Characterization of Swirling Fluidized Bed

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the Mechnical Engineering Programme Universiti Teknologi PETRONAS in partial fulfilment of the requirement for the BACHELOR OF ENGINEERING (Hons) (MECHNICAL ENGINEERING)

Approved by,

(Chin Yee Sing)

UNIVERSITI TEKNOLOGI PETRONAS TRONOH, PERAK May 2012

CERTIFICATION OF ORIGINALITY

I hereby verify that this report was written by **GOO JIA JUN (14029)** and declare 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.

(Goo Jia Jun)

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ABSTRACT

This dissertation is intended to conclude and summarize the overall milestone of Final Year Project, Characterization of Swirling Fluidized Bed. In recent years, the Swirling Fluidized Bed has been regarded as one of the novel designs in fluidization technology. This new technique features an annular-blade distributor which injects the fluidizing gas through a certain inclination, is capable of fluidizing the bed and at the same time causes swirling motion of particles in a circular trajectory. In the present work, the fluidization characteristics and hydrodynamics of a swirling bed are studied using experimental approach. The behavior of gas-particle interaction in a swirling bed in terms of operation regimes, trends of pressure drop across particle bed and hysteresis effects of bed pressure drop with increasing superficial velocity of gas, are explored by varying bed configurations. Three different sizes of spherical Polyvinyl chloride particle, two sizes in irregular shape and two sizes in cylindrical form, are used as bed material by considering four bed weights from 500 g to 2000 g, with increment of 500 g in each step, three blade overlap angles of 9°, 15° and 18°, for air superficial velocities up to approximately 3.5 m/s and two blade inclination of 10° and 15°. In this report, a well-structured review of the literature is constructed to compile the critical and substantive discoveries in the past researches. Furthermore, detailed research methodology and detailed analysis of experiment results are illustrated and expounded. The findings explicitly show that the solid particle size, shape, and bed weight are the major variables that give significant impact on the fluidized bed characteristics, while the blade dimension has relatively smaller effect on the bed behavior. This project has, hopefully, revealed how everything responds in SFB and this correlated relationship could be a precious benchmark in designing a reactor bed. As a conclusion, the research is intended to demonstrate the superiority of SFB over conventional bed. Through this exploration, the author sincerely hopes that this project will become an achievable reference volume for every practitioner in this field, spanning the boundary of various disciplines especially for fluidization engineering.

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ABBREVIATION AND NOMENCLATURES

θ	Blade angle
d	Diameter
$\frac{L}{D}$	Length to diameter ratio
$ ho_{g}$	Gas density
g	Gravitational acceleration constant
μ	Fluid viscosity
ΔP	Pressure drop
U _m	Superficial fluidized velocity
R	Ratio of distributor pressure drop to bed pressure drop
L	Height of bed
G	Mass-flow rate of fluid
D_p	Effective diameter of particles
Ar	Archimedes number
Re _{p, mf}	Reynolds number
ε	Fractional void volume
μ_{g}	Absolute viscosity of fluidizing gas
SFB	Swirling Fluidized Bed
PVC	Polyvinyl chloride
EDM	Electrical Discharge Machining
CNC	Computer Numerical Control
PTV	Particle Tracking Velocimetry

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fluidization, a process of imparting fluidlike characteristic to a bed of solid particles through suspension in fluid that passes through it, has substantial applications in many industrial operations which involve contact between fluid and solids [1], namely granulation, combustion and gasification of solid fuels, shales or solid wastes, drying of particles, metal surface treatments, regenerative heat exchangers, oxidation or reduction of ores, and catalytic thermal cracking. The conventional fluidized bed has certain downsides such as restriction in gas flow rate to avoid elutriation in bed, limitation on particle size, shapes and magnitude of distribution. Circulating fluidized bed, centrifugal fluidized bed, vibro-fluidized bed, and tapered fluidized bed are the diverse designs that have been employed to overcome some of the limitation of the conventional fluidized bed [2]. One of the recent developments to tackle deficiencies of the conventional bed is the Swirling Fluidized Bed (SFB). This novel variant of the fluidized bed features an annular bed and inclined injection of gas though the distributor blades [3], resulting in a swirling motion of solid particles in a confined circular path. This technique of fluidizing the solid particle bed has a number of unique characteristics, and fluidization engineering is concerned with efforts to take the advantageous behaviors and put them to good use.

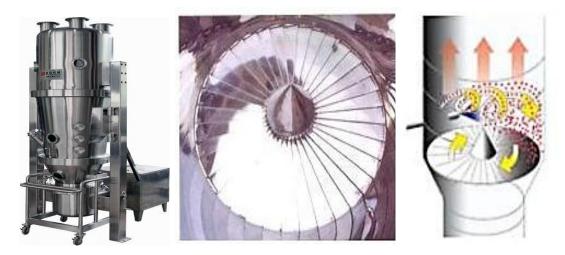


Figure 1.1: Swirling fluidized-bed granulation coating machine Retrieved April 07, 2012 from china-ogpe.

1.2 Problem Statements

Equipment using the swirling bed principle appears to be commercially available for various operations and this new technology has hit the industrial scene in a big way in recent years. Contrariwise, its proud successes do not spur much research efforts, the published information on the characterization of SFB is scanty and in fact there are very few reliable systematic studies of SFB. Arising from extensive literature review, there is still much confusion and contradiction in the reported literature caused by apparent deficiency of credible experimental studies on hydrodynamics characteristics of swirling beds. As a result, the industrial design especially in the reactor application places excessive emphasis on previous practices or on careful scale-up of existing design coupled with liberal sprinkling of safety factors [4]. Consequently, the practice of art governs, technical design from the principle of fluidization characteristic is rarely attempted, and most of the research findings do not seem to be very pertinent in this effort.

1.3 Objectives

This project is aimed to develop a fundamental understanding of the hydrodynamic characteristics of SFB and to attest its superiority over conventional fluidized bed. To explore these properties, detailed experimental studies will be conducted by varying the parameters below:

- i. Blades inclination angle (refer to Figure 1.2)
- ii. Blades overlap angle (refer to Figure 1.2)
- iii. The shape and size of solid particles
- iv. The weight of the bed of particles

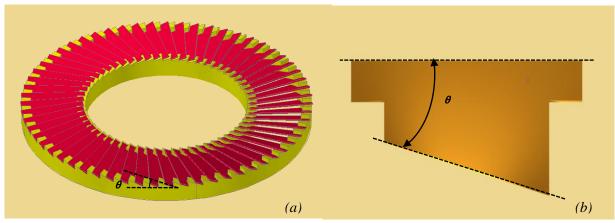


Figure 1.2(a)-(b): Blade inclination angle and blade overlap angle

The hydrodynamic characteristics are comprised of:

- i. Pressure drop across the fluidized bed
- ii. Hysteresis effect of pressure drop
- iii. The flow regimes throughout the fluidization process

In fluidization engineering, these characteristics are fundamental parameters in determining the power required and energy efficiency throughout the process. They also indicate the quality of fluidization and explain the overall hydrodynamic behaviors of the bed. Here the terminology of fluidization quality is defined as the condition of a fluidized bed that possesses an optimal mixing of the gas and the solid particles, with easy handling of bed material, a steady in-bed temperature and mass distribution, and a stable average bed-pressure drop [5].

1.4 Scope of Study

Relatively little has appeared in the open literature related to experiment studies on SFB, the majority of what has been published deals with analytical modeling and other variants of fluidized beds. Therefore, in order to fill the gap of inadequate open references, this project is concerned with hydrodynamic characteristics of fluidization in gas-solid swirling beds; this is a sequel to an earlier work of Jeevaneswary [6]. It is aimed at exploring flow regimes in the beds through visual observation and measurement of bed pressure drops at various flow rates of the gas and at different effects of the parameters mentioned in the Objectives section.

However, the author will not delve into the velocity profile and the motion trajectories of the discrete particles due to time constraint. Furthermore, the formation of 'dead zone' at the center of the bed during operation will not be further investigated. Also, detailed analytical modeling will not be conducted as there are vast literature resources of theoretical studies published by many researchers.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental Concepts of Fluidization Process

Various technological operations often necessitate bringing a granular material into intimate contact with a fluid. The simplest way of doing it is through fluidization process, the common concept that is used by different types of fluidization bed discussed in the Background of Study section. Vinod and Raghavan [7], Pigford and Baron [8], Faizal et al. [9], and Kunii and Levenspiel [4] observed during the increasing rate of fluid flow upwards through a bed of discrete particles, the pressure drop across the bed will also be increasing until a certain rate of flow, all the particles suspended by the flowing gas or liquid. At this time, the frictional drag force between particle and fluid just counterbalances the particles effective weight and the vertical component of the compressive force between adjacent particles disappears. Subsequently, the pressure drop through any section of the bed about equals the weight of fluid and particles, thus the bed is said to be fluidized (see Figure 3.4). This condition and the velocity of fluid corresponding to it are termed incipient fluidization, and incipient fluidizing velocity (or known as minimum fluidization velocity), respectively. The solid plus fluid becomes as mobile as a true fluid and is called fluidized bed. Indeed, the advantages of utilizing fluidized beds include rapid mixing, resistance to rapid temperature changes and high heat and mass transfer rates [10] [11].

Further increase in fluidizing gas flow rate results in the formation of bubbles or particle-free cavities among the bed particles and this regime is known as bubbling regime. These non-uniformly distributed bubbles rise through the bed, bursting when they reach the free surface, scattering particles into the above-bed region, and lastly fall back to the bed. At this condition, the bed is subjected to fluidization process where vigorous mixing occurs and interaction between gas and particles are intense.

The operation reaches slugging regime when the air cavities are large enough to suspend some portion of the bed weight, giving fluctuation in pressure drop. This undesired regime might not happen for every fluidization process, depending on size of the particle and the type of fluidizing gas. At sufficiently high fluidizing velocity, the particle will become entrained progressively, and the pressure drop will then reduce until, finally, all particles are blown out from the containing vessel [12].

