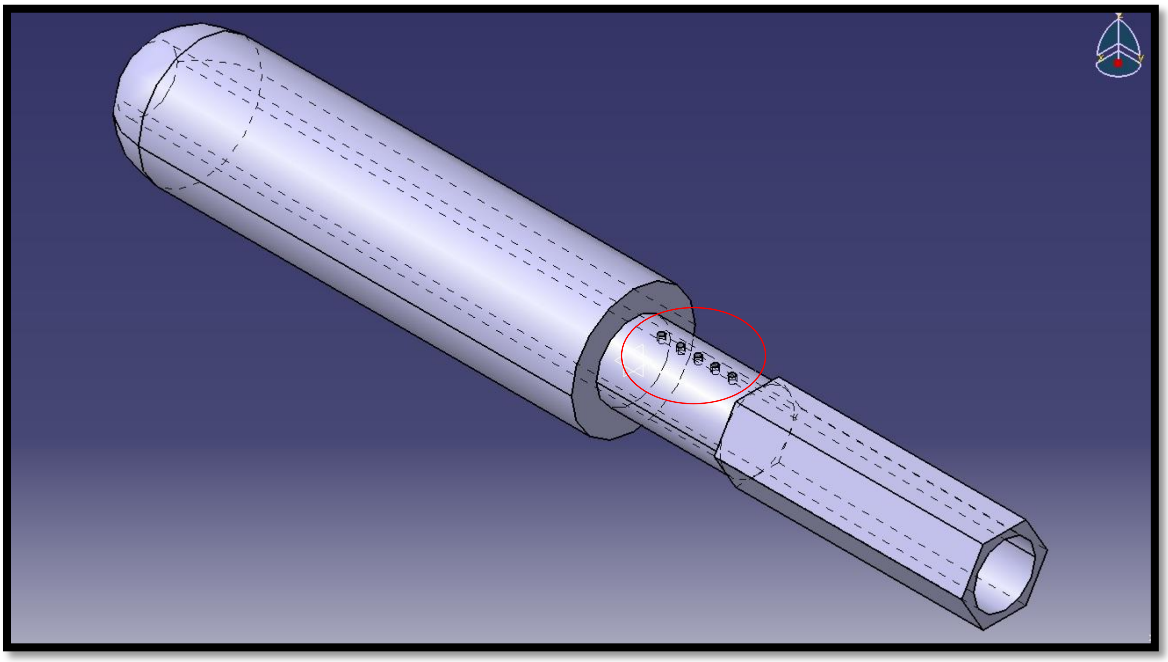


Figure 4.0: Isometric view of the nozzle model

Figure 4.0 shows the standard configurations of the nozzle. The configurations of the nozzle will be manipulated by changing the number of air inlets (circled in red in Figure 4.0). The air inlets will let the air entering the nozzle while water or poultry waste flows through the nozzle. The air will be mixed with the fluid and the effect of the air on the dispersion of the water or poultry waste will be study.

4.2 Nozzle Model Configurations

4.2.1 Number of Holes for Air Intake into the Nozzle

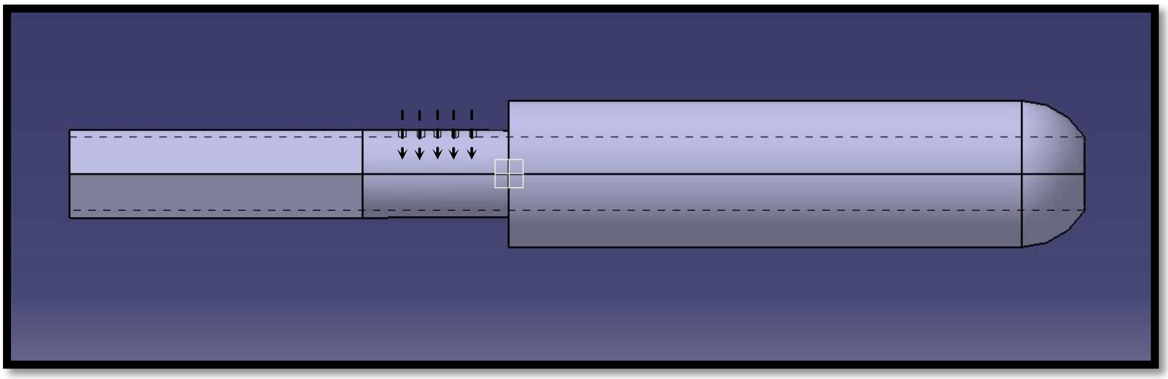


Figure 4.1: Five holes for the air intake

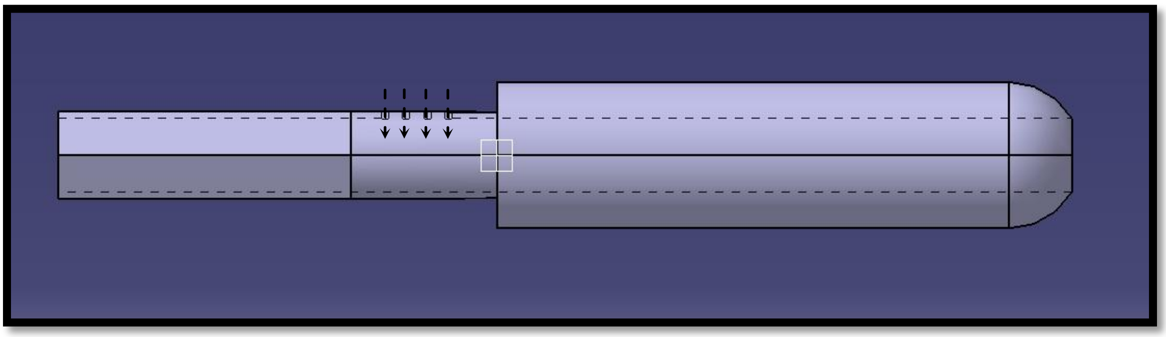


Figure 4.2: Four holes for the air intake

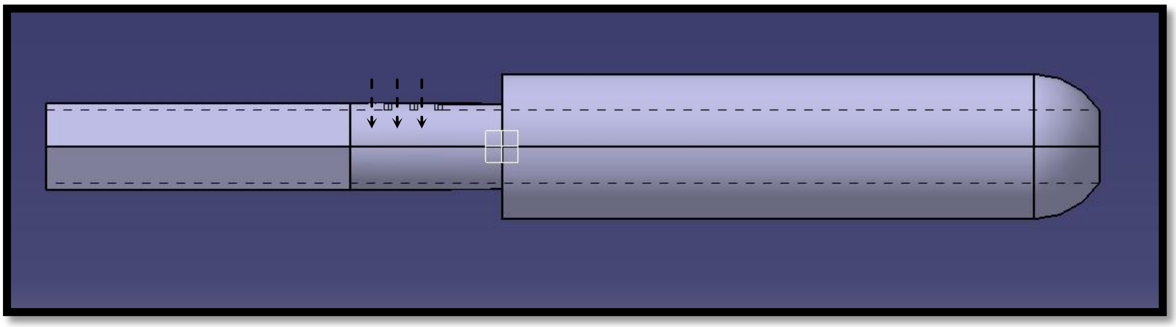


Figure 4.3: Three holes for the air intake

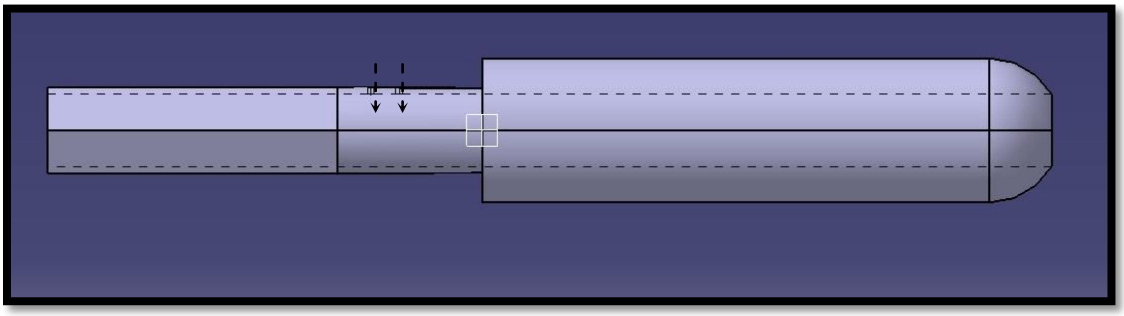


Figure 4.4: Two holes for the air intake

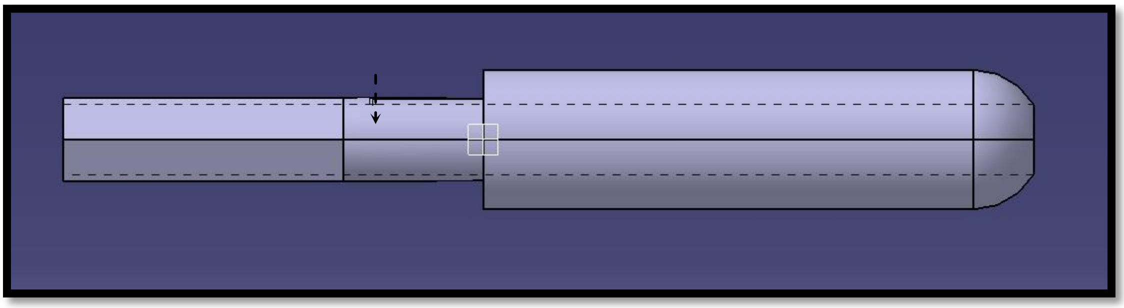


Figure 4.5: Single holes for the air intake

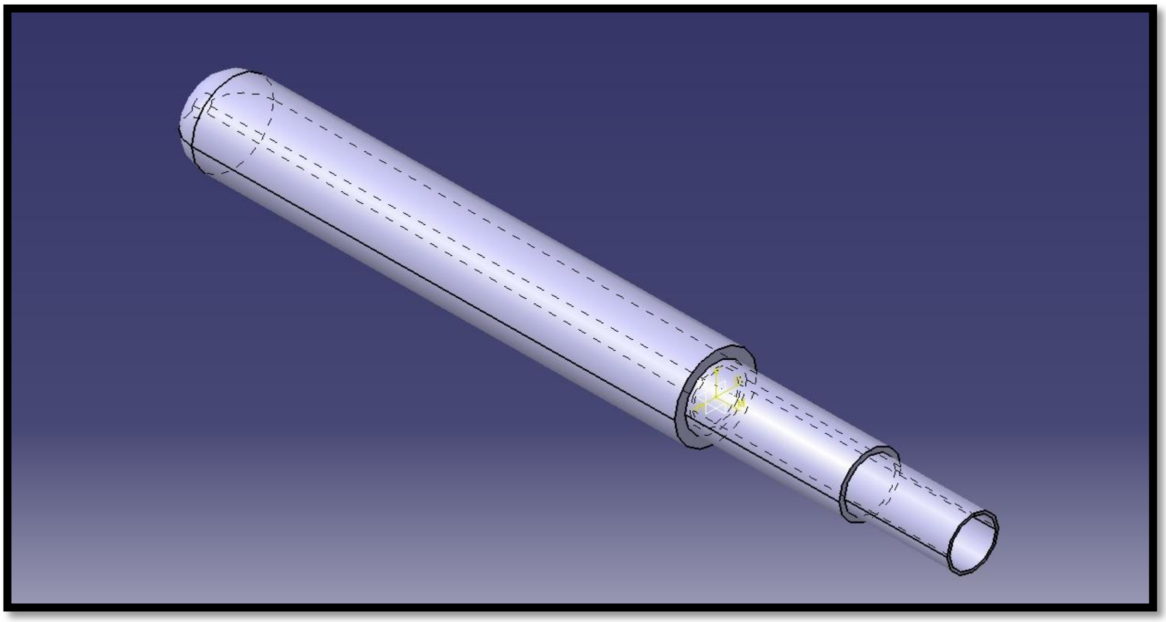


Figure 4.6: Nozzle without holes configurations

Models of the nozzles with different configurations are illustrated in Figure 4.1 to Figure 4.6. The configurations are the air inlets to let the air enters the nozzle while fluid flow through the nozzle. Figure 4.1 shows the configurations of five air inlets. The air inlets are then reduced by factor of one for each configuration models with one air inlets being the last as shown in Figure 4.5. Decreasing air inlets exemplify the diminishing amount of air enters the nozzle and mixed with the fluid flowing through. This is done to study the effect of the amount of air on the dispersion of the fluid.

On the other hand, Figure 4.6 shows the nozzle model without air inlets configuration. This configuration is compared to the air inlet configurations to observe the difference of dispersion with and without the presence of air inside the fluid flowing in the nozzle. The air path entering the nozzle through air inlets is represented by the arrow shown in Figure 4.1 to 4.5.

Each of the configuration models is run through simulations to observe and study the atomization of the fluid. Results procured will be compared.

4.3 Dimensions of Nozzle

The nozzle is modeled using modeling software CATIA with constraints of dimensions. Figure 4.7 shows the nozzle with dimensions.

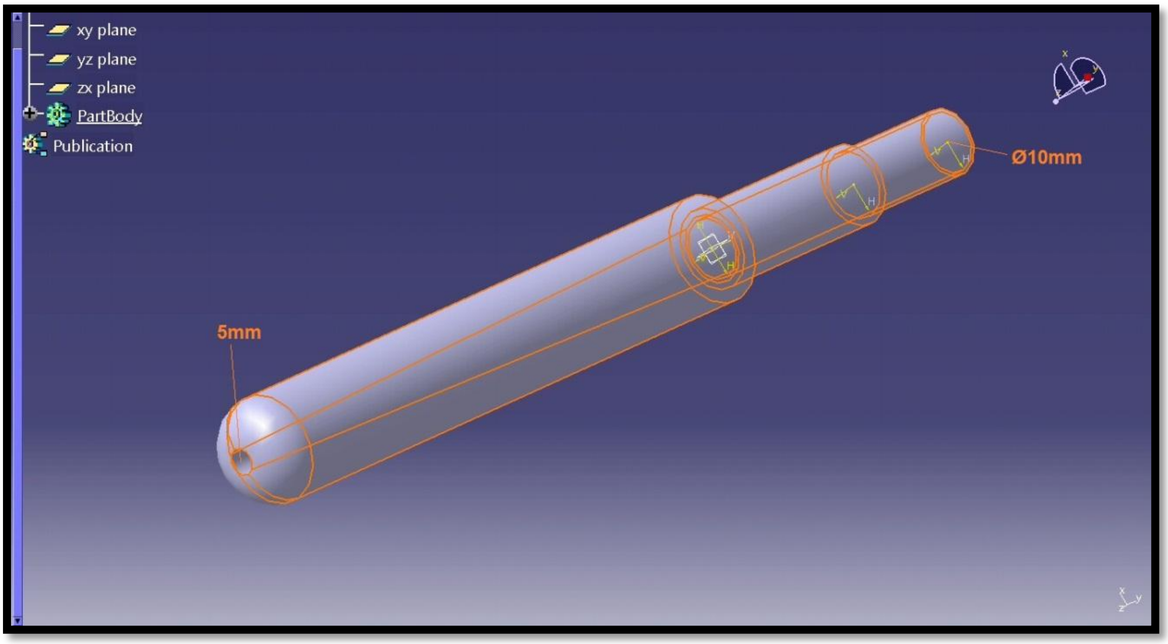


Figure 4.7: Overview of the nozzle dimension (units in mm)

This is a simple pressure atomization nozzle. The outlet diameter of the nozzle which is 5mm is smaller than that of the inlet nozzle (10mm). From inlet, the diameter is reduced gradually until to 5mm at the outlet. This is to increase the pressure of the fluid going through the nozzle which will be converted into momentum to increase the fluid velocity. The high velocity fluid is discharged from the outlet and drag with the surrounding air will create a dispersion, or atomization of fluid.

