Studies on a Two-layer Swirling Fluidized Bed (SFB)

by

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12896

MECHANICAL ENGINEERING

Project Dissertation is submitted in partial fulfillment

of the requirement for the Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2013

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved By,

_____

Chin Yee Sing

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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 my acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

_____

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ACKNOWLEDGEMENTS

First of all, the author would like to express his sincere gratitude to the God for his blessings which provide the author with endless strength and motivation to complete his Final Year Project at Universiti Teknologi PETRONAS (UTP). Besides, the author is indebted to following individuals who have selflessly contributed to the development of training experiences as well as this final report:

Ms. Chin Yee Sing, FYP Supervisor

Assoc. Prof. Dr. Hussain H. Al-Kayiem, FYP Examiner

Assoc. Prof. Dr Tadimalla Varaha Venkata Lakshmi Narasimha Rao, FYP Examiner

Prof. Vijay R. Raghavan, FYP Referee

Dr. Azmi Abdul Wahab, FYP Coordinator

Mr. Vinod Kumar, Graduate Assistant

Mr. Mior Rosgiazhar, Lab Executive

I would like to give my special thanks to my supervisor, Chin Yee Sing for her invaluable advices and exceptional guidance during my study and my final year project. The trust and received from the supervisor in carrying out the study and the patience to supervise the author will always be remembered. I would also like to extend my appreciation to the faculty members, lecturers and post graduate students who have helped in my final year project for their precious time, suggestions and comments.

Finally, I am deeply grateful to my parents who support me throughout my study in UTP. Without their patience, constant support and encouragement, my achievements would not be possible and meaningful.

ABSTRACT

Swirling Fluidized Bed is a newer development of fluidized bed in fluidization technology. A significant amount of research work has been carried out on swirling fluidized bed since 1990s. Even though Two-layer regime swirling fluidized bed has been discovered by previous researchers, a comprehensive understanding on its hydrodynamics characteristics with respect to different designed parameters has not been fully established. Increasing interest on determining the superiority of swirling fluidized bed over conventional bed becomes the driving force of further studying swirling fluidized bed hydrodynamics behaviors as a sequel to the earlier work of the past researchers, especially in Two-layer swirling fluidized bed. In fluidization processes, bed pressure drop is crucial as it determines the power required to achieve fluidization. Full-scale experiment were carried out by assigning the parameters such as particle size, bed weight and superficial velocity in order to study the effect of them on the hydrodynamics characteristics of Two-layer swirling fluidized bed behaviors. In the study, the author started the experiment by manipulating the superficial velocity up to approximately 4.0m/s and bed weight from 500g to 3000g, to find out the particular bed weight when Two-layer regime started appearing and ended the experiment in elutriation regime. Spherical particles of 4mm, 5mm and 6mm were be experimented at each time. Blades with overlap angle of 18˚ and inclination of 10˚ were used in the experiment. The studies show that due to the presence of frictions and electrostatic charge, more energy is required in larger bed weight to achieve fluidization. In addition, as the bottom swirling layer has better quality of fluidization, small bed loadings with lower bed height are encouraged to minimize the bed expansion hence reduce the effect of undesirable top conventional layer while maintaining high value of height of bottom swirling layer and height of top bubbling layer (S:B) ratio.

Contents

LIST OF FIGURES

ABBREVIATION, NOMENCLATURES AND LIST OF SYMBOLS

SFB	Swirling Fluidized Bed
S:B Ratio	Swirling layer height to bubbling layer height ratio
Θ_o	Blade overlapping angle
Θ_i	Blade inclination angle
d	Diameter
ρ	Density
g	Gravitational constant
μ	Fluid viscosity
Δp	Pressure drop
V_s	Superficial Velocity
V_r	Reference Velocity

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fluidization can be defined as an operation by which a bed of solid particles acquires fluid-like properties when passing air or liquid through it. Plenty of fluidized bed concepts such as conventional bed, centrifugal fluidized bed and circulating fluidized bed were patented since a decade ago. Most of them are adopted and applied in many industrial operations which involve direct contact between fluid and solids such as granulation, coal combustion, drying of solids, exfoliation processes, metal surface coatings, and catalytic thermal cracking. Swirling Fluidized Bed (SFB) is one of the recent developments to tackle the drawbacks of the conventional bed such as directional limitation in gas flow rate to prevent elutriation in bed, limitations on the magnitude of gas and particles distribution. This newly designed fluidized bed is equipped with an annular bed where gas injected through the inclined distributor blades, causing a swirling motion of solid particles in a confined circular path. From the studies of past researchers, this swirling fluidizing technique has been proven to be more advantageous to produce a better fluidization quality because of its superior characteristics.

In SFB, Two-layer regime fluidization only exists in relatively deep bed which features of the behaviors of swirling bed and conventional bed, in bottom swirling regime and top bubbling regime respectively upon acquiring sufficient gas superficial velocity (as shown in Figure 1.1). SFB is the most recent variant in fluidized bed which has set a new benchmark in fluidization engineering.

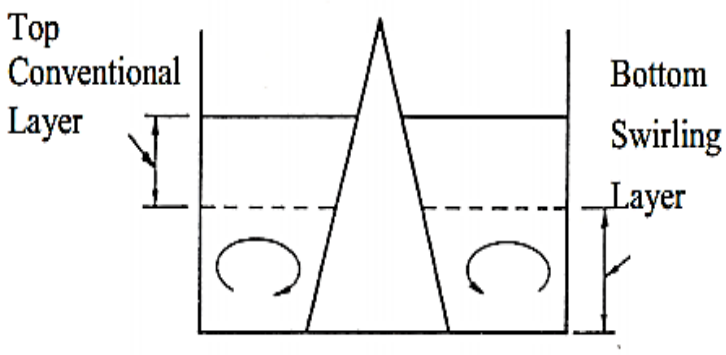


Figure 3.1: Two-layer Regime Fluidization

1.2 Problem Statement

Plenty of researches have been carried out in the SFB field by researchers from different countries. However, relatively little research has been done on the field of Two-layer SFB. According to Paulose [1], swirling fluidized bed possesses superior performance over conventional bed, critical parameters are required to reduce the effect of the undesirable top conventional layer. Inadequacy of available technical references in this field has been the problem since the discovery of Two-layer SFB. This indeed creates the opportunity to the author to study the hydrodynamic characteristics in a SFB with an upper conventional bed in Two-layer regime fluidization.

1.3 Objectives

Bed pressure drop is one of the hydrodynamic characteristics in SFB. Experimental studies on the parameters such as particle size, bed weight and superficial velocity describe the bed behavior which will affect the pressure drop and hydrodynamic behavior of Two-layer SFB. Therefore, the author aims to develop the fundamental understandings on Two-layer SFB based on the objectives below:

i. To study the hydrodynamic performance in a swirling fluidized bed with a suprajacent bubbling bed.
ii. To study the heights of each of the two layers.
iii. To determine the critical parameters such as bed weight, superficial velocity, and particle sizes and shapes to reduce the effect of the top conventional bubbling layer in Two-layer SFB.

1.4 Scope of Study

By taking the earlier work of Sreenivasan and Raghavan [2] on the observation of two-layer regime fluidization and Goo et al. [3] on the study of relatively shallow bed regimes as foundation references, this project is aimed at exploring the different flow regimes in the two-layer beds through visual observation and measurement of bed pressure drops at various flow rates of the gas on different bed weight. The distributor pressure drop is represented by the pressure drop for an empty bed and the total pressure drop is denoted by the pressure drop across a bed of particle. Bed pressure drop is the pressure difference between total pressure drop and distributor pressure drop.

Experimental studies at the changes of two-layer regimes resulted from different combination of parameters such as bed weight, superficial velocity, particle sizes and shapes, and blade overlapping angle and bed inclination angle will be carried out to enable the production of comprehensive analyses and discussion on the hydrodynamic characteristics in Two-layer SFB. Demarcation of bottom swirling regime and top bubbling regime will be done by measuring the height by using the scale attached to the cylindrical bed wall.

On the other hand, the scope of this project does not include the detailed analytical study of Two-layer SFB, formation of dead zone in Two-layer SFB, and trajectory motion of particles.

CHAPTER 2

LITERATURE REVIEW

2.1 Fluidization Fundamentals

Granular materials are always brought closely contacted with flowing fluid in many technological operations. Fluidization is one of the popular processes to be adopted in these operations [4]. Different types of fluidized beds have been vastly studied for industrial implementation and improvement. According to Kunii and Levenspiel [5], Vinod and Raghavan [6] and Faizal et al. [7], the similar observations found in their studies are when increasing the superficial velocity of fluid flowing through a bed containing solid particles, the pressure drop across the bed will keep on increasing until a stage where all the particles are suspended by the flowing fluid. At this moment, it is deduced that the particles weight is counterbalanced by the frictional drag force created by the flowing fluid which is in between particle and fluid. At the same time, Abereruagba et al. [8] claimed that any section of the bed will experience the equal amount of pressure drop, which is approximately equal to the weight of fluid and particles, and thus the bed is said to be fluidized. At this point, incipient fluidization occurs whereby the velocity of the fluid is the minimum fluidization velocity.

Next, at a slightly higher superficial velocity, bubbles cavities will form among the bed particles and this regime is called bubbling regime [9]. The particles that are being fluidized behave like rising bubbles in water. They rise through the bed and burst upon reaching the surface. The particles will fly in all direction before falling back to the bed. Furthermore, slugging regime is reached when the air cavities coalescent to be strong enough to suspend more portion of the bed weight. Vigorous mixing and high heat transfer rate are achieved in this regime [10]. According to Goo et al. [3], this regime is greatly affected by the bed weight and a great fluctuation will be experienced in the bed pressure drop. By further increasing the superficial velocity, the particle will become elutriated, followed by the reduction in pressure drop. Finally, all particles are blown out from the containing vessel in the elutriation regime.

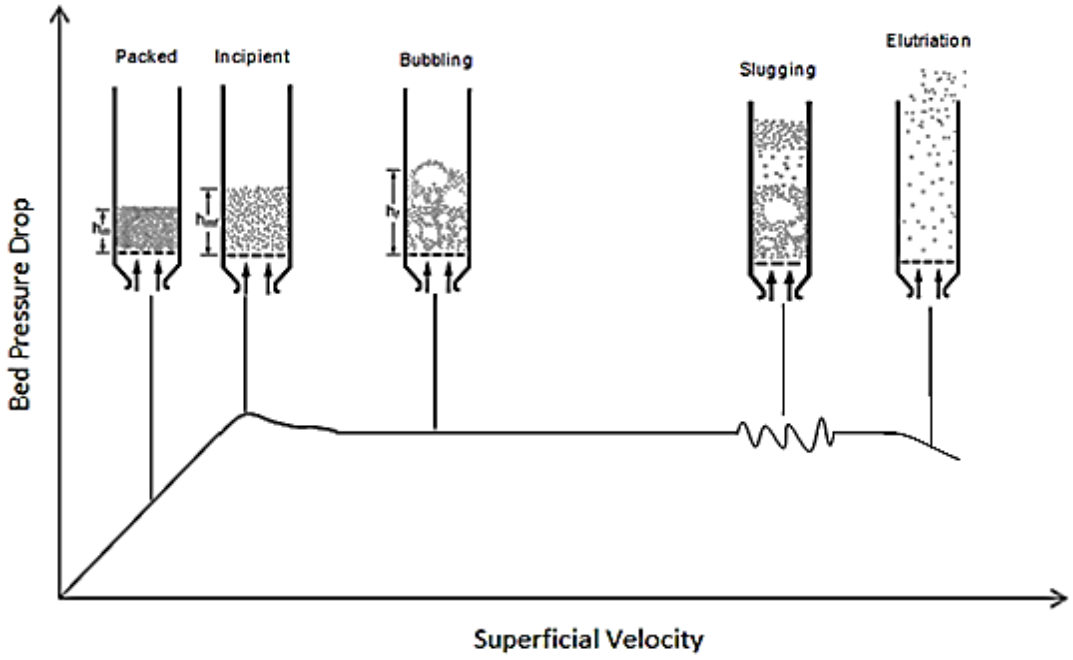


Figure 4.1: Conventional Bed Regimes *(Reproduced from [11])*

2.2 Swirling Fluidized Bed

Sreenivasan and Raghavan [2] have investigated that typical regimes of operation in a swirling fluidized bed consist of packed bed, minimum fluidization, bubbling, slugging, swirling, and elutriation. Therefore, as the flow rate increased, the different flow regimes can be summarized as follows:

i. Packed and static
ii. Bubbling
iii. Wavy motion: The swirling motion extends over a certain arc of the bed, while the remaining arc is static.
iv. Two-layer fluidization: A lower swirling lower layer with a bubbling top layer.
v. Stable swirling: Perfect fluidization occurs and the particles swirl smoothly.

Paulose [1] stated that one of the superior features of SFB is the annular bed, where the injection of gas is through the inclined openings of distributor. Gas entering the bed consists of horizontal and vertical components. The vertical component causes lifting of the particles while the horizontal component creates a swirling motion force toward the bed particles. Thus, the bed can be easily fluidized by the inclined gas injection which causes swirling motion of particles in the containing vessel. A better quality of fluidization can be achieved in a SFB due to its comparatively lower distributor pressure drop compared to conventional bed. Paulose's theory is then realized by Kaewklum et al. [12] in their studies on swirling fluidized bed combustor. An annular spiral air distributor in which the fluid velocity is represented by its axial, radial and tangential components which are capable of giving swirl motion to the bed particles for gas-solid transportation. Vinod et al. [6] also affirmed that SFB has following advantages over conventional fluidized bed:

i. More energy efficient
ii. Lower distributor pressure drop
iii. Higher quality fluidization with better mixing

Sobrino et al. [13] highlighted the importance of distributor pressure drop which functions to disperse the gas uniformly over the whole cross-section of the bed. Paulose [1] said that a good gas distributor shall possess the following qualities:

i. Low distributor pressure drop at the operating velocity to minimize the power consumption.
ii. Strong enough to withstand both thermal and mechanical stresses.
iii. Ability to prevent particle flow back to the plenum chamber at low airflow.
iv. Minimum particle attrition.
v. Ability to prevent distributor attrition.

In fluidized bed processes, bed pressure drop is the main element to define the power required for fluidization and justifies the behaviors of the flow regime. Ergun [14] has stated that the pressure drop in a fluidized bed is due to the simultaneous kinetic and viscous energy losses. The distributor pressure drop is represented by the pressure drop

value for an empty bed and the total pressure drop is denoted by the pressure drop value across a bed of particle. Bed pressure drop is the pressure difference between total pressure drop and distributor pressure drop.