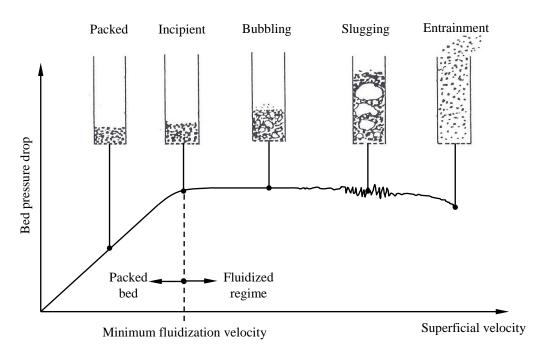
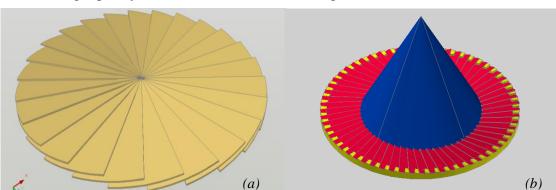


Figure 2.1: Conventional fluidized bed behavior with gas velocity changes

2.2 Swirling Fluidized Bed (SFB)

Sreenivasan and Raghavan [13] had alleged in year 2002 that SFB is the most recent variant in fluidized bed which has set a new benchmark in fluidization engineering. There are plenty of opportunities in this field to be explored in order to improve the SFB as the published information on its characteristic is exiguous. An early work on inclined injection of gas into particle bed was performed by Ouyang and Levenspiel [14] using full width spiral distributor. Their results were perhaps not spectacular to merit further research interest. The change from a full width column to an annular column however renders some remarkable changes in bed behavior. Annular distributor in SFB has the following advantages compared to the conventional bed [9]:

- a) Low distributor pressure drop and more energy efficient
- b) No bubbling, hence absence of slugging and channeling



c) High quality fluidization with better mixing

Figure 2.2(a)-(b): Full width spiral distributor design and annular distributor

Another author, Paulose [15] affirmed the superior feature of SFB which is the annular bed, where the injection of gas through the distributor approaches at certain inclination. Therefore, the gas entering the bed will have two components - horizontal and vertical components. The vertical component causes lifting of the particles. It is this lifting force that is responsible for fluidization. The horizontal component, meanwhile, creates a swirling motion force toward the bed particles. Thus, the inclined gas injection fluidizes the bed and at the same time causes swirling motion of particles on confined circular path [16] [17]. The quality of fluidization can be achieved in a SFB with a comparatively lower distributor pressure drop compared to conventional bed. Paulose's theory is then proven by Kaewklum and Kuprianov [18] after conducting experiments using annular distributor with blade inclination that is capable of giving swirl motion to the bed particles.

2.3 Bed behavior of SFB

In present research work, the author measures the pressure drop difference between the tappings P_1 and P_2 (see Figure 3.4). 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.

Sobrino *et al.* [19] highlighted the importance of distributor pressure drop which disperses the gas as uniformly as possible over the whole cross-section of the bed. If the pressure drop is very low, the air will enter the bed in the zone of lowest pressure drop and it will cause a non-uniform distribution of air flow inside the bed. Meanwhile, in fluidized bed processes, bed pressure drop is the main element to define the power required for fluidization and justifies the behavior of the flow regime.

S. Ergun [20] has asserted that the pressure drop in a fluidized bed is due to the simultaneous kinetic and viscous energy losses. Ergun's equation, which is established using analytical and experimental approaches, shows the relationship of bed pressure drop with flow rate, properties of the fluids, fractional void volume, orientation, size, shape and surface of the granular solid particles. His equation is as following:

Viscous energy losses

Where by,

ΔP - Pressure loss	g_c - Gravitational Constant
G - Mass-flow rate of fluid	ϵ - Fractional void volume
D_p - Effective diameter of particles	μ - Absolute viscosity of fluid
L - Height of bed	U _m - Superficial fluid velocity

Paulose [15] expounded the ratio of the distributor pressure drop to the bed pressure drop, R, is generally considered for the design of distributors in conventional bed. Hiby [21], and Geldart and Baeyens [22] claimed that the value of R depends not only on the distributor type but also on the bed particles, the bed depth, the superficial gas velocity, the bed aspect ratio and then percentage of uneven distribution. Only few researchers have come out with R value according to material and type of blade.

Faizal et al. [9], Sreenivasan and Raghavan [13] affirmed a striking feature that distinguishes the swirling bed from a conventional fluidized bed is that, the pressure drop of the bed increased with superficial velocity after minimum fluidization in their experimental studies, with the plausible explanation of it is proportional to the bed's centrifugal weight. Faizal and his colleagues also found that the blade geometry has less effect on bed performance, compared to fraction of open area and particle size. Their experiment was aimed to study the effect of the superficial velocity, bed weight, blade overlap angle and number of blades on the bed pressure drop.

Vinod and Raghavan [23] in their research on operation of a swirling fluidized bed quoted that the bed pressure drop first showed an upward trend and upon reaching a particular peak value, it started decreasing. This may be attributed to the fact that the bed pressure drop will fall as the resistance from the bed decreases. Besides, they said that the peak in the bed pressure drop can also be explained as being 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 [24] elucidated the fixed and fluidized regions could coexist in fluidizing bed and give a remarkable pressure drop-flow rate hysteresis loop at incipient fluidization. This theory is supported by a recent work done by Jeevaneswary [5] who claimed on the hysteresis effect on SFB. Besides, experimental study conducted by her has proven that the increasing of bed weight would increase the pressure drop

across the bed. She also concluded that spherical particles require higher energy to fluidize followed by elliptical and lastly cylindrical shape. Yet, the effect of overlap angle has not been justified due to the unconvincing experimental results.

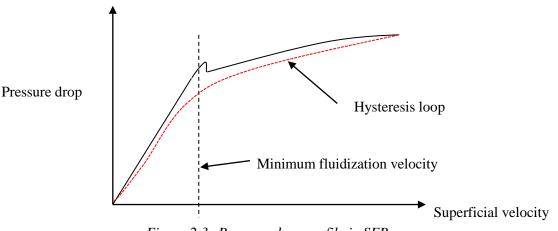


Figure 2.3: Pressure drop profile in SFB

Typical regimes of operation in a conventional fluidized bed include packed bed, minimum fluidization, bubbling, slugging and finally elutriation (see Figure 2.1). While operating a SFB, the following flow regimes occur as the flow rate is increased [13]:

- 1. Bubbling
- 2. Wave motion with dune formation: The swirling motion extends over a certain arc of the bed, while the remaining arc is static.
- 3. Two-layer fluidization: A thin continuously swirling lower layer pairs up with a vigorously bubbling top layer.
- 4. Stable swirling: Perfect fluidization occurs and the particles swirl smoothly.

Only a few researchers had done research on bed pressure drop. However, their respective research usually will be a part of another research. Therefore, the author gets an advantage since his research is fully on various parameters that influence the characteristics of hydrodynamics during the fluidization of particles.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Preliminary Study and Conceptual Design

In order to explore hydrodynamic characteristics of fluidization in gas-solid swirling beds, extensive experimental analysis is conducted as a sequel to an earlier work of Jeevaneswary [6]. The set-up is upgraded for a higher range of gas flow rate, more uniform distribution of gas and higher data accuracy. The process of apparatus improvement will be described in the Detailed Design and Actual Apparatus Set Up section. Project Gantt chart, key milestone and activities flow are developed to boil down various timelines and easily comprehend where the author is in a progression.

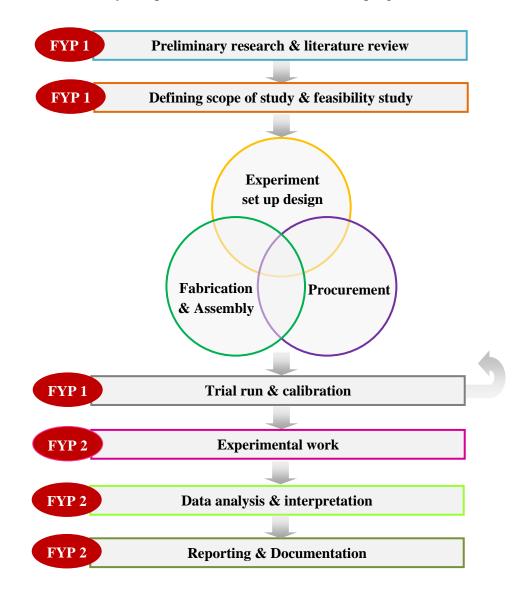


Figure 3.1 : Project activity flow

		Jan			Feb				N	Iar				Ap	or	
No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic															
2	Submission of proposal															
3	Proposal approval by research cluster								-							
4	Preliminary research / literature review															
5	Writing of extended proposal							•								
6	Proposal defense presentation preparation								oreak							
7	 Fabrication and experimental set up CAD drawing , fabrication of blades (EDM) and distributor rings (CNC) Piping and equipment set up 								Mid-semester break							
8	Trial tests and calibrationCalibration of pressure gaugeVerification of errors								W							
9	Experimental work - Data validation using earlier results															
10	Writing of interim draft report															
11	Completion of interim report															

10

Table 3.1: Gantt chart and key milestone for FYP 1

Submission of interin report

1 - Manipula - Manipula	ate of inclination angle ate of overlap angle ate of bed weight ate of particle dimension rogress report	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
 Manipula Manipula Manipula Manipula Manipula Writing of pro Data analysis 	ate of inclination angle ate of overlap angle ate of bed weight ate of particle dimension rogress report																
3 Data analysis																	
	3								reak								
4 Writing of dra									ter b								
	aft report								səmə,								
5 Completion o	of dissertation (soft bound)								Mid-semester break								
6 Writing of tec	chnical paper								1								
7 Preparation of	of Oral Presentation																
8 Completion o	of dissertation (hard bound)																

Table 3.2: Gantt chart and key milestone for FYP 2

Principally, the apparatus is categorized into 3 segments, namely, input, test bench, and output as illustrated below:



In prefatory designs of the experiment set-up, these three major divisions are broke into basic components that must be employed in the experiment in order to create general concept of the arrangement and configuration of the apparatus.

	Apparatus	
Input	Test Bench	Output
 Blower Piping and fittings Weight balance Vernier caliper 	 Plenum chamber Distributor Blades Blades supports Cone Pressure tappings Cylindrical bed wall Particles Orifice plate 	Digital pressure gaugeData recorder

Figure 3.3 : Fundamental division to basic must-have component

The schematic diagram of the conceptual test set-up is shown as following:

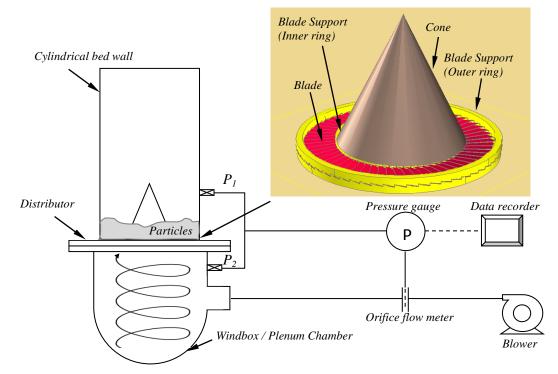


Figure 3.4: Conceptual test set up configuration

3.2 Detailed Design and Actual Apparatus Set Up

This test set-up comprises a Plexiglas cylindrical container acting as a bed wall as shown in Figure 3.5/6 (a). The cylinder is mounted on the flexible version of annular spiral distributor, which is inspired by the spiral distributor design developed by Ouyang and Levenspiel [14]. Unlike them, wherein the overlapping blades formed as full sections of a circle is permanently welded together, the annular distributor is made of sixty blades [3], which are not tack welded at the center (Figure 3.5/6(d)). It features the lightweight and detachable concepts for the ease of varying the configurations with different overlapping and inclination during research work. The inclined overlapping blades help to direct the air at the designed angle. The 1mm-thick aluminium trapezoidal shaped blades are cut by wire electrical discharge machining (EDM) and arranged on Computer Numerical Control (CNC) machined outer and inner stepped rings (Figgure 3.5/6 (c)). The outer rings are supported by a Bakelite block, while the inner rings are placed on a metal hub mounted at the center disk. Both the bed wall and distributor are mounted on the plenum chamber, a hollow cylinder with a hole at one side for the air entry. The chamber is connected to the high pressure centrifugal blower with Polyvinyl chloride pipes, this blower is able to provides higher range of gas flow rate relatively to earlier set up. Air enters the plenum chamber via tangential entry and expands before entering the annular distributor (Figure 3.5/6(b)). This feature results in more uniform distribution of gas compared to set up used by Jeevaneswary [6].