This simple pressure nozzle will be used as a benchmark to study the effect of holes configuration of the nozzle to the atomization of fluid.

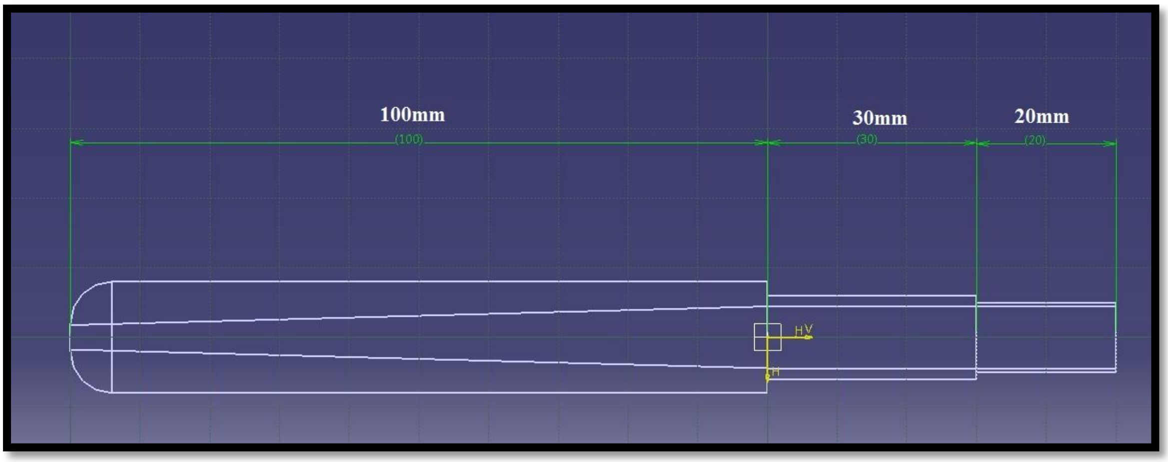


Figure 4.8: Side view of the nozzle dimension (units in mm)

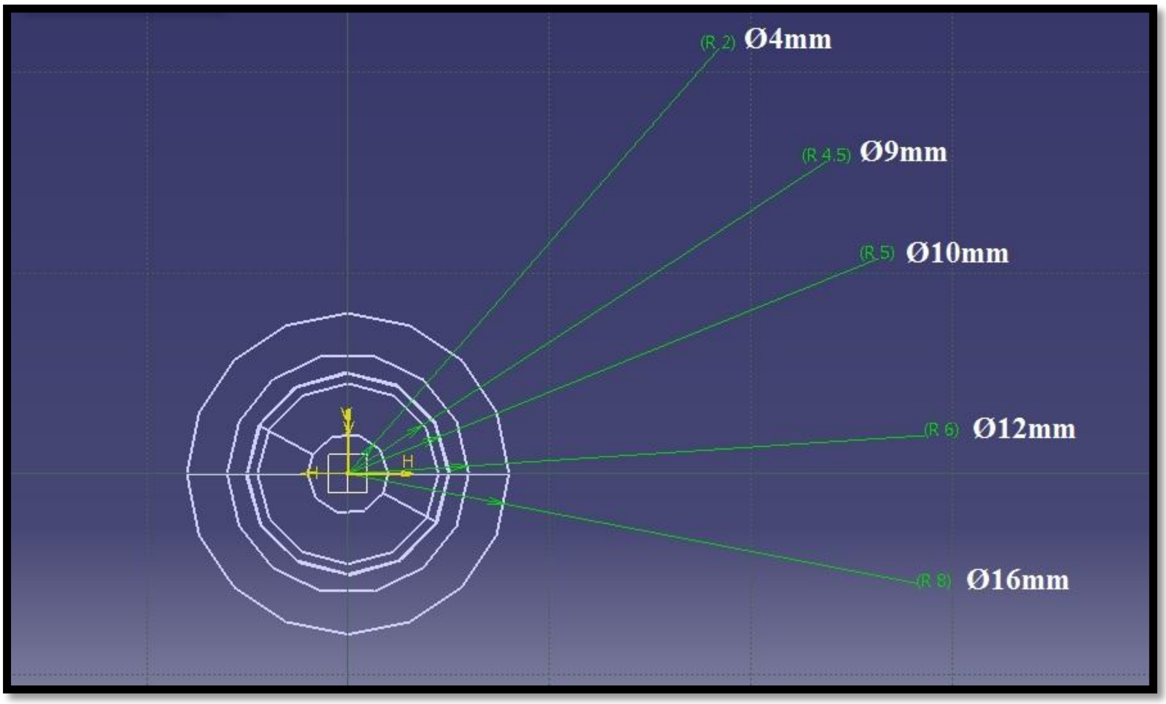


Figure 4.9: Back view of the nozzle dimension (units in mm)

The same dimensions are used for the model in FLUENT 6.3 for simulation. The dimension is for the fabrication of nozzle to be used for experiment purposes.

4.4 Simulation Setup

Detailed modeling of the nozzle was created using modeling software CATIA.

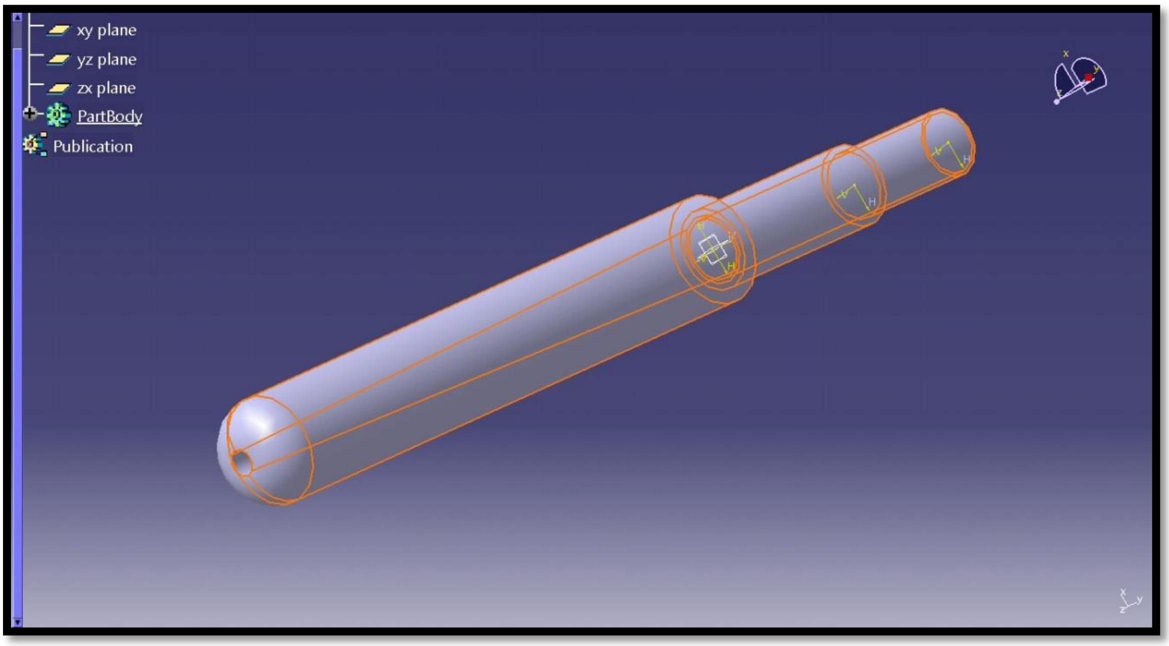


Figure 4.10: 3D view of the nozzle

The nozzle model in Figure 4.10 is ready for simulation. Before a simulation could be performed, the nozzle must undergo a meshing process. The meshing of the nozzle is conducted using the software ANSYS for Fluid Dynamic (FLUENT 6.3). The nozzle model is converted to a 2D model as shown in Figure 4.11. Meshing is then performed on the nozzle model prior to simulation.

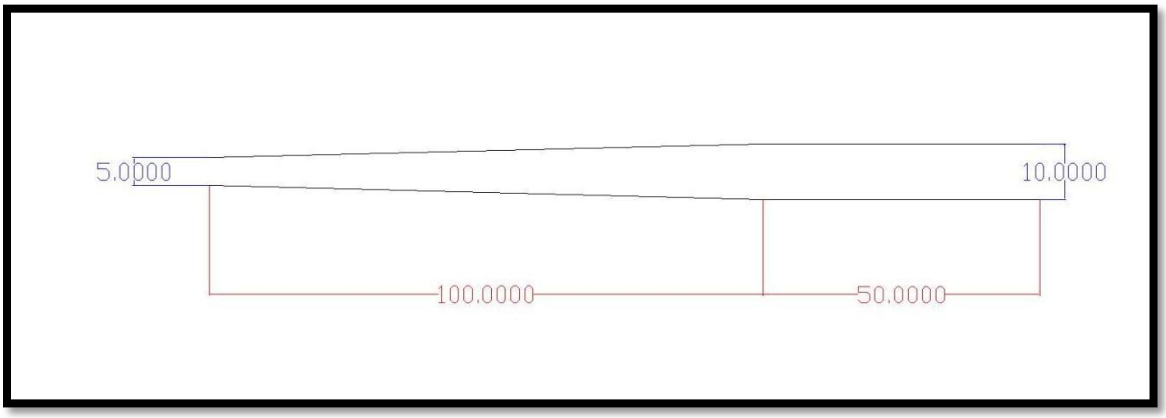


Figure 4.11: 2D Cross section of the nozzle for 2D meshing. (Units in mm)

4.4.1 Meshing

Meshing is an important process before a simulation can be done. Meshing is required for the calculations to be done by the computer. A mesh runs through the surface and calculations are solved for each quadrant.

Mesh is applied to the 2D model of the nozzle using GAMBIT modeling software before it is imported to FLUENT 6.3 for simulations.

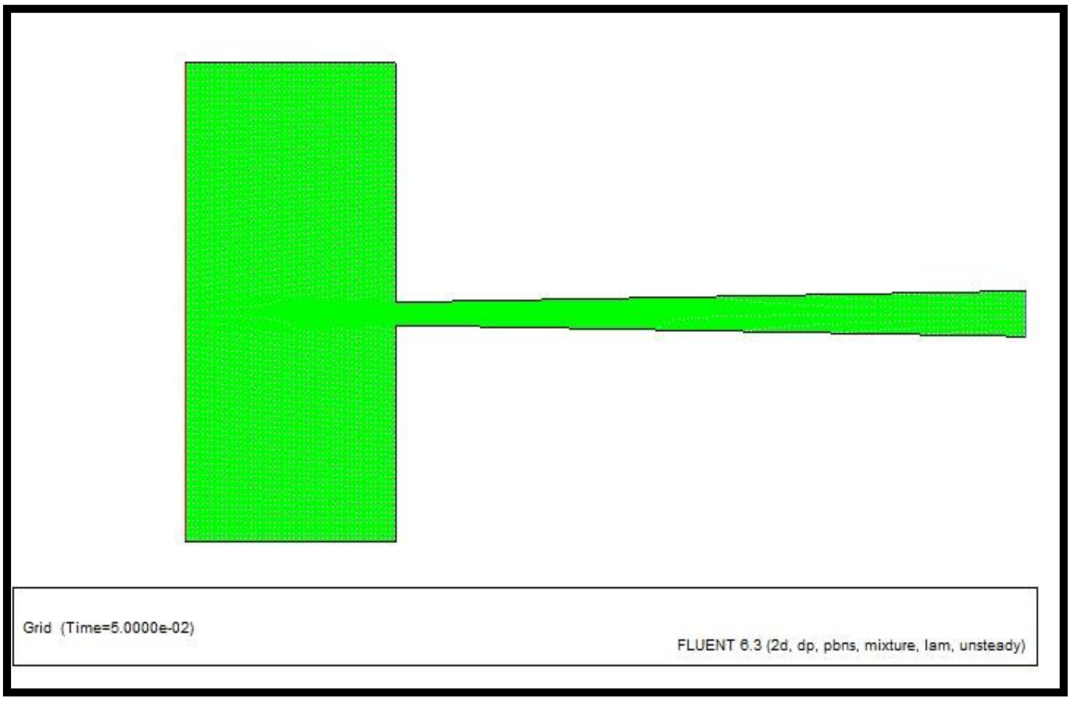


Figure 4.12: Mesh grid on the model.

Once the mesh is applied in GAMBIT, the mesh grid appears as green region as shown in the Figure 4.12 when viewed in FLUENT 6.3. The grid consists of 28000 volume cells constructed to solve the simulation numerically. For this simulation, quadrilateral mesh type is applied and the mesh unit is set to be 0.003. After the mesh is applied, the model is imported into FLUENT 6.3 for simulation.

4.4.2 Mixture Model

In order to observe the drag between air and liquid of atomization, a mixture model for the simulation is used. A mixture model is one of the multiphase models of simulations. A multiphase model is required because there is a mixture of liquid and air at some point in the simulation. In this case, the two phases are air and water or poultry waste.

A few changes need to be done to the 2D simulation model to cater to the multiphase model requirement. A box is constructed at the end of the nozzle outlet for observation of the atomization.