Vinod and Raghavan [4] observed that the bed pressure drop curve grows in an increasing trend with increasing superficial velocity. The curve behaves like a camel hump when it reaches a particular peak value, then it begins to decrease. This can be reasoned by decrease in inter-particle friction leads the bed pressure drop to decrease as the air cavities escape continuously from the bed particles. Besides, they further explained on the peak in the bed pressure drop is due to the additional energy required for rearrangement of the "locked" particles from the packed state in order to get them fluidized. Peng and Fan [15] pointed out the coexistence of fixed and fluidized regions in fluidizing bed contributes to pressure drop-flow rate hysteresis loop at incipient fluidization.

2.3 Two-layer Swirling Fluidized Bed

Sreenivasan and Raghavan [2] reported that the two-layer fluidization only happens in relatively deeper bed. It is claimed that two-layer regime only appears when the static bed height is greater than 45mm. However, this parameter might vary when the experiment is switched to another experimental setup with different bed diameter and area. Two-layer regime is formed when the minimum two-layer velocity is reached, a thin continuously swirling lower layer and a vigorously bubbling top layer is visible. It can be explained by the azimuthal component of the velocity vanishes at the interface between the two layers. This theory is fully supported by Paulose [1] in his findings that as the gas penetrated deeper into the bed, its horizontal momentum is attenuated, and finally dies out at certain height above the distributor, if the bed is sufficiently deep. On the other hand, if the bed is shallow, the velocity of the gas leaving the bed will still possess two directional components.

Apart from that, Goo et al. [3] have investigated operation regimes and reported the existence of two-layer fluidized bed in deep bed which consists of 2000g bed

loadings (as shown in Figure 2.2). It is observed that two layers are made up of constantly swirling bottom layer and an aggressively bubbling top layer. They have further discussed that the two-layer regimes would merge into a fully swirling region if the by continuously increasing gas velocity to be high enough before the elutriation regime occurs. Since the author's focus is only the two-layer regime (marked with red star in Figure 2.2), it provides useful information on the initial parameters to be used to kick start the experiment.

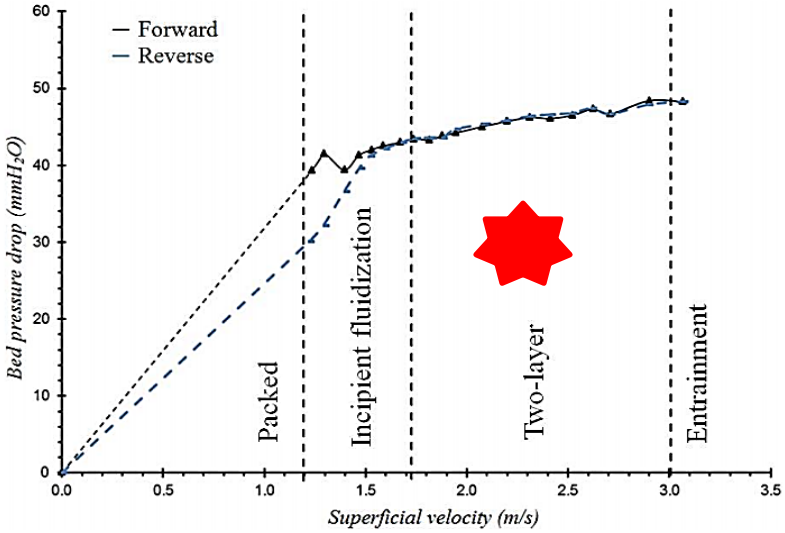


Figure 2.2: Flow regimes for deep bed (2000g of cylindrical particle L/D=4.10mm), [3]

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Project Activities

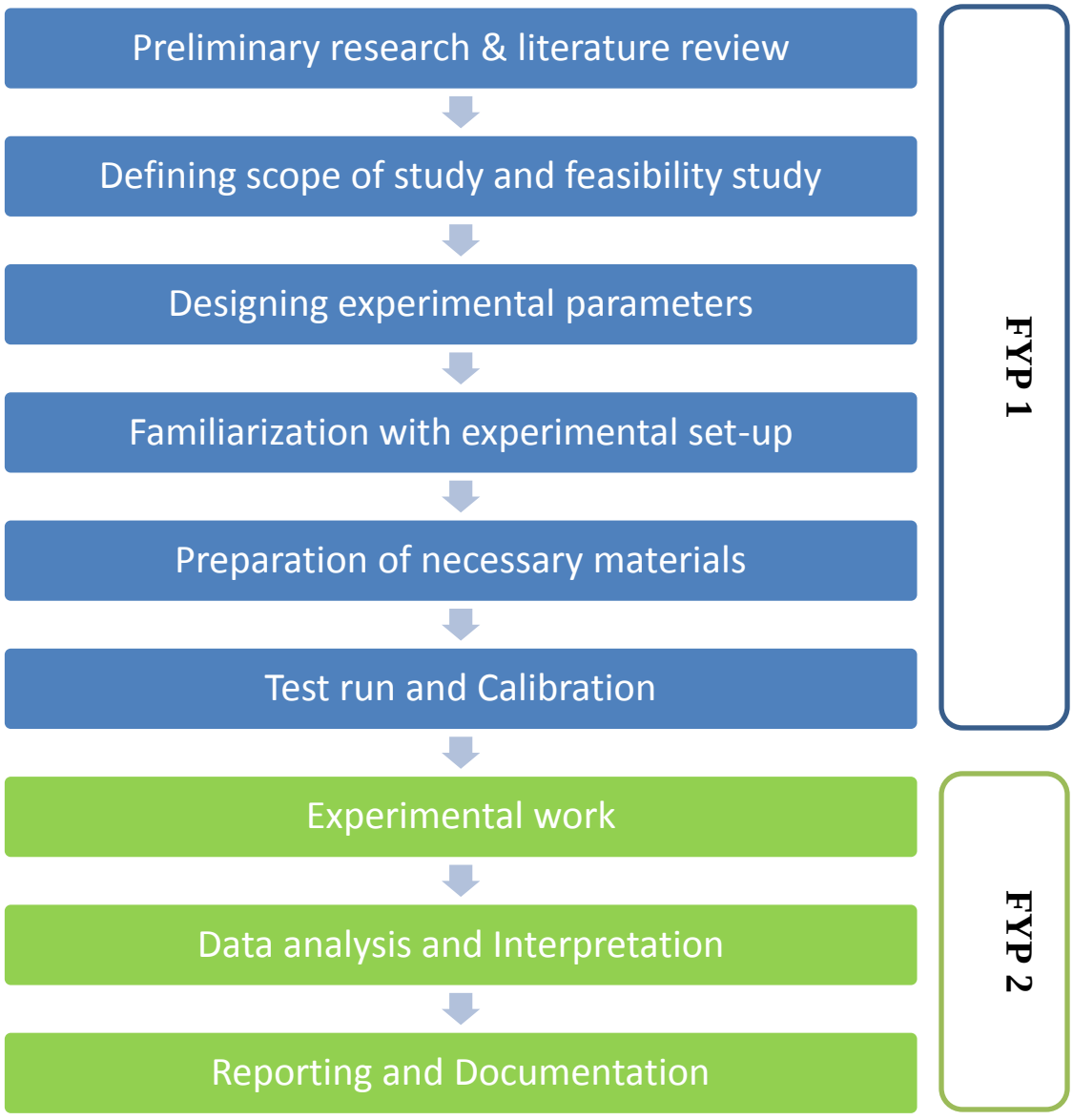


Figure 3.1: Project Activities Flow

In FYP 1, research has been conducted to acquire better understanding of SFB concept. A comprehensive literature review has been produced to aid the author in further reasoning the findings in the experiment work. Then, the author has refined the scope of study for the project to ensure it is feasible to be completed within the allocated time frame. Next, the author discusses with the FYP Supervisor in designing the experimental parameters. The parameters include the bed weight, superficial velocity of gas, bed sizes, and blade overlapping and inclination angle will be used to conduct the experiment.

Besides that, the author takes the initiative to get familiarized with the existing experimental setup to ensure a smooth flow of experimental work in future. Apart from that, in preparing for the required materials (spherical particles with different diameters), the author has booked the seizing apparatus and seizing the required particles in the Geoscience Lab. This is to ensure that the particles used are with uniform size in order to produce quality result. After that, upon receiving approval for lab access, the author is able to carry out the calibration work onto the experiment setup in the hydraulic lab. Several trial runs were carried out to ensure the experiment setup was properly calibrated and is able to produce consistent result.

In FYP 2, the author has scheduled to carry out the entire experiment work based on the designed parameters. Later, data analysis and interpretation will be carried out based on the result obtained and it is then followed by reporting and documentation.

As for project key milestone, the author managed to produce the results and analyses of findings on 4mm, 5mm and 6mm spherical particles. Chapter 4.0 Result and Discussions has clearly analyzed and discussed the findings of the experiments. A Gantt Chart (as shown in Section 3.2) is produced with listed deadline and event target dates to guide the author in achieving the targeted milestones. The author has progressed satisfactorily and successfully achieved the project plans as scheduled.

3.2 Study Plan (Gantt Chart)

No	Details / Week	1	2	3	4	5	6	7	Mid-semester Break	8	9	10	11	12	13	14
1	Selection of project topic	√														
2	Submission of proposal		√													
3	Proposal approval by Supervisor and Coordinator			√												
4	Preliminary research/ literature review			√	√											
5	Preparation of Extended Proposal					√	√									
6	Familiarization with Experimental Setup							√								
7	Proposal Defense Presentation Preparation									√	√					
8	Trial Tests and Calibration											√	√	√		
10	Preparation of Interim Draft Report														√	
11	Completion/ Submission of Interim Report															√

Figure 3.2: Gantt Chart and Key Milestones for FYP 1

No	Details / Week	1	2	3	4	5	6	7	Mid-semester Break	8	9	10	11	12	13	14
1	Experimental Work - Manipulate particle diameter - Manipulate bed weight - Manipulate superficial velocity	√	√	√	√	√	√	√								
2	Preparation of progress report	√	√	√	√	√	√	√		√						
3	Data Analysis									√	√	√	√			
4	Preparation of Draft Report											√	√	√		
5	Preparation of Technical Paper													√	√	
6	Preparation of Oral Presentation														√	
7	Completion/ Submission of Dissertation														√	√

√ Progressed Milestones

3.3 Experiment Equipment Setup and Hardware.

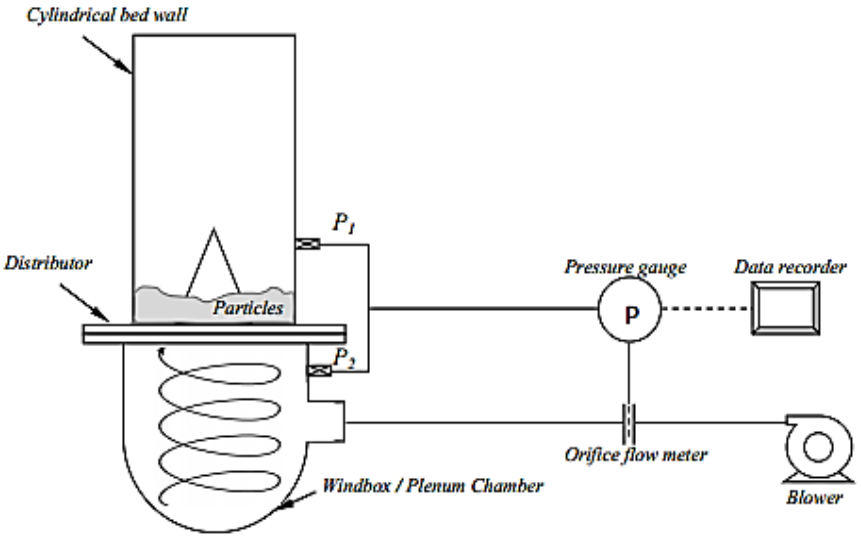


Figure 3.4: Schematic Diagram of Experimental Setup [3]

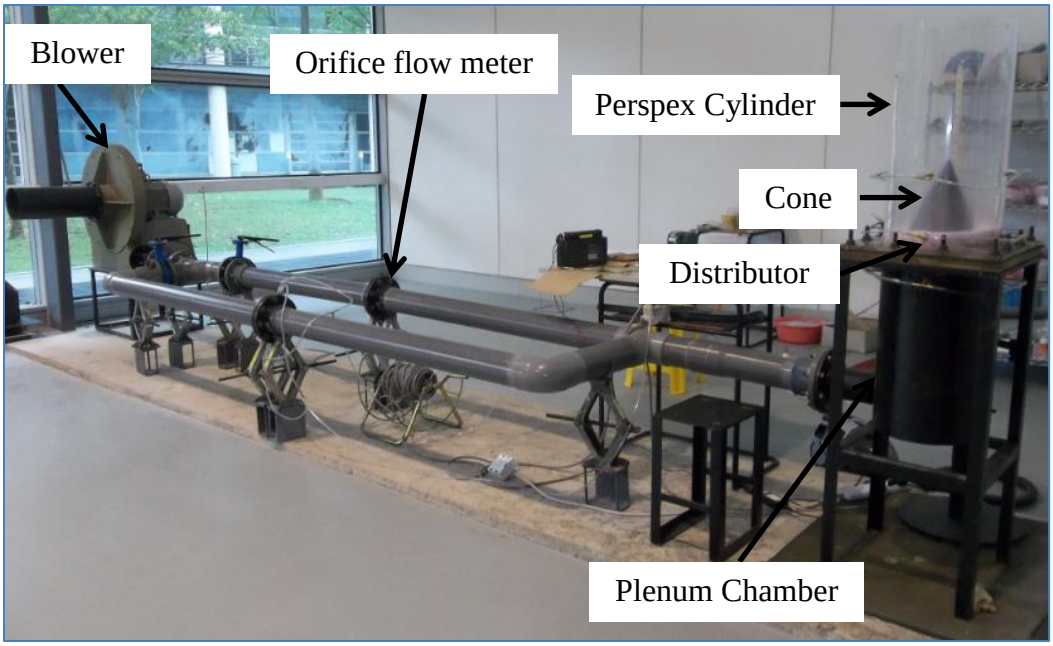


Figure 3.5: Actual Experimental Setup

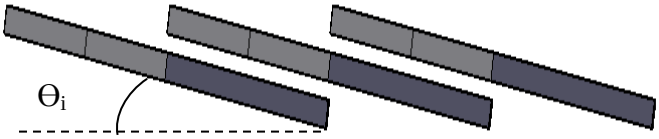


Figure 3.6: Blade Inclination Angle, Θ_i

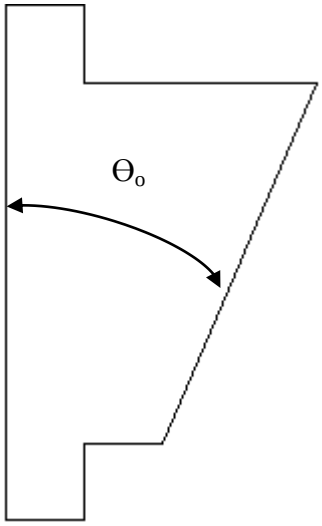


Figure 3.7: Blade Overlapping Angle, Θ_o

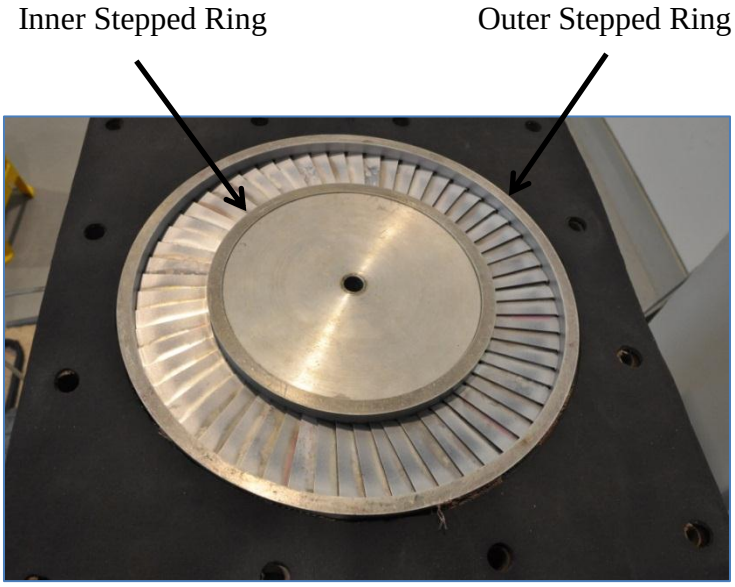


Figure 3.8: Distributor with the Arrangement of Blades between Inner and Outer Stepped Rings

