# Particle Flow in Moving Beds

by

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10758

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## CERTIFICATION OF APPROVAL

### Particle Flow in Moving Beds

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A project dissertation submitted to the
Chemical Engineering Programme
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(CHEMICAL ENGINEERING)

Approved by,

(PROF. DUVVURI SUBBARAO)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 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.

MOHD HAFZANIZAM BIN SALLEH

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# ABSTRACT

This project discussed about the project titled "Particle Flow in Moving Beds". This report consists of the project's background, objectives, problem statements, scope of work, literature review, methodology, results, discussions and conclusion. In this work, the author reports a study of solid particle flow in moving bed reactor. In moving bed reactor, the catalyst which is solid particle will flow downward from top to the bottom and it will be recycling back to the top after regeneration. Meanwhile, the gases will cross-flow through the catalyst from the side through the moving beds. In this project, the author will use L-Valve as the representation of the moving bed reactor. There are a few parameters the effect the particle flow in the moving beds. Parameters that will be discussed in this study are aeration rate and particle flow in L-Valve. The relationship of these two parameters will be investigated in the series of experiment to determine how particle flow in the L-Valve affected by aeration rate. From the result of this experiment, an equation will be tested to know how the particles flow in the L-Valve given certain aeration rate. Moreover, this relationship can be used as a solid flow control in the cross-flow rice dryer. The uses of relationship of aeration rate and the solid withdrawal can be used to replace screw mechanism that energy consuming in the removal dried rice in cross-flow dryer. In addition of this experiment, the rice dryer with the counter flow gas drying will be modeled. The rice dryer will be based on the California rice dryer type but with multiple stacks.

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

In this project, "Particle Flow in Moving Beds", the basic thing that needed to be study is the movement of the particles in the moving bed reactor. Moving bed reactor is different from fluidized bed. Moving beds has a downward flow of solid catalyst while the gas reactant will cross flow through the moving catalyst from the side direction. The catalyst will moving downward and it will be recycle back into the reactor after regeneration. Moving beds with gas cross flow used in drying, non-catalytic reactors and catalytic reactors with decaying catalysts. This type of operation also can be used in rice drying operation. The particles move downward by gravity. They offer plug flow for solids as well as gas. Pressure drop for gas flow will also be low. Withdrawal of solids is the critical issue. Also in rice drying operation in cross-flow dryer, the use of screw mechanism still practiced. Use of dense phase pneumatic transport in horizontal pipes attached to the silo/bin can be one option. Such systems are known as L-Valves for solid flow control. In this project, flow rate of the solid particles in the L-valve as a function of the aeration flow will be investigated. Besides, the function of aeration rate vs. solid particles mass flow rate will be investigated. For the rice dryer, the multiple stacks of California dryer will be modeled in this experiment.

## 1.2 Problem Statement

Information on flow of solids in moving beds and L-valves as a function of aeration rates is very limited. This is because the companies that use this type of reactor are not sharing the information about the flow of solids in moving bed reactors as it is confidential. So, a study needs to be done to understand this type of reactor even more. This type of reactor is the most efficient and cost lower than other type of reactor. Moreover, the application of such a system for a 2-D bed modular unit for drying applications will be investigated in this project. Besides, in Malaysia, rice drying still using batch dryer and this project can be used as the basis in transferring the rice particle in cross-flow dryer without using the screw mechanism.

## 1.3 Objectives

The objectives of this study are as below:

- To investigate the effect of aeration rate on particle flow in moving bed/L-valve.
- To investigate the relationship of solid particles mass flow rate to the function of aeration rate.
- To verify equation for particle flow rate in moving bed /L-valves as a function of aeration rate.

## 1.4 Scope of Study

The scope of this study is to do the experiment to investigate the effect of different aeration rate to the movement of particles in L-Valve. It is important to understand the effect of the different aeration rate to the particle flow in moving beds. The size of particles also affects the particle flow in moving beds. This study is to prove this theory and develop an equation to determine how these parameters will affect the particle flow in moving beds. Besides, the effects of manipulative aeration rate to the solid particles mass flow rate will be investigated in this experiment. When the aeration rate is changing, the different solid particles mass flow rate will be resulted. For the rice dryer, the study of the design of dryer will be conducted.

For Final Year Project 2, the following work scope is continued from previous work scope as the semester commences:

- Equipment preparation for the experiment.
- Do the experiment.
- Collect data from the experiment.
- Analyze the data.
- Verify equation with the experiment data.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Radial Flow Moving Bed Reactor

Moving bed reactor is different from packed bed reactor. Moving bed reactor has a downward flow of solid particles from gravity force while the gas reactant will cross flow through the moving catalyst from the side direction. This method has improve the efficiency and obtain a continuous process is to move the solid countercurrent to the fluid. Countercurrent flow keeps the mass transfer zone (MTZ) stationary inside the reactor.

In an axial flow reactor, gas enters at the top and flows downward through the catalyst bed. The product exits at the bottom. In a radial flow reactor, the solid enters at the top and exits at the bottom, meanwhile the gas cross flows across an annular catalyst bed to a center pipe. The radial flow reactors provide larger mean cross-sectional area and reduce distance of travel for flow compared to axial flow reactors. The main advantages of radial flow in comparison to axial flow reactors are the low pressure drop and the high flow capacity.

There are two types of radial flow reactors depending on whether the catalyst bed is fixed or moving inside the reactor. They are the radial flow fixed bed reactor (RFBR) and the radial flow moving bed reactor (RFMBR). Both types can be found in the catalytic reformer processes. The common moving bed reactor that used is RFMBR. RFMBR is a reactor in which the solids moves at a low velocity that around 1 mm/s under the influence of gravity. Due to this low velocity, the moving bed void fraction is considered to be constant and therefore, the hydrodynamics of an RFBR and an RFMBR are similar. Due to this similarity, this work is applicable to both types.

Compared with axial flow fixed bed reactors, RFMBR possess numerous advantages including low pressure drop, high flux capacity, possibility of using small sized catalysts and easy coupling of chemical reaction and catalyst regeneration *(Song, Wang, Jin, Gong, 1993)*. For vapor–phase catalytic chemical reactions whose catalyst decays slowly but reversibly, continuous operation with a lower pressure drop is possible by use of a RFMBR. Figure 2.1 shows the difference between types of reactor that used with the time of working catalysts before regeneration.

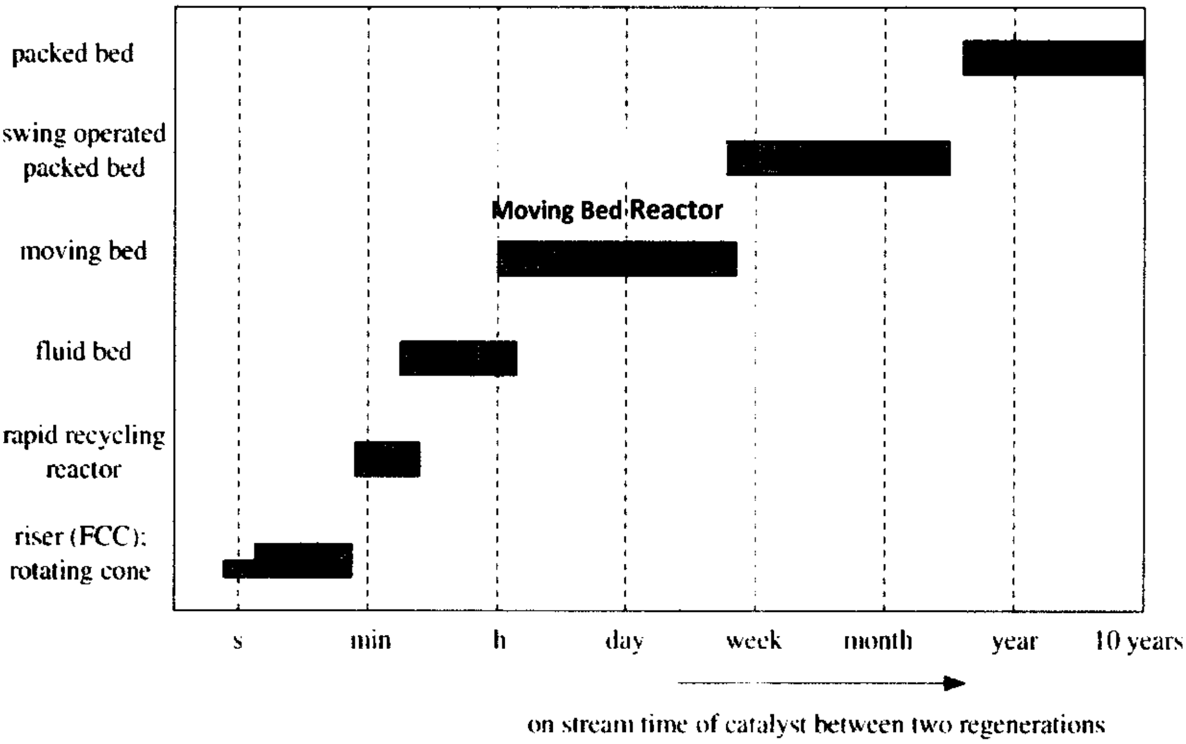


Figure 2.1: Type of Reactor Used for Different Working Time of Catalyst.

This reactor is particularly suitable for catalytic reactions in which the catalyst needs continuous regeneration, because the catalyst particle bed can move downward continuously under steady state conditions. The deactivated catalyst can be withdrawn from the reactor and the fresh or regenerated catalyst can be introduced into the reactor continuously. RFMBR are widely used for catalytic reforming of Naphtha to Aromatics, dehydrogenation of Propane where the catalyst decays slowly over a period of weeks to months and continuous removal of decayed catalyst for regeneration and recycling makes the process a continuous operation. Besides, California column dryers for drying rice where it provide plug flow of rice for continuous withdrawal of dried rice as well as short contact time (plug flow) between hot air and particles *(Rice Quality Workshop,2003).*

The residence time of the catalyst can be easily controlled by regulating the circulation rate of the catalyst *(Pilcher, Bridgwater, 1990).* With the above advantages, the RFMBR can be used in a number of gas-solid contacting operations involving chemical catalytic reactions, mass transfer and separation processes. Figure 2.2 shows the common structure of RFMBR. The catalyst inserted at the top of reactor and move downward where it will be recycled back after regeneration.

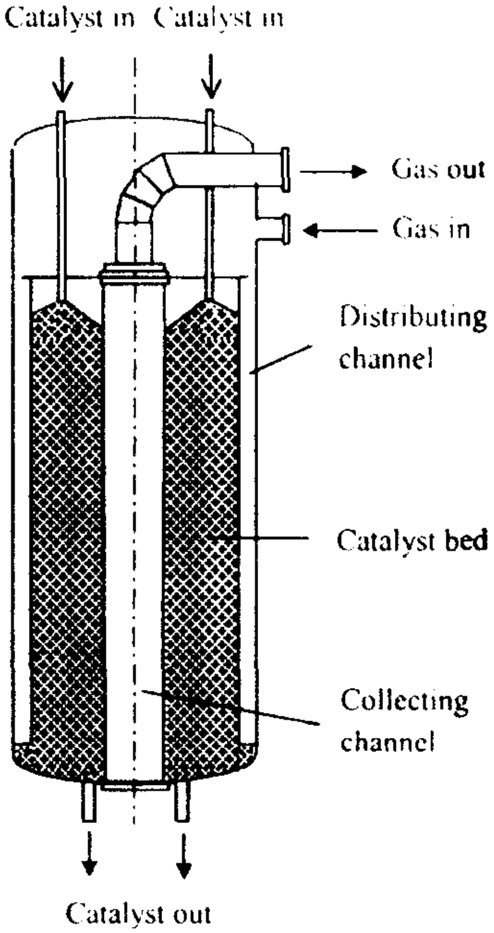


Figure 2.2: Schematic of RFMBR *(Mu, Wang, Wang, Jin, 2002)*

The gas flow is considered to be two-dimensional because of the axial symmetry of RFMBRs; hence the velocity field of the gas phase in the particle bed can be represented by two one-dimensional velocities in the axial and radial directions *(Song, Jin, Yu, 1994)* Figure 2.3 illustrates another schematic of RFMBR with the detail catalyst particle flow and gas flow.