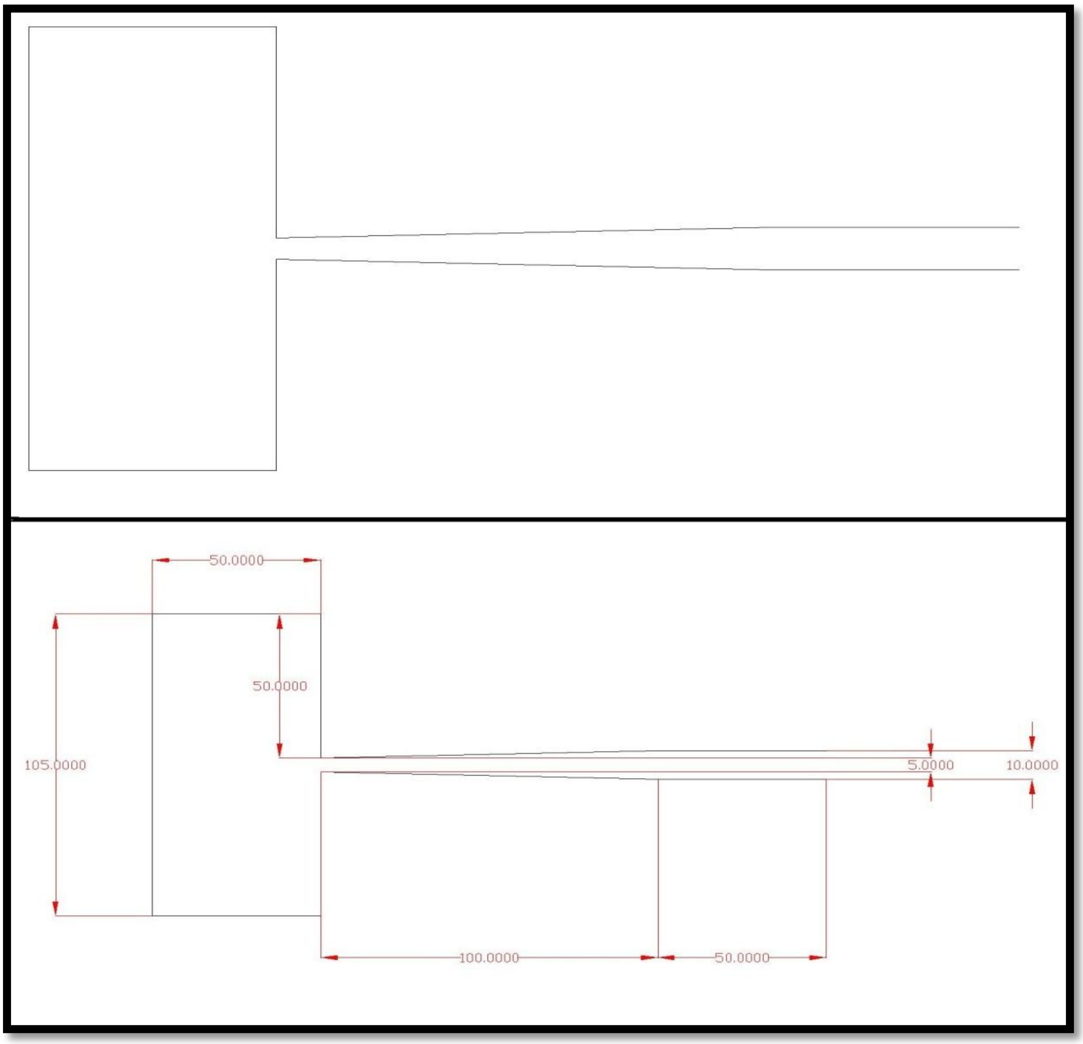


Figure 4.13: Configured 2D model for simulation (with dimension in **mm**)

The box contains stationary air. The liquid/slurry is discharged from the nozzle outlet and drag will occur between air and the liquid/slurry. In the simulation, the air is added to the box through patching VOF (volume of fluid). In other words, the air is simply mark into the box. A set of coordinates is required to set the air patch in place.

Figure 4.14: Air patch in the simulation

The red patch in the box represents the stationary air. Liquid/slurry from the nozzle will collide with the air once it is discharge from the outlet. Before the iteration, the patch of air needs to be adapted with the volume fraction of 1. This means that the red region is fully occupied by air.

4.4.3 Boundary Conditions

Boundary conditions are an important element in the simulation. In a simulation, only certain region is selected to run the simulation and there are special regions that borders with the environment. These borders need to have specific parameters and conditions for the simulation to run. Different parameters in the border will produce different simulation result.

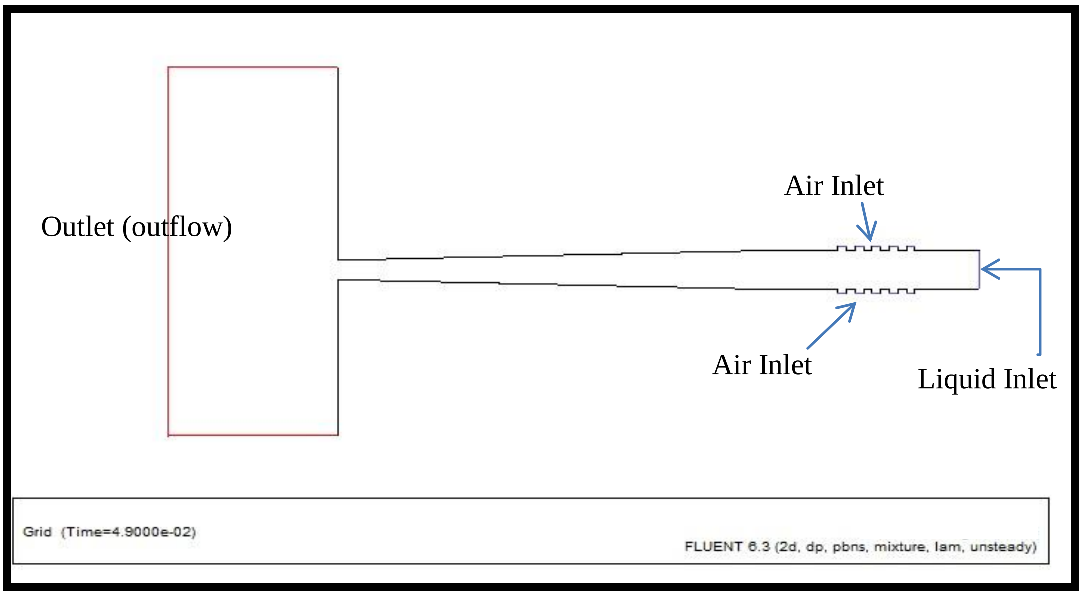


Figure 4.15: Simulation boundaries

Table 6 shows the pump specifications that will pump the liquid through the nozzle. The pump model is OGAWA 5.5HP gasoline engine with 2” water pump.

Table 4.0: Pump specifications

Model	**OK50E**
Power	5.5HP
Total Head	24m
Max Capacity	500 L/min
Max Suction	8m
Fuel Capacity	3.6 Liter

The pump has maximum capacity of 500 liter/min. In this simulation, it is assume that the pump work at its best. Thus, the maximum capacity of the pump is converted into velocity of the liquid measured in meter per second (m/s) and the liquid will be pumped into the nozzle.

Pump maximum capacity, 500 Liter/min

Converting it into cubic meter per second,

= 0.00833 m^3/s (volume flow rate)

Using the formula, $Q = VA$

$$Cross\ sectional\ area\ of\ pipe\ x\ velocity = volume\ flow\ rate$$

Inlet diameter of nozzle = 10mm = 0.01m

Thus, Cross Sectional Area = (π) (0.01) (0.01) = 0.000314 m^2

$$(0.000314m^2)Vm/s = 0.008333m^3/s$$

Velocity = 26.52 m/s

The value above is the boundary condition for the liquid inlet which is the velocity of the liquid flow into the nozzle. The velocity of air for this boundary is set to be V=0m/s because there is no air coming into this inlet.

The outlet boundary condition for the nozzle simulation model is set to the environment air pressure which 1 atm. The air velocity is set to be 0.01m/s at the air inlet when there is air coming in from the inlet.

Operating condition for the simulation is set to include gravity. The gravity with the magnitude of -9.81m/s is set to clarify that there is gravity acting throughout the fluid flowing through the nozzle.

4.5 Results and Analysis

Water properties:

Density	998.2 kg/m^3
Viscosity	0.001003 kg/m-s

Poultry waste properties:

Density	800.0 kg/m^3
Viscosity	10.0 kg/m-s

The value for properties of poultry waste and water is obtained from the experiment.

- **Simulation result for simple, no-hole nozzle configuration:**

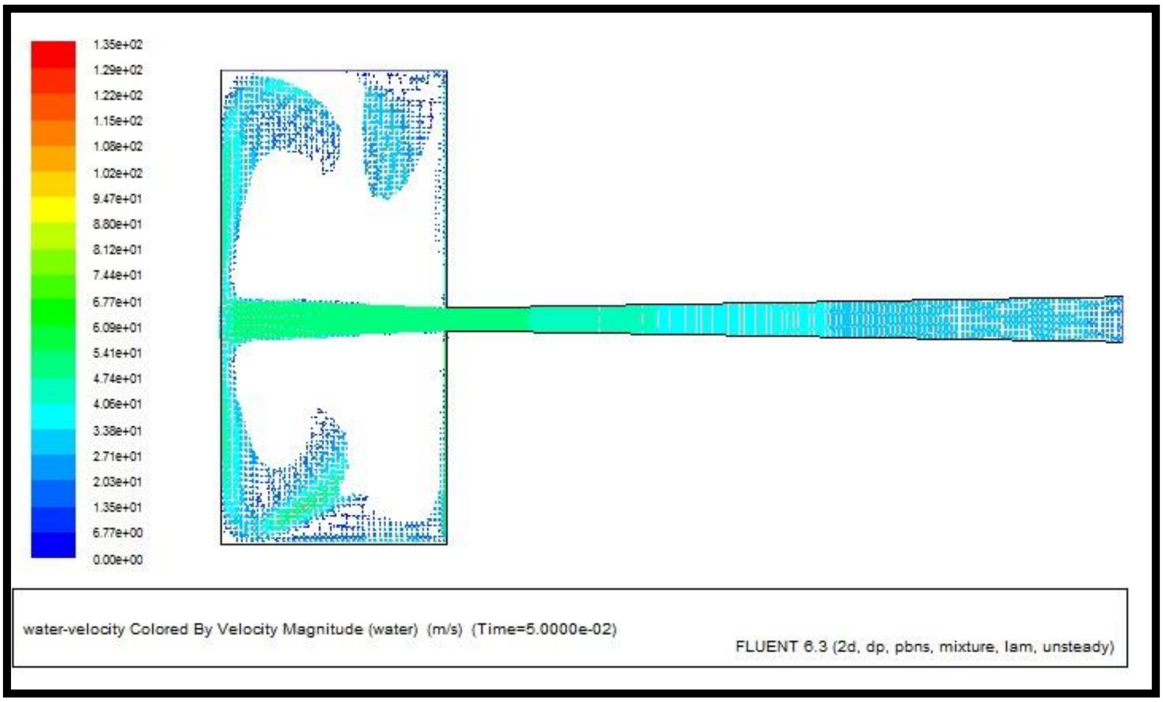


Figure 4.16: Velocity vector magnitude for water

Figure 4.16 shows the simulation result of water velocity magnitude after the water is pumped through the nozzle. The dispersion of water vector can be seen at the nozzle outlet.

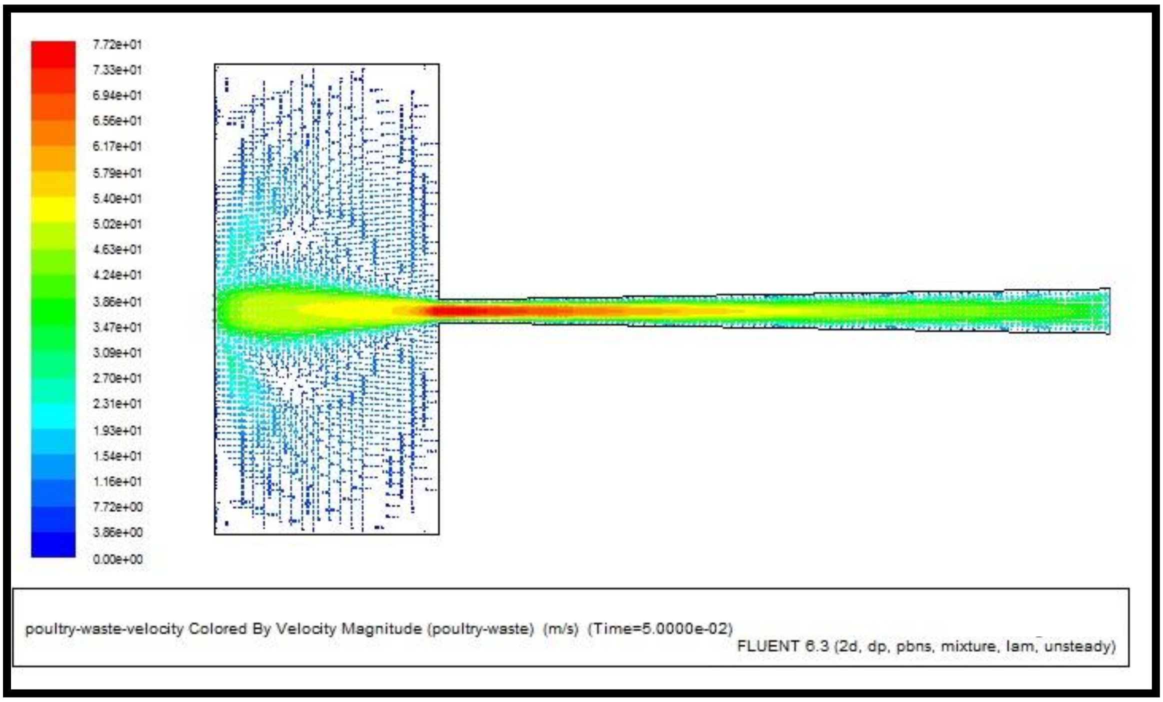


Figure 4.17: Velocity vector magnitude for poultry waste

Figure 4.17 shows the simulation result for poultry waste. The velocity vector dispersion can be seen at the nozzle outlet as the poultry waste is pumped through the nozzle.

From the two figures above, the dispersion of poultry waste is much more apparent than water. The dispersion of water is more of a jet blast straight out of the outlet. Meanwhile, for the poultry waste, the velocity is greater at the nozzle outlet and as it reaches the outlet of the nozzle, velocity decreases and dispersion occurs.