Orifice plates are mounted at middle of the pipe connecting the blower and plenum chamber to quantify the air flow rate. A hollow metal cone is centrally located at the base of the bed. The presence of this cone causes the superficial velocity of the air passes through the distributor to increase, as it reduces the overall cross section of the bed. Hence, this design can operate with relatively deeper beds at high velocity without the problem of particle elutriation. Besides that, it also eliminates the 'dead zone' at the center of the bed. The air flow rate through the bed is obtained by measuring pressure drop across an orifice plate. Two pressure tappings, P_1 and P_2 are provided on the set up, one on the bed wall, the other below the distributor plane, linked to the pressure gauge though pressure fittings and plastic tubes, to measure the pressure drops in mm of water. Each pressure tapping comprises four measuring points located at each quadrant of the cylinders to obtain average or mean value of pressure reading. In the effort to obtain higher data accuracy, data logger is used to record the average value of pressure readings for certain period of time. The snapshot of overall equipment setup is shown in Figure 3.7, the details and dimensions are illustrated in Figure 3.8. A total of seven types of particles with different dimensions are used in the experiment, as tabulated in Figure 3.9.

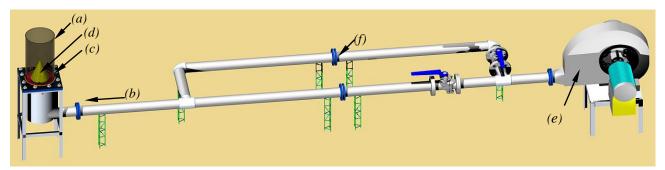


Figure 3.5: Computer aided design of apparatus set up

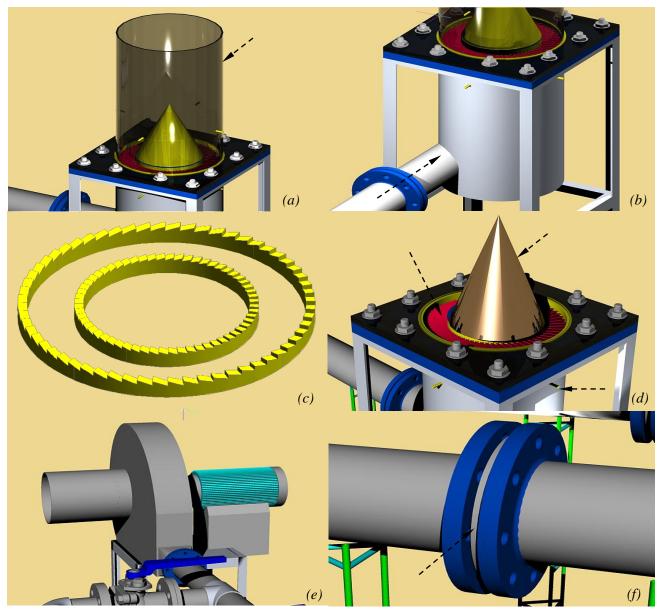


Figure 3.6(a)-(f): Components of the apparatus set up: (a) cylinder Perspex mounted on top of distributorplane, (b) tangential air entry into plenum chamber, (c) inner & outer blade support rings, (d) distributor, cone & pressure tapping positions, (e) high pressure centrifugal blower, (f) orifice plate



Figure 3.7: Actual apparatus set up

3.3 Tools Dimension and Specification

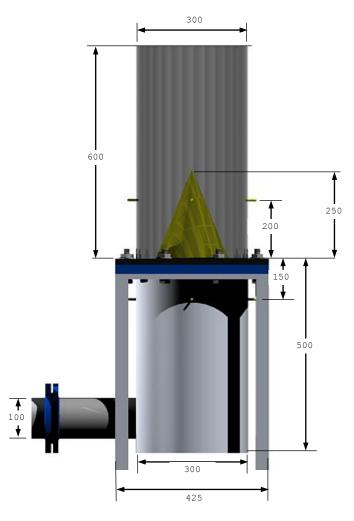


Figure 3.8: Fluidized bed dimension (in unit of mm)

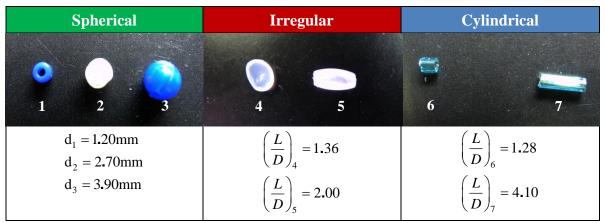


Figure 3.9: Particle shapes and dimensions

GRAPHTEC midi logger GL820

GL220_820APS

		CHI C	G1 G2 G3 G4 L2 L2 L4 L4 L2 L2 L4 L4 L3 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4 L4	
GRAPHTEC -AUG THE - AUG	HIGH SOUGH ALL AND ALL		940 -0228 Y	Model
				Software version
AUX 1234				

Figure 3.10: Data recorder and software version

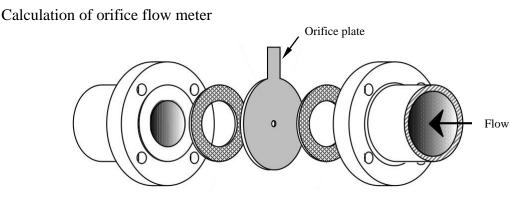


Figure 3.11: Flow through an orifice plate

Superficial Velocity, $V_{superficial} = \frac{Fluiziding air flow rate, Q}{Bed area, A_{bed}}$

Fluidizing air flow rate, Q

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

Whereby, Pipe diameter, D = 0.1 m Orifice diameter hole, d = 0.062 m Coefficient of discharge, C_d = 0.668 Air density, $\rho_{air} = 1.2 \text{ kg/m}^3$ Beta ratio, $\beta = \frac{d}{D} = \frac{0.062}{0.1} = 0.62$ Orifice plate area, $A_o = \frac{\pi \times d^2}{4} = \frac{\pi \times 0.062^2}{4} = 0.003019 \text{ m}^2$ Bed area = $\frac{\pi}{4}$ (Bed outer diameter, d_o^2 – Bed inner diameter, d_i^2) = $\frac{\pi}{4}$ (0.3² – 0.2²) = 0.03927 m²

Thus,

Superficial Velocity,
$$V_{superficial} = \frac{0.003019 \times 0.668 \times \sqrt{\frac{2 \times 9.81 \times \left(\frac{\text{Pressure difference, }\Delta P}{1.2}\right)}{1 - 0.62^4}}}{0.03927}$$

= 0.2249 \sqrt{Pressure difference, }\Delta P

3.4 Experiment Procedures

- 1. Blades of overlap angle 9° are arranged on the 10° inner stepped ring at Bakelite and the 10° outer stepped ring is placed on the blades to keep the blades in place.
- 2. The thin carbon steel disk of 5 mm thick is screwed at the center of the bed above the stepped rings in order to keep the blades in place tightly.
- 3. Then, the central cone is screwed at the center of the bed.
- 4. Next, the Perspex cylinder is screwed with bolts and nuts to the plenum chamber.
- 5. The experiment set up is tested with the blower switched on to confirm the experiment set up works well without any failure or leakage.
- 6. Blower is switched on again.
- 7. Then, the distributor pressure drop is measured at different air flow rates.
- 8. The air flow rate is varied progressively using electronic speed controller of blower.
- 9. The air flow rate is measured using an orifice flow meter.
- 10. The bed is loaded with 500 g cylindrical particle.
- 11. The total pressure drop across the bed and distributor is measured for different air flow rate.
- 12. Then, the experiment is continued with 1000 g and 1500 g and 2000 g of cylindrical particle.
- 13. The experiment is repeated for blade overlap angles of 15° and 18° with six others particles shapes.
- 14. All procedures are repeated using 15 $^{\circ}$ of blade inclination angle.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 **Operation Regimes**

The operation regimes of a conventional fluidized bed throughout the fluidization process consist of packed bed, incipient fluidization, bubbling, slugging and lastly elutriation. Since this paper does not study the bed pressure drop during packed bed regime, the trend is therefore represented with a dotted straight line. However, the pressure drop curve is predicted to be linear initially, and then it might curve upwards to reflect the higher resistance of a turbulent flow of gas through the particle interstices. In operating a SFB, the author observed that it has distinctive regimes of operations when operating a comparatively shallow bed and deep bed. In packed bed regime, the shallow bed has height range of 5 mm to 20 mm while in relatively deep bed, its height ranges between 35 mm to 45 mm. In the relatively shallow bed (Figure 4.1), with the increase of fluidizing gas superficial velocity, packed bed regime occurs before the incipient fluidization. The incipient fluidized regime is the minimum fluidization condition before the bed is led to swirling condition. Some particles are even started to agitate (minor bubbling) and about to swirl at this stage. Subsequently, wavy regime occurs, swirling motion is observed at a certain arc length of the bed, while the remaining section forms a static dune. The swirling particle is initiated from one end of the dune and will be accumulated at the back of the dune (refer to Figure 4.3). Further increase in gas velocity results in progressive swirling motion of the bed. This regime is often desired as the interaction between the gas and particle is optimum and the heat and mass transfer rates are at peak. At sufficiently high fluidizing velocity, the particles are entrained gradually, until finally, all particles are blown out from the containing vessel.

During the operation of a relatively deep bed, 2000 g bed loading for instance (Figure 4.2), the packed bed and incipient fluidization regimes are still existed, however, a two-layer bed is observed as claimed by Sreenivasan and Raghavan [13]. These two layers are made up of constantly swirling bottom layer and an aggressively bubbling top layer (Figure 4.4). This is due to the fact that the horizontal force component of the injected gas is attenuated and disappears at the interface between these layers when the gas is flowing through the bed. These layers would, perhaps, be merged to a fully swirling

region if the gas velocity is high enough or an entrainment regime might occur when the gas flow rate is increased continuously.