Figure 3.9: Digital Pressure Data Logger

Figure 3.10: 4mm, 5mm and 6mm Spherical Particles

The experimental setup consists of Perspex cylinder which provides a transparent cylindrical wall to accommodate bed particles. The cylinder is screwed on top of the annular spiral distributor, which consists of 60 blades held tightly by the inner and outer stepped rings. The inner ring is placed on the center metal hub while the outer ring is supported by a Bakelite block. The inclination angle determined by the stepped ring directs the gas flow to pass through and enter the bed at the designed angle. Both the cylindrical wall and blade distributor are mounted on top of the Plenum Chamber.

The air flow supplied by the blower will pass through the pipe before reaching the hollow cylinder of the Plenum Chamber. An orifice plate is mounted at the middle of pipe connection in between the blower and Plenum Chamber to quantify the air flow rate. In the particle bed, a metal cone is mounted on top of the center metal hub. This is intended to reduce the overall cross section of the air passes through the distributor and

cause the air superficial velocity to increase. It also eliminates the dead zone at the center of the bed based on the Vikram et al. [16].

As shown in Figure 3.4, P1 and P2 are two tappings attached to the bottom of distributor and side wall of cylindrical bed respectively. Each tapping has 4 measuring points located at each quadrant of the cylinders to obtain average value of pressure drop. Digital pressure Data Logger (shown in Figure 3.9) is used to record the value of pressure reading at different point by adjusting the valve on the rubber pipe.

3.4 Experimental Procedures

i. In setting up the equipment setup, blades of overlap angle 18˚ are arranged on the 10˚ inner stepped ring at Bakelite and the 10˚ outer stepped ring to obtain 10˚ inclination angle.
ii. The thin carbon steel disk of 5 mm thick is placed on top of the inner stepped rings in order to keep the blades tightly.
iii. The cone is screwed at the center of the bed.
iv. The perspex cylinder is screwed with bolts and nuts to the Plenum Chamber.
v. Inspection of experiment setup is carried out by switching on the blower to ensure the setup can function well without leakage.
vi. The distributor pressure drop is measured at different air flow rates when the bed is empty.
vii. The air flow rate is varied by using electronic speed controller of blower.
viii. The air flow rate is measured using an orifice flow meter.
ix. The bed is loaded with 500g of 4mm spherical particles.
x. The total pressure drop across the bed and distributor is measured for different air flow rate.
xi. The bed pressure drop can be obtained by getting the difference between total pressure drop and distributor pressure drop.
xii. When two-layer regime is detected, top bubbling & bottom swirling layers height is measured (from the scale at the cylindrical bed wall).
xiii. The experiment is stopped when elutriation regime is noticed.
xiv. The experiment is repeated with an additional of 500g of 4mm particles at each interval until the bed is weighed 3000g.
xv. Step xiv to step xv are repeated for 5mm and 6mm spherical particles.

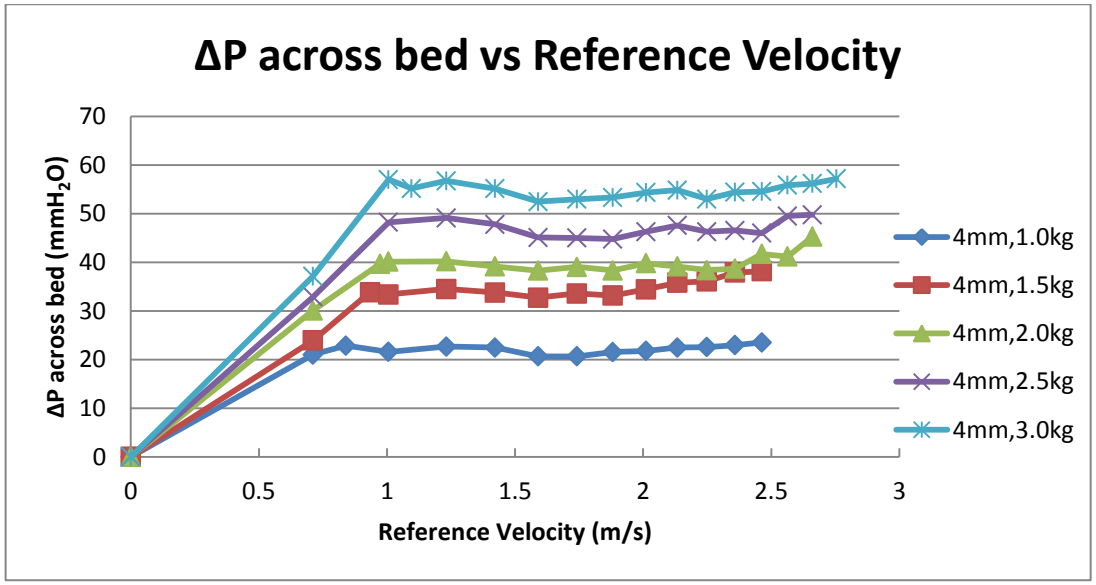
CHAPTER 4

RESULTS AND DISCUSSIONS

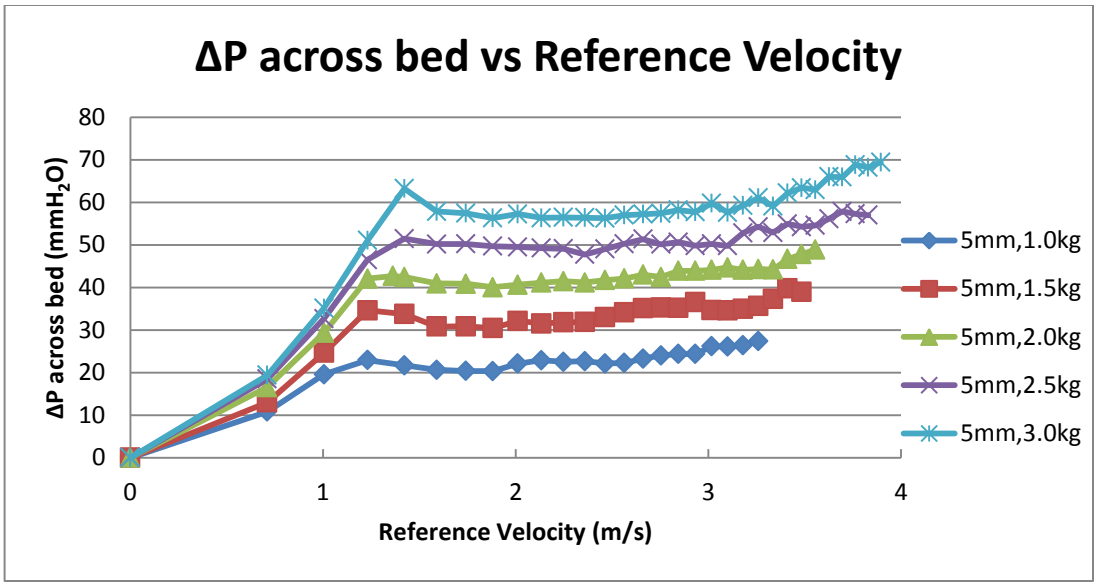
The Reference Velocity used in this report is analogous to Superficial Velocity in other references.

4.1 Effects of Bed Weights

Figure 4.1 shows the variation of pressure drop across the bed under the manipulation of increasing reference velocity on different bed weights of 4mm, 5mm and 6mm spherical particles.



(a)



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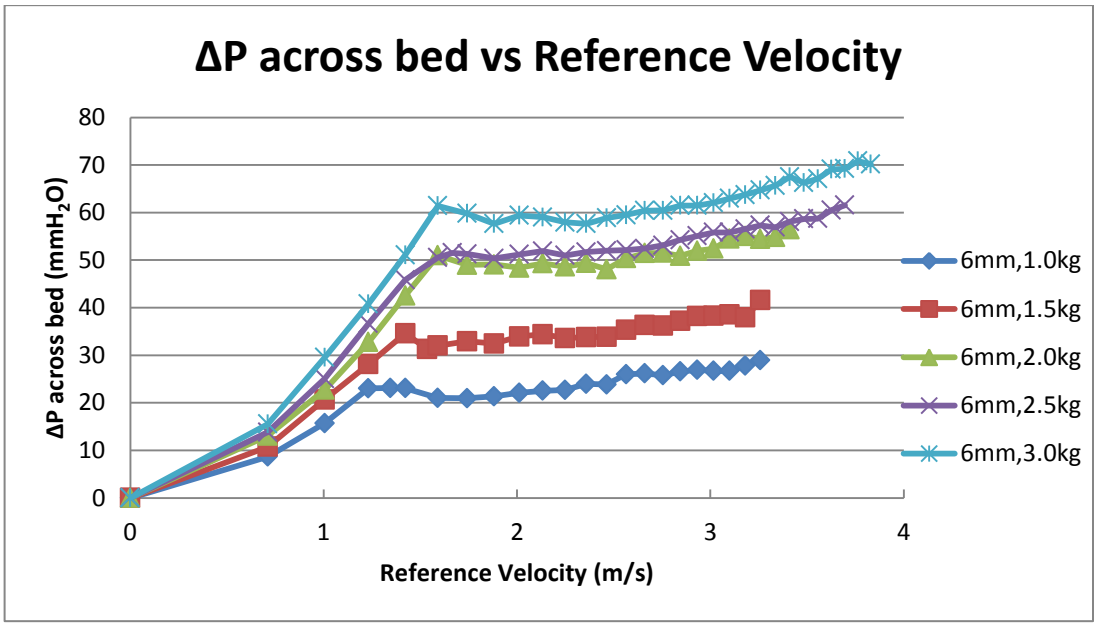


(c)

Figure 4.1: Graph of ΔP across bed vs Reference Velocity in (a) 4mm, (b) 5mm and (c) 6mm spherical particles

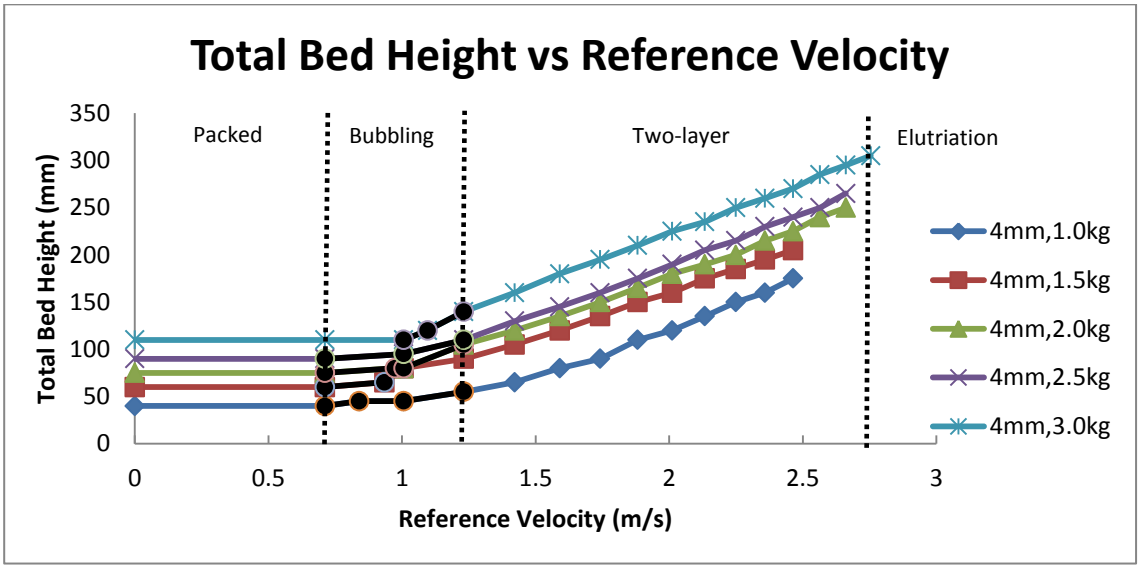
The bed weights are increased from 1.0kg to 3.0kg with an increment of 0.5kg each to determine the effect of bed weights onto the pressure drop. The plots indicates the higher the bed weight, the higher the pressure drop. This phenomenon can be

explained by when the bed weight is increased, the total particle surface area exposed to the fluidizing air will increase due to the increase in the number of bed particles. Consequently, the frictional drag force created by the fluidizing air when passing through the particles surface increases due to the increase in total particle surface area. In order for the fluidizing air to pass through the particles, additional energy is required to overcome the friction which results in the increase of pressure drop across the bed.

Furthermore, a trend of increasing pressure drop can be observed upon minimum fluidization. This can be reasoned by as the reference velocity increases, the frequency of interaction between the particles and particles becomes more and more and causes inter-particle friction to increase. Therefore, more energy is required from the gas flow to overcome the inter-particle friction and separate the particles before escaping out of the bed loadings.

4.2 Total Bed Height vs Reference Velocity

Figure 4.2 illustrates the relationship between the Total Bed Height and Reference Velocity on different bed weights of 4mm, 5mm and 6mm spherical particles.