Poultry waste produces much more dispersion due to the fact that poultry waste has much higher viscosity as compare to water. The simulation proves the general rule “higher viscosity, larger dispersion”. From the result, it was found that simple pressure nozzle is a decent atomizer for poultry waste and further nozzle configurations can be apply to see the effect on the dispersion of the poultry waste.

- **Simulation result for four-holes nozzle configuration:**

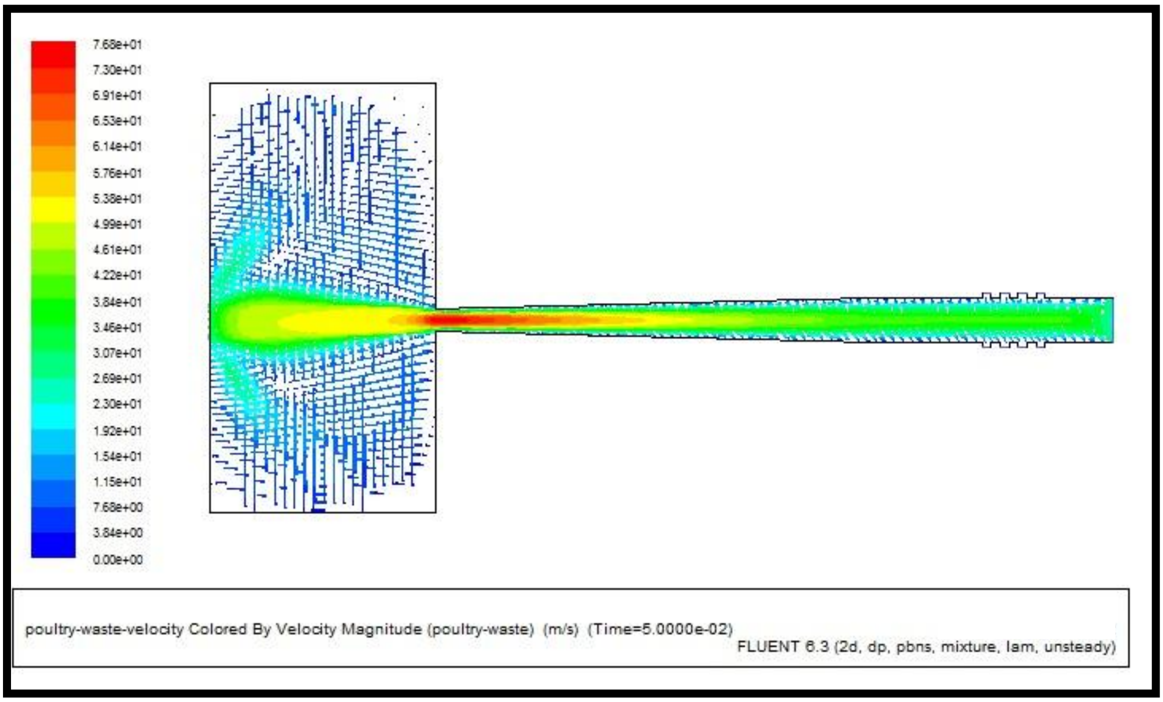


Figure 4.18: Velocity vector magnitude for poultry waste for four-hole configuration

Figure 4.18 shows the simulation result of velocity magnitude vector for nozzle configuration with four holes. As the figure suggests, the overall velocity of the poultry waste in the nozzle has not change. The dispersion can be observed a bit more apparent and wider. This may be caused by the air from air inlets mixing together with the poultry waste. The air mix inside the poultry waste provide a better dispersion when compare with the no hole nozzle configuration previously.

The dispersion can be observed by the blue vector contour in Figure 7.8. The blue contour indicate the velocity of the poultry waste is lower compare to the velocity of the poultry waste in the middle of the dispersion, which is yellow in color. This suggest that the drag of the poultry waste and the surrounding air occurs, causing the poultry waste velocity to decrease and ultimately, disperse. The same velocity contour can be observed on other simulation results for other configurations (refer Figure 4.19 and Figure 4.20 as well as Figures A1 to Figure A16 in the Appendix A).

- **Simulation result for three-holes nozzle configuration**

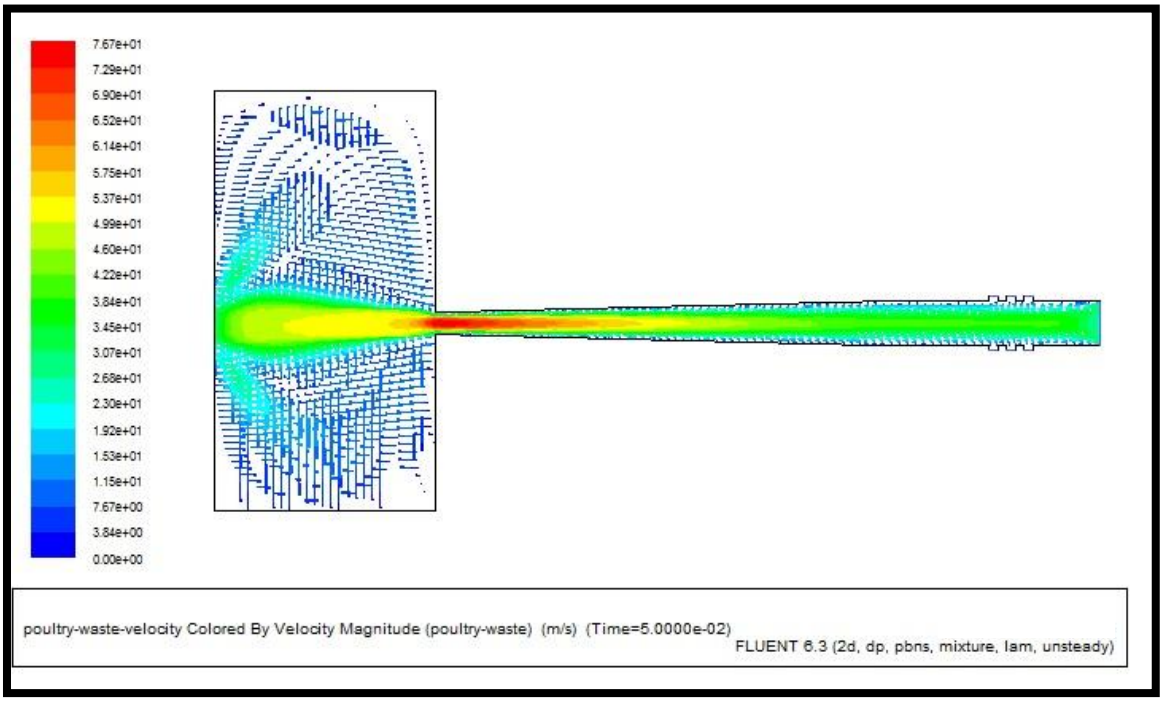


Figure 4.19: Velocity vector magnitude for poultry waste for three-hole configuration

Figure 4.19 shows the velocity magnitude vector result of the simulation for three-hole nozzle configuration. From the figure, the overall velocity has not change as compared to the no-hole configuration but the dispersion observed is a bit bigger. It is roughly observed from the simulation result that the angle of the dispersion is wider. This could suggest that the velocity of the poultry waste at the nozzle outlet is great enough to cause a drag with the air to produce the wide dispersion. The air from the air inlet mix with the poultry waste has given the poultry waste a change in momentum velocity for the dispersion.

- **Simulation result for one-hole nozzle configuration**

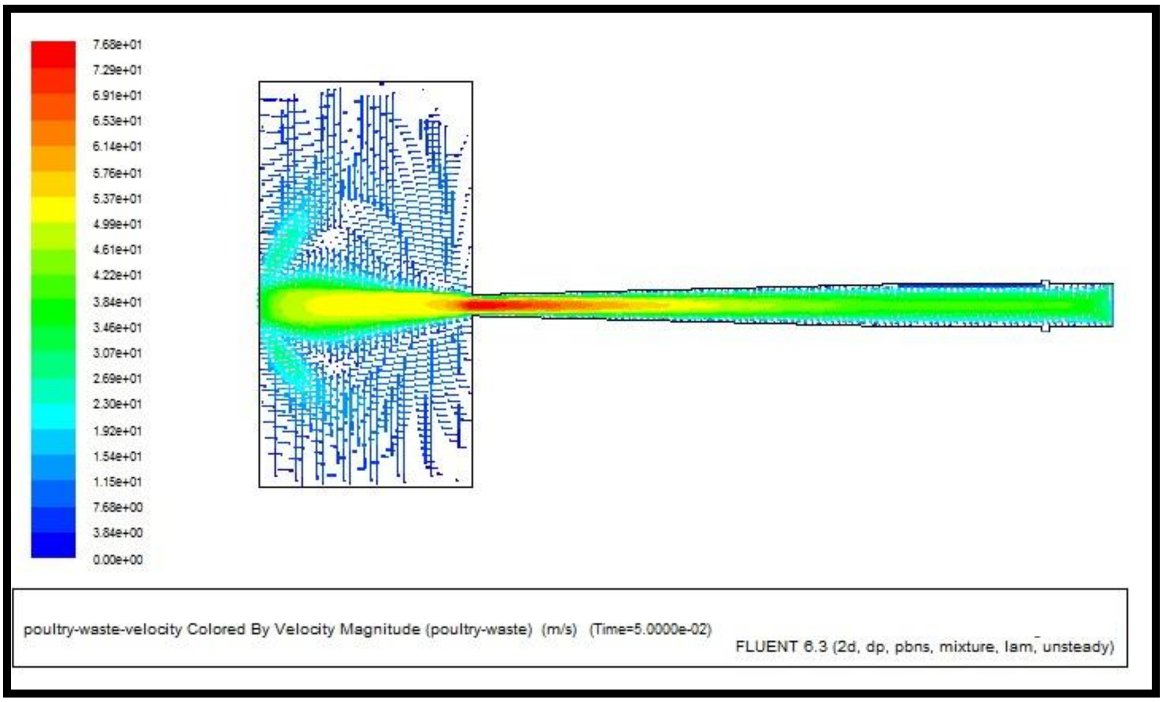


Figure 4.20: Velocity vector magnitude for poultry waste for one-hole configuration

Figure 4.20 shows simulation result of velocity vector magnitude for one-hole configuration nozzle. The figure shows dispersion but a little bit less spread out as compare to three-hole and four-hole configuration nozzle. The velocity at the nozzle outlet is still great enough to provide for the dispersion to occur, however, the amount of air coming from the air inlet is insufficient to produce wider dispersion of the poultry waste. Based on the velocity vector, one-hole nozzle configuration has longer high velocity stream poultry waste (colored yellow in the contour) compared to the other two configurations.

Finally, the effect of the number of air inlets on dispersion is too little to be observed, but upon meticulous observation, the difference can be seen. Based on the simulation results, the more air inlets available for air intake, the better and wider dispersion of the poultry waste produced. The configuration of adding air inlets to the nozzle is improving the dispersion of the poultry waste. The other results for the simulations can be referred to Appendix A.

4.5.1 Comparison to Experiment

An experiment almost similar to the simulation was performed. The experiment however focuses on the observation of the dispersion of poultry waste and the angle of dispersion.

Figure 4.21 shows the result of the experiment of the poultry waste dispersion using standard no-hole configuration pressure nozzle.

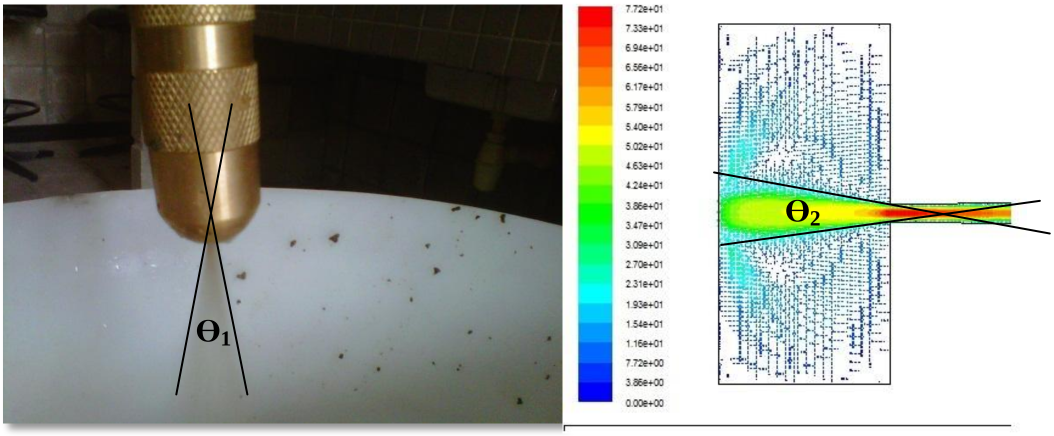


Figure 4.21: Atomization angle of poultry waste

The experiment was performed using the same pump specifications thus the result should be similar to the simulation. Figure 4.21 shows the atomization angle of the poultry waste for experiment and simulation of the no-hole nozzle configuration. After measurement, it was found that Θ_1 (experimental) is 21.0° and Θ_2 (simulation) is 19.2° for the no-hole nozzle configuration. Through observation and measurement, it was found that the angle of the dispersion is similar to the dispersion in the simulation for the no-hole configuration nozzle (refer to Figure 4.17).

Table 4.1: Comparison of simulation result with experiment data by Nadhir [1]

Material	**Level of Nozzle Opening**	**Spray Angle(°)**	**Simulation Angle(°)**	**Angle Difference(°)**	**Simulation(°) / Experiment(°)**	**Similarity %**
Poultry Processing Waste	None	21	19.2	1.8	19.2/21	91.43
	A	30	26	4	26/30	86.67
	B	33	31	2	31/33	93.94
	C	38	35	3	35/38	92.11
	D	43	40	3	40/43	93.02
	E	46	43	3	43/46	93.48
Average						**91.78**

Table 4.1 shows the full results of the experiment. The experiment uses pressure nozzle with five holes opening for air inlet, similar to the nozzle model in the simulations. Table 4.1 shows result of spray angle with increasing number of air holes opening. The letter indicate the number of opening use with A representing one hole opening and E referring to five holes opening. From the result, as the number of holes increases, the wider the dispersion.

The results of the experiment are in parity with the simulation as the simulation also shows an increase in the angle of dispersion with the increasing number of air inlets. However, there is no method to compare the velocity with the experiment, as the experiment is by observation only. Only the angle of the dispersion of the poultry waste can be seen as having similarity between experiment and simulation.