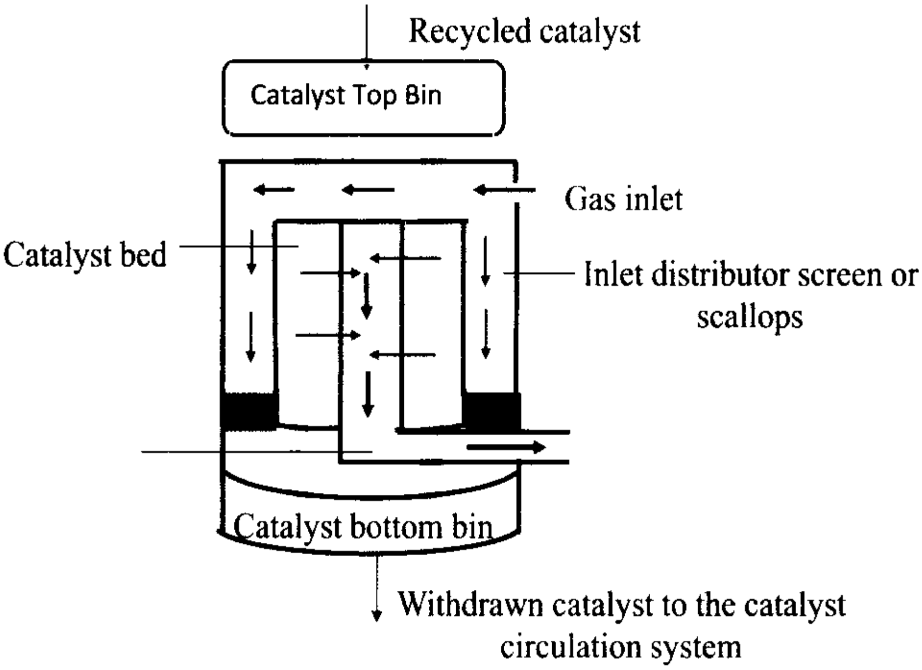


Figure 2.3: Detail Flow of Solid and Gas in RFMBR

## 2.2 L-Valve

L-Valve is the most common types of non-mechanical valves. This valve is shaped like the letter 'L' and the most common non-mechanical valve because it is easiest to construct. Besides, it is also slightly efficient than other non-mechanical valves such as J-Valve. Solid particles flow through L-Valve because of drag forces on the particles by the aeration gas. When aeration gas is added to L-Valve gas flows downward through the particles and around the constricting bend. This relative gas-solids flow produces a frictional drag force on the solid particles in the direction of flow. When this drag force exceeds the force required to overcome the resistance to solids flow around the bend the solid flow through the valve.

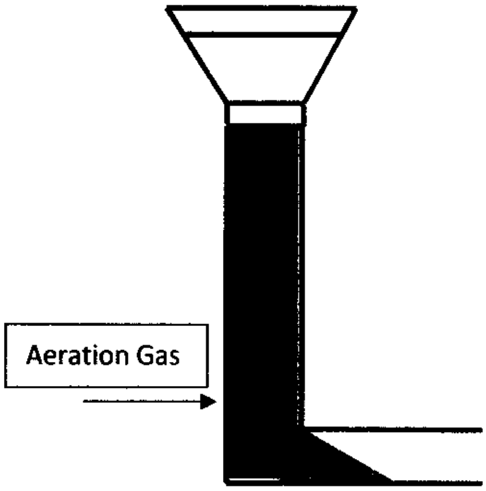


Figure 2.4: L-Valve Structure

When aeration is added to a non-mechanical valve, solids do not begin to flow immediately. The initial aeration gas added is not enough to produce the frictional for required to start solids flow. Above the threshold amount of gas required to initiate solids flow, additional aeration gas added to the valve causes the solids flow rate to increase and reducing the amount of aeration to the valve causes the solids flow rate to decrease.

L-Valve work best with materials having average particle size between 100 and 5000 microns *(T.M Knowlton, 1997)*. Materials with average particle sizes greater than about 2000 microns require substantial amounts of gas to generate the drag forces required to make the solids flow around the constricting bend. For the larger solids particle, less surface area is available for the generation of the drag forces required to make the solids flow in L-Valve.

The aeration rate provided to stand pipe will split to up flow stream, $Q_U$ and down flow stream, $Q_D$ depending on the relative packed bed resistance for gas flow. At threshold aeration rate, $Q_{TH}$, solids will be initiated to flow through the bend as the enough drag force is generated. The increment of external aeration rate will increase the gas drag force on solid particles and resulted higher solid mass flow rate and throat area near 90° bend near the upper wall. The solid flow rate depends on aeration rate, Q, standpipe diameter, D, height of standpipe, $H_U$, length of downstream flow path, $H_D$, particle diameter, $D_p$, particle density, $\rho_p$, gas density, $\rho_g$ and gas viscosity, $\mu$. Below, in Figure 2.5, the location of $H_U$, $H_D$, $Q_U$ and $Q_D$ are shown:

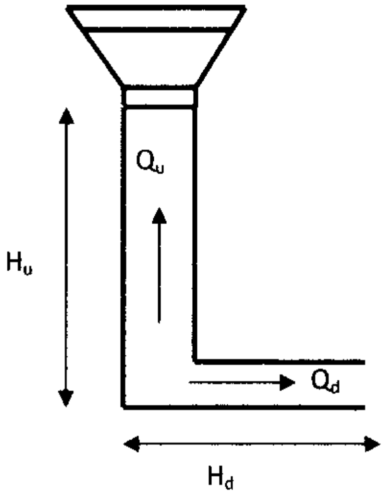


Figure 2.5: Location of $H_U$, $H_D$, $Q_U$ and $Q_D$

The formula for $Q_{TH}$ is as below:

$$Q_{TH} = f_u \frac{\pi D_t^2}{4} U_{mf} \frac{H_u + H_d}{H_d}$$

$$Q_{TH} = f_u X$$

$$Q_{TH} = 0.07X$$

The value of 0.07 is estimated from the expermental observations reported in literature. Therefore X defined as below:

$$X = \frac{\pi D_t^2}{4} U_{mf} \frac{H_u + H_d}{H_d}$$

To find value of $U_{mf}$, the formula below is used:

$$U_{mf} = \frac{R_{emf}\mu}{\rho_g D_p}$$

To get value of $R_{emf}$, the formula below is used:

$$R_{emf} = \left(33.7^2 + \frac{0.0408 D_p^3 g(\rho_p - \rho_g)\rho_g}{\mu^2}\right)^{0.5} - 33.7$$

To find the maximum solid mass flow rate, Beverloo equation is used:

$$W_{max} = 0.58\rho_p(1-\varepsilon)g^{0.5}\left(D_t - 1.5D_p\right)^{2.5}$$

The model for particle flow rate is done by *(Subbarao,2010)* show the relationship of aeration rate with solid particle mass flow rate as shown in equation below:

$$(Q - Q_{Th})\frac{\rho_p(1-\varepsilon)}{\varepsilon} = \left(1 + 2640\frac{D_p^2}{D_t^2}\frac{W_{max}}{W}\right)W$$

## 2.3 Rice Dryer

Over 80% of California's rice is dried in continuous-flow, heated-air dryers. The most common type is called a column dryer, Figure 2.6, where rice flows by gravity downward between two screens, separated by 6 to 12 inches. Heated air flows horizontally through the screens. This dryer is sometimes called a cross-flow dryer because the air flows at a 90 degree angle to the flow of rice. Metering rolls, at the bottom of the screens, control the rate of rice flow through the dryer. Rice is removed from the metering rolls with screw conveyors. Air is supplied at a rate of 2 to 4 cubic feet per minute-pound and heated to 130° to 165°F depending on rice residence time in the dryer.

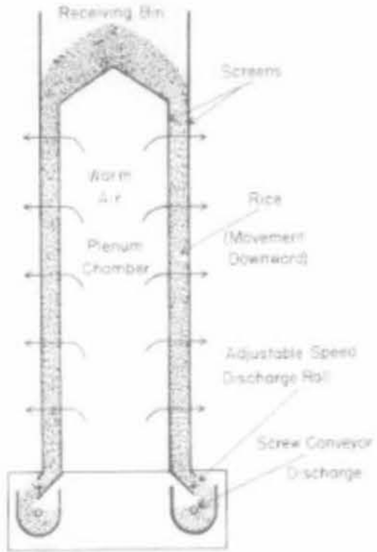


Figure 2.6: Cross Flow Rice Dryer

This type of dryer has several disadvantages compared with mixing-type dryers *(Wasserman, Miller, Golden, 1965)*. Rice tends to flow straight down between the screens, without much horizontal movement. This means that the rice close to the hot air plenum is always exposed to the hottest air and dries more than the rice next to the screen near the air exhaust. Also rice next to the screens flows slower than the rice in the middle between the two screens. This leads to even more variability in the amount of drying experienced by individual grains. Some dryer designs include mixing sections to reduce moisture variability.

Commercial operators have found that finger-type mixers are very effective in minimizing kernel to kernel moisture variability. Two other types of dryers are designed to mix the rice as it flows through the dryer. The baffle dryer, Figure 2.7, causes the rice to flow in a zig-zag pattern and heated air flows through openings between baffles. Distance between baffles is generally about 6 inches.