As mentioned earlier in Introduction section, bed pressure drop increases gradually with the increase of air velocity upon minimum fluidization. This distinct feature differentiates the SFB from conventional beds. This relationship indirectly shows that there is an additional downward-acting force besides bed weight that requires to be overcome after incipient fluidization. This extra force is more likely contributed by the increase of the bed wall friction caused by the centrifugal force that pushes the particles towards the bed wall when swirling occurs. The centrifugal force acts horizontally, and normal to the column wall. It has two friction components that are parallel to the wall: One acts to oppose the swirling motion and the other acts downward as centrifugal weight to oppose the upward bed expansion. The pressure drops are predicted to initially decline and will further decease with gas velocity until all particles are blown out from the cylindrical bed.

Besides the bed loadings, the flow pattern is also influenced by the shape and size of the particle. By applying the principle of sand dune formation in desert, the formation of dune is easier (with high angle of repose) to be initiated in the bed particles of high angularity, smaller size, and swallower bed. Particles with greater angularity interlock better with each other, resulting in higher intergranular friction, and meanwhile smaller particles are easier to be carried by the fluidized gas. Therefore, the deep bed (2000 g) of cylindrical particles with the smaller L/D ratio is observed to undergo wavy regime prior to two-layer regime.

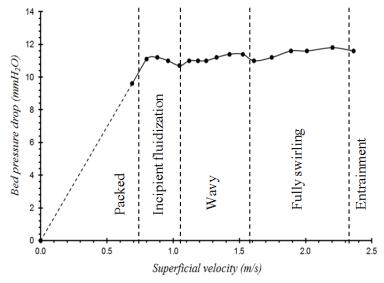


Figure 4.1: Flow regimes for shallow bed (500 g of spherical particle d=2.70 mm at overlap angle of 18°)

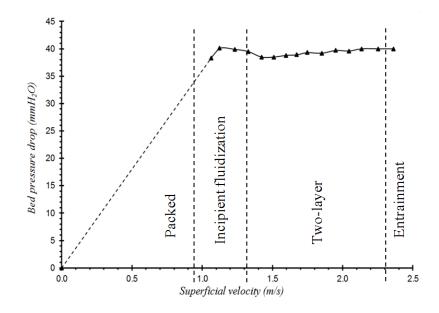


Figure 4.2 : Flow regimes for deep bed (2000 g of irregular shape particle L/D=2.00 at overlap angle of 18°)

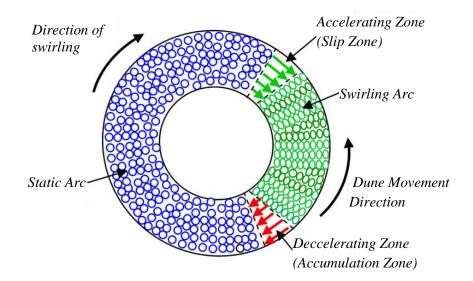


Figure 4.3: Top view of the bed and distributor

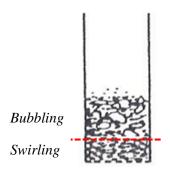


Figure 4.4: Two-layer regime

4.2 Hysteresis Effect of Bed Pressure Drop

Observing the trend of pressure drop across the bed in the reverse direction (Figure 4.5, 4.6), the particles are defluidized by reducing the air superficial velocity. The operation regime of the particles follows the same patterns as in the forward fluidizing direction corresponding to the value of superficial velocity. During forward fluidization, as the gas velocity increases, the bed pressure drop first shows an upward trend and upon reaching a particular peak value, it drops till it reaches the conventional bed value before starting to rise steadily again because of the frictional resistance due to swirling of the particles. Interestingly, during defluidization, the bed pressure drop decreases without exhibiting a significant hump at incipient fluidization, and its value is lower than the theoretical bed pressure drop indicated by the green dotted line. This can be explained thus: During the forward direction, additional energy is required for perturbing of the 'locked' particles from the packed bed regime in order to get them fluidized. This hysteresis effect suggests that the operation of swirling fluidized bed has history dependent behavior. In fact, if the bed is re-fluidized, the peak in the bed pressure drop would not be seen as the packed bed arrangement had been unlocked permanently during the first fluidization.

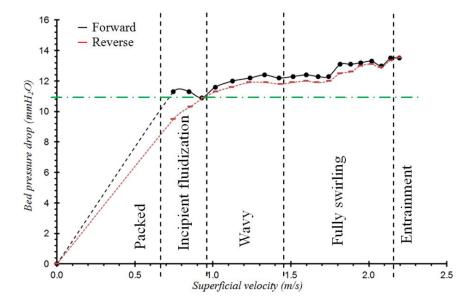


Figure 4.5: Flow regimes for shallow bed (500 g of irregular particle shape with L/D=1.36 mm) at overlap angle of 18°

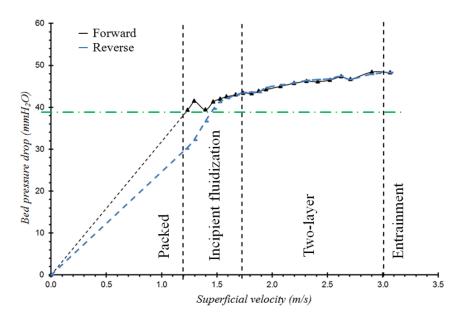


Figure 4.6: Flow regimes for deep bed (2000 g of cylindrical particle with L/D=4.10 mm) at overlap angle of 18°

In calculating the theoretical pressure drop, the author uses correlation recommended by Chitester et al. [25] for coarse particles:

$$\operatorname{Re}_{p,mf} = \left[\left(28.7 \right)^2 + 0.0494 Ar \right]^{0.5} - 28.7$$

Where Ar is given by

$$Ar = \frac{d_p^{3} \rho_g \left(\rho_p - \rho_g\right) g}{\mu_g^{2}}$$
$$U_{mf} = Re_{p,mf} \mu_g \left(\frac{\rho_g}{d_p}\right)$$

Using Ergun Equation [20],

$$\Delta P = \left[\frac{150\mu_g \left(1-\varepsilon\right)^2 U_{mf}}{\varepsilon^3 d_p^2} + \frac{1.75(1-\varepsilon)\rho_g U_{mf}^2}{\varepsilon^3 d_p}\right]L$$

Where by,

 $\Delta P - Pressure drop$ Ar - Archimedes number $d_p - Effective diameter of particles$ L - Height of bed $\rho_g - Fluidizing gas density$ $\rho_p - Particle density$

- Re_{p, mf} Reynolds number ε - Fractional void volume
- μ_g Absolute viscosity of fluidizing gas
- U_{mf} Superficial fluid velocity

g - gravitational acceleration

4.3 Effect of Bed Loadings

Bed weights are increased from 500 g to 2000 g in steps of 500 g to study the effect of bed loading (weight) variation, which is also linearly corresponding to the respective bed height. Figures 4.7-4.9 illustrate the trends of bed pressure drop in mm of water against the air superficial velocity with a cone as the center body. The trends clearly indicate that higher bed loading results in higher bed pressure drop for all types of particles shapes and dimensions. The reason of this relationship is that as bed height (or amount of bed particles) increases happens, the amount of particle surface area that requires to be passed by the air before releasing to the bed free surface is also increased. It indirectly shows that in SFB, the bed loading is one of the important parameters to be considered in order to achieve high fluidization quality. In practical situations, the amount of energy provided for fluidization process is often limited, therefore processing a high bed loading may cause poor fluidization quality due to reduced swirling at the upper layer, given specific residence time and energy, and conversely, fluidizing a low bed loading is inefficient in terms of energy utilization.

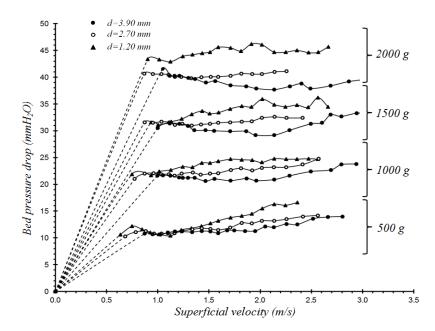


Figure 4.7: Bed pressure drop against gas superficial velocity for variable bed loading of spherical shape at overlap angle 18°

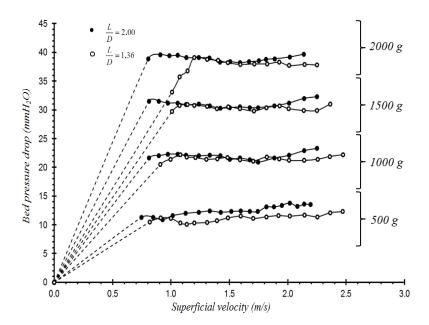


Figure 4.8: Bed pressure drop against gas superficial velocity for variable bed loading of irregular shape at overlap angle 18°

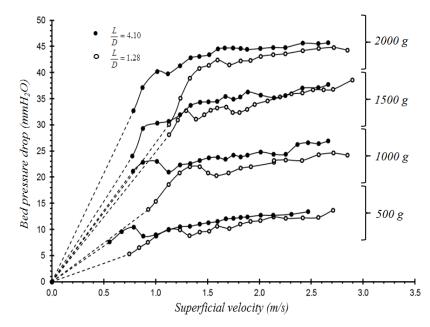


Figure 4.9: Bed pressure drop against gas superficial velocity for variable bed loading of cylindrical shape at overlap angle 18°

4.4 Effect of Particle Size

Figures 4.7-4.9 exemplify the trends of bed pressure drop variation against the air superficial velocity at different particle sizes. The trends clearly show that in the packed region and also fluidization region, larger particles of all shapes have lower pressure drop

across the bed. This is due to the fact that smaller size particles in fact have a larger surface area per unit volume. In other words, additional energy is required to overcome the surface friction between particle and fluidizing air when smaller particles are used. The large surface area has greater absorption of angular momentum from the gas to cause more vigorous swirling. Thus, the pressure drop is higher for smaller particles. In addition, larger particles are capable of withstanding higher superficial velocity as the bed expansion occurs slower and thus swirling longer before entrainment occurs [4]. This graph reflects that it is advantageous to use larger particle for fluidization process. On the other hand, a larger interfacial area is good for transport processes. Therefore, rather than dismiss the smaller particles, it will be better to leave the question open: it depends on the particular process, whether it is kinetic-controlled or diffusion-controlled.

4.5 Effect of Particle Shape

A remarkable result is that the cylindrical bed particles require a lower pressure drop relative to other shapes (Figures 4.10-4.13). The plausible reason is that the cylindrical particles tend to rearrange themselves horizontally in a direction transverse to the flow of the fluidizing gas. This result is rather counterintuitive. It would be more normal to believe that the cylindrical particles will assume an orientation in which they will experience less drag, that is, aligned in the flow direction. However, support for the observed behavior comes from the fact that tree logs floating downstream or icebergs at sea take a preferred orientation transverse to the direction of the stream. The constructal theory of natural systems formulated by Professor A. Bejan [26] offers a scientific explanation for the observation.