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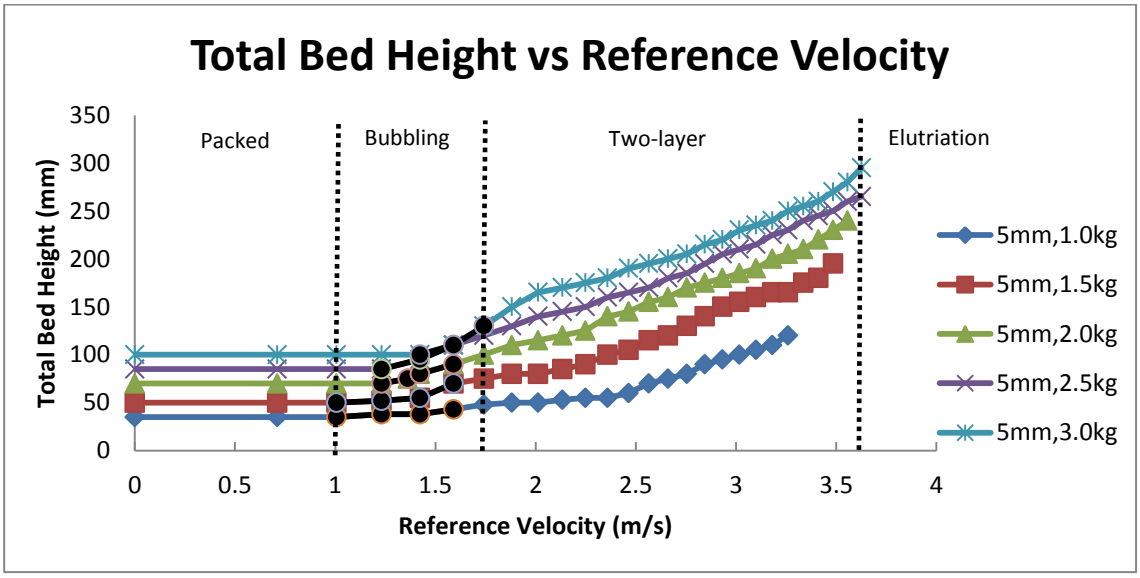

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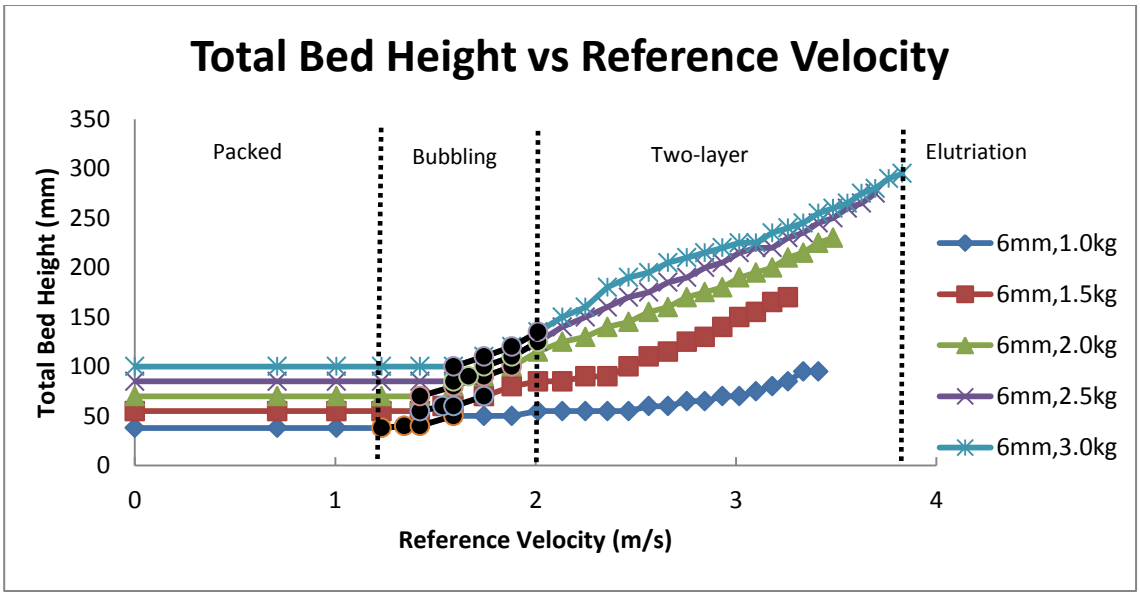


(c)

Figure 4.2: Graph of Total Bed Height vs Reference Velocity in (a) 4mm, (b) 5mm and (c) 6mm spherical particles

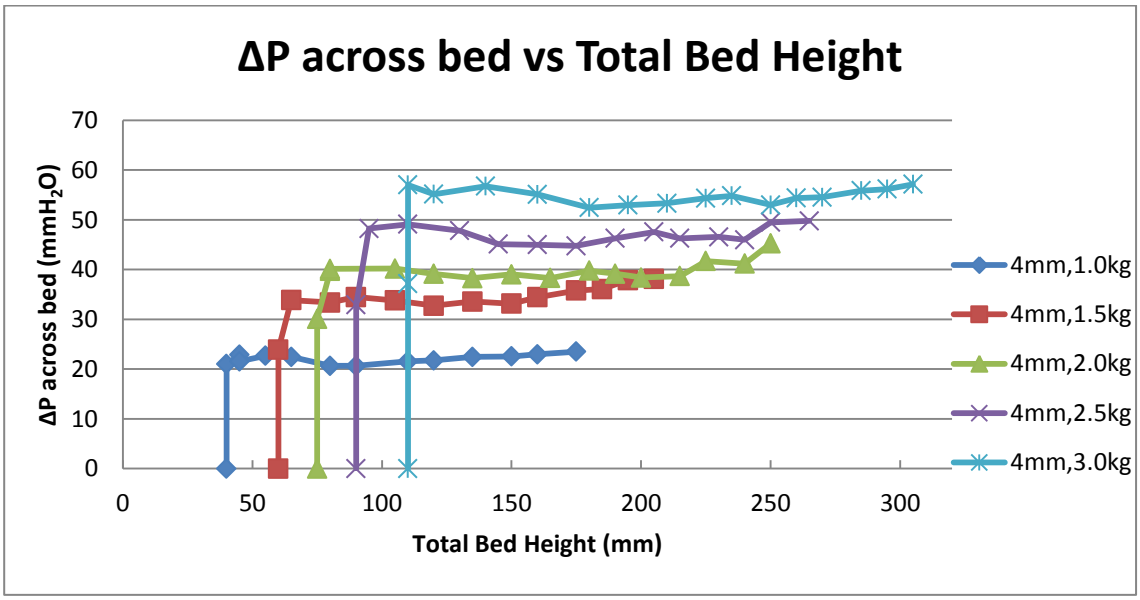
The Total Bed Height is the summation of bubbling layer height and the swirling layer height. The higher the reference velocity, the higher the bed height will be. The horizontal line represents packed bed. Upon reaching minimum fluidization velocity, the bed starts bubbling. Further increase in reference velocity, two-layer regime will start appearing with top bubbling layer and bottom swirling layer. Finally, the plot ends when the bed reaches elutriation regime. It can be seen that bubbling regime only appears for a short period of time before two layer regime start appearing. This has shown the superior characteristics of swirling fluidized bed which are able to minimize the undesirable effects contributed by bubbling regime. This phenomenon can be explained by the gas injected from the inclined distributor can be resolved into horizontal and vertical components. The horizontal component of gas injection is able to induce swirling regime in the bed of particles and enables the fluidization process to sustain longer before the bed is elutriated.

Another finding shows that the bed particles with larger diameter are more capable of withstanding higher reference velocity before the bed experiences elutriation

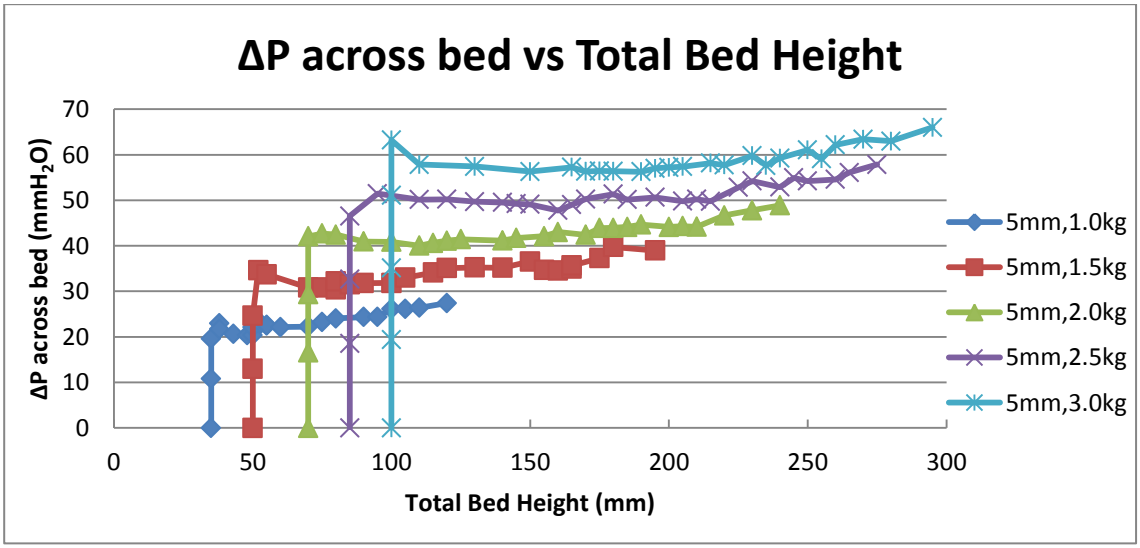
regime. This is because the larger diameter particle has smaller surface area per unit volume. Hence, the bed pressure drop experienced is relatively lower compared to the bed with smaller diameter particles. The friction produced is also relatively lower which prolongs the two-layer regime during fluidization before the bed is elutriated.

4.3 Bed Pressure Drop vs Total Bed Height

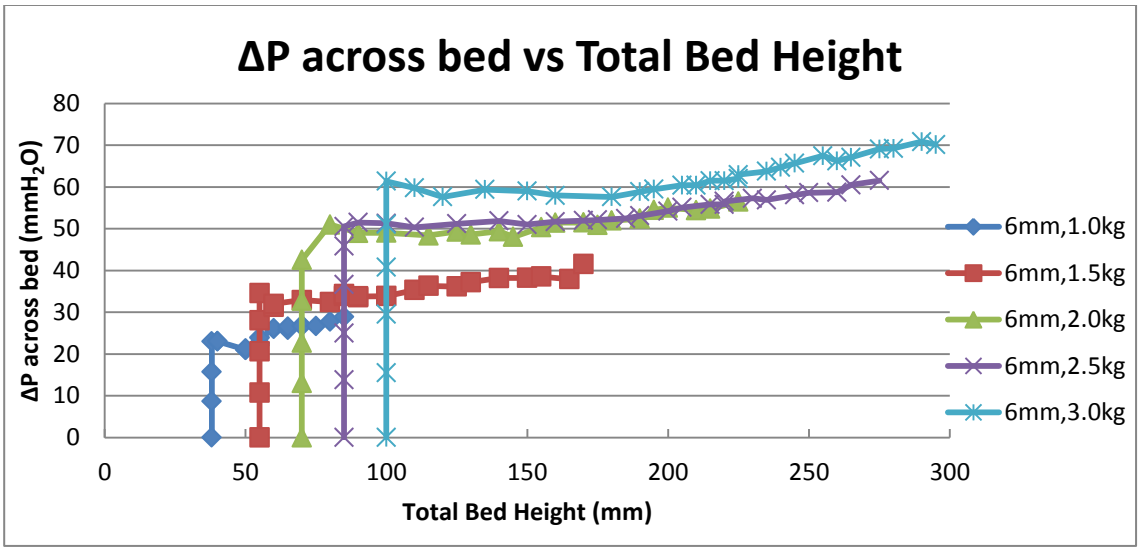
Figure 4.3 illustrates the variation of pressure drop across the bed with the expansion of total bed height when increasing the reference velocity of gas flow on different bed weights of 4mm, 5mm and 6mm spherical particles.



(a)



(b)



(c)

Figure 4.3: Graph of ΔP across bed vs Total Bed Height in (a) 4mm, (b) 5mm and (c) 6mm spherical particles

The total bed height is the summation of top swirling layer height and bottom bubbling layer height. The straight vertical line indicates the packed bed regime. Upon minimum fluidization, it clearly shows an increasing trend in pressure drop across the bed with expansion in total bed height. This observation can be reasoned by the bed expands more and more with increasing gas reference velocity. The angular momentum carried by the fluidizing gas is absorbed by the particles to cause the bed to have more vigorous swirling. Hence, more particles surface area is in contact with the cylindrical wall. In SFB, all the bed particles experience centrifugal force created by the inclined gas injection which is discussed earlier by Paulose [1]. The bed particles tend to be pushed against the cylindrical wall and hence the friction between particles and cylindrical wall is increased. Thus, more pressure drop across the bed is experienced as the less and less gas flow is able to escape from the particles with increasing bed loadings.

In addition, the bed particles have also experienced electrostatic force produced by the electrostatic charges generated from the friction between the moving particles and the cylindrical wall (as shown in Figure 4.4). It happens similarly with the attraction

of plastic wrap to one's hand when it is removed from a package. This phenomenon can be easily seen that particles stick to the cylindrical wall when the blower is switched off at the end of the experiment run. The attraction force between the particles and cylindrical wall produced due the presence of electrostatic charges requires additional energy from the fluidizing air to break the electrostatic bond. Hence, the pressure drop across the bed increases as the height of particles in contact with the bed wall increases with increasing bed loadings and reference velocity.