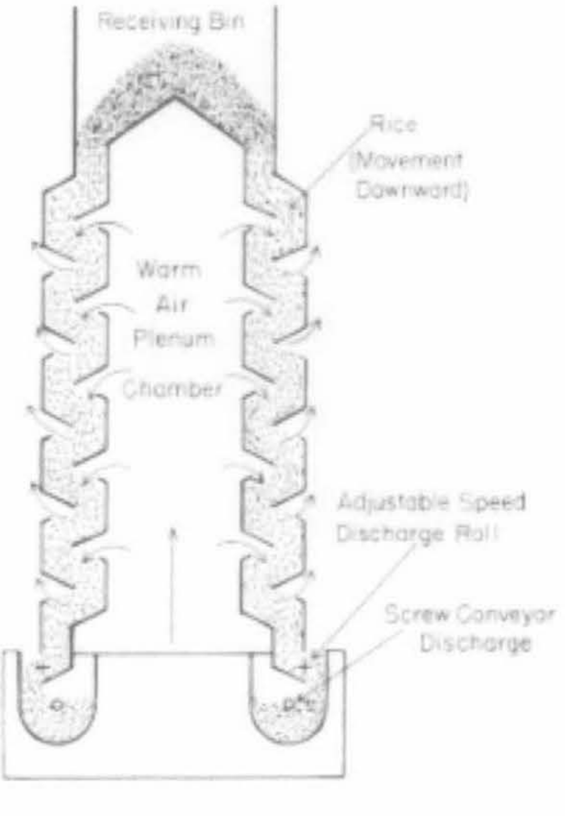


Figure 2.7: Zig-Zag Cross-Flow Rice Dryer

Most rice drying operations in California use cross-flow column dryers. Rice is subject to lower milling yields if it is dried too quickly. Quality is maintained by drying in several 20 to 30 minute long passes through a dryer. Between passes, rice is stored in temporary holding bins. This is called tempering and allows moisture to equalize within kernels. Most tempering is accomplished in about four hours although drying schedules often dictate that the rice must be held for about 24 hours between passes. A recirculating batch dryer, Figure 2.8, is the most widely used system in Asia. Paddy is loaded into the tempering section and it slowly flows downward to the drying section. After passing through the drying section it is returned to the tempering section and the process is repeated until the batch of rice is dry. The units usually remove water a rate of 0.6 to 1.0 %/hr and have holding capacities of 800 kg to 20 tons. However, this dryer use a lot of time for the same amount of rice compare to the cross-flow drier. In other word, the cross-flow dryer is more efficient and less time consuming.

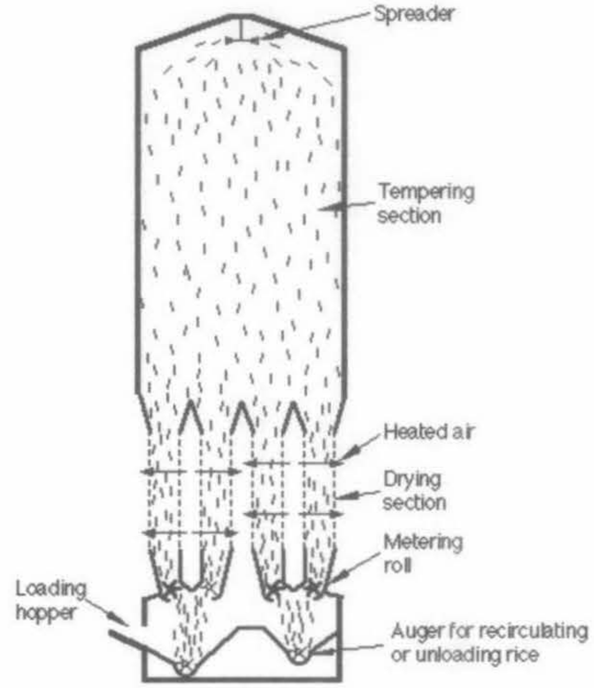


Figure 2.8: Recirculating Batch Rice Dryer

Because of their lower cost and higher efficiency, the cross-flow rice dryer can be introduced in Malaysia. Most of rice drying operations in California has used cross-flow column dryers. However, withdrawal of solids is the critical issue in this dryer. There is still application of screw mechanism in removing the dried rice. This mechanism uses a lot of power and very expensive. So, in this project, the aeration rate relationship with particle flow in L-Valve can be used in the application to remove the dried rice from cross-flow dryer with only the aeration rate.

# CHAPTER 3

# METHODOLOGY

## 3.1 Methodology and Project Work Flow

For this project, the author needs to do some steps to achieve the objectives. First of all, the author needs to understanding the concept of particle flow in moving beds. L-Valve mechanism also must be studied. Then, after all the concept and theory studies, one experiment to investigate the relationship between the aeration rate and particle flow need to be identified. In Final Year Project 1 the preparation of the experiment apparatus has been done.

The experiment will be done in Final Year Project 2. After the experiment is done, the data will be collected. This data will be analyzed and used to develop an equation that can relate between aeration rates with particle flow in L-Valve.

The procedure for the experiment that will be done for this project is as below:

### 3.1.1 Experiment: Particle Flow in Moving Beds

**Apparatus:** L-valve, hose, solid particles (sagu), air compressor.

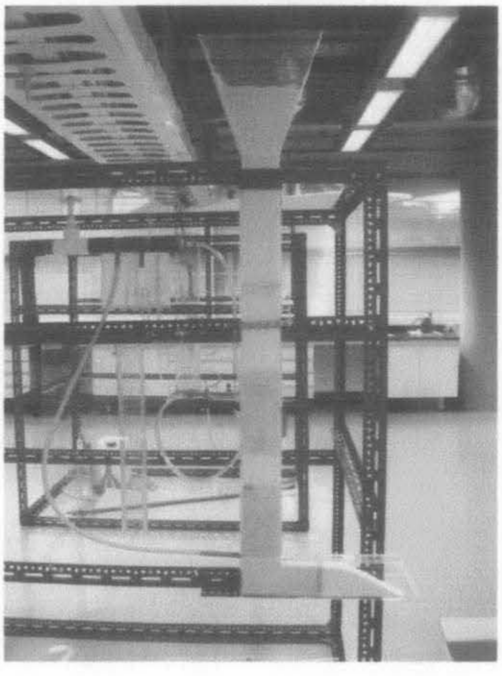


Figure 3.1: Actual Experiment Setup for L-Valve

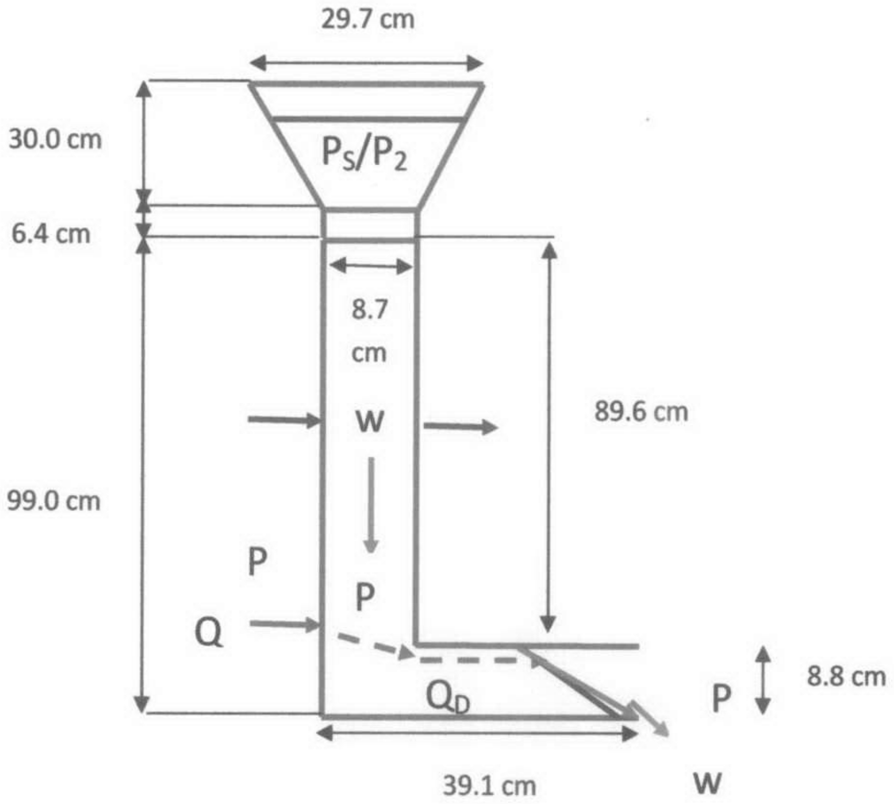


Figure 3.2: Experiment Setup for L-Valve

### 3.1.2 Procedure (Solid Flow Pattern):

1) The experiment will conduct as shown above in Figure 3.1 and Figure 3.2.
2) Start the air compressor with the certain aeration rate.
3) The flow rate of air will be measured using orifice meter.
4) The difference of water height will be recorded.
5) The solid particles will be put in the hopper.
6) A hose from air compressor will be connected at the hole on the standpipe.
7) The flow of the solid particle will be observed when it first moved.
8) The moment the solid particles move, the movement of the solid particles will be recorded in the transparent graph paper.
9) The level of solid particle in the standpipe must be always in the hopper.
10) This trial will be repeated for two more times for higher accuracy.
11) The experiment will be repeated with the four different other aeration rates.
12) The plot of the solid particle will be used to develop the equation of the aeration rate and particle flow.

### 3.1.3 Procedure (Solid Mass Flow Rate):

1) The experiment will conduct as shown above in Figure 3.1 and Figure 3.2.
2) Start the air compressor with the certain aeration rate.
3) The flow rate of air will be measured using orifice meter.
4) The difference of water height will be recorded.
5) The solid particles will be put in the hopper.
6) A hose from air compressor will be connected at the hole on the standpipe.
7) The solid particles will be collected for 30 seconds starting when the solid starts flow.
8) The level of solid particle in the standpipe must be always in the hopper.
9) Measure the mass of solid particles collected.
10) This trial will be repeated for two more times for higher accuracy.
11) The experiment will be repeated with the four different other aeration rates.
12) The plot of the solid particle will be used to develop the equation of the aeration rate and particle flow.

### 3.2 Orifice Meter

An orifice plate is a device used for measuring the volumetric flow rate. It uses the same principle as a Venturi nozzle, namely Bernoulli's principle which states that there is a relationship between the pressure of the fluid and the velocity of the fluid. When the velocity increases, the pressure decreases and vice versa. An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, with the hole in the middle, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena contracta point. As it does so, the velocity and the pressure changes. By measuring the difference in fluid pressure between the normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation. In this experiment, $D_1$ is 2.6mm and $D_2$ is 0.6 mm.