In engineering terms, the result has practical implications. It shows that in swirling fluidizing beds, with a more deterministic behavior than the conventional fluidized beds with a chaotic behavior, it is advantageous to use solids of cylindrical shape rather than spherical shape, both for the lower bed pressure drop, as well as the higher interfacial area per unit volume for effective transport of heat and species. The spherical shape particles have the highest bed pressure drop followed by irregular shapes. Irregular shape particles have slight "constructal effects" and tend to reposition themselves in a way to facilitate the flow of fluidizing fluid.

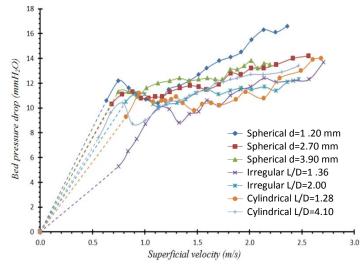


Figure 4.10 : Bed pressure drop against gas superficial velocity for variable particle shape weighted 500 g

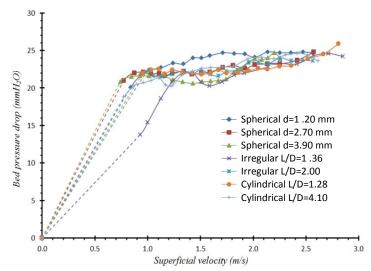


Figure 4.11: Bed pressure drop against gas superficial velocity for variable particle shape weighted 1000 g

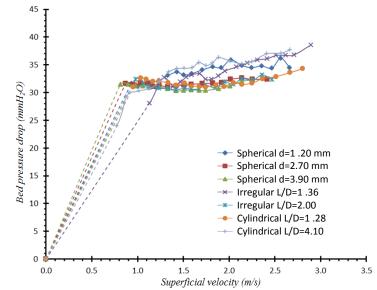


Figure 4.12: Bed pressure drop against gas superficial velocity for variable particle shape weighted 1500 g

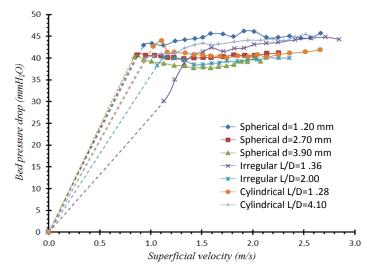


Figure 4.13: Bed pressure drop against gas superficial velocity for variable particle shape weighted 2000 g

4.6 Effect of Blade Overlap Angle

The effect of blade overlap angle variation is insignificant compared to other parameters. Intuitively, the higher overlapping angle is seen to impose higher pressure drop since the air flows through a further blade gap, thus higher friction and resistance.

This parameter does not demonstrate significant relationship in terms of bed pressure drop especially for the spherical and irregular shapes. In fact, these two shapes show a contradictory relationship that higher overlapping angle requires lower pressure drop. The finding yields that this theory is only applicable to the operation of the cylindrical particles. Results are shown in Figures 4.14-4.16.

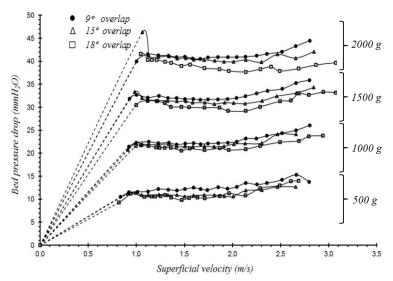


Figure 4.14: Bed pressure drop against gas superficial velocity for variable blade overlap angle with spherical particle d=3.90 mm

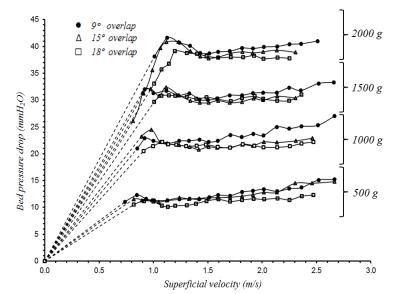


Figure 4.15: Bed pressure drop against gas superficial velocity for variable blade overlap angle with irregular particle shape L/D=2.00

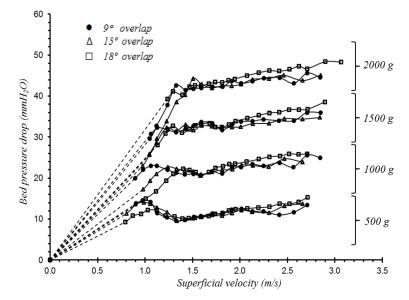


Figure 4.16: Bed pressure drop against gas superficial velocity for variable blade overlap angle with cylindrical particle L/D=4.10

4.7 Distributor Pressure Drop

Logically, as mentioned in the earlier section, the higher overlapping angle may be thought to impose higher pressure drop since the air flows through a longer blade gap, with higher friction and resistance [16]. However, from the experimental results as illustrated in Figure 4.17, it seems that the friction is not the dominant parameter in determining this pressure drop, the flow pattern of the gas injected from the blade gap is the main factor in this case. The further blade gap is able to drive the injection of gas into the desired inclination more effectively after dispersing from the distributor (Figure 4.18). The blade inclination angle is θ but the gas exits from the blades at a larger angle α . This is due to the growth of the boundary layer that is not symmetrical on the two blades. With longer overlap angle. i.e., longer blades, the flow tends more to fully developed flow. It is anticipated that this effectiveness peaks at a certain overlap angle and a higher pressure drop will occur due to the friction. The same concept applies to inclination angle, in which upwards flow from plenum chamber experiences more change in direction when entering the distributor at lower inclination. Thus, distributor pressure drop is significantly lower at higher inclination angle.

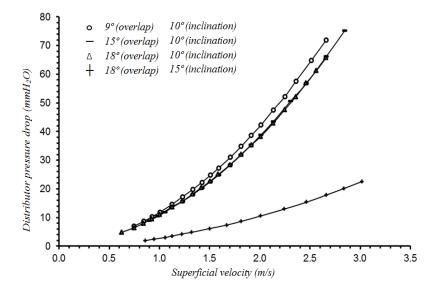


Figure 4.17: Distributor pressure drop for variable blade overlap and inclination angles, fluidizing gas direction after dispersing through empty bed

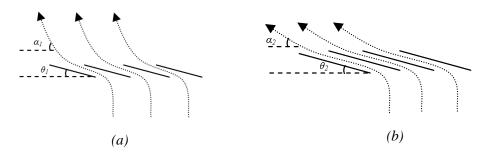


Figure 4.18 (a)-(b): Injection of gas at (a) smaller blade overlap angle, (b) larger blade overlap angle

4.8 Slugging Period

In the wavy regime, at a certain superficial velocity, the particles begin to pile up causing a dune to form. Air continues to move particles up to the pile until the pile is so steep that it collapses under its own weight. The collapsing particles come to rest when it reaches just the right steepness to keep the dune stable. The particles at the slip region will be carried by the fluidizing gas in circular path and accumulate at the other side of dune. This causes the coriolis effect that the dune moves in the opposite direction with the fluidizing gas. Referring to the trend of the slugging time in Figure 4.20, this parameter is mainly affected by the variation of bed loadings and particles sizes. In relatively small and shallow loading, the formation of the dune occurs at lower air velocity and they tend to accumulate with each other rather than slip away, causing another side of arc unfilled as the volume of bed is small. Thus, the overall dune movement is slow. During the increasing of gas velocity, the height of the dune becomes lower as more particles from the slip face are brought to the other side via the empty arc, causing the dune to elongate. This elongation brings the effect that the movement of the dune becomes faster as it moves and at the same time it extends, until the dune is low enough to be brought to swirl and this marks the occurrence of next regime (Figure 4.19(a) and Figure 4.3).

In a bed of large particles and high loading, the increasing of gas superficial velocity also encourages the slip face to slip, then swirl and accumulate at the other end. However, the remaining arc is filled by particle with lower level, the height of the dune decreases with the increasing of air velocity, and the remaining arc increases in height, until it reaches the next regime where both are at the same level. The slugging time becomes longer with the increasing of gas velocity due to the absence of the elongation occurrence and when the particles height of the remaining arc becomes higher, it is more difficult for the fluidizing gas to carry the particle to form dune (Figure 4.19(b)).

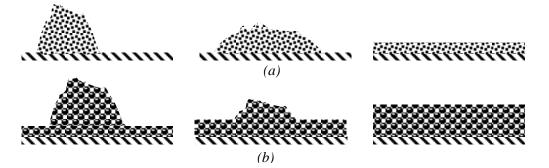


Figure 4.19 (a)-(b): Slugging regimes in circumferential view for bed of (a) small particle and shallow loading and (b) large particle and deep loading

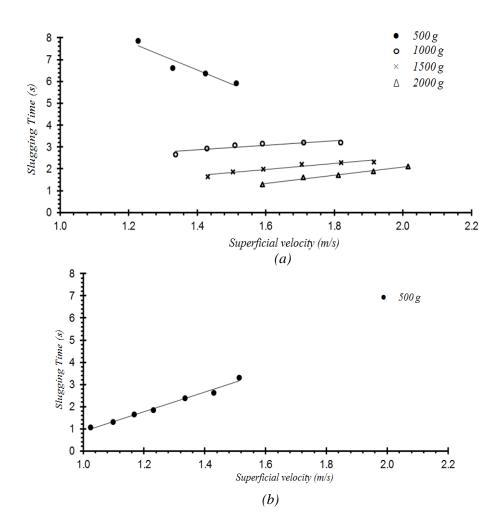


Figure 4.20(a)-(b): Slugging time for (a) sphere particle d=1.2 mm, (b) sphere particle d=3.9 mm, at overlap angle of 18°

4.9 Effect of Blade Inclination Angle

In the case of blade inclination angle, the value of pressure drop represents the flow resistance of the bed and the momentum transferred from gas to the particles (and to the kinetic energy gained by the particles as a result).

When the air enters at smaller inclination, it has a greater angular momentum and causes a more vigorous swirling of the bed particles. This can be observed visually. So, with more momentum transferred from the air, its pressure drop is higher. Therefore, from the bed pressure drop trend in Figure 4.21, larger inclination angle has lower bed pressure drop due to the lower momentum transferred to the particles.