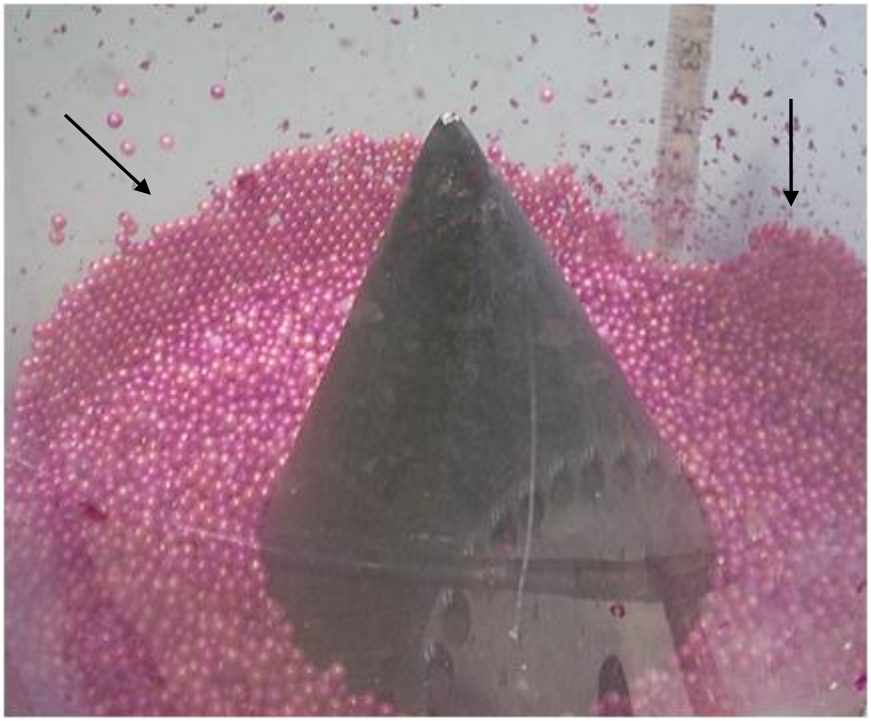
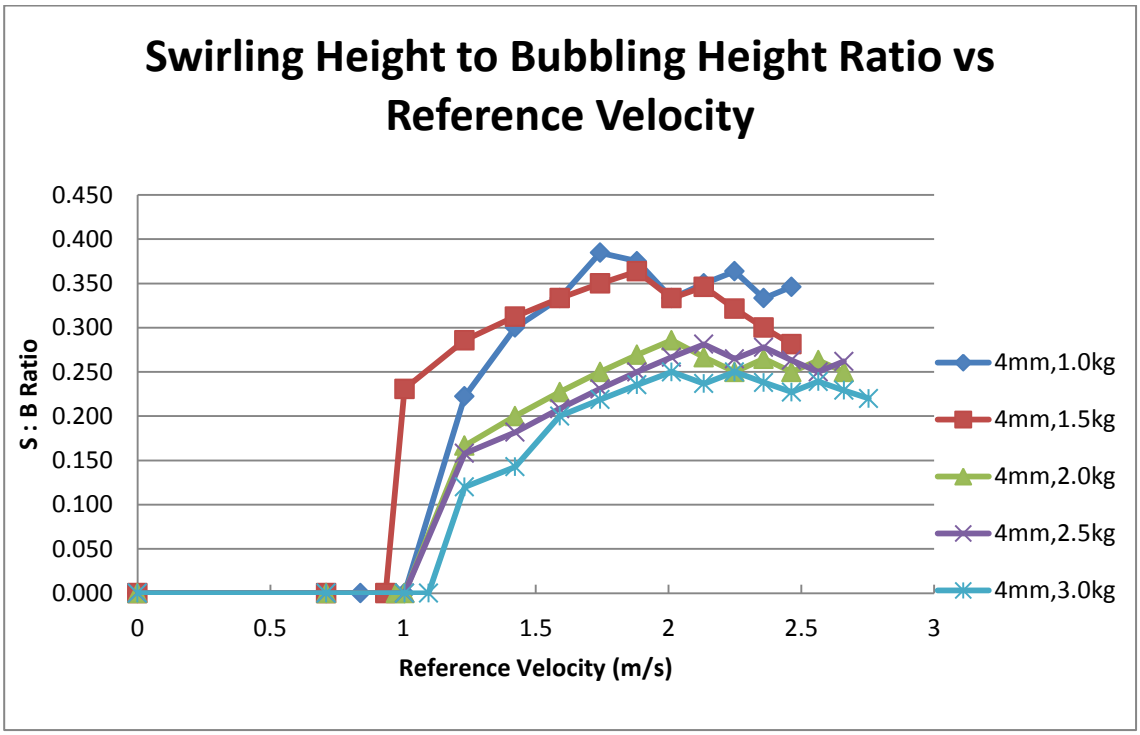


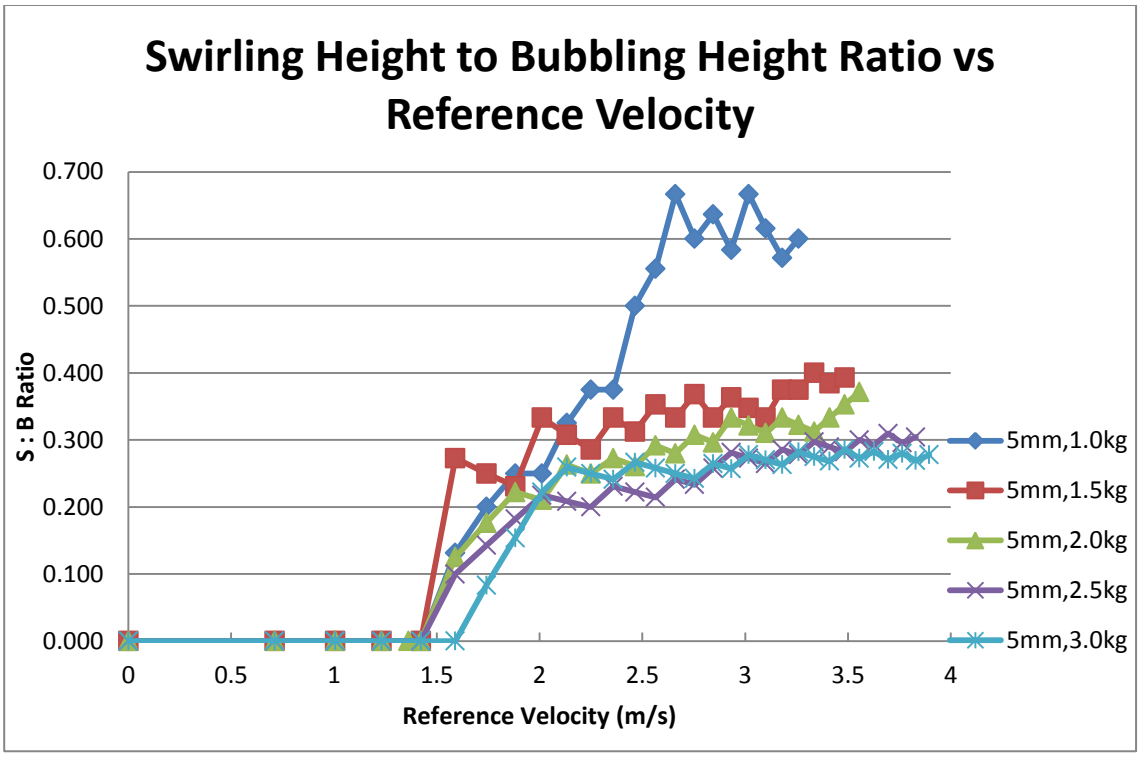
Figure 4.4: Presence of Electrostatic Force between Bed Particles and Cylindrical Wall at the end of experiment run

4.4 Swirling Height to Bubbling Height Ratio

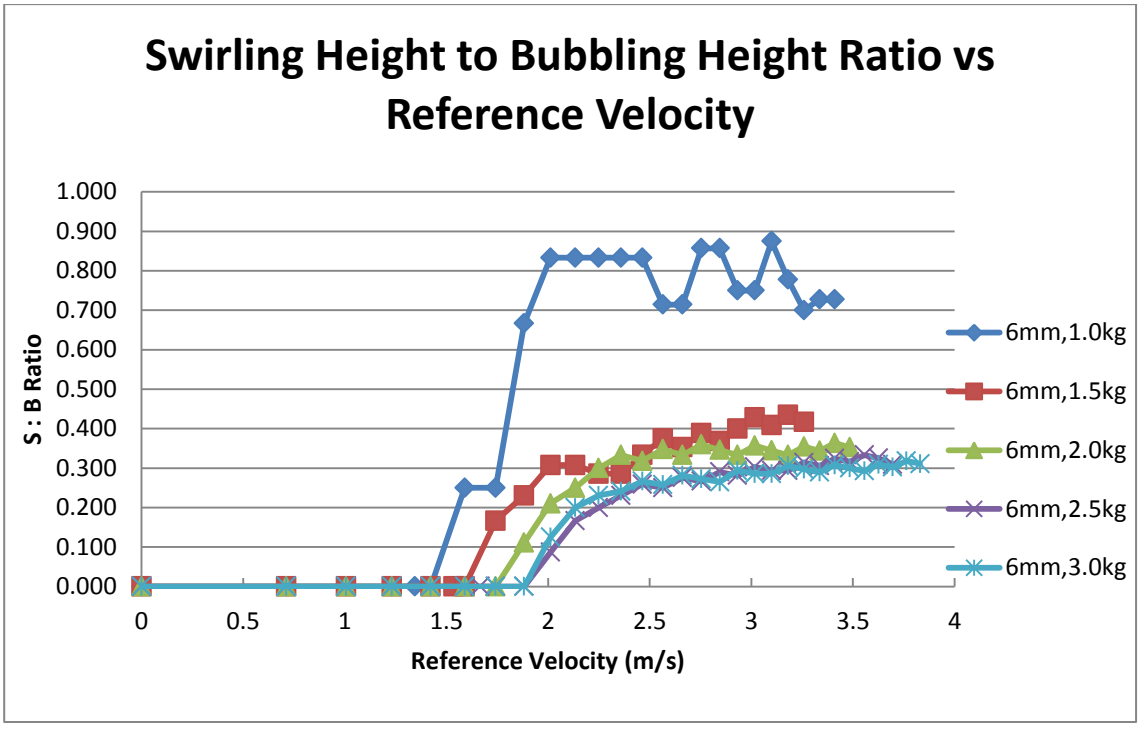
Figure 4.5 exemplifies the variation of swirling height to bubbling height ratio against increasing reference velocity on different bed weights of 4mm, 5mm and 6mm spherical particles.



(a)



(b)



(c)

Figure 4.5: Graph of Swirling Height to Bubbling Height Ratio vs Reference Velocity in (a) 4mm, (b) 5mm and (c) 6mm spherical particles

After running the experiments on 4mm and 5mm spherical particle, it can be deduced and observed that it is impossible to get rid of the undesirable top conventional layer in two-layer SFB. Then, swirling height to bubbling height ratio (S:B ratio) is inspired by the idea of reducing the effect of conventional bubbling layer in two-layer SFB. It acts as an indicator to enable the users to always opt for the higher value in S:B ratio as it is required to preserve the swirling regime as much as possible to achieve the better the quality of fluidization. From the plot, a clear observation can be made that the lightest bed loading carries the highest S:B ratio and S:B ratio decreases with increasing bed loadings. These findings can be explained by initiation of bottom swirling layer becomes harder and harder as the bed loadings increase. Higher reference velocity of gas flow is required to produce bottom swirling regime as there are more weights in the top bubbling layer pressing on them in heavier bed loadings. Hence, heavy bed loadings are not encouraged due to its poor performance of fluidization.

Concerning with the effort to reduce the spikes in the graphs shown in Figure 4.5 (a)-(c), the author would like to recommend that more repeatability of the experiment should be carried out in order to produce a more accurate and consistent trend of result. Due to time constraint and limited number of experimental setup, the experiment was only repeated for 2 times. The graphs show spiky trend towards the end of the fluidization process because heights measurement is becoming difficult as the bed is vigorously fluidized in two-layer regime. Demarcation between top bubbling and bottom swirling layers is unclear as the bed is approaching elutriation regime.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In this study, the hydrodynamics behavior of Two-layer SFB has been analyzed and studied based on the result obtained from the experiments. The main highlights of the findings are as below:

i. For all sizes of spherical particles bed, higher bed weight results in higher pressure drop across the bed, thus more energy is required to achieve fluidization.
ii. Larger diameter bed particle is preferred in fluidization because it can withstand higher reference velocity and experience less bed pressure drop, hence it prolongs the two-layer regime before the bed enters elutriation regime.
iii. During bed expansion, the increase in the friction and electrostatic force between particles and bed wall results in higher pressure drop across the bed, larger air reference velocity is needed overcome the friction in order to fluidize the bed of particles.
iv. In order to maintain the high value of S:B ratio as bottom swirling layer has better quality of fluidization, small bed loadings with lower bed height are encouraged to minimize the bed expansion hence reduce the effect of undesirable top conventional layer.

In a nutshell, the project covers the experimental study of the hydrodynamics characteristics of Two-layer Swirling Fluidized Bed. The outcomes of this project have provided informative and technical references on the field of Two-layer SFB. This experimental study has brought some project significances to the fluidization engineering which are the advantageous characteristics of swirling regime have been optimized to increase the efficiency of energy used during fluidization. Consequently, the operational cost of the fluidization processes could be reduced and finally increase the productivity.

With the provided functioning experimental setup available, it smoothens the progress of the project preparation work by saving the author's time in new equipment setup fabrication. Additionally, a well prepared Gantt Chart would help the author to stay focused in meeting with the listed deadlines and target dates. Therefore, this project is proved feasible to be completed within the given time frame.

The key milestones of the project have been progressed satisfactorily. The author managed to get familiarized with the proposed experimental procedures and other concerns regarding to some technical equipment adjustments. As far as it has progressed, the author has successfully come out with the result on the 4mm, 5mm and 6mm spherical particles and result validation has been obtained from the comparison made with the results trend done by the past researchers. Analyses and discussions have been carried out onto the findings of the experiment results.

Lastly, the author would like to take the opportunity to recommend detailed analytical studies of two-layer SFB to be carried out in future. It is believed that more accurate discussion and reasoning can be made which will be useful to serve as a benchmark for scaling up purpose of the reactor capacity. Besides, the author would like to suggest that natural particles to be used in future since the synthetic plastic beads that are being used now show electrostatic charge phenomenon throughout the experiment.

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APPENDICES

APPENDIX A

Example of calculation of Reference Velocity

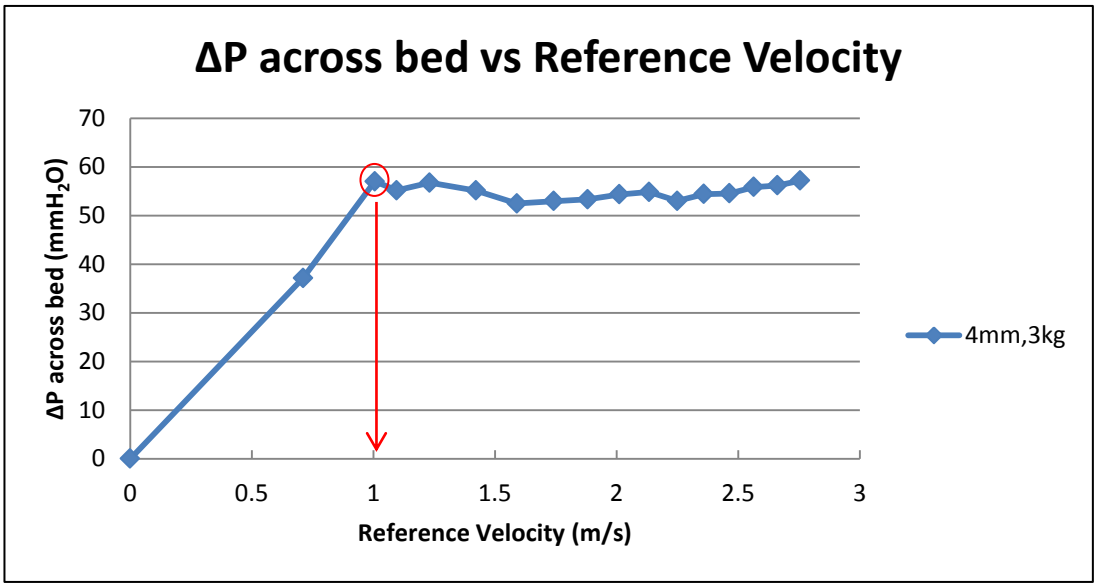

Figure A1: Graph of ΔP across bed vs Reference Velocity for Spherical Particle of 4mm diameter and 3kg bed weight.