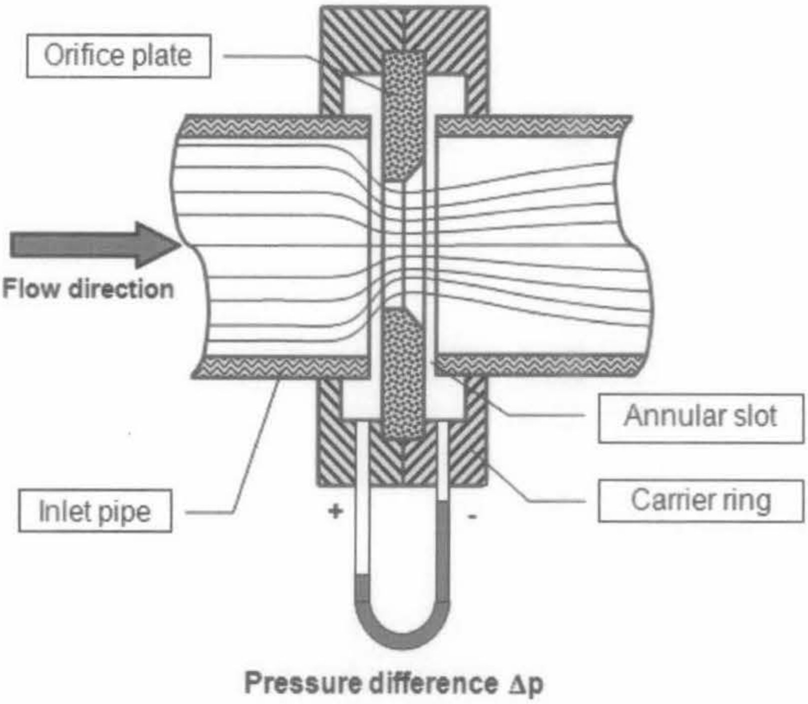


Figure 3.3: Model of Orifice Meter

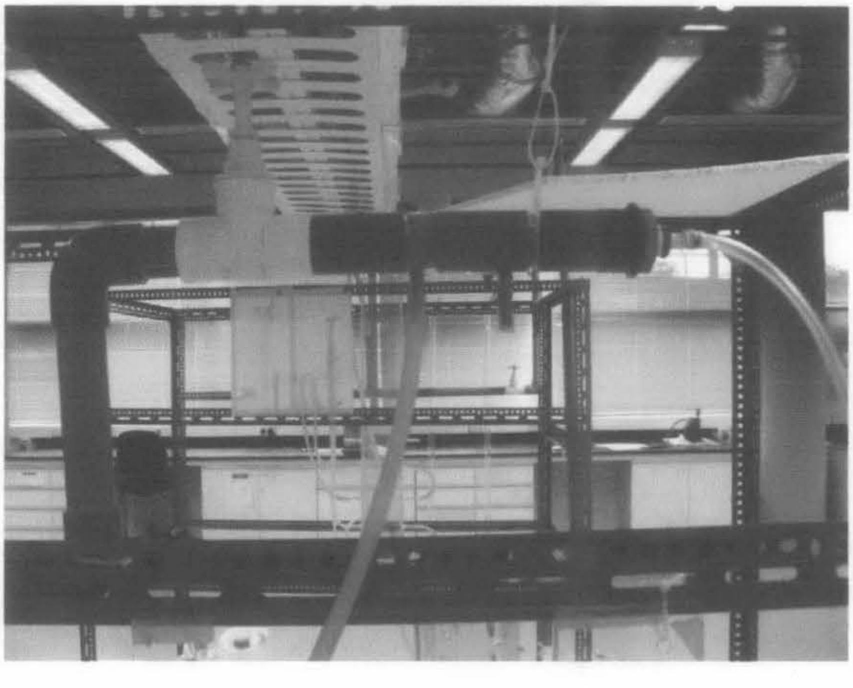


Figure 3.4: Actual Orifice Meter

Equation of Orifice Meter

$$P_1 + \frac{1}{2}\rho_{gas}V_1^2 = P_2 + \frac{1}{2}\rho_{gas}V_2^2$$
$$P_1 - P_2 = \frac{1}{2}\rho_{gas}V_2^2 - \frac{1}{2}\rho_{gas}V_1^2$$

By continuity equation:

$$Q = A_1V_1 = A_2V_2 \quad or$$
$$V_1 = \frac{Q}{A_1} \quad and \quad V_2 = \frac{Q}{A_2}$$

Solving for air flow rate, Q:

$$P_1 - P_2 = \frac{1}{2}\rho_{gas}\left(\frac{Q}{A_2}\right)^2 - \frac{1}{2}\rho\left(\frac{Q}{A_1}\right)^2$$
$$Q = A_2\sqrt{\frac{2(P_1 - P_2)/\rho_{gas}}{1 - (A_2/A_1)^2}}$$
$$Q = A_2\sqrt{\frac{1}{1 - (d_2/d_1)^4}}\sqrt{2(P_1 - P_2)/\rho_{gas}}$$

$$Q = c_d\frac{\pi}{4}D_2^2\sqrt{\frac{1}{1 - (d_2/d_1)^4}}\sqrt{2(P_1 - P_2)/\rho_{gas}}$$

For the pressure difference in pivot tube,

$$P_1 - P_2 = \Delta P = \rho_{water}g\Delta h$$

$d_1$=2.6 cm= 0.026 m

$d_2$=0.6 cm= 0.006 m

$\rho_{water}$=997.0479 kg.m$^{-3}$

$\rho_{gas}$=1.1839 kg.m$^{-3}$

g=9.81 m.s$^{-2}$

$c_d$=0.6

Table 3.1: Aeration Rate Calculation

| $\Delta h(m)$ | $\Delta P(Pa)$ | Q($m^3$/s) | Q($cm^3$/s) |
|---|---|---|---|
| 0.145 | 1418.2508 | $8.3154\text{x}10^{-4}$ | 831.5 |
| 0.255 | 2494.1652 | $1.1028\text{x}10^{-3}$ | 1102.8 |
| 0.315 | 3081.0276 | $1.2256\text{x}10^{-3}$ | 1225.6 |
| 0.465 | 4548.1836 | $1.4891\text{x}10^{-3}$ | 1489.1 |
| 0.630 | 6162.0551 | $1.7333\text{x}10^{-3}$ | 1733.3 |

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Result

### 4.1.1 Solid Particle Flow Pattern

For Q= 831.5cm$^3$/s:

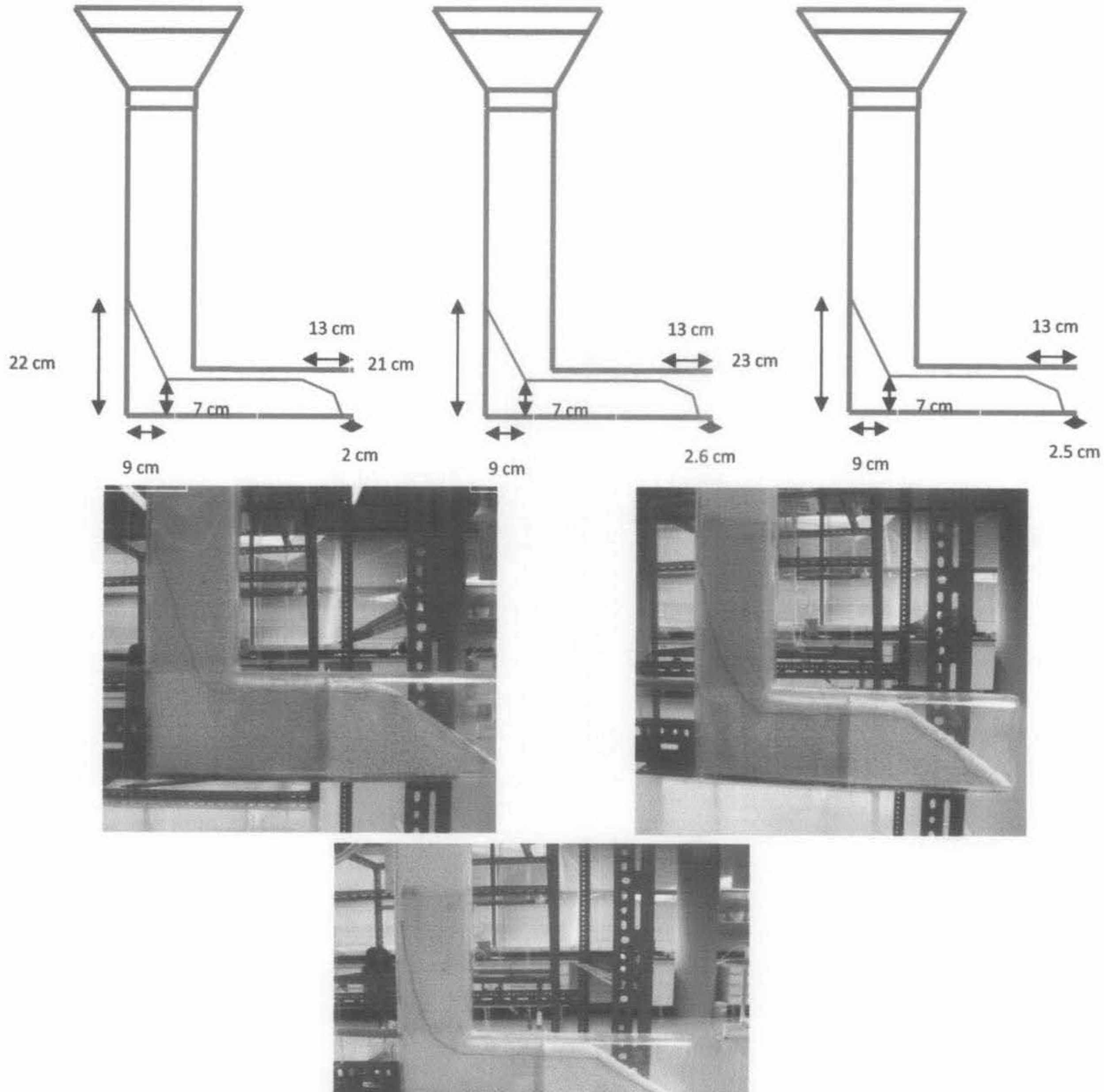


Figure 4.1: Particle Flow for Q= 831.5cm$^3$/s

For Q= 1102.8cm$^3$/s:

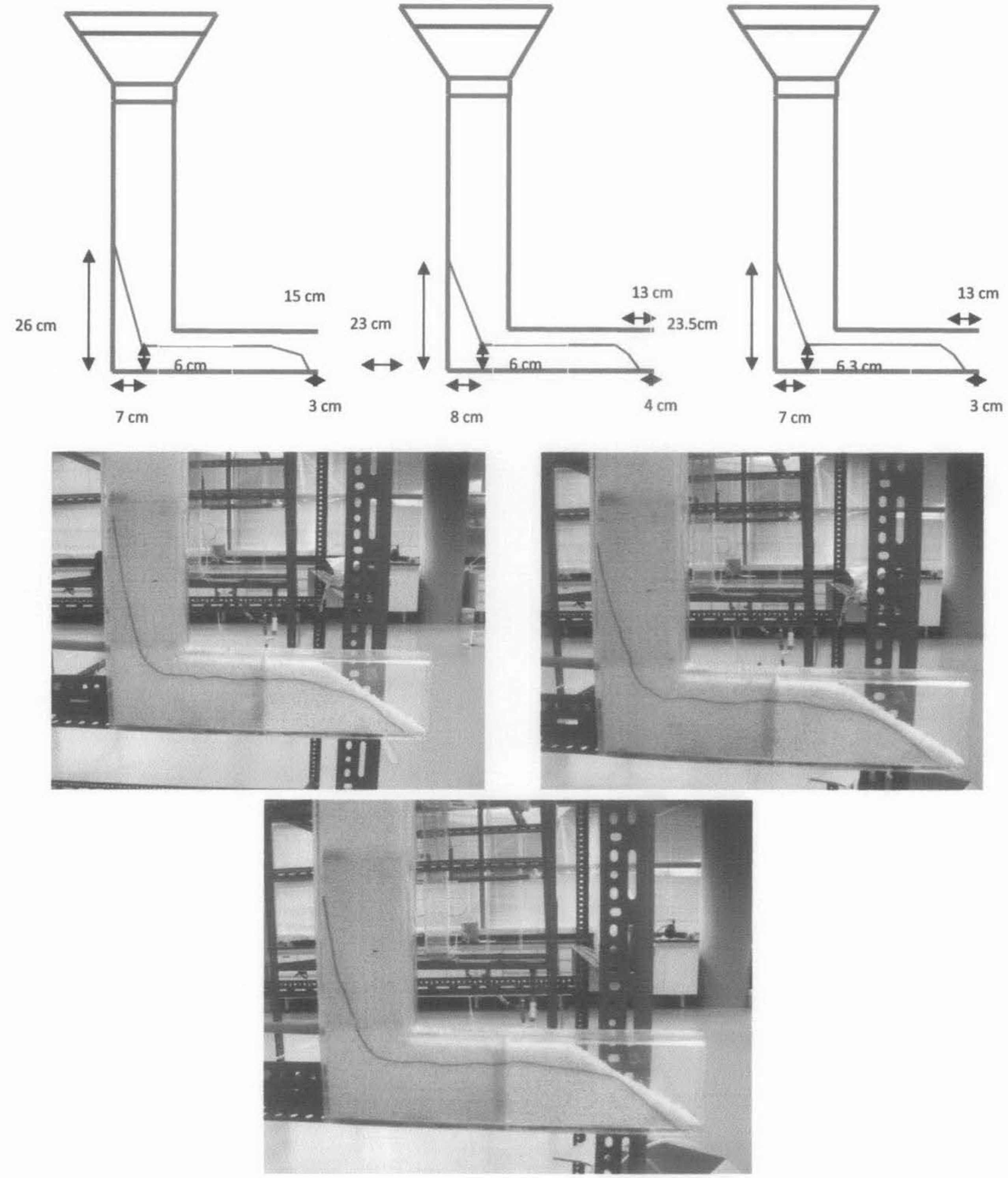


Figure 4.2: Particle Flow for Q= 1102.8cm$^3$/s

For Q= 1225.6cm$^3$/s:

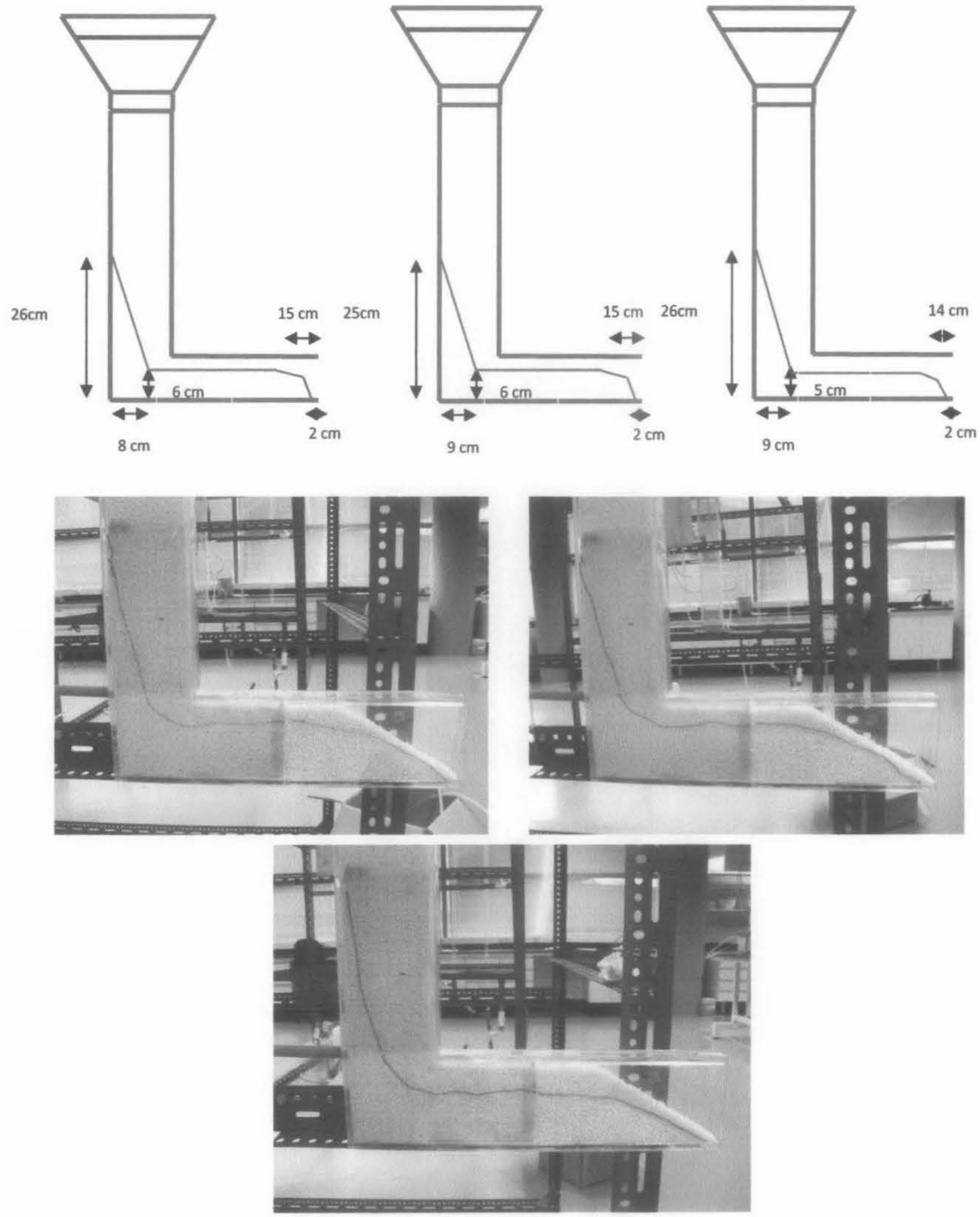
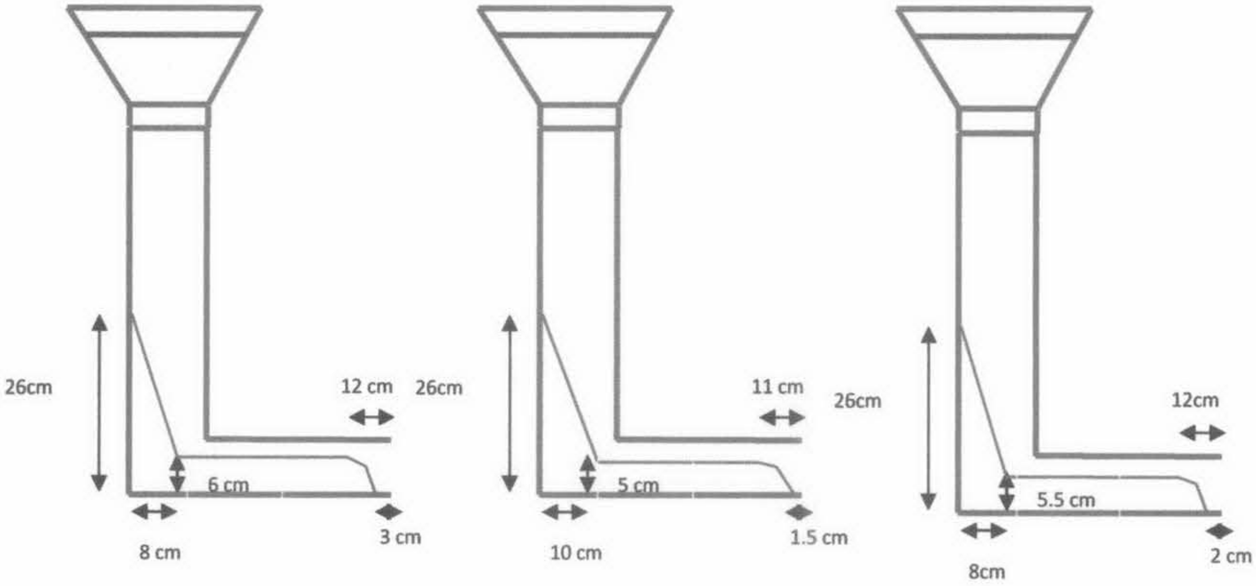


Figure 4.3: Particle Flow for Q= 1225.6cm$^3$/s

For Q= 1489.1cm$^3$/s:



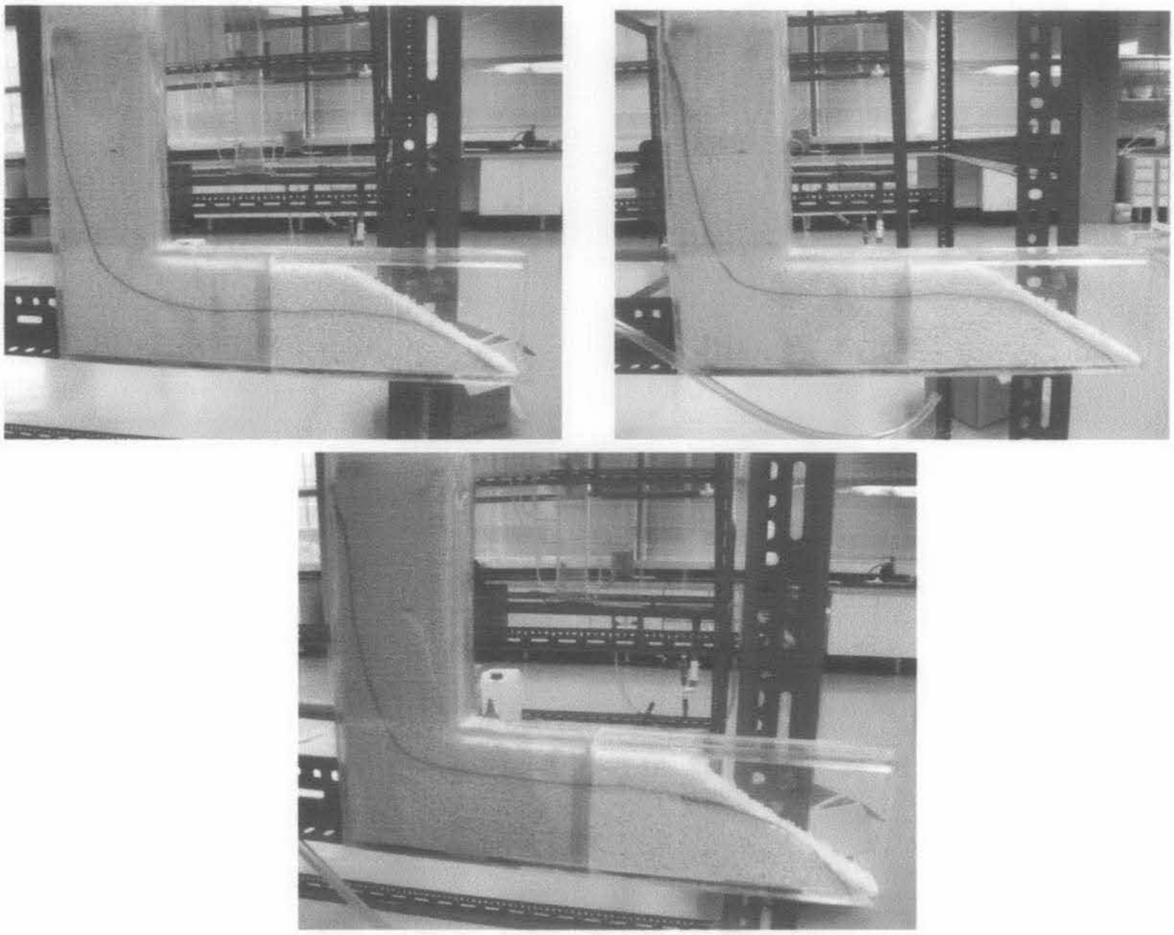


Figure 4.4: Particle Flow for Q= 1489.1cm$^3$/s

For Q= 1733.3cm$^3$/s:

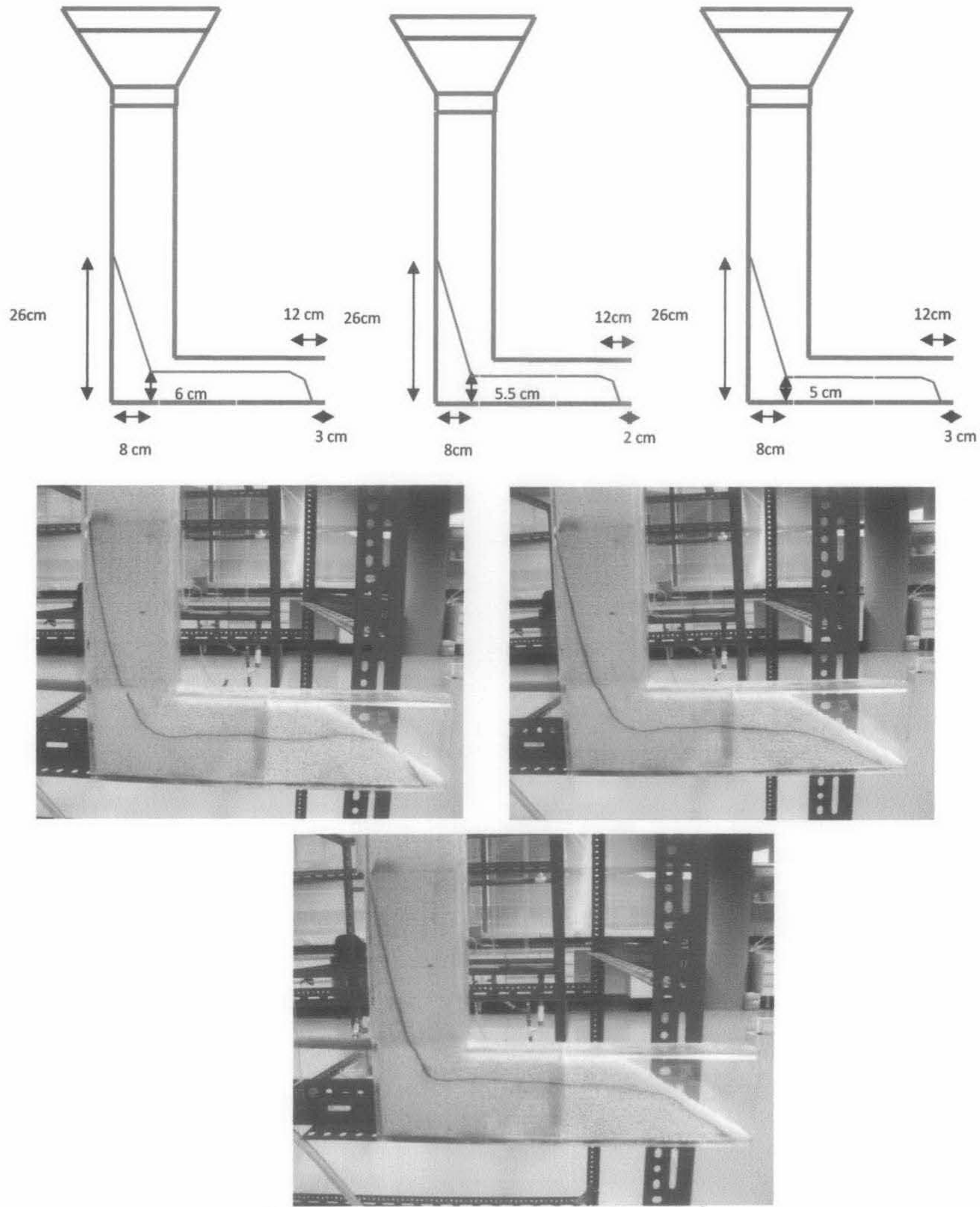


Figure 4.5: Particle Flow for Q= 1733.3cm$^3$/s

### 4.1.2 Mass Flow Rate

Table 4.1: Mass Flow Rate Result

| Flow rate(cm$^3$/s) | First Trial(g/s) | Second Trial(g/s) | Third Trial(g/s) | Average(g/s) |
|---|---|---|---|---|
| 831.5 | 44.3996 | 47.1726 | 53.3367 | 48.3029667 |
| 1102.8 | 125.9876 | 120.5568 | 128.6574 | 125.067267 |
| 1225.6 | 170.1028 | 168.8935 | 172.7699 | 170.588733 |
| 1489.1 | 307.2449 | 297.7726 | 294.3789 | 299.7988 |
| 1733.3 | 368.7876 | 359.8653 | 370.2634 | 366.305433 |