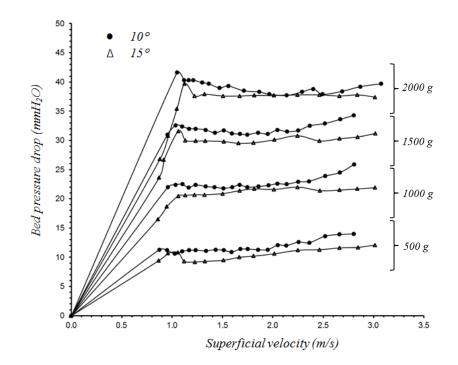


Figure 4.21: Bed pressure drop against gas superficial velocity for variable blade inclination angle with spherical particle d=3.90 mm

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In the thorough analysis of raw data, the hydrodynamics behavior of the novel gasparticle contacting technique of the SFB has been studied through a series of experiments. The findings indicate that:

- i. The order of flow regimes in SFB with shallow bed are packed bed, incipient fluidization, wavy regime, and finally entrainment regime. Meanwhile the deep bed is prone to undergo a two-layer regime before the particles are entrained.
- ii. The bed pressure drop exhibits hysteresis effect at incipient conditions which indicates that the operation of swirling fluidized bed is history dependent.
- iii. Higher bed loading has higher bed pressure drop, hence requires more energy for fluidization.
- iv. Larger solid particles size have lower pressure drop of bed and capable of withstanding the condition of high gas superficial velocity.
- v. Cylindrical particles have the lowest bed pressure drop among all the shapes as they have the tendency to position themselves to facilitate the flowing fluid.
- vi. Larger blade overlapping angle imposes additional pressure drop, particularly at the distributor since the air is now forced to flow through higher resistance.
- vii. Particle size, shape, and bed weight are the most significant variables that have more impact on the bed characteristics, while the blade dimension has relatively smaller effect on the bed behavior.
- viii. The slugging time is affected by the effect of the bed loading, particle size and particle shape.
 - ix. Larger overlap angle and larger blade inclination angle exhibit lower distributor pressure drop.
 - x. Smaller inclination angle of gas injection has higher bed pressure drop.

To conclude, this project is a comprehensive experimental study of hydrodynamic characteristics of swirling fluidized beds. Based on boiled down deadlines, and target dates as listed in the Gantt chart, the overall research progress is notable and reaching the target. Research set up is installed as design and the primary data which is analyzed and interpreted shows interesting results and considerably accurate to show the influence of each parameter on the bed behavior. In short, this project is definitely feasible to be completed within the study timeframe with its undeniable significance towards fluidization engineering. The parameter of blades configurations in terms of inclination angle will be studied in details later as the blades and the support rings require complex fabrication process. The author recommends that the hydrodynamics of newly invented multistage bed to be studied in comparison with to the single stage bed, as this study may perhaps contribute in revealing the rationale on of the energy conservation technology. Perhaps, in future study, particle tracking velocimetry (PTV) can be used to investigate the interstitial motion of individual particles and its relations with the characteristic flow structures formed in fluidized beds without disturbing the flow field.

CHAPTER 6

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CHAPTER 7

APPENDICES

APPENDIX A: EXAMPLE OF SUPERFICIAL VELOCITY CALCULATION

Example of superficial velocity calculation for spherical particle, d=2.7 mm at 500g

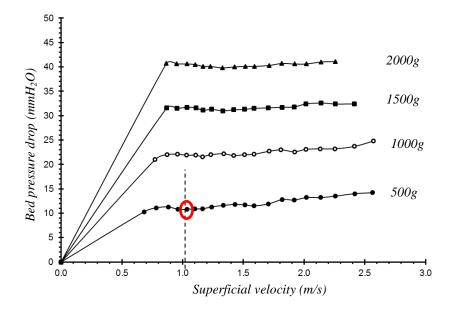


Figure 7.1: Bed pressure drop against superficial velocity for variable bed loading for spherical particle, d=2.7 mm

At the circled point,

Pressure drop across orifice plate is $20.1 \text{ mmH}_2\text{O}$ (reading taken from differential pressure transmitter),

From the orifice calculation,

Superficial Velocity, $V_{superficial} = 0.2249\sqrt{Pressure difference}, \Delta P$ = $0.2249\sqrt{20.1}$ = 1.01 m/s (as shown is Figure 7.1)

APPENDIX B:	PARTIAL EXPERIMENT RAW DATA (Table 7.3)
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Shape: Sphe	erical Size: d	=1.2mm Mas	ss: 500g Incli	ination: 10de	g Overlap: 18deg	-				_					1
	ΔP acros	s orifice	Superfica	d Velocity	ΔP across distributor	ΔP across distril	outor with particle	ΔP acr	oss bed			Slugging	Time		
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH ₂ O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	5	s	s	5	s	
1	7.900	8.300	0.693	0.711	4.500	15.100	11.200	10.600	6.700						Incipient
2	11.000	10.700	0.818	0.807	6.100	18.300	15.600	12.200	9.500						Bubbling
3	14.100	14.300	0.926	0.933	7.700	19.300	17.600	11.600	9.900						Bubbling
4	16.900	17.400	1.014	1.029	9.200	20.200	21.400	11.000	12.200						Bubbling
5	20.100	20.400	1.106	1.114	10.700	21.400	21.500	10.700	10.800						Bubbling
6	24.900	25.300	1.231	1.241	13.400	23.800	23.800	10.400	10.400						Bubbling
7	29.700	30.100	1.345	1.354	15.400	26.900	26.600	11.500	11.200	7.830	7.990	7.670	7.930	7.855	Slugging
8	34.800	35.000	1.455	1.460	17.900	29.700	29.400	11.800	11.500	6.600	6.550	6.620	6.740	6.628	Slugging
9	40.000	40.500	1.560	1.570	20.100	32.300	32.400	12.200	12.300	6.330	6.470	6.350	6.330	6.370	Slugging
10	45.200	45.300	1.659	1.661	22.400	35.100	35.200	12.700	12.800	5.760	6.050	5.970	5.850	5.908	Slugging
11	49.800	50.000	1.741	1.745	24.700	37.900	37.900	13.200	13.200						Swirling
12	57.700	57.500	1.874	1.871	28.100	41.900	41.700	13.800	13.600						Swirling
13	65.200	65.500	1.992	1.997	31.700	45.800	46.000	14.100	14.300						Swirling
14	72.600	72.300	2.102	2.098	35.100	49.600	49.500	14.500	14.400						Swirling
15	80.300	80.400	2.211	2.212	38.000	53.500	53.300	15.500	15.300						Swirling
16	90.000	90.000	2.341	2.341	42.600	58.900	58.800	16.300	16.200						Entrrain
17	99.600	100.000	2.462	2.467	47.300	63.400	63.400	16.100	16.100						Entrrain
18	109.900	-	2.586	-	51.800	68.400	-	16.600	-						Entrrain
Shape: Sphe			ss: 1000g Inc	lination: 10d	eg Overlap: 18deg					_					1
	ΔP acros	1		d Velocity	ΔP across distributor		outor with particle		oss bed			Slugging			-
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	S	s	S	S	S	
1	13.900	13.600	0.920	0.910	8.100	28.200	27.200	20.100	19.100						Incipient
2	17.200	17.000	1.023	1.017	9.600	31.300	31.000	21.700	21.400						Start bubbling
3	20.200	19.800	1.109	1.098	11.100	33.500	33.200	22.400	22.100						Bubbling
4	25.000	24.900	1.234	1.231	13.800	36.500	35.900	22.700	22.100						Bubbling
5	30.400	30.000	1.360	1.351	15.800	39.100	38.300	23.300	22.500						Bubbling
6	35.200	35.400	1.464	1.468	18.300	41.500	41.600	23.200	23.300	2.720	2.680	2.600	2.680	2.670	Slugging
7	40.200	40.500	1.564	1.570	20.500	44.500	44.500	24.000	24.000	2.890	2.980	2.970	2.890	2.933	Slugging
8	44.900	45.400	1.653	1.662	22.800	46.800	46.700	24.000	23.900	3.050	3.010	3.110	3.140	3.078	Slugging
9	49.800	49.600	1.741	1.738	25.100	49.400	48.700	24.300	23.600	3.160	3.170	3.230	3.090	3.163	Slugging
10	57.700	57.300	1.874	1.868	28.500	53.200	52.400	24.700	23.900	2.980	2.960	3.050	3.080	3.018	Slugging
	65.200	64.600	1.992	1.983	32.100	56.700	56.700	24.600	24.600	3.030	3.010	3.010	3.050	3.025	Slugging
11		72.500	2.105	2.101	35.400	59.900	60.500	24.500	25.100						Swirling
12	72.800							24400	25.100	1	1	1	1		Swirling
12 13	80.000	80.000	2.207	2.207	38.400	62.500	63.500	24.100		_					
12 13 14				2.345	38.400 43.000	62.500 67.800	63.500 67.800	24.100 24.800	23.100						Swirling
12 13 14 15	80.000 89.900 100.000	80.000 90.300 100.000	2.207 2.339 2.467	2.345 2.467	43.000 47.700	67.800 72.400	67.800 72.700	24.800 24.700	24.800 25.000						
12 13 14 15 16	80.000 89.900	80.000 90.300	2.207 2.339 2.467 2.583	2.345 2.467 2.588	43.000 47.700 52.200	67.800	67.800	24.800	24.800						Swirling
12 13 14 15	80.000 89.900 100.000	80.000 90.300 100.000	2.207 2.339 2.467	2.345 2.467	43.000 47.700	67.800 72.400	67.800 72.700	24.800 24.700	24.800 25.000						Swirling Swirling