At the point in the red circle in Figure A1:

ΔP across bed= 57 mmH_2O

$$\text{Reference Velocity, } V_r = \frac{0.00302 \times 0.668 \times \sqrt{\frac{2 \times g \times (\frac{\text{Pressure Difference, } \Delta P}{1.2})}{1 - (0.062)^4}}}{0.03927}$$

$$= 0.2249 \times \sqrt{\text{Pressure Difference, } \Delta P}$$

$$= 0.2249 \times \sqrt{57}$$

$$= \mathbf{1.10\ m/s}$$

Note: The Reference Velocity here is analogous to Superficial Velocity calculation in other references.

APPENDIX B

Calculation of Reference Velocity

$$\text{Reference Velocity, } V_r = \frac{\text{Fluidizing air flow rate, } Q}{\text{Bed area, } A_{bed}}$$

Fluidizing air flow rate, Q

$$= \text{Orifice plate hole area, } A_o \times \text{ Coefficient of discharge, } C_d \times \sqrt{\frac{2 \times g \times (\frac{\text{Pressure Difference, } \Delta P}{\text{Air density, } \rho_{air}})}{1 - (\text{Beta ratio, } \beta)^4)}}$$

Where,

Pipe diameter, D = 0.1 m

Orifice hole diameter, d= 0.062 m

Coefficient of discharge, C_d = 0.668

Air density, ρ_{air}= 1.2 kg/m^3

Beta ratio, $\beta = \frac{d}{D} = \frac{0.062}{0.1} = 0.62$

Orifice plate area, $A_o = \frac{\pi \times d^2}{4} = \frac{\pi \times 0.062^2}{4} = 0.00302 m^2$

Bed area $= \frac{\pi}{4}$ (Bed outer diameter, d_o^2 – Bed inner diameter, d_i^2)

$= \frac{\pi}{4} (0.3^2 - 0.2^2)$

$= 0.03927 m^2$

Therefore,

$$\text{Reference Velocity, } V_r = \frac{0.00302 \times 0.668 \times \sqrt{\frac{2 \times g \times (\frac{\text{Pressure Difference, } \Delta P}{1.2})}{1 - (0.062)^4)}}}{0.03927}$$

$$= 0.2249 \times \sqrt{\text{Pressure Difference, } \Delta P}$$

Note: The Reference Velocity here is analogous to Superficial Velocity calculation in other references.