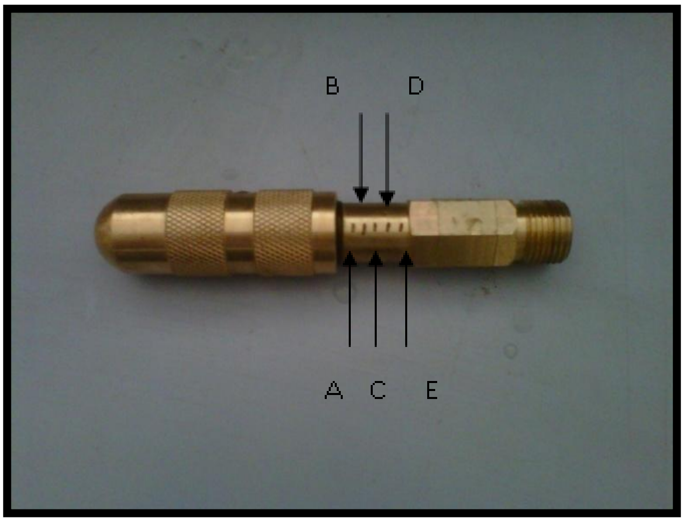


Figure 4.22: Level of nozzle opening.

Taking on the average percentage difference for spray angle of poultry waste dispersion from the simulation and experiment, it was found from calculation that the simulation results are almost similar to that of the experiment (refer to Table 4.1). The simulation accuracy, as compared to the experiment results, is around 92%. The simulation showed results almost similar to the experiment data.

In the nutshell, the experiment verifies the simulation to be around 92% accurate based on observation and measurement of the angle of poultry waste dispersion for the no-hole nozzle configuration. An experiment using the Laser Doppler Anemometry can be performed to further verify the simulation results on the aspect of velocity of the atomization particles.

4.6 Other Related Discussion

4.6.1 Other Configurations

The results of other configuration of the nozzle (two-hole and five-hole configuration) are not shown as the results are almost similar to the one-hole configuration and four-hole configuration respectively. It can be assumed that the effect is almost too little on the dispersion of the poultry waste. Yet, the result for both of the configuration is available in the Appendix A.

4.6.2 Air Inlet

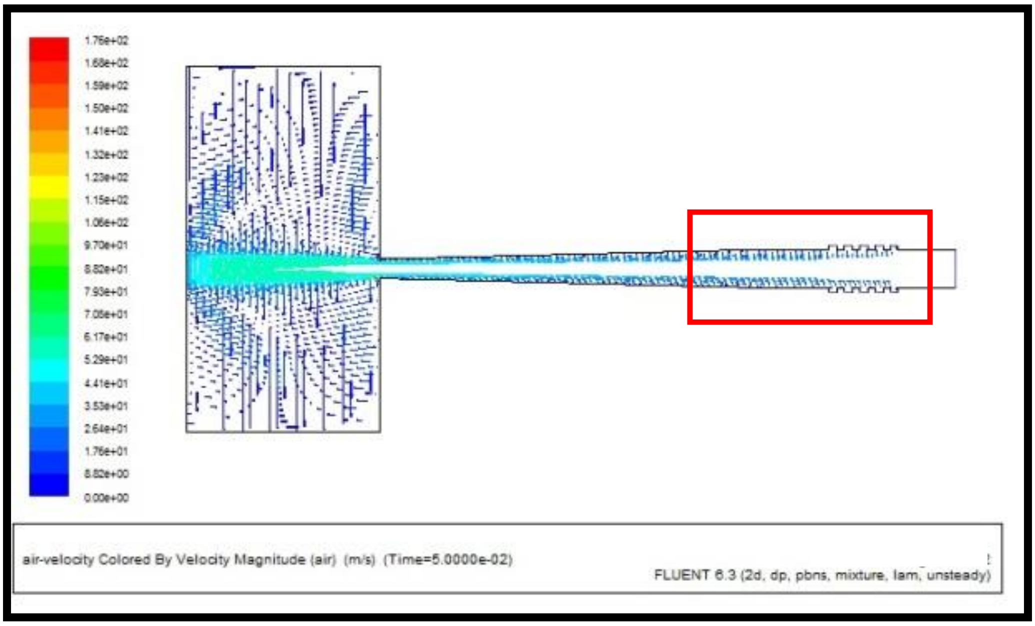


Figure 4.23: Air vector from the air inlets

Figure 4.23 shows the air velocity vector from the air inlet of the nozzle. This is to show the existence of air mix with the poultry waste in the configuration of the nozzle in the simulation. As observed from the simulation results previously, the air helps in the dispersion of the poultry waste. The air enters through the air inlet and affects the dispersion range of the poultry waste

Referring to Appendix B, the contour of poultry waste volume fraction, at the air inlet boundary for each nozzle configuration, there is blue contour. This indicates that the volume fraction of poultry waste at that boundary is 0. This is due to the boundary being occupied 100% by air. Furthermore, Appendix C shows the air velocity vector in the simulation.

Referring to Appendix C, the velocity vector of air shows there is air coming into the nozzle. Ultimately, this is to show the existence of air in the holes configuration nozzle.

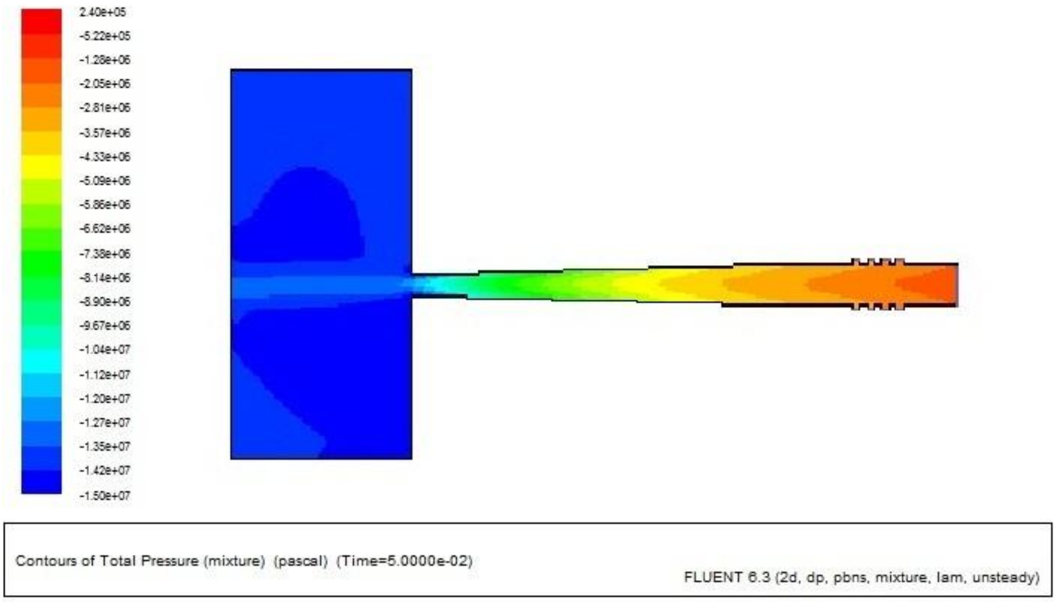


Figure 4.24: Total pressure of the poultry waste in the simulation

Figure 4.24 shows the total pressure of the poultry waste in the simulation. From the figure, the pressure of the poultry waste can be observed across the nozzle with a negative value. This indicates that the pressure inside the nozzle is less than the pressure outside the nozzle. According to Bernoulli’s principle, the pressure of the fluid decreases as the fluid velocity increases. Due to the outside pressure being greater than the pressure inside the nozzle, the air from the outside is pulled into the nozzle and mix with the poultry waste. This also explains why the poultry waste does not come out of the air inlet. Total pressure for other configurations can be found in Appendix A.

Celebrated Bernoulli equation states that:

$$p + \frac{1}{2}\rho V^2 + \gamma z = \text{Constant along streamline}$$

Where,

p = pressure V = velocity of fluid

ρ = fluid density γ = elevation

From the equation, for it to be constant along streamline, pressure and fluid velocity must balance each other. If pressure value goes up, the velocity value must go down to assume the constant value. In other words, the pressure value is inversely proportional to velocity. Thus, this explains why the pressure inside the nozzle is lower compare to the outside pressure, which is due to the fluid velocity inside the nozzle is higher.

4.6.3 Other Results of Simulation

The simulation also produced result on the other parameters such as static pressure, total pressure and the volume fraction of water/poultry waste. These results can be view in Appendix A.

4.6.4 Water and Poultry Waste Slurry

The simulation is to be tested both with water and poultry waste slurry. The first simulation will be run using the water property for the fluid in simulation as to set a benchmark. Then the poultry waste slurry properties will be used in the simulation. Both results will be compared.

The properties of both poultry waste slurry and water is different, thus the result returned will also be different. The slurry is more viscous than that of water. Therefore, it is expected that the droplets of the slurry after atomization will be bigger than water droplets.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The development of the drying-spraying system is vital as it allows the increase of energy recovery of poultry waste in its original form. This research will help in discovering new methods of recovering energy and possibly a new source of renewable energy. As the planet’s high dependent on fossil fuel which is depleting as time progresses, it is an absolute essential to discover new way of extracting energy from new, different resources. The extraction of energy from poultry waste might be one of the solutions.

In this research, the effective drying-spraying system will help increase the potential of poultry waste in providing energy. The nozzle plays an important role on the rate of energy recovery that can be recovered from a poultry waste, which in its essential form contain high moisture content. By developing effective nozzle configurations for the drying-spraying system, a new potential source of energy could be unlocked.

From the simulation results, a nozzle configuration as simple as a pressure nozzle with air holes is able to produce dispersion of the poultry waste to be used in the extraction of energy. The result shows that the more air inlets configuration, the more effective dispersion produced by the nozzle. The difference in the effect of dispersion for all air inlets nozzle configuration is little to be observed, but the effect is still noticeable if observed carefully. For this research, all of the objectives are met. Simulation is successfully run to analyze the atomization of the poultry waste. The more air inlets added to the nozzle improves the dispersion. A different type of nozzle could be used to observe the atomization that it will produce.

Furthermore, the poultry waste shows more dispersion as compare to water. This is due to the fact that poultry waste is more viscous.

5.2 Recommendation

The objective of this research is to find an effective nozzle of drying-spraying system to optimize the combustion of poultry waste. Utilizing a different nozzle design or configuration, even possibly a different type of nozzle, could help find a better atomization of the slurry poultry waste and thus a better drying-spraying system. This will directly enhance the combustion of the poultry waste inside the Fluidized Bed Combustor.

One of the likely nozzle types that can be used to further improve the atomization is the air-spray atomizer type nozzle. For this type of nozzle, the liquid stream is disrupted by high speed air at the nozzle. This will cause liquid to disperse. The energy from the air pressure will assist in the atomization of the liquid [3].

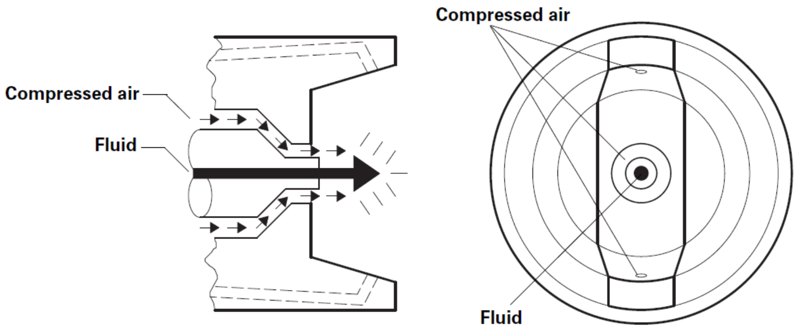


Figure 5.0: An example of air-spray atomizer [3]

Other nozzle configuration that can be simulated to study the effect on dispersion is the slanted air inlets. This is to experiment effect of the way the air enters the nozzle at an angle has on the dispersion of the poultry waste. Figure 5.1 and 5.2 show the nozzle model with slanted air inlets

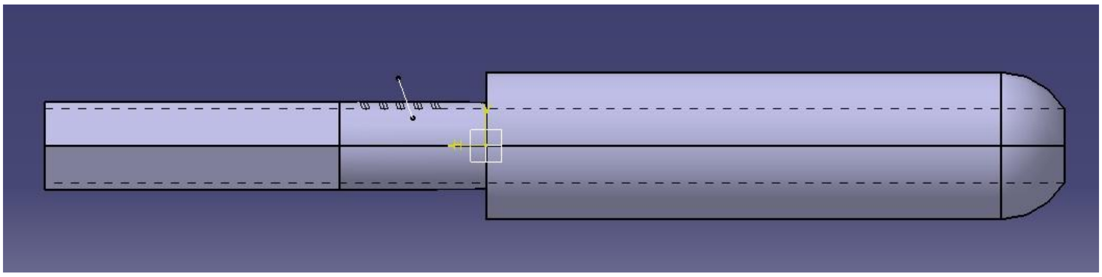


Figure 5.1: Slanted air inlets nozzle configuration 1

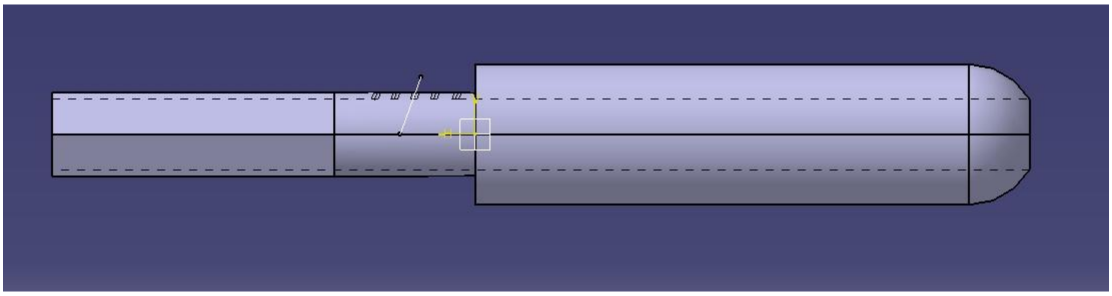


Figure 5.2: Slanted air inlets nozzle configuration 2

This type of nozzle configuration could provide a new or even better dispersion of the poultry waste. The slanted inlets will effect the air velocity vector entering the nozzle and it has on the dispersion of poultry waste can be study and analyze.