Shape: Sphe	erical Size: d=	1.2mm Mas	S. 1500g IIIC		eg Ovenap. 10deg									
Data No.	ΔP acros	s orifice	Superfica	al Velocity	ΔP across distributor	ΔP across distrib	utor with particle	ΔP acro	oss bed		Sluggir	ng Time		
Data NU.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	s	s	s	s	
1	17.100	16.800	1.020	1.011	9.600	41.200	39.700	31.600	30.100					Incipient
2	19.800	19.800	1.098	1.098	11.100	42.200	41.400	31.100	30.300					Bubbling
3	25.100	24.900	1.236	1.231	13.800	45.500	45.400	31.700	31.600					Bubbling
4	30.000	30.500	1.351	1.363	15.800	48.000	48.000	32.200	32.200					Bubbling
5	34.900	34.900	1.458	1.458	18.300	51.400	51.000	33.100	32.700					Bubbling
6	40.400	40.400	1.568	1.568	20.500	54.200	54.200	33.700	33.700	1.730	1.600	1.600	1.640	Slugging
7	44.600	44.600	1.648	1.648	22.800	56.000	55.900	33.200	33.100	1.850	1.780	1.740	1.860	Slugging
8	50.000	49.800	1.745	1.741	25.100	58.500	58.600	33.400	33.500	1.970	2.040	2.100	1.980	Slugging
9	57.300	57.600	1.868	1.873	28.500	62.600	62.700	34.100	34.200	2.280	2.230	2.240	2.220	Slugging
10	65.300	65.400	1.994	1.995	32.100	66.700	66.300	34.600	34.200	2.400	2.300	2.350	2.220	Slugging
11	72.300	72.200	2.098	2.096	35.400	69.900	69.600	34.500	34.200	2.460	2.450	2.480	2.320	Slugging
12	80.400	79.900	2.212	2.205	38.400	74.300	73.300	35.900	34.900		Minors	lugging		Slugging
13	90.100	89.900	2.342	2.339	43.000	77.900	77.500	34.900	34.500					Swirling
14	99.600	99.800	2.462	2.465	47.700	82.200	82.400	34.500	34.700					Swirling
15	109.600	109.700	2.583	2.584	52.200	87.000	87.000	34.800	34.800					Swirling
16	120.000	119.700	2.703	2.699	57.000	91.400	91.100	34.400	34.100					Swirling
17	129.700	129.800	2.810	2.811	61.300	97.500	97.400	36.200	36.100					Entrrain
18	139.700	-	2.916	-	65.900	100.400	-	34.500	-					Entrrain
Shape: Sphe	rical Sizo d-	4.0												
					eg Overlap: 18deg	ΔP across distrib	utor with particle	ΔP acro	oss bed		Sluggir	ng Time		
Data No.	ΔP acros Forward			lination: 10de al Velocity Reverse	eg Overlap: 18deg ΔP across distributor	ΔP across distrib Forward	utor with particle Reverse	ΔP acro Forward	oss bed Reverse	T1	Sluggir T2	ng Time T3	Tavg	Observation
Data No.	ΔP acros Forward	s orifice Reverse	Superfica Forward	al Velocity Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse				Tavg s	Observation
	ΔP acros Forward mmH ₂ O	s orifice Reverse mmH ₂ O	Superfica Forward <i>m/sec</i>	al Velocity Reverse <i>m/sec</i>	ΔP across distributor mmH $_2O$	Forward mmH ₂ O	Reverse mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	T1 5	T2	T3	-	
1	ΔP acros Forward mmH ₂ O 17.000	s orifice Reverse mmH ₂ O 17.100	Superfica Forward <i>m/sec</i> 1.017	Al Velocity Reverse <i>m/sec</i> 1.020	ΔP across distributor mmH ₂ O 9.600	Forward <i>mmH</i> ₂ <i>O</i> 52.500	Reverse mmH ₂ O 48.700	Forward <i>mmH</i> ₂ O 42.900	Reverse mmH ₂ O 39.100		T2	T3	-	Incipient
1 2	ΔP acros Forward <i>mmH</i> ₂ O 17.000 20.200	s orifice Reverse mmH ₂ O 17.100 19.600	Superfica Forward m/sec 1.017 1.109	Velocity Reverse m/sec 1.020 1.092	ΔP across distributor mmH ₂ O 9.600 11.100	Forward mmH ₂ O 52.500 54.400	Reverse mmH ₂ O 48.700 52.600	Forward mmH ₂ O 42.900 43.300	Reverse mmH ₂ O 39.100 41.500		T2	T3	-	Incipient Bubbling
1 2 3	ΔP acros Forward <i>mmH</i> ₂ O 17.000 20.200 24.900	Reverse mmH ₂ O 17.100 19.600 25.100	Superfica Forward <i>m/sec</i> 1.017 1.109 1.231	Velocity Reverse m/sec 1.020 1.092 1.236	ΔP across distributor mmH ₂ O 9.600 11.100 13.800	Forward mmH ₂ O 52.500 54.400 56.700	Reverse mmH ₂ O 48.700 52.600 56.300	Forward mmH ₂ O 42.900 43.300 42.900	Reverse mmH ₂ O 39.100 41.500 42.500		T2	T3	-	Incipient Bubbling Bubbling
1 2 3 4	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400	Reverse mmH ₂ O 17.100 19.600 25.100 30.300	Superfice Forward <i>m/sec</i> 1.017 1.109 1.231 1.360	Image: Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.358	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800	Forward mmH ₂ O 52.500 54.400 56.700 59.700	Reverse mmH ₂ O 48.700 52.600 56.300 59.100	Forward mmH ₂ O 42.900 43.300 42.900 43.900	Reverse mmH₂O 39.100 41.500 42.500 43.300		T2	T3	-	Incipient Bubbling Bubbling Bubbling
1 2 3 4 5	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200	sorifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300	Superfict Forward m/sec 1.017 1.109 1.231 1.360 1.464	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600		T2	T3	-	Incipient Bubbling Bubbling Bubbling Bubbling
1 2 3 4 5 6	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200	Superfica Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300		T2	T3	-	Incipient Bubbling Bubbling Bubbling Bubbling Swirling
1 2 3 4 5 6 7	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400 44.900	sorifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900	Superfica Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000 67.500	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.700	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500	S	T2 <i>s</i>	T3 <i>s</i>	S	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling
1 2 3 4 5 6	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200	Superfica Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300		T2	T3	-	Incipient Bubbling Bubbling Bubbling Bubbling Swirling
1 2 3 4 5 6 7 8	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 49.800	sorifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.600	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500 45.200	s 	T2 \$ 1.350	T3 s 1.300	s 1.280	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain
1 2 3 4 5 6 7 8 9	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 49.800 57.600	sorifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748 1.874	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500	Forward mmH₂O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 45.600 45.500	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500 45.200 45.900	s 	T2 s 1.350 1.580	T3 s 1.300 1.580	s 1.280 1.610	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10	ΔP acros Forward mmH₂O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 49.800 57.600 64.700	sorifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100	Forward mmH₂O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000 77.000	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 44.700 45.600 45.500 44.900 46.200	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500 45.200 45.900 44.900	\$ 	T2 s 1.350 1.580 1.710	T3 5 1.300 1.580 1.700	s 1.280 1.610 1.720	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10 11	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 44.900 49.800 57.600 64.700 72.200	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800 72.500	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985 2.096	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986 2.101	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100 35.400	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000 77.000 81.600	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000 81.800	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 44.700 45.600 45.500 44.900	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500 45.200 45.900 44.900 46.400	s 1.250 1.650 1.660 1.860	T2 s 1.350 1.710 1.910 2.170	T3 5 1.300 1.580 1.700 1.910	s 1.280 1.610 1.720 1.900	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10 11 12	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 44.900 44.900 57.600 64.700 72.200 80.000	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800 72.500 80.000	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985 2.096 2.207	l Velocity Reverse <i>m/sec</i> 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986 2.101 2.207	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100 35.400 38.400	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000 65.000 67.500 70.700 74.000 77.000 81.600 84.500	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000 81.800 84.600	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 44.700 45.600 45.500 44.900 46.200 46.100	Reverse mmH ₂ O 39.100 41.500 42.500 43.600 43.600 44.500 45.200 45.900 46.400 46.200 45.400	s 1.250 1.650 1.660 1.860	T2 s 1.350 1.710 1.910 2.170	T3 s 1.300 1.580 1.700 1.910 2.100	s 1.280 1.610 1.720 1.900	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10 11 11 12 13	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 44.900 49.800 57.600 64.700 72.200 80.000 89.900	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800 72.500 80.000 89.600	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985 2.096 2.207 2.339	I Velocity Reverse m/sec 1.020 1.092 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986 2.101 2.207 2.335	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100 35.400 38.400 43.000	Forward mmH ₂ O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000 77.000 81.600 84.500 87.700	Reverse mmH ₂ O 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000 81.800 84.600 88.400	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 44.700 45.600 45.500 44.900 46.200 46.100 44.700	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.300 44.500 45.200 45.900 46.400 46.200	s 1.250 1.650 1.660 1.860	T2 s 1.350 1.710 1.910 2.170	T3 s 1.300 1.580 1.700 1.910 2.100	s 1.280 1.610 1.720 1.900	Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10 11 12 13 14	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 44.900 44.900 57.600 64.700 72.200 80.000 89.900 99.800	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800 72.500 80.000 89.600 100.500	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985 2.096 2.207 2.339 2.465	I Velocity Reverse m/sec 1.020 1.020 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986 2.101 2.207 2.335 2.473	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100 35.400 38.400 43.000 47.700	Forward mmH₂O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000 77.000 81.600 84.500 87.700 92.400	Reverse mmH 20 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000 81.800 84.600 88.400 92.900	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.500 44.500 44.500 44.700 45.600 46.200 46.200 44.700 44.700	Reverse mmH ₂ O 39.100 41.500 42.500 43.600 43.600 44.500 45.200 45.900 46.400 46.200 45.200	s 1.250 1.650 1.660 1.860	T2 s 1.350 1.710 1.910 2.170	T3 s 1.300 1.580 1.700 1.910 2.100	s 1.280 1.610 1.720 1.900	Incipient Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain Entrrain
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	ΔP acros Forward mmH ₂ O 17.000 20.200 24.900 30.400 35.200 40.400 44.900 44.900 44.900 64.700 72.200 80.000 89.900 99.800 109.800	s orifice Reverse mmH ₂ O 17.100 19.600 25.100 30.300 35.300 40.200 44.900 50.200 57.700 64.800 72.500 80.000 89.600 100.500 110.500	Superfice Forward m/sec 1.017 1.109 1.231 1.360 1.464 1.568 1.653 1.741 1.873 1.985 2.096 2.207 2.339 2.465 2.585	I Velocity Reverse m/sec 1.020 1.032 1.236 1.358 1.466 1.564 1.653 1.748 1.874 1.986 2.101 2.207 2.335 2.473 2.594	ΔP across distributor mmH ₂ O 9.600 11.100 13.800 15.800 18.300 20.500 22.800 25.100 28.500 32.100 35.400 38.400 43.000 47.700 52.200	Forward mmH₂O 52.500 54.400 56.700 59.700 62.500 65.000 67.500 70.700 74.000 77.000 81.600 84.500 87.700 92.400 97.200	Reverse mmH 20 48.700 52.600 56.300 59.100 61.900 64.800 67.300 70.300 74.400 77.000 81.800 84.600 88.400 92.900 97.800	Forward mmH ₂ O 42.900 43.300 42.900 43.900 44.200 44.200 44.500 44.500 45.600 45.500 44.900 46.200 46.100 44.700 45.000	Reverse mmH ₂ O 39.100 41.500 42.500 43.300 43.600 44.500 45.200 46.400 46.200 45.200 45.400 46.400 45.200	s 1.250 1.650 1.660 1.860	T2 s 1.350 1.710 1.910 2.170	T3 s 1.300 1.580 1.700 1.910 2.100	s 1.280 1.610 1.720 1.900	Incipient Bubbling Bubbling Bubbling Swirling Swirling Entrrain Entrrain Entrrain