APPENDIX C

Experimental Raw Data

Particle Type: Spherical Particle Size: 4mm Bed Weight: 1000g Initial Bed Height: 40mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	40	0	0	40	0.000	0.133
1	10	0.71	8.8	29.8	21	Packed	40	0	0	40	0.000	0.133
2	15.35	0.84	13.01	35.87	22.86	Start Bubbling	0	0	45	45	0.000	0.150
3	20	1.01	15.9	37.46	21.56	Bubbling	0	0	45	45	0.000	0.150
4	30	1.23	22.3	44.96	22.66	Bubbling + Swirling	0	10	45	55	0.222	0.183
5	40	1.42	30.05	52.5	22.45	Bubbling + Swirling	0	15	50	65	0.300	0.217
6	50	1.59	38.3	58.95	20.65	Bubbling + Swirling	0	20	60	80	0.333	0.267
7	60	1.74	44.8	65.44	20.64	Bubbling + Swirling	0	25	65	90	0.385	0.300
8	70	1.88	52	73.54	21.54	Bubbling + Swirling	0	30	80	110	0.375	0.367
9	80	2.01	57.75	79.5	21.75	Bubbling + Swirling	0	30	90	120	0.333	0.400
10	90	2.13	64.5	86.96	22.46	Bubbling + Swirling	0	35	100	135	0.350	0.450
11	100	2.25	72.11	94.65	22.54	Bubbling + Swirling	0	40	110	150	0.364	0.500
12	110	2.36	79	101.96	22.96	Bubbling + Swirling	0	40	120	160	0.333	0.533
13	120	2.46	85.16	108.68	23.52	Bubbling + Swirling	0	45	130	175	0.346	0.583
14	130	2.56	91.61	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 4mm Bed Weight: 1500g Initial Bed Height: 60mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	***m/sec***	***mmH_2O***	***mmH_2O***	***mmH_2O***		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	60	0	0	60	0.000	0.200
1	10	0.71	8.8	32.74	23.94	Packed	60	0	0	60	0.000	0.200
2	17.26	0.93	13.95	47.8	33.85	Start Bubbling	0	0	65	65	0.000	0.217
3	20	1.01	15.9	49.28	33.38	Bubbling + Swirling	0	15	65	80	0.231	0.267
4	30	1.23	22.3	56.78	34.48	Bubbling + Swirling	0	20	70	90	0.286	0.300
5	40	1.42	30.05	63.83	33.78	Bubbling + Swirling	0	25	80	105	0.313	0.350
6	50	1.59	38.3	71.03	32.73	Bubbling + Swirling	0	30	90	120	0.333	0.400
7	60	1.74	44.8	78.38	33.58	Bubbling + Swirling	0	35	100	135	0.350	0.450
8	70	1.88	52	85.16	33.16	Bubbling + Swirling	0	40	110	150	0.364	0.500
9	80	2.01	57.75	92.18	34.43	Bubbling + Swirling	0	40	120	160	0.333	0.533
10	90	2.13	64.5	100.28	35.78	Bubbling + Swirling	0	45	130	175	0.346	0.583
11	100	2.25	72.11	108.19	36.08	Bubbling + Swirling	0	45	140	185	0.321	0.617
12	110	2.36	79	116.88	37.88	Bubbling + Swirling	0	45	150	195	0.300	0.650
13	120	2.46	85.16	123.3	38.14	Bubbling + Swirling	0	45	160	205	0.281	0.683
14	130	2.56	91.61	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 4mm Bed Weight: 2000g Initial Bed Height: 75mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	***m/sec***	***mmH_2O***	***mmH_2O***	***mmH_2O***		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	75	0	0	75	0.000	0.250
1	10	0.71	8.8	38.9	30.1	Packed	75	0	0	75	0.000	0.250
2	18.75	0.97	15.53	55.24	39.71	Start Bubbling	0	0	80	80	0.000	0.267
3	20	1.01	15.9	56.03	40.13	Bubbling	0	0	80	80	0.000	0.267
4	30	1.23	22.3	62.48	40.18	Bubbling + Swirling	0	15	90	105	0.167	0.350
5	40	1.42	30.05	69.19	39.14	Bubbling + Swirling	0	20	100	120	0.200	0.400
6	50	1.59	38.3	76.58	38.28	Bubbling + Swirling	0	25	110	135	0.227	0.450
7	60	1.74	44.8	83.85	39.05	Bubbling + Swirling	0	30	120	150	0.250	0.500
8	70	1.88	52	90.3	38.3	Bubbling + Swirling	0	35	130	165	0.269	0.550
9	80	2.01	57.75	97.54	39.79	Bubbling + Swirling	0	40	140	180	0.286	0.600
10	90	2.13	64.5	103.65	39.15	Bubbling + Swirling	0	40	150	190	0.267	0.633
11	100	2.25	72.11	110.5	38.39	Bubbling + Swirling	0	40	160	200	0.250	0.667
12	110	2.36	79	117.68	38.68	Bubbling + Swirling	0	45	170	215	0.265	0.717
13	120	2.46	85.16	126.86	41.7	Bubbling + Swirling	0	45	180	225	0.250	0.750
14	130	2.56	91.61	132.79	41.18	Bubbling + Swirling	0	50	190	240	0.263	0.800
15	140	2.66	97.43	142.67	45.24	Bubbling + Swirling	0	50	200	250	0.250	0.833
16	150	2.75	104.96	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 4mm Bed Weight: 2500g Initial Bed Height: 90mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	90	0	0	90	0.000	0.300
1	10	0.71	8.8	41.7	32.9	Packed	90	0	0	90	0.000	0.300
2	20	1.01	15.53	63.75	48.22	Start Bubbling	0	0	95	95	0.000	0.317
3	30	1.23	22.3	71.4	49.1	Swirling + Bubbling	0	15	95	110	0.158	0.367
4	40	1.42	30.05	77.85	47.8	Swirling + Bubbling	0	20	110	130	0.182	0.433
5	50	1.59	38.3	83.4	45.1	Swirling + Bubbling	0	25	120	145	0.208	0.483
6	60	1.74	44.8	89.78	44.98	Swirling + Bubbling	0	30	130	160	0.231	0.533
7	70	1.88	52	96.75	44.75	Swirling + Bubbling	0	35	140	175	0.250	0.583
8	80	2.01	57.75	104.03	46.28	Swirling + Bubbling	0	40	150	190	0.267	0.633
9	90	2.13	64.5	112.05	47.55	Swirling + Bubbling	0	45	160	205	0.281	0.683
10	100	2.25	72.11	118.39	46.28	Swirling + Bubbling	0	45	170	215	0.265	0.717
11	110	2.36	79	125.55	46.55	Swirling + Bubbling	0	50	180	230	0.278	0.767
12	120	2.46	85.16	131.14	45.98	Swirling + Bubbling	0	50	190	240	0.263	0.800
13	130	2.56	91.61	141.11	49.5	Swirling + Bubbling	0	50	200	250	0.250	0.833
14	140	2.66	97.43	147.19	49.76	Swirling + Bubbling	0	55	210	265	0.262	0.883
15	150	2.75	104.96	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 4mm Bed Weight: 3000g Initial Bed Height: 110mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	110	0	0	110	0.000	0.367
1	10	0.71	8.8	45.94	37.14	Packed	110	0	0	110	0.000	0.367
2	20	1.01	15.53	72.53	57	Packed	110	0	0	110	0.000	0.367
3	23.75	1.10	18.88	74.03	55.15	Start Bubbling	0	0	120	120	0.000	0.400
4	30	1.23	22.3	79.05	56.75	Swirling + Bubbling	0	15	125	140	0.120	0.467
5	40	1.42	30.05	85.16	55.11	Swirling + Bubbling	0	20	140	160	0.143	0.533
6	50	1.59	38.3	90.75	52.45	Swirling + Bubbling	0	30	150	180	0.200	0.600
7	60	1.74	44.8	97.76	52.96	Swirling + Bubbling	0	35	160	195	0.219	0.650
8	70	1.88	52	105.3	53.3	Swirling + Bubbling	0	40	170	210	0.235	0.700
9	80	2.01	57.75	112.09	54.34	Swirling + Bubbling	0	45	180	225	0.250	0.750
10	90	2.13	64.5	119.33	54.83	Swirling + Bubbling	0	45	190	235	0.237	0.783
11	100	2.25	72.11	125.1	52.99	Swirling + Bubbling	0	50	200	250	0.250	0.833
12	110	2.36	79	133.39	54.39	Swirling + Bubbling	0	50	210	260	0.238	0.867
13	120	2.46	85.16	139.69	54.53	Swirling + Bubbling	0	50	220	270	0.227	0.900
14	130	2.56	91.61	147.45	55.84	Swirling + Bubbling	0	55	230	285	0.239	0.950
15	140	2.66	97.43	153.6	56.17	Swirling + Bubbling	0	55	240	295	0.229	0.983
16	150	2.75	104.96	162.11	57.15	Swirling + Bubbling	0	55	250	305	0.220	1.017
17	160	2.84	111.71	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 5mm Bed Weight: 1000g Initial Bed Height: 35mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	***m/sec***	***mmH_2O***	***mmH_2O***	***mmH_2O***		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	35	0	0	35	0.000	0.117
1	10	0.71	8.8	19.61	10.81	Packed	35	0	0	35	0.000	0.117
2	20	1.01	15.9	35.48	19.58	Packed	35	0	0	35	0.000	0.117
3	30	1.23	22.3	45.23	22.93	Start bubbling	0	0	38	38	0.000	0.127
4	40	1.42	30.05	51.71	21.66	Bubbling	0	0	38	38	0.000	0.127
5	50	1.59	38.3	58.91	20.61	Bubbling + Swirling (minor slugging)	0	5	38	43	0.132	0.143
6	60	1.74	44.8	65.18	20.38	Bubbling + Swirling (minor slugging)	0	8	40	48	0.200	0.160
7	70	1.88	52	72.33	20.33	Bubbling + Swirling (minor slugging)	0	10	40	50	0.250	0.167
8	80	2.01	57.75	79.84	22.09	Bubbling + Swirling	0	10	40	50	0.250	0.167
9	90	2.13	64.5	87.38	22.88	Bubbling + Swirling	0	13	40	53	0.325	0.177
10	100	2.25	72.11	94.61	22.5	Bubbling + Swirling	0	15	40	55	0.375	0.183
11	110	2.36	79	101.64	22.64	Bubbling + Swirling	0	15	40	55	0.375	0.183
12	120	2.46	85.16	107.28	22.12	Bubbling + Swirling	0	20	40	60	0.500	0.200
13	130	2.56	91.61	113.85	22.24	Bubbling + Swirling	0	25	45	70	0.556	0.233
14	140	2.66	97.43	120.7	23.27	Bubbling + Swirling	0	30	45	75	0.667	0.250
15	150	2.75	104.96	128.98	24.02	Bubbling + Swirling	0	30	50	80	0.600	0.267
16	160	2.84	111.71	136.06	24.35	Bubbling + Swirling	0	35	55	90	0.636	0.300
17	170	2.93	118.69	143.05	24.36	Bubbling + Swirling	0	35	60	95	0.583	0.317
18	180	3.02	125.89	152.03	26.14	Bubbling + Swirling	0	40	60	100	0.667	0.333
19	190	3.10	133.91	160.01	26.1	Bubbling + Swirling	0	40	65	105	0.615	0.350
20	200	3.18	140.14	166.53	26.39	Bubbling + Swirling	0	40	70	110	0.571	0.367
21	210	3.26	146.03	173.44	27.41	Bubbling + Swirling	0	45	75	120	0.600	0.400
22	220	3.34	153.26	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 5mm Bed Weight: 1500g Initial Bed Height: 50mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	50	0	0	50	0.000	0.167
1	10	0.71	8.8	21.79	12.99	Packed	50	0	0	50	0.000	0.167
2	20	1.01	15.9	40.54	24.64	Start Bubbling	50	0	0	50	0.000	0.167
3	30	1.23	22.3	56.93	34.63	Bubbling	0	0	52	52	0.000	0.173
4	40	1.42	30.05	63.79	33.74	Bubbling	0	0	55	55	0.000	0.183
5	50	1.59	38.3	69.11	30.81	Bubbling + Swirling	0	15	55	70	0.273	0.233
6	60	1.74	44.8	75.64	30.84	Bubbling + Swirling	0	15	60	75	0.250	0.250
7	70	1.88	52	82.43	30.43	Bubbling + Swirling	0	15	65	80	0.231	0.267
8	80	2.01	57.75	89.89	32.14	Bubbling + Swirling	0	20	60	80	0.333	0.267
9	90	2.13	64.5	96.04	31.54	Bubbling + Swirling	0	20	65	85	0.308	0.283
10	100	2.25	72.11	103.91	31.8	Bubbling + Swirling	0	20	70	90	0.286	0.300
11	110	2.36	79	110.85	31.85	Bubbling + Swirling	0	25	75	100	0.333	0.333
12	120	2.46	85.16	118.16	33	Bubbling + Swirling	0	25	80	105	0.313	0.350
13	130	2.56	91.61	125.74	34.13	Bubbling + Swirling	0	30	85	115	0.353	0.383
14	140	2.66	97.43	132.53	35.1	Bubbling + Swirling	0	30	90	120	0.333	0.400
15	150	2.75	104.96	140.21	35.25	Bubbling + Swirling	0	35	95	130	0.368	0.433
16	160	2.84	111.71	146.89	35.18	Bubbling + Swirling	0	35	105	140	0.333	0.467
17	170	2.93	118.69	155.25	36.56	Bubbling + Swirling	0	40	110	150	0.364	0.500
18	180	3.02	125.89	160.58	34.69	Bubbling + Swirling	0	40	115	155	0.348	0.517
19	190	3.10	133.91	168.49	34.58	Bubbling + Swirling	0	40	120	160	0.333	0.533
20	200	3.18	140.14	175.13	34.99	Bubbling + Swirling	0	45	120	165	0.375	0.550
21	210	3.26	146.03	181.69	35.66	Bubbling + Swirling	0	45	120	165	0.375	0.550
22	220	3.34	153.26	190.55	37.29	Bubbling + Swirling	0	50	125	175	0.400	0.583
23	230	3.41	158.18	197.93	39.75	Bubbling + Swirling	0	50	130	180	0.385	0.600
24	240	3.48	165.75	204.71	38.96	Bubbling + Swirling	0	55	140	195	0.393	0.650
25	250	3.56	173.66	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 5mm Bed Weight: 2000g Initial Bed Height: 70mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	70	0	0	70	0.000	0.233
1	10	0.71	8.8	25.35	16.55	Packed	70	0	0	70	0.000	0.233
2	20	1.01	15.9	45.23	29.33	Packed	70	0	0	70	0.000	0.233
3	30	1.23	22.3	64.35	42.05	Packed	70	0	0	70	0.000	0.233
4	36.71	1.36	28.2	70.88	42.68	Start bubbling	0	0	75	75	0.000	0.250
5	40	1.42	30.05	72.49	42.44	Bubbling	0	0	80	80	0.000	0.267
6	50	1.59	38.3	79.24	40.94	Bubbling + Swirling	0	10	80	90	0.125	0.300
7	60	1.74	44.8	85.65	40.85	Bubbling + Swirling	0	15	85	100	0.176	0.333
8	70	1.88	52	92.03	40.03	Bubbling + Swirling	0	20	90	110	0.222	0.367
9	80	2.01	57.75	98.36	40.61	Bubbling + Swirling	0	20	95	115	0.211	0.383
10	90	2.13	64.5	105.6	41.1	Bubbling + Swirling	0	25	95	120	0.263	0.400
11	100	2.25	72.11	113.55	41.44	Bubbling + Swirling	0	25	100	125	0.250	0.417
12	110	2.36	79	120.15	41.15	Bubbling + Swirling	0	30	110	140	0.273	0.467
13	120	2.46	85.16	126.86	41.7	Bubbling + Swirling	0	30	115	145	0.261	0.483
14	130	2.56	91.61	133.69	42.08	Bubbling + Swirling	0	35	120	155	0.292	0.517
15	140	2.66	97.43	140.44	43.01	Bubbling + Swirling	0	35	125	160	0.280	0.533
16	150	2.75	104.96	147.38	42.42	Bubbling + Swirling	0	40	130	170	0.308	0.567
17	160	2.84	111.71	155.59	43.88	Bubbling + Swirling	0	40	135	175	0.296	0.583
18	170	2.93	118.69	162.6	43.91	Bubbling + Swirling	0	45	135	180	0.333	0.600
19	180	3.02	125.89	170.03	44.14	Bubbling + Swirling	0	45	140	185	0.321	0.617
20	190	3.10	133.91	178.58	44.67	Bubbling + Swirling	0	45	145	190	0.310	0.633
21	200	3.18	140.14	184.28	44.14	Bubbling + Swirling	0	50	150	200	0.333	0.667
22	210	3.26	146.03	190.34	44.31	Bubbling + Swirling	0	50	155	205	0.323	0.683
23	220	3.34	153.26	197.44	44.18	Bubbling + Swirling	0	50	160	210	0.313	0.700
24	230	3.41	158.18	204.85	46.67	Bubbling + Swirling	0	55	165	220	0.333	0.733
25	240	3.48	165.75	213.55	47.8	Bubbling + Swirling	0	60	170	230	0.353	0.767
26	250	3.56	173.66	222.55	48.89	Bubbling + Swirling	0	65	175	240	0.371	0.800
27	260	3.63	179.21	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 5mm Bed Weight: 2500g Initial Bed Height: 85mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	***m/sec***	***mmH_2O***	***mmH_2O***	***mmH_2O***		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	85	0	0	85	0.000	0.283
1	10	0.71	8.8	27.3	18.5	Packed	85	0	0	85	0.000	0.283
2	20	1.01	15.53	48.19	32.66	Packed	85	0	0	85	0.000	0.283
3	30	1.23	22.3	68.81	46.51	Packed	85	0	0	85	0.000	0.283
4	40	1.42	30.05	81.49	51.44	Start bubbling	0	0	95	95	0.000	0.317
5	50	1.59	38.3	88.46	50.16	Swirling + Bubbling	0	10	100	110	0.100	0.367
6	60	1.74	44.8	95.03	50.23	Swirling + Bubbling	0	15	105	120	0.143	0.400
7	70	1.88	52	101.7	49.7	Swirling + Bubbling	0	20	110	130	0.182	0.433
8	80	2.01	57.75	107.25	49.5	Swirling + Bubbling	0	25	115	140	0.217	0.467
9	90	2.13	64.5	113.74	49.24	Swirling + Bubbling	0	25	120	145	0.208	0.483
10	100	2.25	72.11	121.2	49.09	Swirling + Bubbling	0	25	125	150	0.200	0.500
11	110	2.36	79	126.75	47.75	Swirling + Bubbling	0	30	130	160	0.231	0.533
12	120	2.46	85.16	134.18	49.02	Swirling + Bubbling	0	30	135	165	0.222	0.550
13	130	2.56	91.61	141.86	50.25	Swirling + Bubbling	0	30	140	170	0.214	0.567
14	140	2.66	97.43	148.76	51.33	Swirling + Bubbling	0	35	145	180	0.241	0.600
15	150	2.75	104.96	155.1	50.14	Swirling + Bubbling	0	35	150	185	0.233	0.617
16	160	2.84	111.71	162.34	50.63	Swirling + Bubbling	0	40	155	195	0.258	0.650
17	170	2.93	118.69	168.49	49.8	Swirling + Bubbling	0	45	160	205	0.281	0.683
18	180	3.02	125.89	176.1	50.21	Swirling + Bubbling	0	45	165	210	0.273	0.700
19	190	3.10	133.91	183.68	49.77	Swirling + Bubbling	0	45	170	215	0.265	0.717
20	200	3.18	140.14	192.94	52.8	Swirling + Bubbling	0	50	175	225	0.286	0.750
21	210	3.26	146.03	200.25	54.22	Swirling + Bubbling	0	50	180	230	0.278	0.767
22	220	3.34	153.26	206.14	52.88	Swirling + Bubbling	0	55	185	240	0.297	0.800
23	230	3.41	158.18	213.11	54.93	Swirling + Bubbling	0	55	190	245	0.289	0.817
24	240	3.48	165.75	219.98	54.23	Swirling + Bubbling	0	55	195	250	0.282	0.833
25	250	3.56	173.66	228.23	54.57	Swirling + Bubbling	0	60	200	260	0.300	0.867
26	260	3.63	179.21	235.31	56.1	Swirling + Bubbling	0	60	205	265	0.293	0.883
27	270	3.70	186.11	243.94	57.83	Swirling + Bubbling	0	65	210	275	0.310	0.917
28	280	3.76	192	249.29	57.29	Bubbling + Swirling	0	65	220	285	0.295	0.950
29	290	3.83	199.16	256.16	57	Bubbling + Swirling	0	70	230	300	0.304	1.000
30	300	3.90	206.18	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 5mm Bed Weight: 3000g Initial Bed Height: 100mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	100	0	0	100	0.000	0.333
1	10	0.71	8.8	28.2	19.4	Packed	100	0	0	100	0.000	0.333
2	20	1.01	15.53	50.66	35.13	Packed	100	0	0	100	0.000	0.333
3	30	1.23	22.3	73.35	51.05	Packed	100	0	0	100	0.000	0.333
4	40	1.42	30.05	93.26	63.21	Packed	100	0	0	100	0.000	0.333
5	50	1.59	38.3	96.15	57.85	Start bubbling	0	0	110	110	0.000	0.367
6	60	1.74	44.8	102.23	57.43	Swirling + Bubbling	0	10	120	130	0.083	0.433
7	70	1.88	52	108.3	56.3	Swirling + Bubbling	0	20	130	150	0.154	0.500
8	80	2.01	57.75	115.01	57.26	Swirling + Bubbling	0	30	135	165	0.222	0.550
9	90	2.13	64.5	120.83	56.33	Swirling + Bubbling	0	35	135	170	0.259	0.567
10	100	2.25	72.11	128.55	56.44	Swirling + Bubbling	0	35	140	175	0.250	0.583
11	110	2.36	79	135.38	56.38	Swirling + Bubbling	0	35	145	180	0.241	0.600
12	120	2.46	85.16	141.41	56.25	Swirling + Bubbling	0	40	150	190	0.267	0.633
13	130	2.56	91.61	148.61	57	Swirling + Bubbling	0	40	155	195	0.258	0.650
14	140	2.66	97.43	154.65	57.22	Swirling + Bubbling	0	40	160	200	0.250	0.667
15	150	2.75	104.96	162.34	57.38	Swirling + Bubbling	0	40	165	205	0.242	0.683
16	160	2.84	111.71	169.88	58.17	Swirling + Bubbling	0	45	170	215	0.265	0.717
17	170	2.93	118.69	176.44	57.75	Swirling + Bubbling	0	45	175	220	0.257	0.733
18	180	3.02	125.89	185.66	59.77	Swirling + Bubbling	0	50	180	230	0.278	0.767
19	190	3.10	133.91	191.55	57.64	Swirling + Bubbling	0	50	185	235	0.270	0.783
20	200	3.18	140.14	199.39	59.25	Swirling + Bubbling	0	50	190	240	0.263	0.800
21	210	3.26	146.03	207.08	61.05	Swirling + Bubbling	0	55	195	250	0.282	0.833
22	220	3.34	153.26	212.33	59.07	Swirling + Bubbling	0	55	200	255	0.275	0.850
23	230	3.41	158.18	220.36	62.18	Swirling + Bubbling	0	55	205	260	0.268	0.867
24	240	3.48	165.75	229.16	63.41	Swirling + Bubbling	0	60	210	270	0.286	0.900
25	250	3.56	173.66	236.63	62.97	Swirling + Bubbling	0	60	220	280	0.273	0.933
26	260	3.63	179.21	245.21	66	Swirling + Bubbling	0	65	230	295	0.283	0.983
27	270	3.70	186.11	252.04	65.93	Swirling + Bubbling	0	65	240	305	0.271	1.017
28	280	3.76	192	260.81	68.81	Swirling + Bubbling	0	70	250	320	0.280	1.067
29	290	3.83	199.16	267.34	68.18	Bubbling + Swirling	0	70	260	330	0.269	1.100
30	300	3.90	206.18	275.59	69.41	Bubbling + Swirling	0	75	270	345	0.278	1.150
31	310	3.96	214.39	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 6mm Bed Weight: 1000g Initial Bed Height: 38mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	38	0	0	38	0.000	0.127
1	10	0.71	8.8	17.48	8.68	Packed	38	0	0	38	0.000	0.127
2	20	1.01	15.9	31.61	15.71	Packed	38	0	0	38	0.000	0.127
3	30	1.23	22.3	45.34	23.04	Packed	38	0	0	38	0.000	0.127
4	35.74	1.34	27.03	50.14	23.11	Start Bubbling	0	0	40	40	0.000	0.133
5	40	1.42	30.05	53.1	23.05	Bubbling	0	0	40	40	0.000	0.133
6	50	1.59	38.3	59.33	21.03	Bubbling + Swirling	0	10	40	50	0.250	0.167
7	60	1.74	44.8	65.74	20.94	Bubbling + Swirling	0	10	40	50	0.250	0.167
8	70	1.88	52	73.35	21.35	Bubbling + Swirling	0	20	30	50	0.667	0.167
9	80	2.01	57.75	79.84	22.09	Bubbling + Swirling	0	25	30	55	0.833	0.183
10	90	2.13	64.5	87.04	22.54	Bubbling + Swirling	0	25	30	55	0.833	0.183
11	100	2.25	72.11	94.8	22.69	Bubbling + Swirling	0	25	30	55	0.833	0.183
12	110	2.36	79	102.98	23.98	Bubbling + Swirling	0	25	30	55	0.833	0.183
13	120	2.46	85.16	109.01	23.85	Bubbling + Swirling	0	25	30	55	0.833	0.183
14	130	2.56	91.61	117.6	25.99	Bubbling + Swirling	0	25	35	60	0.714	0.200
15	140	2.66	97.43	123.6	26.17	Bubbling + Swirling	0	25	35	60	0.714	0.200
16	150	2.75	104.96	130.75	25.79	Bubbling + Swirling	0	30	35	65	0.857	0.217
17	160	2.84	111.71	138.26	26.55	Bubbling + Swirling	0	30	35	65	0.857	0.217
18	170	2.93	118.69	145.61	26.92	Bubbling + Swirling	0	30	40	70	0.750	0.233
19	180	3.02	125.89	152.58	26.69	Bubbling + Swirling	0	30	40	70	0.750	0.233
20	190	3.10	133.91	160.61	26.7	Bubbling + Swirling	0	35	40	75	0.875	0.250
21	200	3.18	140.14	167.93	27.79	Bubbling + Swirling	0	35	45	80	0.778	0.267
22	210	3.26	146.03	174.94	28.91	Bubbling + Swirling	0	35	50	85	0.700	0.283
23	220	3.34	153.26	183.64	30.38	Bubbling + Swirling	0	40	55	95	0.727	0.317
24	230	3.41	160.49	190.58	30.09	Bubbling + Swirling	0	40	55	95	0.727	0.317
25	240	3.48	167.72	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 6mm Bed Weight: 1500g Initial Bed Height: 55mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	55	0	0	55	0.000	0.183
1	10	0.71	8.8	19.54	10.74	Packed	55	0	0	55	0.000	0.183
2	20	1.01	15.9	36.56	20.66	Packed	55	0	0	55	0.000	0.183
3	30	1.23	22.3	50.4	28.1	Packed	55	0	0	55	0.000	0.183
4	40	1.42	30.05	64.65	34.6	Packed	55	0	0	55	0.000	0.183
5	46.64	1.54	35.89	67.16	31.27	Start Bubbling	0	0	60	60	0.000	0.200
6	50	1.59	38.3	70.31	32.01	Bubbling	0	0	60	60	0.000	0.200
7	60	1.74	44.8	77.74	32.94	Bubbling + Swirling	0	10	60	70	0.167	0.233
8	70	1.88	52	84.45	32.45	Bubbling + Swirling	0	15	65	80	0.231	0.267
9	80	2.01	57.75	91.69	33.94	Bubbling + Swirling	0	20	65	85	0.308	0.283
10	90	2.13	64.5	98.89	34.39	Bubbling + Swirling	0	20	65	85	0.308	0.283
11	100	2.25	72.11	105.71	33.6	Bubbling + Swirling	0	20	70	90	0.286	0.300
12	110	2.36	79	112.8	33.8	Bubbling + Swirling	0	20	70	90	0.286	0.300
13	120	2.46	85.16	119.03	33.87	Bubbling + Swirling	0	25	75	100	0.333	0.333
14	130	2.56	91.61	126.95	35.34	Bubbling + Swirling	0	30	80	110	0.375	0.367
15	140	2.66	97.43	133.76	36.33	Bubbling + Swirling	0	30	85	115	0.353	0.383
16	150	2.75	104.96	141.15	36.19	Bubbling + Swirling	0	35	90	125	0.389	0.417
17	160	2.84	111.71	148.91	37.2	Bubbling + Swirling	0	35	95	130	0.368	0.433
18	170	2.93	118.69	156.9	38.21	Bubbling + Swirling	0	40	100	140	0.400	0.467
19	180	3.02	125.89	164.15	38.26	Bubbling + Swirling	0	45	105	150	0.429	0.500
20	190	3.10	133.91	172.46	38.55	Bubbling + Swirling	0	45	110	155	0.409	0.517
21	200	3.18	140.14	178.09	37.95	Bubbling + Swirling	0	50	115	165	0.435	0.550
22	210	3.26	146.03	187.61	41.58	Bubbling + Swirling	0	50	120	170	0.417	0.567
23	220	3.34	153.26	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 6mm Bed Weight: 2000g Initial Bed Height: 70mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	70	0	0	70	0.000	0.233
1	10	0.71	8.8	21.86	13.06	Packed	70	0	0	70	0.000	0.233
2	20	1.01	15.9	38.63	22.73	Packed	70	0	0	70	0.000	0.233
3	30	1.23	22.3	55.05	32.75	Packed	70	0	0	70	0.000	0.233
4	40	1.42	28.2	70.76	42.56	Packed	70	0	0	70	0.000	0.233
5	50	1.59	30.05	81.04	50.99	Start Bubbling	0	0	80	80	0.000	0.267
6	60	1.74	38.3	87.3	49	Bubbling	0	0	90	90	0.000	0.300
7	70	1.88	44.8	93.86	49.06	Bubbling + Swirling	0	10	90	100	0.111	0.333
8	80	2.01	52	100.39	48.39	Bubbling + Swirling	0	20	95	115	0.211	0.383
9	90	2.13	57.75	107.06	49.31	Bubbling + Swirling	0	25	100	125	0.250	0.417
10	100	2.25	64.5	113.14	48.64	Bubbling + Swirling	0	30	100	130	0.300	0.433
11	110	2.36	72.11	121.5	49.39	Bubbling + Swirling	0	35	105	140	0.333	0.467
12	120	2.46	79	127.05	48.05	Bubbling + Swirling	0	35	110	145	0.318	0.483
13	130	2.56	85.16	135.53	50.37	Bubbling + Swirling	0	40	115	155	0.348	0.517
14	140	2.66	91.61	143.06	51.45	Bubbling + Swirling	0	40	120	160	0.333	0.533
15	150	2.75	97.43	148.95	51.52	Bubbling + Swirling	0	45	125	170	0.360	0.567
16	160	2.84	104.96	155.84	50.88	Bubbling + Swirling	0	45	130	175	0.346	0.583
17	170	2.93	111.71	163.66	51.95	Bubbling + Swirling	0	45	135	180	0.333	0.600
18	180	3.02	118.69	171.11	52.42	Bubbling + Swirling	0	50	140	190	0.357	0.633
19	190	3.10	125.89	180.41	54.52	Bubbling + Swirling	0	50	145	195	0.345	0.650
20	200	3.18	133.91	188.96	55.05	Bubbling + Swirling	0	50	150	200	0.333	0.667
21	210	3.26	140.14	194.61	54.47	Bubbling + Swirling	0	55	155	210	0.355	0.700
22	220	3.34	146.03	200.85	54.82	Bubbling + Swirling	0	55	160	215	0.344	0.717
23	230	3.41	153.26	209.74	56.48	Bubbling + Swirling	0	60	165	225	0.364	0.750
24	240	3.48	158.18	218.95	60.77	Bubbling + Swirling	0	60	170	230	0.353	0.767
25	250	3.56	165.75	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 6mm Bed Weight: 2500g Initial Bed Height: 85mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	85	0	0	85	0.000	0.283
1	10	0.71	8.8	22.61	13.81	Packed	85	0	0	85	0.000	0.283
2	20	1.01	15.53	40.58	25.05	Packed	85	0	0	85	0.000	0.283
3	30	1.23	22.3	58.95	36.65	Packed	85	0	0	85	0.000	0.283
4	40	1.42	30.05	75.9	45.85	Packed	85	0	0	85	0.000	0.283
5	50	1.59	38.3	88.84	50.54	Packed	85	0	0	85	0.000	0.283
6	54.86	1.67	41.44	92.96	51.52	Start Bubbling	0	0	90	90	0.000	0.300
7	60	1.74	44.8	96.11	51.31	Bubbling	0	0	100	100	0.000	0.333
8	70	1.88	52	102.34	50.34	Bubbling	0	0	110	110	0.000	0.367
9	80	2.01	57.75	108.94	51.19	Swirling + Bubbling	0	10	115	125	0.087	0.417
10	90	2.13	64.5	116.4	51.9	Swirling + Bubbling	0	20	120	140	0.167	0.467
11	100	2.25	72.11	123.11	51	Swirling + Bubbling	0	25	125	150	0.200	0.500
12	110	2.36	79	130.71	51.71	Swirling + Bubbling	0	30	130	160	0.231	0.533
13	120	2.46	85.16	137.12	51.96	Swirling + Bubbling	0	35	135	170	0.259	0.567
14	130	2.56	91.61	143.73	52.12	Swirling + Bubbling	0	35	140	175	0.250	0.583
15	140	2.66	97.43	149.88	52.45	Swirling + Bubbling	0	40	145	185	0.276	0.617
16	150	2.75	104.96	158.08	53.12	Swirling + Bubbling	0	40	150	190	0.267	0.633
17	160	2.84	111.71	165.95	54.24	Swirling + Bubbling	0	45	155	200	0.290	0.667
18	170	2.93	118.69	173.79	55.1	Swirling + Bubbling	0	45	160	205	0.281	0.683
19	180	3.02	125.89	181.73	55.84	Swirling + Bubbling	0	50	165	215	0.303	0.717
20	190	3.10	133.91	189.75	55.84	Swirling + Bubbling	0	50	170	220	0.294	0.733
21	200	3.18	140.14	196.69	56.55	Swirling + Bubbling	0	50	170	220	0.294	0.733
22	210	3.26	146.03	203.33	57.3	Swirling + Bubbling	0	55	175	230	0.314	0.767
23	220	3.34	153.26	210.16	56.9	Swirling + Bubbling	0	55	180	235	0.306	0.783
24	230	3.41	158.18	216.26	58.08	Swirling + Bubbling	0	60	185	245	0.324	0.817
25	240	3.48	165.75	224.4	58.65	Swirling + Bubbling	0	60	190	250	0.316	0.833
26	250	3.56	173.66	232.4	58.74	Bubbling + Swirling	0	65	195	260	0.333	0.867
27	260	3.63	179.21	239.71	60.5	Bubbling + Swirling	0	65	200	265	0.325	0.883
28	270	3.70	186.11	247.65	61.54	Bubbling + Swirling	0	65	210	275	0.310	0.917
29	280	3.76	192	-	-	Elutriation	-	-	-	-	-	-