An experiment using the Laser Doppler Anemometer can be conduct to verify this simulation. The laser beam will be able to track the velocities of the droplets from the atomization and the data collected can be compared to this simulation.

REFERENCE

[1] Muhammad Nadhir Othman Hasbi and Mohd Shiraz Aris, "Development of an Effective Spraying Technique for Energy Recovery from Poultry Processing Waste", Final Year Project II Technical Paper, *Universiti Teknologi PETRONAS,* 2011.

[2] G. Petrecca, R. Preto, "The Use of Poultry Manure to Produce Clean Electric Power", *Faculty of Engineering University of Pavia*, 2010.

[3] GRACO INC. (1995). *Atomization: Learning Module.* Concept and Theory Training. (Authors: Tony Brajdich, Michelle Hagman, Bob Lind, Glen Muir, Al Orr)

[4] Michael L. Murphy, "Fluidized Bed Technology: Solution to Animal Waste Disposal", *Seventeenth Annual International Pittsburgh Coal Conference,* 2000.

[5] Liuqing Xu, Yuming Xing, "Study for Spray Characteristic of an Internal-mixing Air Atomizing Nozzle", *School of Aeronautical Science and Engineering Beihang University,* 2011.

[6] 3 January 2012, <http://www.cfd-online.com/Wiki/Meshing>.
CFD Online. 3January 2012 <http://www.cfd-online.com/Wiki>

[7] Hossam S. Aly, Tholudin M. Lazim, Yehya A. Eldainy, Mohammad Nazri Mohd Jaafar, "Mathematical Modeling of Droplet Atomization Using the Population Balance Equation", *Department of Aeronautical Engineering, Faculty of Mechanical Engineering University Teknologi Malaysia,* 2009.

APPENDIX A: FIGURES OF SIMULATION RESULTS

NO HOLE CONFIGURATION (WATER):

Figure A1

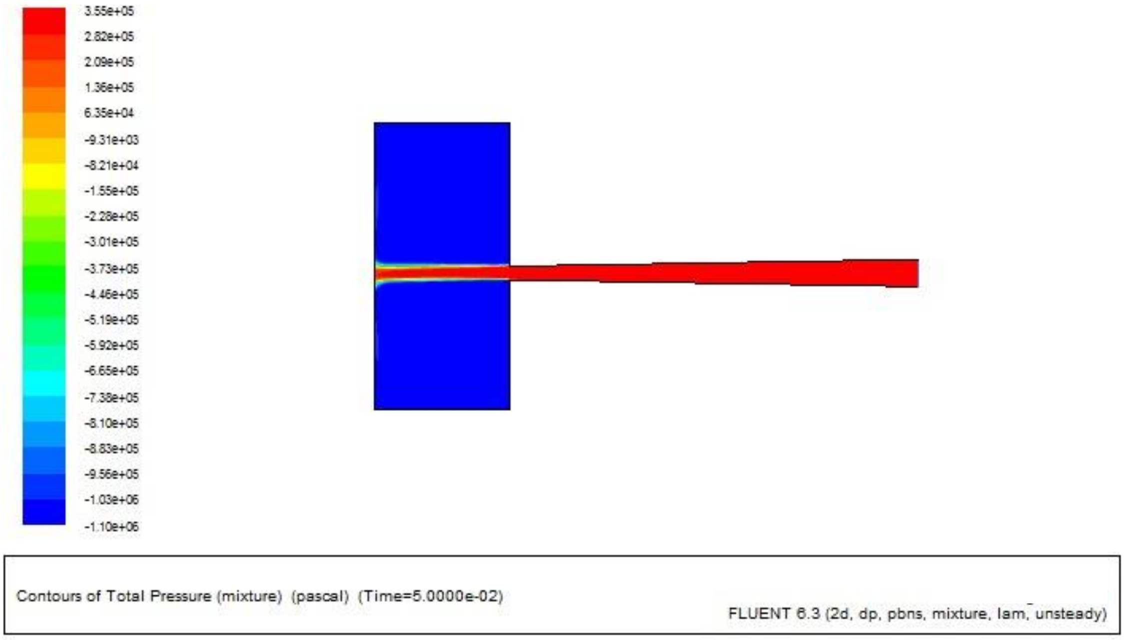


Figure A2

NO HOLE CONFIGURATION (POULRTY WASTE):

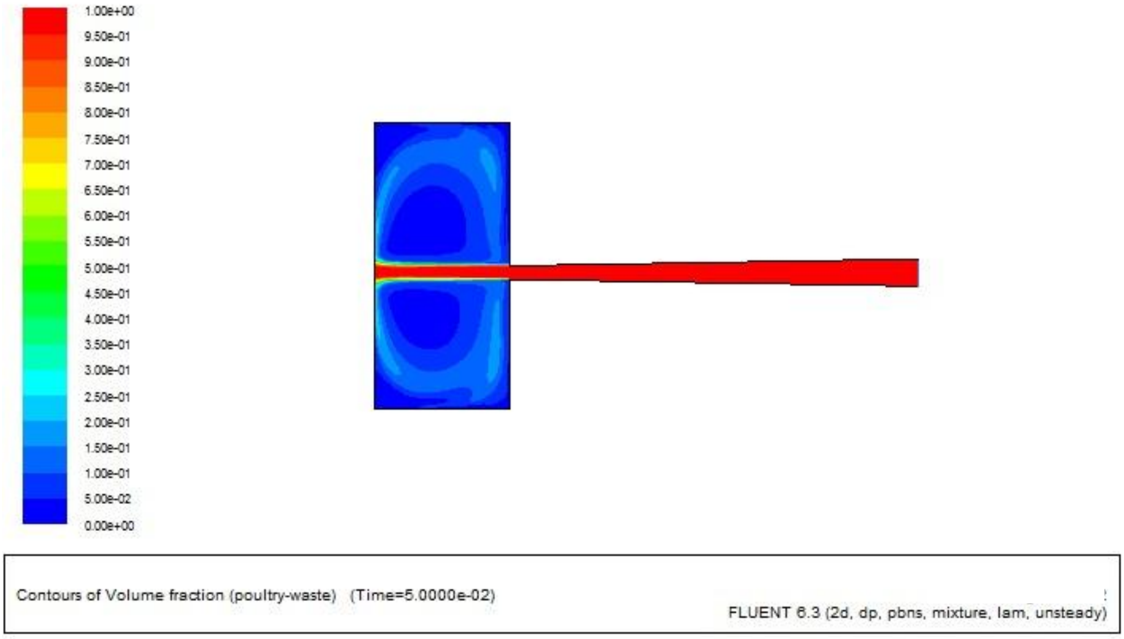


Figure A3

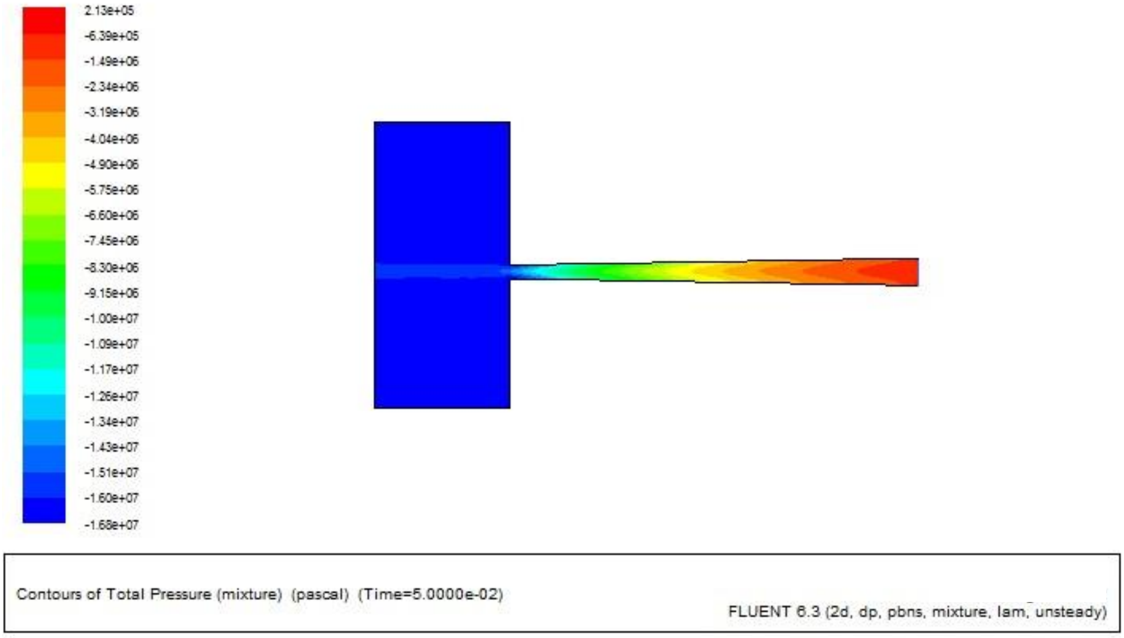


Figure A4

ONE-HOLE CONFIGURATION NOZZLE (POULTRY WASTE):

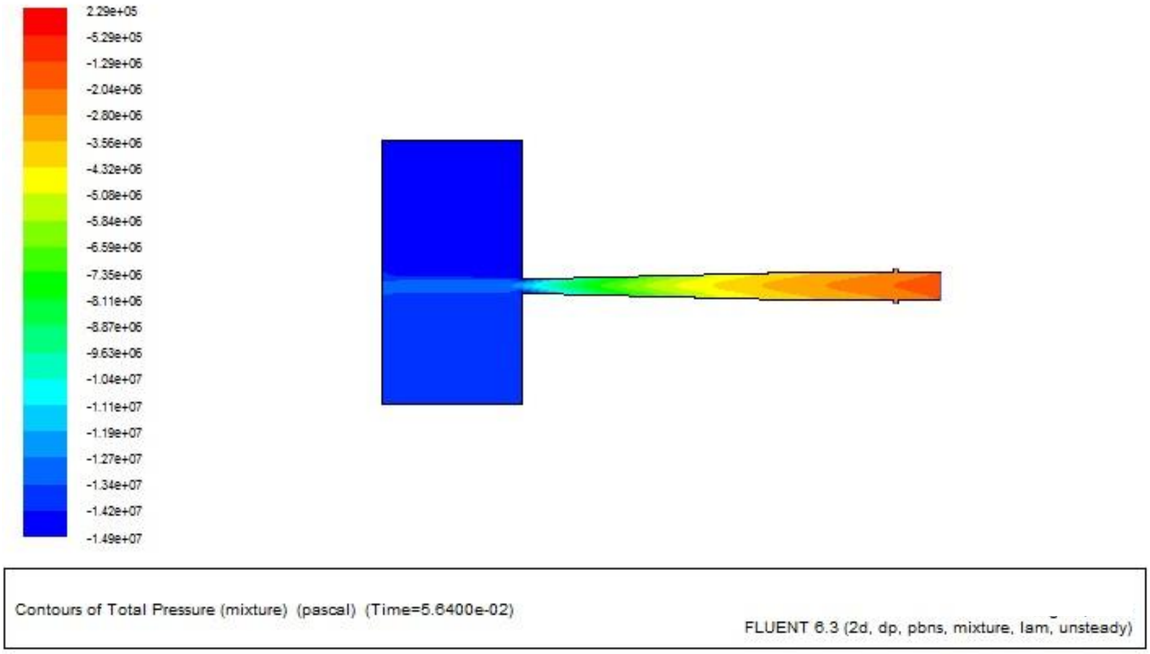


Figure A5

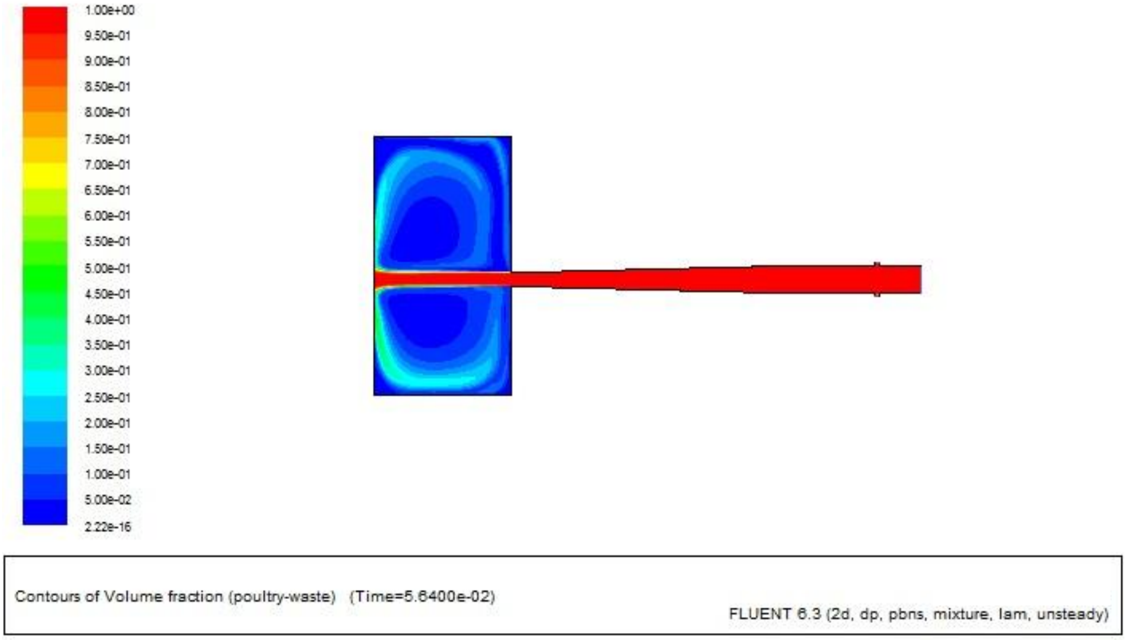


Figure A6

TWO-HOLE CONFIGURATION NOZZLE (POULTRY WASTE):