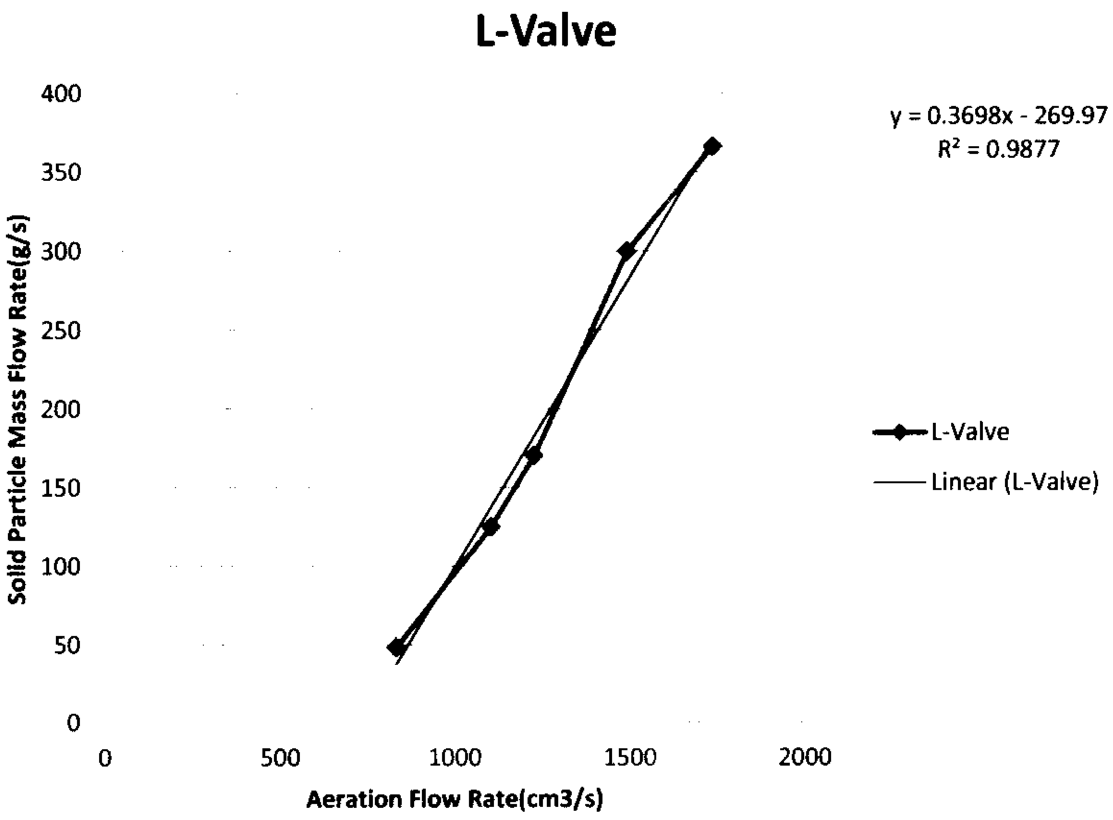


Figure 4.6: Graph of Solid Particle Mass Flow Rate vs. Aeration Flow Rate

### 4.1.3 Design of Dryer

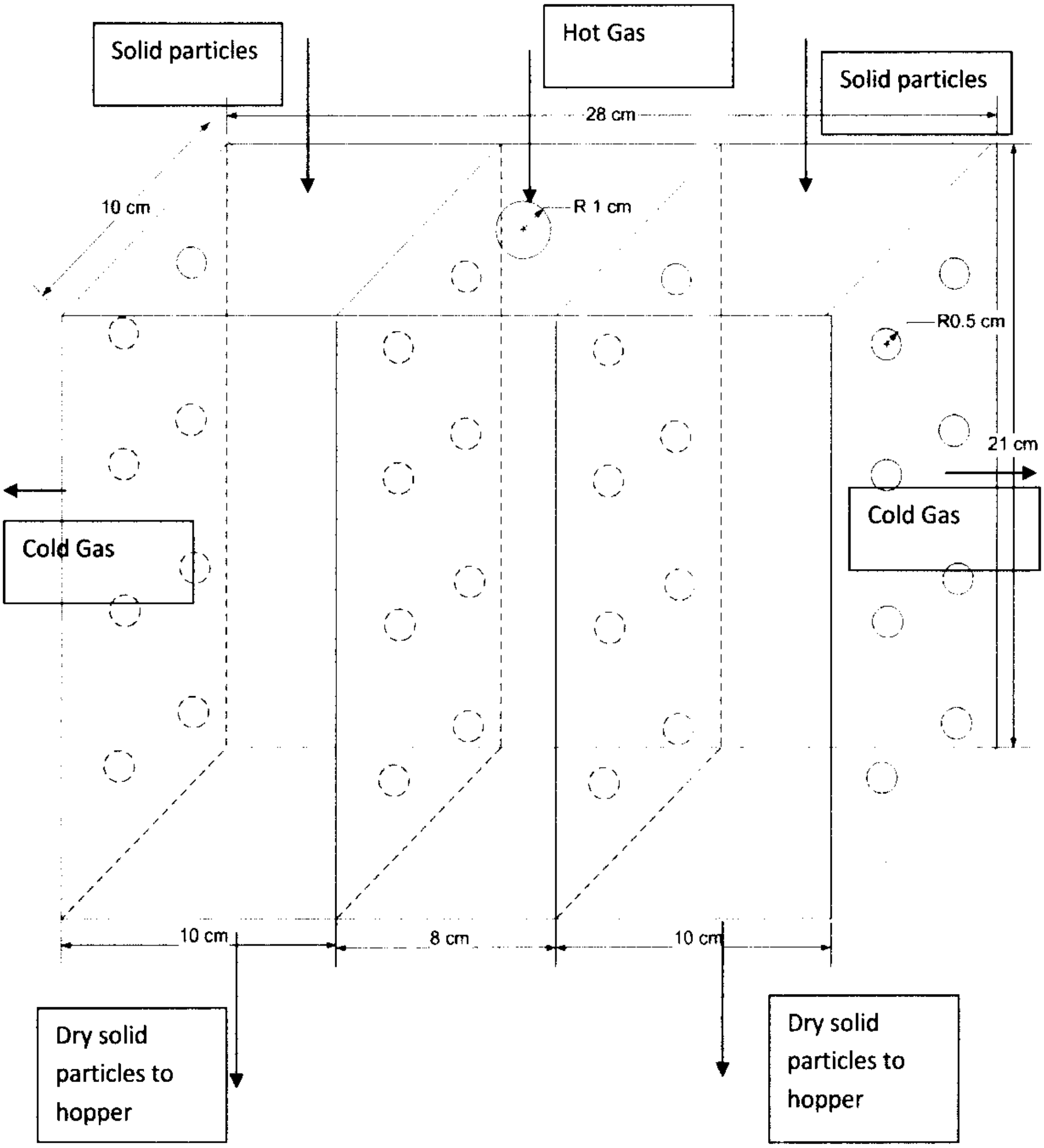


Figure 4.7: Design of Dryer

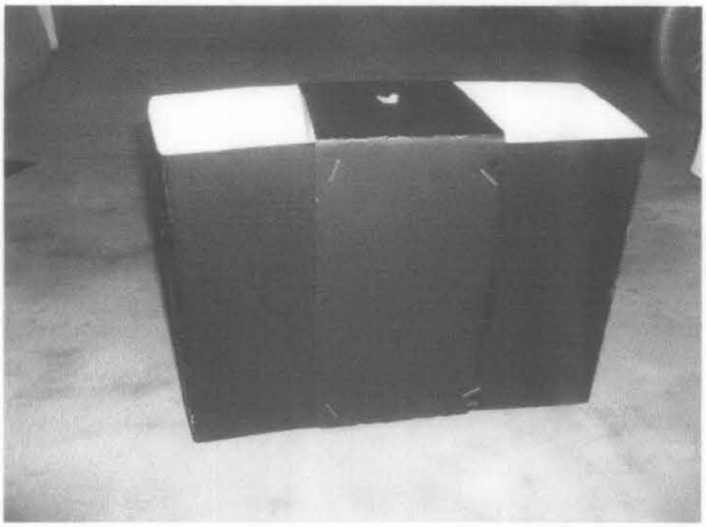


Figure 4.8: Front View of Prototype

Figure 4.9: Side View of Prototype

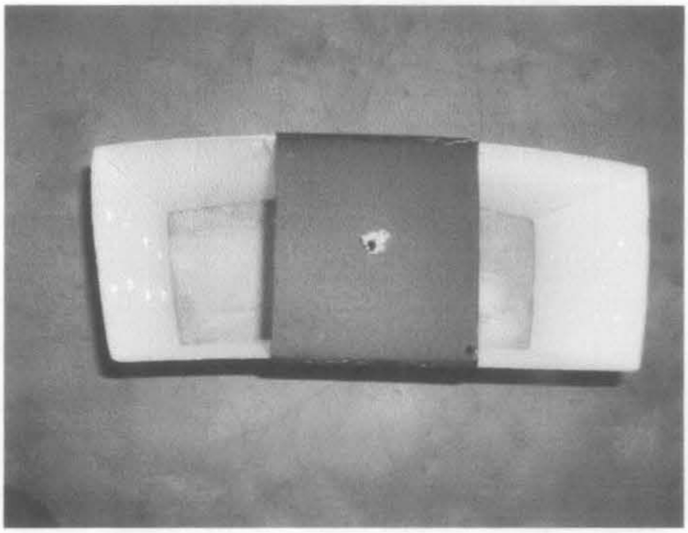


Figure 4.10: Above View of Prototype

## 4.2 Discussion

From the experiment, the pattern of solid particle flow will be more aggressive when the aeration rate is higher. This is due to the increment of gas drag force thus the solid particle will moving faster when the aeration rate is increase. However, at some point of aeration rate, the pattern of the solid particle flow will be constant. This is because the solid mass flow rate is approaching maximum mass flow rate, $W_{max}$ in this experiment. The drag force of aeration gas is failed to move larger amount of solids when the value of mass flow rate approaching $W_{max}$. However, until the value of solid mass flow rate is still not approaching $W_{max}$, the solid mass flow rate is still increasing while the pattern is not changing. However, pattern of solid flow will be constant when the value $W_{max}$ is achieved.

Based on the results that obtained from this experiment, the five readings show that the solid particles will move faster when higher aeration rate used. However, based on the literature, the movement of solid particles will be constant at one point. The expected analysis from the experiment would be to find relationship between aeration with the particle flow in L-Valve that represents moving beds.

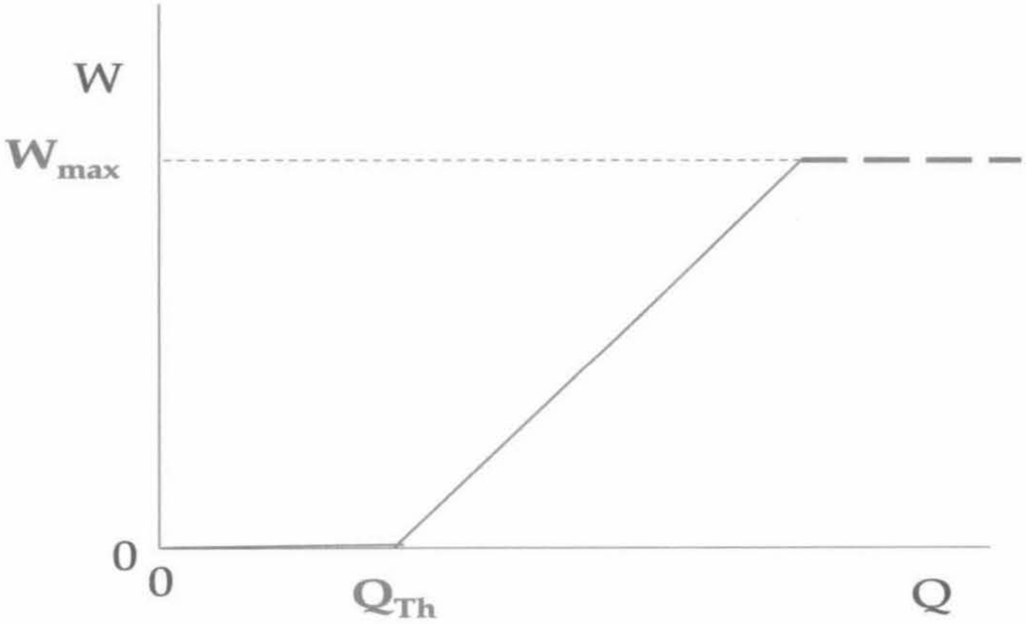


Figure 4.11: General Result

Figure 4.11 show how the graph that obtained should looks like. Below is the defintion of $W_{max}$ and $Q_{TH}$.

$W_{max}$=Maximum solid flow rate (g/s)

$Q_{TH}$=Threshold aeration rate ($cm^3$/s)

In this experiment, we want to find the value of the $W_{max}$ and $Q_{TH}$.

| | |
|---|---|
| **$Q_{Th}$** | **?** |
| **$W_{max}$** | **?** |

To find value of $W_{max}$. Beverloo Equation is used:

$$W_{max} = 0.58\rho_p(1-\varepsilon)g^{0.5}\left(D_t - 1.5D_p\right)^{2.5}$$

General information:

$\rho_p = 1.15\ g/cm^3$

$D_p = 1.5mm = 0.15cm$

$\varepsilon = 0.4$

$$D_t = 4 \times \frac{cross\ sectional\ area}{wetted\ perimeter}$$

$$= 4 \times \frac{2.8 \times 8.8}{23.2}$$

$$= 4.25\ cm$$

$g = 9.81\,m/s^2 = 981\ cm/s^2$

$$W_{max} = 0.58(1.15)(1-0.4)(981)^{0.5}\left(4.25 - 1.5(0.15)\right)^{2.5}$$

$$W_{max} = 407.40g/s$$

Threshold gas velocity,$Q_{TH}$:

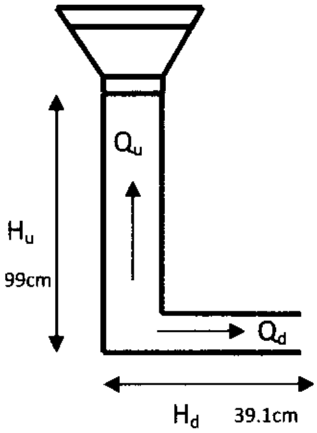
$$Q_{TH} = f_u \frac{\pi D_t^2}{4} U_{mf} \frac{H_u + H_d}{H_d}$$

$$Q_{TH} = f_u X$$

$$Q_{TH} = 0.07X$$

Therefore,

$$X = \frac{\pi D_t^2}{4} U_{mf} \frac{H_u + H_d}{H_d}$$



To find value of $U_{mf}$,

$$U_{mf} = \frac{R_{emf}\mu}{\rho D_p}$$

$$R_{emf} = \left(33.7^2 + \frac{0.0408 D_p^3 g(\rho_p - \rho_g)\rho_g}{\mu^2}\right)^{0.5} - 33.7$$

$$R_{emf} = \left(33.7^2 + \frac{0.0408(0.15)^3(981)(1.15 - 0.0011839)0.0011839}{0.00018^2}\right)^{0.5} - 33.7$$

$$R_{emf} = 48.80 cm/s$$

With the obtained $R_{emf}$ value, $U_{mf}$ is calculated:

$$U_{mf} = \frac{48.80 \times 0.00018}{0.0011839 \times 0.15}$$

$$U_{mf} = 49.46 cm/s$$

Value of X calculated:

$$X = \frac{\pi \times 4.25^2}{4} 49.46 \frac{99 + 39.1}{39.1}$$

$$X = 2478.40\ cm^3/s$$

The value of $Q_{TH}$ is as below:

$$Q_{TH} = 0.07X$$

$$Q_{TH} = 0.07 \times 2478.40$$

$$Q_{TH} = 173.49g/s$$

$$(Q - Q_{Th})\frac{\rho_p(1-\varepsilon)}{\varepsilon} = \left(1 + 2640\frac{D_p^2}{D_t^2}\frac{W_{max}}{W}\right)W$$

$$(Q - 173.49)\frac{1.149(1-0.4)}{0.4} = \left(1 + 2640\frac{(0.15)^2}{(4.25)^2}\frac{407.05}{W}\right)W$$

$$(Q - 173.49)1.72 = W + 1338.62$$

$$W = 1.72Q - 1338.62 - 298.40$$

$$W = 1.72Q - 1637.02$$

From the experimental data, the equation that obtained is as below:

$$W = 0.3698Q - 269.97$$

The equation from the calculation data is obtained as below:

From calculation:

$$W = 1.72Q - 1636.83$$

From experiment:

$$W = 0.3698Q - 269.97$$

Comparison of the equation:

$$\big(0.215(W = 1.72Q - 1636.83)\big) \cong (W = 0.3698Q - 269.97)$$

The equation that obtained from the experiment is lower by the factor of 0.215 compared to the equation that obtained from the calculation. This is happen because the equation that used in the calculation is actually used in the 3-D system where the L-Valve that used is cylindrical in shape while in the experiment that conducted in this project is 2-D system and the L-Valve used is not cylindrical where the shape is square.