Particle Type: Spherical Particle Size: 6mm Bed Weight: 3000g Initial Bed Height: 100mm

Data No.	ΔP across orifice	Reference Velocity	ΔP across distributor	ΔP across distributor with particle	ΔP across bed	Observation	Height (mm)			Total Bed Height	Swirling : Bubbling	Height : Diameter
	mmH_2O	m/sec	mmH_2O	mmH_2O	mmH_2O		Packed	Swirling	Bubbling			
0	0	0	0	0	0	Packed	100	0	0	100	0.000	0.333
1	10	0.71	8.8	24.34	15.54	Packed	100	0	0	100	0.000	0.333
2	20	1.01	15.53	45.04	29.51	Packed	100	0	0	100	0.000	0.333
3	30	1.23	22.3	63.08	40.78	Packed	100	0	0	100	0.000	0.333
4	40	1.42	30.05	81.15	51.1	Packed	100	0	0	100	0.000	0.333
5	50	1.59	38.3	99.71	61.41	Packed	100	0	0	100	0.000	0.333
6	60	1.74	44.8	104.59	59.79	Start Bubbling	0	0	110	110	0.000	0.367
7	70	1.88	52	109.65	57.65	Bubbling	0	0	120	120	0.000	0.400
8	80	2.01	57.75	117.15	59.4	Swirling + Bubbling	0	15	120	135	0.125	0.450
9	90	2.13	64.5	123.53	59.03	Swirling + Bubbling	0	25	125	150	0.200	0.500
10	100	2.25	72.11	130.08	57.97	Swirling + Bubbling	0	30	130	160	0.231	0.533
11	110	2.36	79	136.64	57.64	Swirling + Bubbling	0	35	145	180	0.241	0.600
12	120	2.46	85.16	144.04	58.88	Swirling + Bubbling	0	40	150	190	0.267	0.633
13	130	2.56	91.61	151.1	59.49	Swirling + Bubbling	0	40	155	195	0.258	0.650
14	140	2.66	97.43	157.85	60.42	Swirling + Bubbling	0	45	160	205	0.281	0.683
15	150	2.75	104.96	165.41	60.45	Swirling + Bubbling	0	45	165	210	0.273	0.700
16	160	2.84	111.71	173.21	61.5	Swirling + Bubbling	0	45	170	215	0.265	0.717
17	170	2.93	118.69	180.19	61.5	Swirling + Bubbling	0	50	170	220	0.294	0.733
18	180	3.02	125.89	187.95	62.06	Swirling + Bubbling	0	50	175	225	0.286	0.750
19	190	3.10	133.91	196.88	62.97	Swirling + Bubbling	0	50	175	225	0.286	0.750
20	200	3.18	140.14	203.89	63.75	Swirling + Bubbling	0	55	180	235	0.306	0.783
21	210	3.26	146.03	210.74	64.71	Swirling + Bubbling	0	55	185	240	0.297	0.800
22	220	3.34	153.26	218.93	65.67	Swirling + Bubbling	0	55	190	245	0.289	0.817
23	230	3.41	158.18	225.68	67.5	Swirling + Bubbling	0	60	195	255	0.308	0.850
24	240	3.48	165.75	232.01	66.26	Swirling + Bubbling	0	60	200	260	0.300	0.867
25	250	3.56	173.66	240.78	67.12	Swirling + Bubbling	0	60	205	265	0.293	0.883
26	260	3.63	179.21	248.29	69.08	Swirling + Bubbling	0	65	210	275	0.310	0.917
27	270	3.70	186.11	255.34	69.23	Bubbling + Swirling	0	65	215	280	0.302	0.933
28	280	3.76	192	262.85	70.85	Bubbling + Swirling	0	70	220	290	0.318	0.967
29	290	3.83	199.16	269.33	70.17	Bubbling + Swirling	0	70	225	295	0.311	0.983
30	300	3.90	206.18	-	-	Elutriation	-	-	-	-	-	-

APPENDIX D

Project Recognitions

2013 International Conference on Advances in Energy and Environmental Science

July 30-31, Guangzhou, China

Notification of Paper Acceptance

Dear Authors,

The Scientific Committee has completed its review of your paper submitted for the 2013 International Conference on Advances in Energy and Environmental Science (ICAEES 2013). The final decision is made base on the peer-review reports, the scientific merits and the relevance.

We are pleased to inform you that your paper as follow has now been accepted by the Scientific Committee and will be published in international journal "Advanced Materials Research", and will be indexed by EI COMPENDEX and Thomson ISTP.

Manuscript Number	ES1531
Authors	Wong Chee King, Chin Yee Sing
Title	Experimental Study on the Hydrodynamics of Two-Layer Swirling Fluidized Bed

Notes:

1. Please revise your manuscript according to the detailed comments and suggestions from the referees. And make sure that your paper is in strict accordance with the format of the journal.

2. Please read the attached registration form carefully and make sure that you pay the registration fees in time.

Any questions, please do not hesitate to contact us.

The Committee of ICAEES 2013
Hong Kong Industrial Technology Research Centre
2013-06-04