Figure A7

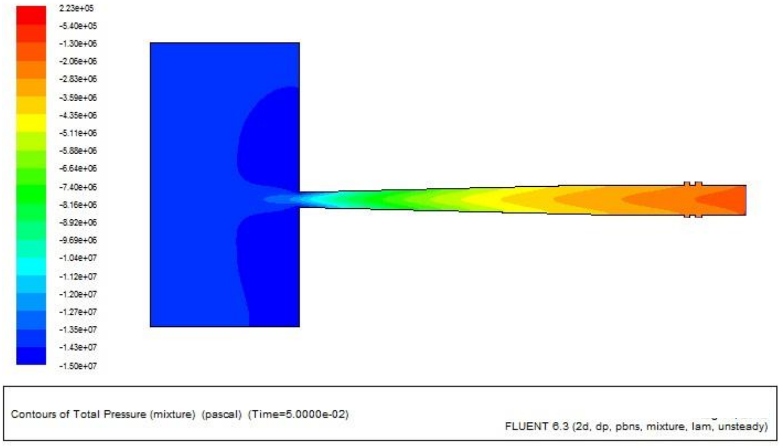


Figure A8

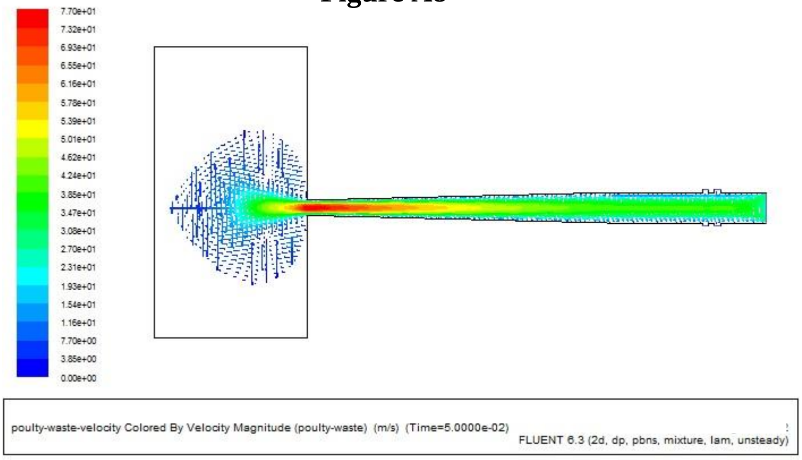


Figure A9

THREE-HOLE CONFIGURATION NOZZLE (POULTRY WASTE):

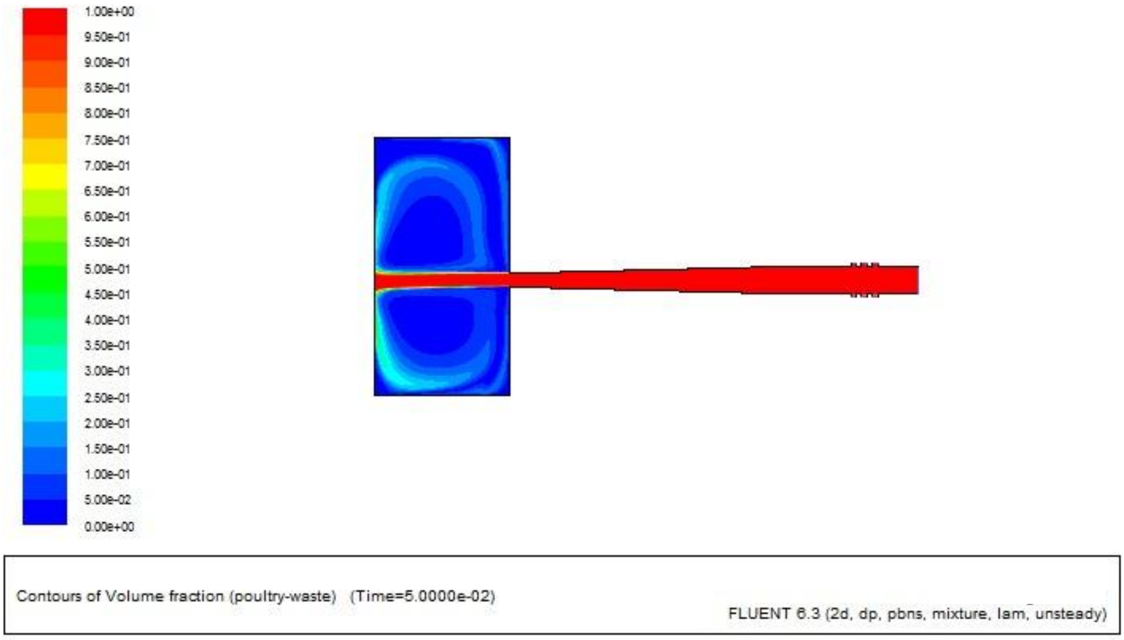


Figure A10

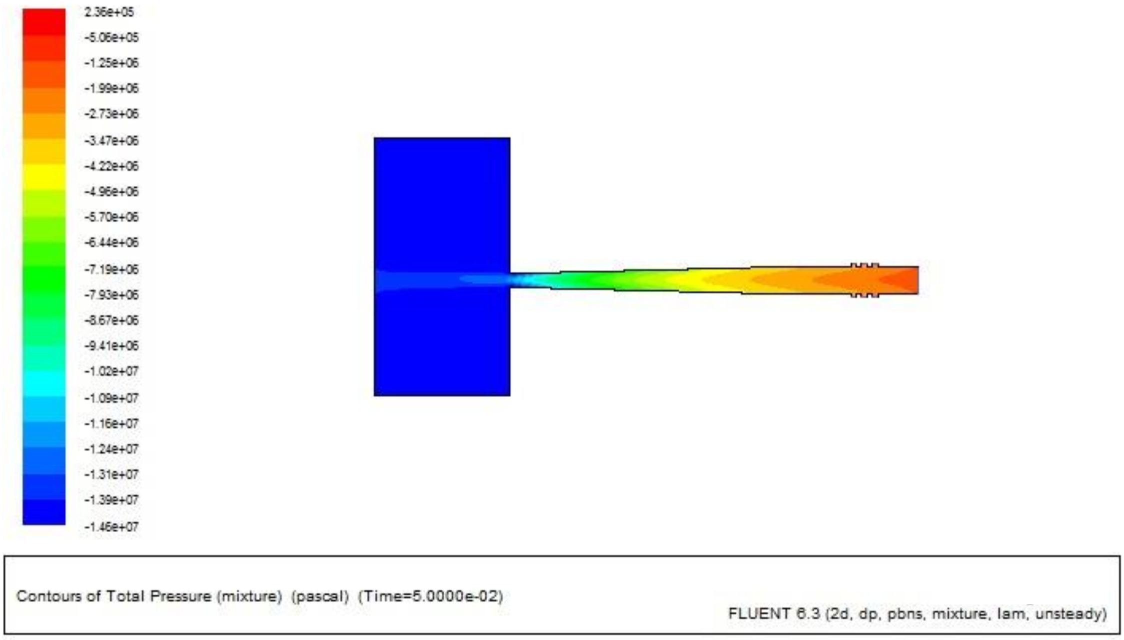


Figure A11

FOUR-HOLE CONFIGURATION NOZZLE (POULTRY WASTE):

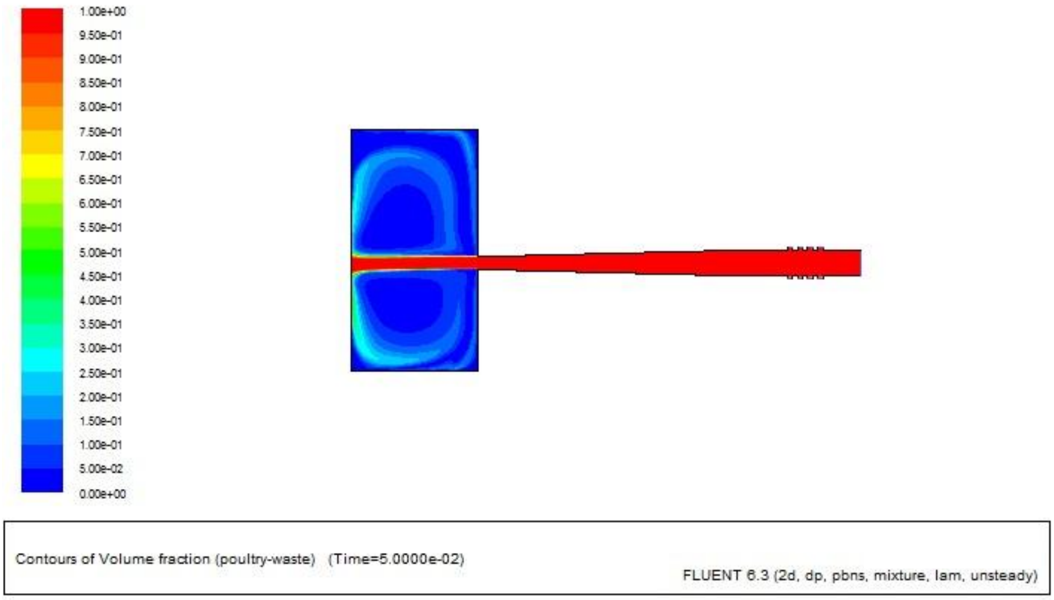


Figure A12

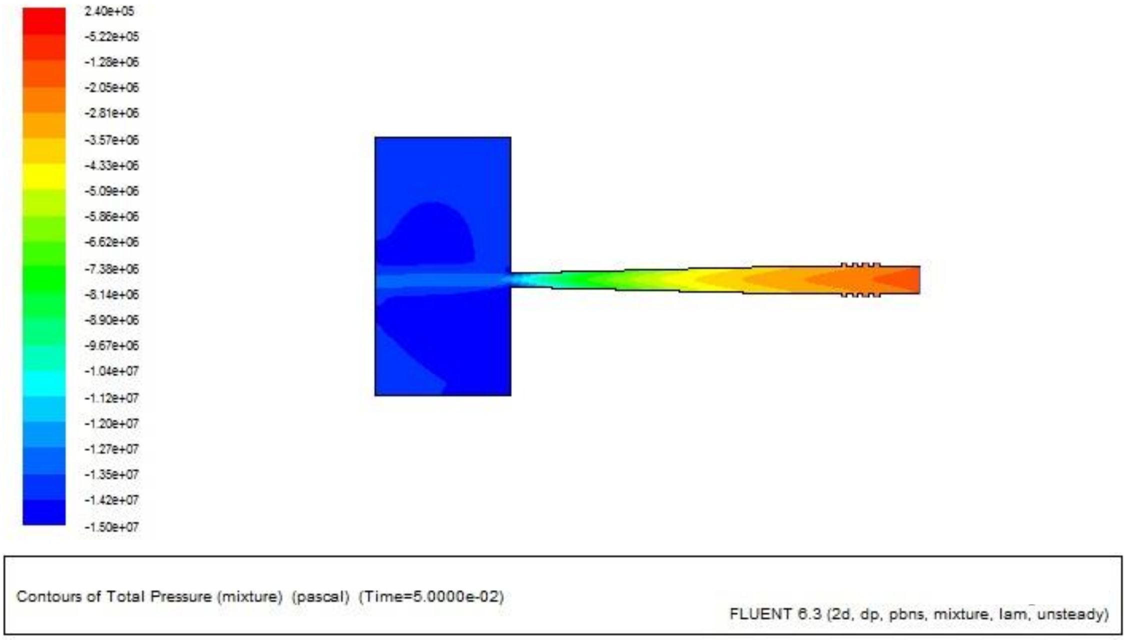


Figure A13

FIVE-HOLE CONFIGURATION NOZZLE (POULTRY WASTE):