The error analysis is done to compare this two equation in Table 4.2 and Table 4.3 below:

Table 4.2: Error Analysis Between Calculation and Experimental

| Aeration Flow Rate, Q ($cm^3/s$) | Experimental (g/s) | Calculation (g/s) | Error (%) |
|---|---|---|---|
| 1000 | 99.83 | 83.17 | 20.03 |
| 1200 | 173.79 | 427.17 | 59.32 |
| 1400 | 247.75 | 771.17 | 67.87 |
| 1600 | 321.71 | 1115.17 | 71.15 |
| 1800 | 395.67 | 1459.17 | 72.88 |

Table 4.3: Error Analysis Between Calculation and Experimental With 0.215 Correlation

| Aeration Flow Rate, Q ($cm^3/s$) | Experimental (g/s) | Calculation (g/s) | Error (%) |
|---|---|---|---|
| 1000 | 99.83 | 17.88 | 458.28 |
| 1200 | 173.79 | 91.84 | 89.23 |
| 1400 | 247.75 | 165.80 | 49.43 |
| 1600 | 321.71 | 239.76 | 34.18 |
| 1800 | 395.67 | 313.72 | 26.12 |

As shown in this expected result, the threshold aeration rate is the aeration rate where the solid start to move while maximum solid flow rate is the point where the increased aeration rate will not affect the solid flow rate. Besides, we also want to find the slope for the graph to know the optimum aeration that needed for a certain weight of solid particles that needed to be removed from the L-Valve or the moving beds. Based on the error analysis, the error is too big. This equation is not suitable for this experiment because this equation is specifically for the 3-D Model of L-Valve while in this project, 2-D model is used. Because of that the value for $Q_{TH}$ that obtained is too low and the equation for the straight line of solid particles mass flow rate vs. aeration rate is too big. However, the value of $W_{max}$ is still in the range.

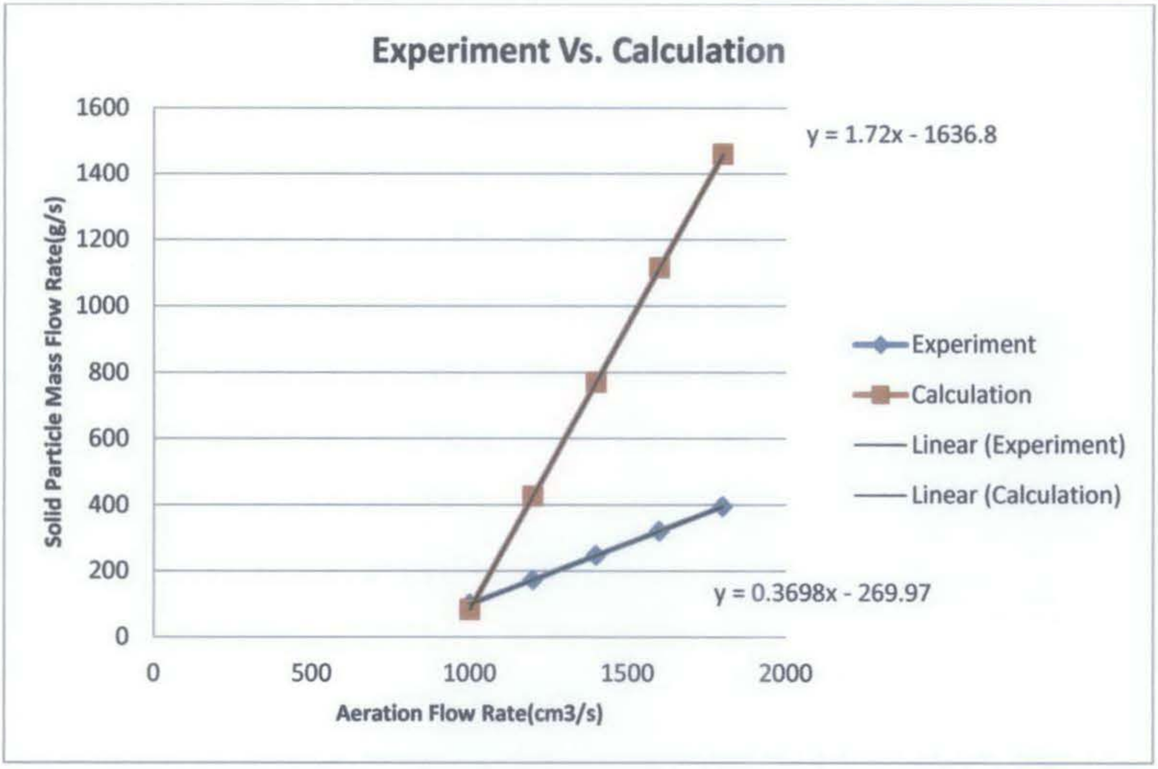


Figure 4.12: Comparison of Experimental and Calculation Data

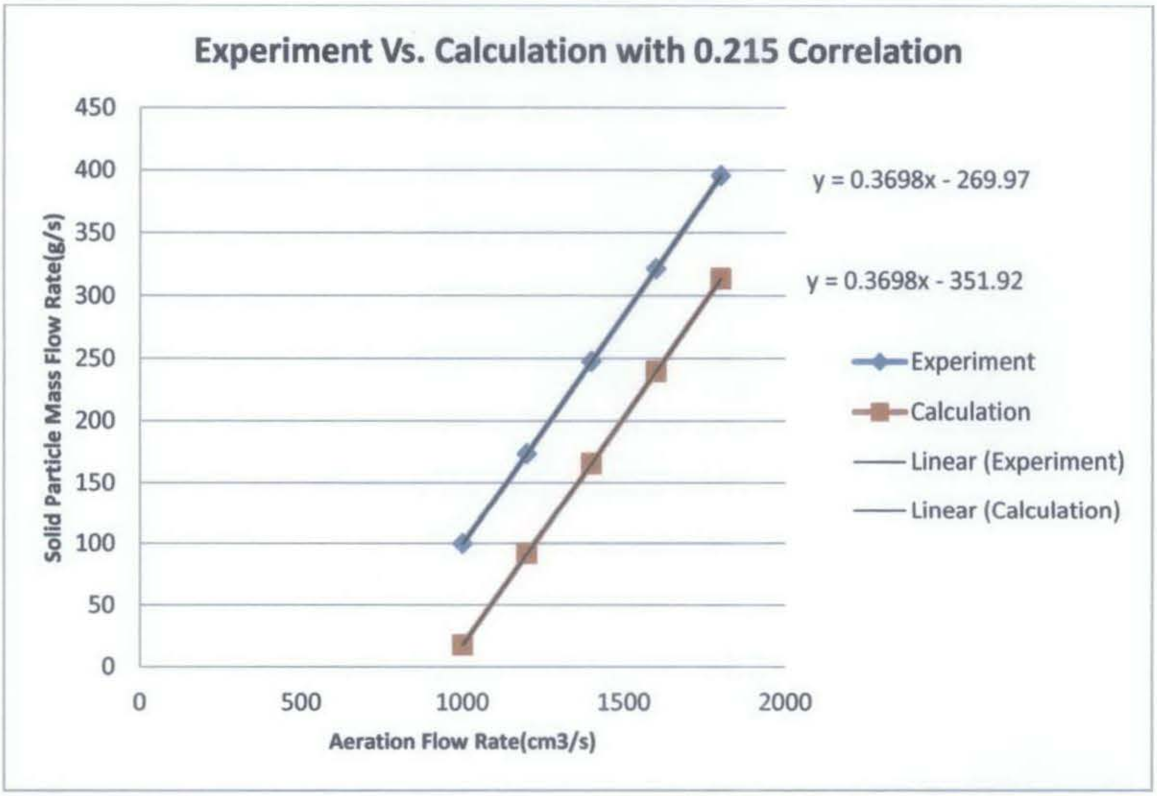


Figure 4.13: Comparison of Experimental and Calculation Data with 0.215 Correlation

From figure 4.12 and 4.13, the comparison of data from experimental and calculation is done in the graph. From the earlier equation, the difference of slope is too big and the pattern of graph is very differ for equation and calculation. However, when the 0.215 correlation is added to calculated equation, the graph is look alike but with the different y-intercept. This is due to some parameters not yet discover in this experiment. The calculated equation is supposedly have lower error but due to the equation given is supposedly used for 3-D model, the 2-D model that is used in this experiment is not too suitable. However, from this experiment the equation that obtained can be used for the 2-D model mass flow rate prediction. The equation is as below:

$$W = 0.3698Q - 269.97$$

For the design of rice dryer, the prototype that designed is based on the California dryer. However, this dryer can be stack with more of this dryer to increase the product of dry rice. With this type of dryer, the pressure drop in rice dryer can be decreased compare to the batch dryer that commonly used in Malaysia. This fabricated model is done with the cardboard to show the general shape of the dryer that proposed. This model can be improved with the addition of scrambler inside the space of solids moving to increased the contact time with hot gas. Due to time shortage, only the California dryer concept is applied to this proposed of dryer. This dryer also can dry the rice with a lot more efficient. With the radial flow gas, the drying process will take place wholly to the grain. The surface area of rice that touch with hot gas is higher compare to using batch dryer. With this type of dryer, the space of dryer can be optimized compare to the batch dryer. However, the cost of this dryer will be more than the batch dryer due to more equipment needed. The maintenance also will be increased using this type of dryer compare to the batch dryer. Although the cost is higher than batch dryer, the efficiency of this dryer is supposedly higher than batch dryer. With slightly more cost, the efficiency of rice drying can be increased. This is very good for industry of rice drying.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In our industry the radial flow moving bed reactor are widely used. For example, chemical reaction process whose catalyst decays reversibly and rather quickly, continuous operation, is possible by use of a moving bed of catalyst which slide down through the reactor under the gravity, while the reaction mixture is passed horizontally cross through the bed. The flow of solids in moving beds and L-valves as a function of aeration rates has been investigated in this project. So, when the aeration rate is increased, the pattern and the mass flow rate of solids will also increase. Besides, the withdrawal of solids is the critical issue in cross-flow rice dryer which is also a type of moving beds. Screw mechanism still practiced to remove the dried rice from drier which is expensive and high power consumption. Use of dense phase pneumatic transport in horizontal pipes attached to the silo/bin which is L-Valves for solid flow control also being investigated throughout the relationship of aeration rate and solid particle flow. The L-Valve that can be used in removing rice from the silo is more efficient and cost-saving. The L-Valve can be used in the rice dryer as the hopper to collect from the rice dryer. When the rice needed to removed from the hopper into the sacks, the aeration gas can be started to remove the rice from the L-Valve. The aeration rate can be adjusted for difference amount of rice collected. So, the higher aeration rate used will increased the solid mass flow rate. This project is very important for implemented this technology in the rice drying process. Besides, to also make it easier, the new type of rice dryer is also proposed. The rice dryer that proposed is more effective and efficient compare to the batch dryer that used throughout Malaysia. The pressure drop in the proposed dryer is also lower and can saving the cost in the operation of rice dryer.

## 5.2 Recommendations

For this project, there are a few recommendations that can be applied. The effects of the size, density and shape of solid particle to the solid discharge rate also can be investigated. This mean that if, the different solid particles used such as sand, flour or rice, how will these solids particle will move with certain aeration rate Besides, the effect of the different sizes of bed to the solid discharge rate also can be investigated. The different size of beds can be manipulated with changing the $H_U$ or $H_D$ of the models. Besides the diameter of the beds also can be manipulated to be tested thus improving this study. For these parameters to be tested, a long time periods are needed. The type of apparatus also must be changed to the 3-D model to test the equation from literature. The rice drying in cross-flow dryer is very good for rice industry in Malaysia due to its efficiency and energy saving. However, the uses of batch dryer are still commercial in Malaysia. For the most efficient rice dryer, the zig-zag dryer also must be further studies because this type dryer has a low pressure drop and also has more mixing between rice particle and hot gas. These two advantages are very important in rice drying because it can lead to the more efficient and low-cost dryer. Moreover, the topic of particle flow in moving beds also received very little attention in academic circles though they are widely used in the industry. With the solid discharge mechanism using aeration rate, the cross-flow rice dryer can still be improved.

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