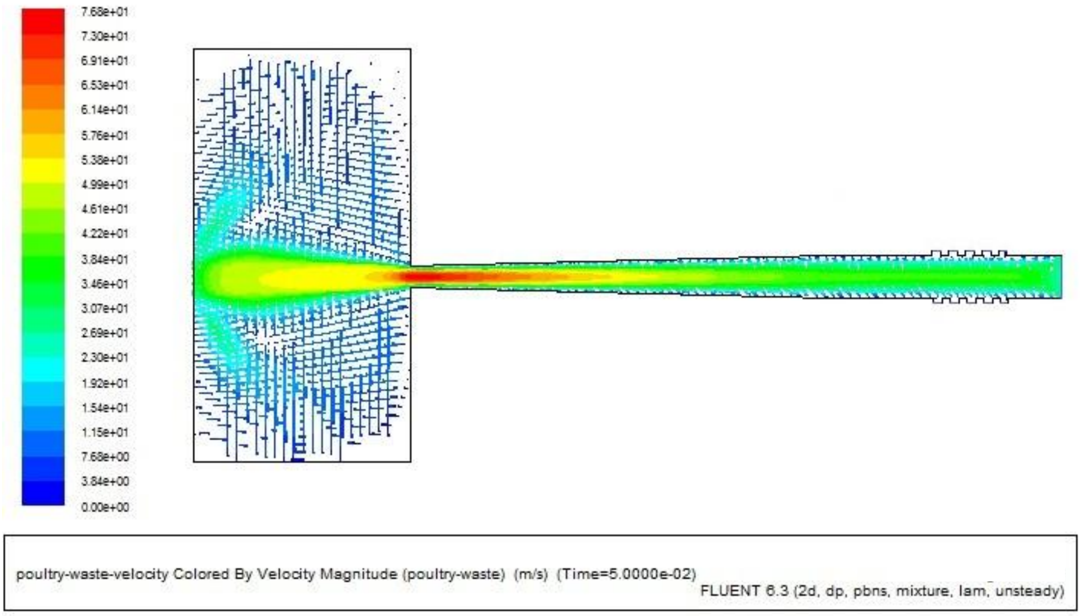


Figure A14

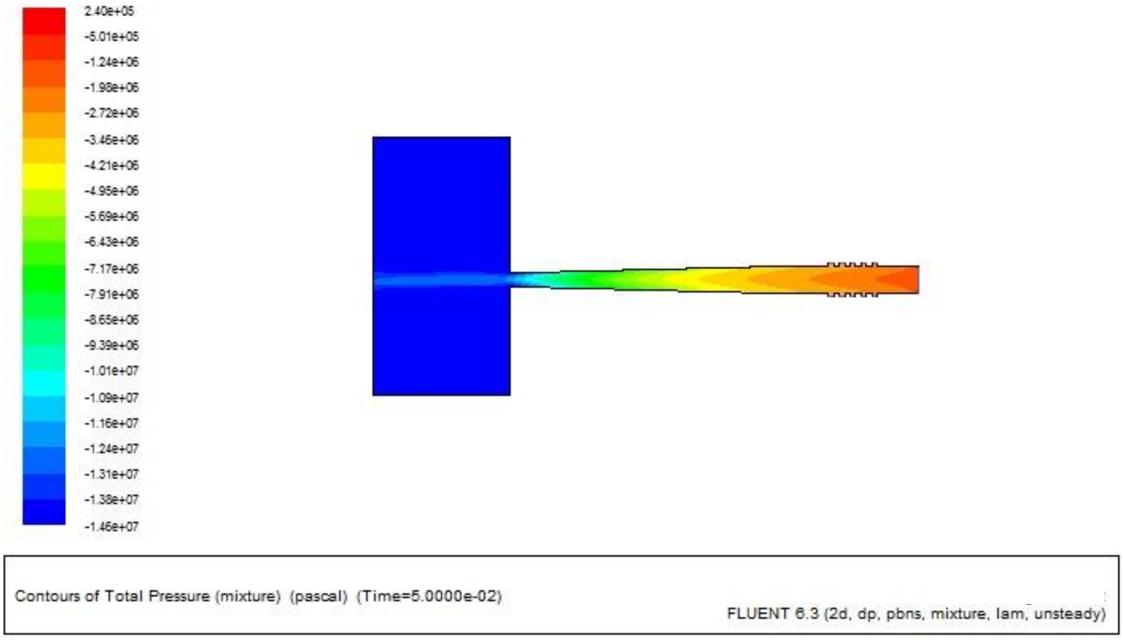


Figure A15

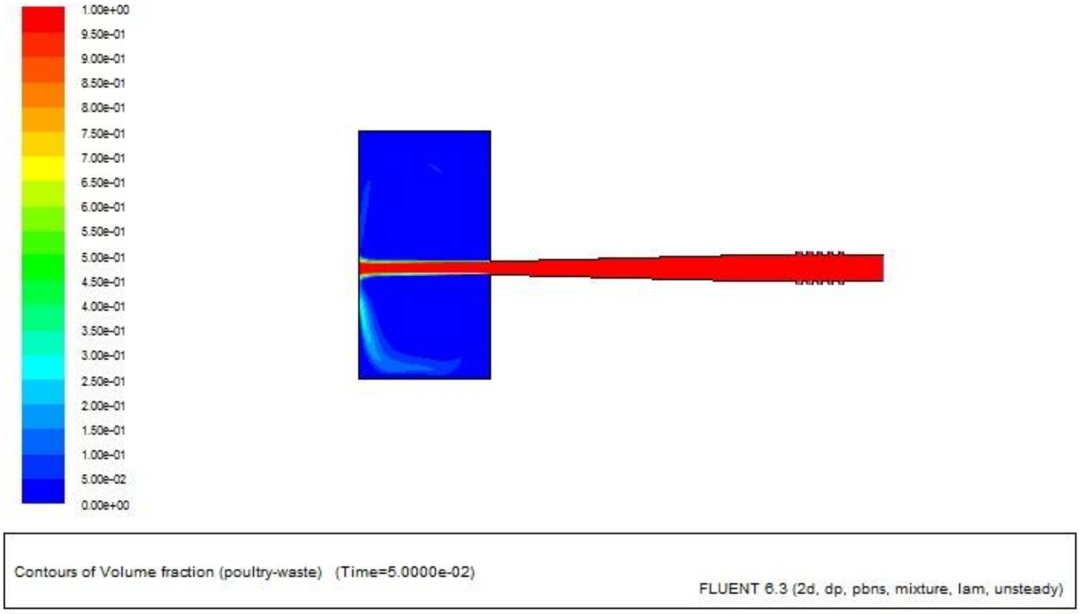

1.00e+00
9.50e-01
9.00e-01
8.50e-01
8.00e-01
7.50e-01
7.00e-01
6.50e-01
6.00e-01
5.50e-01
5.00e-01
4.50e-01
4.00e-01
3.50e-01
3.00e-01
2.50e-01
2.00e-01
1.50e-01
1.00e-01
5.00e-02
0.00e+00
Contours of Volume fraction (poultry-waste) (Time=5.0000e-02)
FLUENT 6.3 (2d, dp, pbns, mixture, lam, unsteady)

Figure A16

APPENDIX B: CLOSE UP CONTOUR OF THE VOLUME FRACTION OF POULTRY WASTE IN THE NOZZLE

Reference

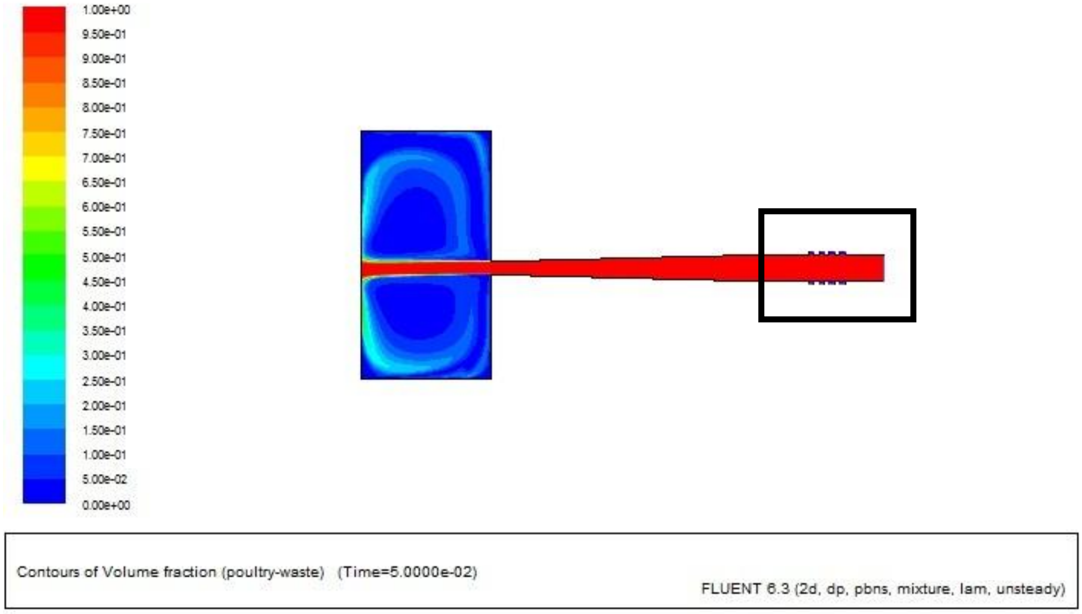


Figure B1

One hole:

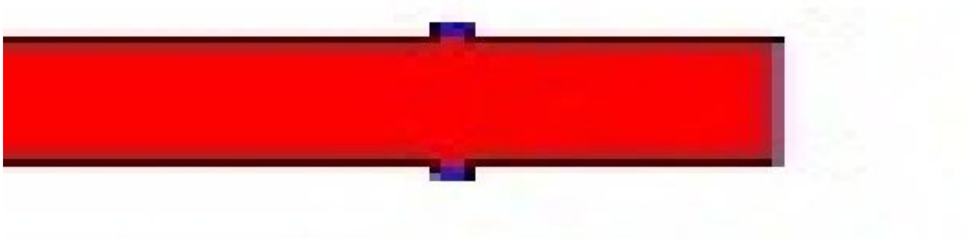


Figure B2

Two hole:

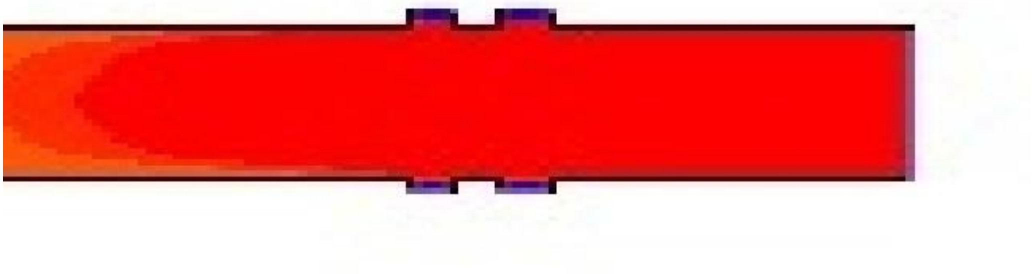


Figure B3

Three hole:

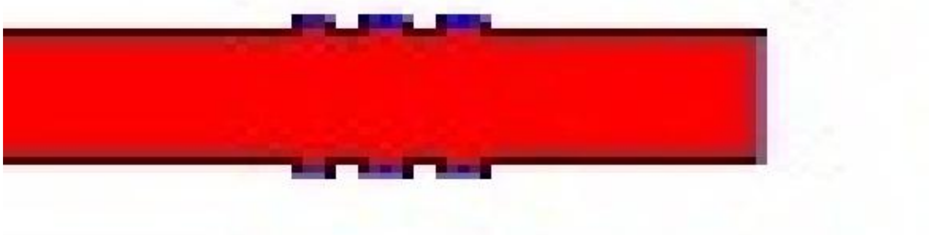


Figure B4

Four hole:

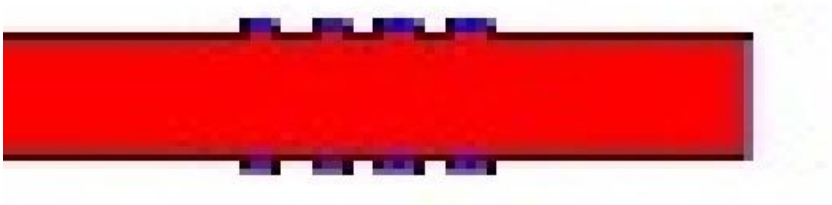


Figure B5

Five hole:

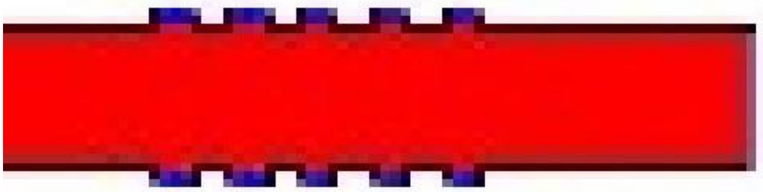


Figure B6

APPENDIX C: CLOSE UP OF VELOCITY VECTOR OF POULTRY WASTE INSIDE THE NOZZLE

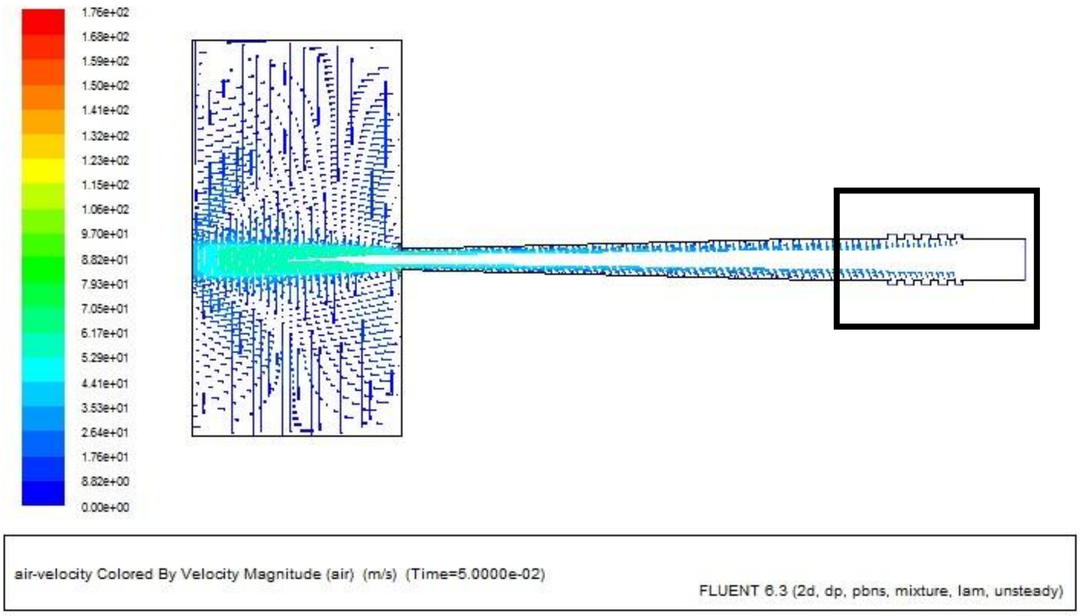


Figure C1

Figure C2

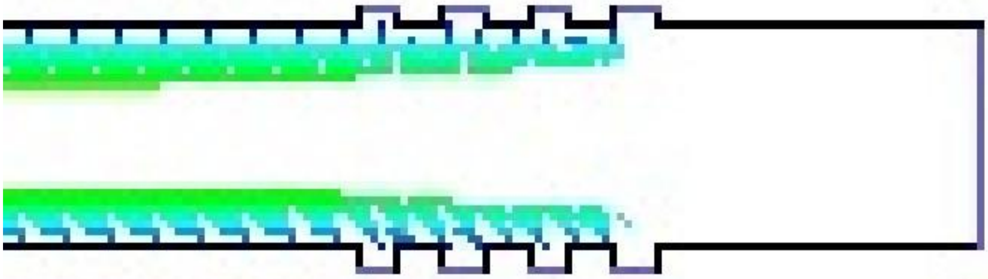


Figure C3

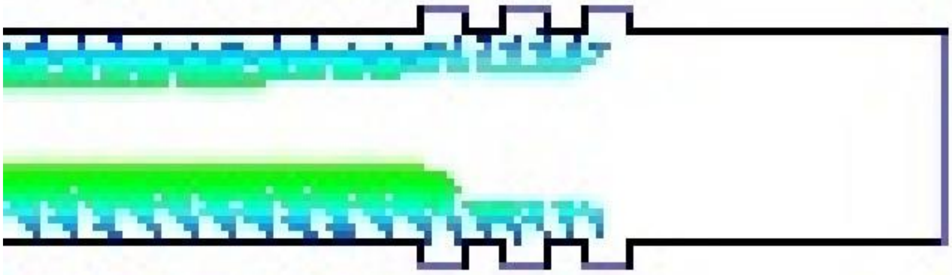


Figure C4

Figure C5

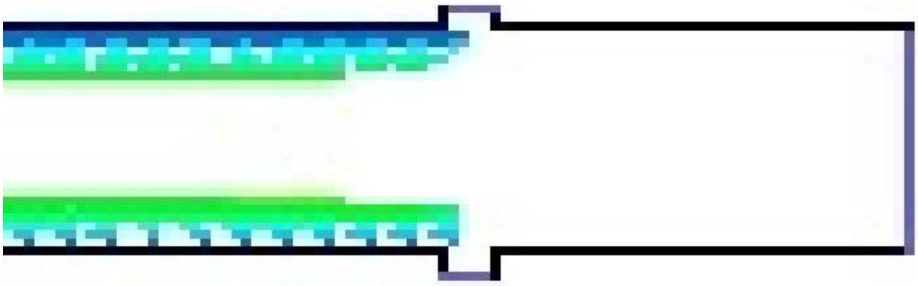


Figure C6