18

140.100

2.920

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65.900

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45.700

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Entrrain

111.600

	ΔP acro	ss orifice	Superfica	l Velocity	AD assess distributes	ΔP across distr	ibutor with particle	ΔP acr	oss bed		SI	ugging Tii	me		
Data No.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	5	5	5	5	s	
1	9.400	9.600	0.756	0.764	5.600	15.200	15.500	9.600	9.900						Incipient
2	12.600	12.600	0.876	0.876	7.000	18.100	18.200	11.100	11.200						Bubbling
3	15.300	15.300	0.965	0.965	8.500	19.700	19.800	11.200	11.300						Bubbling
4	18.200	18.400	1.053	1.058	10.100	21.100	21.300	11.000	11.200						Start swirling
5	21.700	22.000	1.149	1.157	11.600	22.300	22.700	10.700	11.100	1.750	1.880	1.850	1.820	1.825	Slugging
6	24.700	24.400	1.226	1.219	12.800	23.800	23.900	11.000	11.100	2.120	2.150	2.150	2.120	2.135	Slugging
7	27.800	27.600	1.301	1.296	14.300	25.300	25.500	11.000	11.200	2.410	2.310	2.310	2.280	2.328	Slugging
8	30.700	31.100	1.367	1.376	15.900	26.900	27.000	11.000	11.100	2.660	2.600	2.630	2.500	2.598	Slugging
9	34.700	34.800	1.453	1.455	17.700	28.900	28.900	11.200	11.200	3.600	3.440	3.280	3.410	3.433	Slugging
10	40.000	40.300	1.560	1.566	20.000	31.400	31.700	11.400	11.700						Swirling
11	45.900	46.300	1.672	1.679	22.800	34.200	34.400	11.400	11.600						Swirling
12	51.100	51.500	1.764	1.771	25.700	36.700	36.800	11.000	11.100						Swirling
13	60.000	59.900	1.911	1.910	29.500	40.700	41.100	11.200	11.600						Swirling
14	70.300	70.600	2.069	2.073	33.900	45.500	45.900	11.600	12.000						Swirling
15	79.600	80.100	2.201	2.208	38.600	50.200	50.100	11.600	11.500						Swirling
16	95.700	95.600	2.414	2.412	45.700	57.500	57.400	11.800	11.700						Swirling
17	109.900	-	2.586	-	52.300	63.900	-	11.600	-						Entrain

Shape: Spherical Size: d=2.7mm Mass: 1000g Inclination: 10deg Overlap: 18deg

Data No.	ΔP acros	s orifice	Superfica	l Velocity	ΔP across distributor	ΔP across distr	ibutor with particle	ΔP acro	oss bed		Sluggir	ng Time		
Data NO.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	T3	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	5	s	s	s	
1	11.100	11.100	0.822	0.822	6.300	26.300	26.500	20.000	20.200					Incipient
2	15.300	15.500	0.965	0.971	8.500	30.600	30.800	22.100	22.300					Bubbling
3	19.000	19.200	1.075	1.081	10.100	32.500	32.700	22.400	22.600					Bubbling
4	21.400	21.700	1.141	1.149	11.600	33.600	33.800	22.000	22.200					Bubbling
5	27.500	28.200	1.294	1.310	14.300	36.300	36.600	22.000	22.300					Bubbling
6	34.600	35.100	1.451	1.462	17.700	39.500	40.300	21.800	22.600					Start swirling
7	39.700	39.800	1.555	1.557	20.000	41.800	41.900	21.800	21.900					Swirling
8	45.500	45.300	1.664	1.661	22.800	44.400	44.400	21.600	21.600					Swirling
9	51.600	51.600	1.772	1.772	25.700	47.500	47.400	21.800	21.700					Swirling
10	60.300	59.600	1.916	1.905	29.500	51.700	51.100	22.200	21.600					Swirling
11	70.400	70.400	2.070	2.070	33.900	56.000	55.800	22.100	21.900					Swirling
12	80.800	79.800	2.218	2.204	38.600	60.800	60.400	22.200	21.800					Swirling
13	91.200	90.800	2.356	2.351	44.100	65.800	65.000	21.700	20.900					Swirling
14	99.000	98.500	2.455	2.449	47.700	69.800	68.800	22.100	21.100					Swirling
15	110.100	110.200	2.589	2.590	52.300	74.700	74.600	22.400	22.300					Swirling
16	119.400	-	2.696	-	56.600	78.900	-	22.300	-					Entrain

D-4- N	ΔP acros	s orifice	Superfica	al Velocity	AD a super all shells at an	ΔP across distr	ibutor with particle	ΔP acro	oss bed		Sluggir	ng Time		
Data No.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	T3	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	s	s	s	s	
1	12.800	12.700	0.883	16.716	7.000	39.500	36.400	32.500	29.400					Incipient
2	19.000	18.800	1.075	30.107	10.100	42.600	42.300	32.500	32.200					Bubbling
3	22.000	22.000	1.157	38.113	11.600	44.100	43.700	32.500	32.100					Bubbling
4	27.700	27.400	1.299	52.974	14.300	46.500	45.900	32.200	31.600					Bubbling
5	34.200	34.200	1.443	73.871	17.700	49.200	48.900	31.500	31.200					Swirling
6	39.900	39.500	1.558	91.692	20.000	51.700	51.400	31.700	31.400					Swirling
7	45.400	45.600	1.662	113.732	22.800	54.600	54.100	31.800	31.300					Swirling
8	51.100	51.700	1.764	137.301	25.700	58.300	56.900	32.600	31.200					Swirling
9	60.300	60.400	1.916	173.377	29.500	61.900	60.600	32.400	31.100					Swirling
10	70.800	70.300	2.076	217.705	33.900	66.300	65.900	32.400	32.000					Swirling
11	80.200	80.200	2.210	265.276	38.600	69.900	69.400	31.300	30.800					Swirling
12	91.600	91.600	2.361	323.802	44.100	75.000	75.000	30.900	30.900					Swirling
13	99.400	99.000	2.460	363.822	47.700	78.800	78.400	31.100	30.700					Swirling
14	110.200	109.900	2.590	425.533	52.300	83.800	83.400	31.500	31.100					Swirling
15	119.900	-	2.702	-	56.600	88.200	-	31.600	-					Entrain
nape: Spl	nerical Size: d=2.7	mm Mass: 2000g	Inclination: 2	10deg Overla	p: 18deg									
		7mm Mass: 2000g ss orifice	1	10deg Overla 11 Velocity		ΔP across distr	ibutor with particle	ΔP acro	oss bed		Sluggir	ng Time		
			1	-	p: 18deg ΔP across distributor	ΔP across distr Forward	ibutor with particle Reverse	ΔP acro Forward	oss bed Reverse	T1	Sluggir T2	ng Time T3	Tavg	Observation
	ΔP acros	s orifice	Superfica	al Velocity			•			T1 s			Tavg s	Observation
	ΔP acros Forward	s orifice Reverse	Superfica Forward	al Velocity Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse		T2	T3		Observation Incipient
ata No.	ΔP acros Forward mmH ₂ O	ss orifice Reverse mmH ₂ O	Superfica Forward <i>m/sec</i>	l Velocity Reverse <i>m/sec</i>	ΔP across distributor mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O		T2	T3		
Data No.	ΔP acros Forward mmH ₂ O 15.200	ss orifice Reverse mmH ₂ O 14.800	Superfica Forward <i>m/sec</i> 0.962	Neverse Meverse Meverse 0.949	ΔP across distributor mmH ₂ O 8.500	Forward <i>mmH</i> ₂ <i>O</i> 48.800	Reverse mmH ₂ O 48.000	Forward <i>mmH</i> ₂ <i>O</i> 40.300	Reverse <i>mmH</i> ₂ <i>O</i> 39.500		T2	T3		Incipient
2	ΔP acros Forward <i>mmH</i> ₂ O 15.200 19.000	ss orifice Reverse mmH ₂ O 14.800 19.300	Superfica Forward m/sec 0.962 1.075	Al Velocity Reverse <i>m/sec</i> 0.949 1.084	ΔP across distributor mmH ₂ O 8.500 10.100	Forward mmH ₂ O 48.800 51.100	Reverse mmH₂O 48.000 51.300	Forward mmH ₂ O 40.300 41.000	Reverse mmH ₂ O 39.500 41.200		T2	T3		Incipient Bubbling
1 2 3	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100	Superfice Forward m/sec 0.962 1.075 1.226	l Velocity Reverse <i>m/sec</i> 0.949 1.084 1.211	ΔP across distributor mmH ₂ O 8.500 10.100 12.800	Forward mmH ₂ O 48.800 51.100 53.300	Reverse mmH 2 O 48.000 51.300 52.900	Forward mmH ₂ O 40.300 41.000 40.500	Reverse mmH ₂ O 39.500 41.200 40.100		T2	T3		Incipient Bubbling Bubbling
Data No.	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500	Superfica Forward m/sec 0.962 1.075 1.226 1.356	l Velocity Reverse <i>m/sec</i> 0.949 1.084 1.211 1.340	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800	Forward mmH ₂ O 48.800 51.100 53.300 55.500	Reverse mmH ₂ O 48.000 51.300 52.900 55.100	Forward mmH ₂ O 40.300 41.000 40.500 39.700	Reverse mmH ₂ O 39.500 41.200 40.100 39.300		T2	T3		Incipient Bubbling Bubbling Bubbling
2 3 4 5	ΔP acros Forward mmH 2 O 15.200 19.000 24.700 30.200 35.300	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900	Superfica Forward m/sec 0.962 1.075 1.226 1.356 1.466	Velocity Reverse m/sec 0.949 1.084 1.211 1.340 1.458	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800		T2	T3		Incipient Bubbling Bubbling Bubbling Bubbling
2 3 4 5 6	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900 39.600	Superfica Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553	Network Reverse m/sec 0.949 1.084 1.211 1.340 1.458 1.553 1.553	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500		T2	T3		Incipient Bubbling Bubbling Bubbling Bubbling Swirling
1 2 3 4 5 6 7	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600 45.600	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900 39.600 45.900	Superfica Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553 1.666	Network Reverse m/sec 0.949 1.084 1.211 1.340 1.458 1.553 1.672	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000 22.800	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700 62.300	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500 62.400	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700 39.500	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500 39.500		T2	T3		Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling
Data No.	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600 45.600 51.900	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900 39.600 45.900 51.600	Superfica Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553 1.666 1.777	Velocity Reverse m/sec 0.949 1.084 1.211 1.340 1.458 1.553 1.672 1.772	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000 22.800 25.700	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700 62.300 65.500	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500 62.400 65.100	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700 39.500 39.800	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500 39.500 39.600 39.400		T2	T3		Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Swirling
Data No.	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600 45.600 51.900 60.500	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900 39.600 45.900 51.600 60.100	Superfica Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553 1.666 1.777 1.919	l Velocity Reverse <i>m/sec</i> 0.949 1.084 1.211 1.340 1.458 1.553 1.672 1.772 1.913	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000 22.800 25.700 29.500	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700 62.300 65.500 69.100	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500 62.400 65.100 68.800	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700 39.500 39.800 39.600	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500 39.600 39.400 39.300		T2	T3		Incipient Bubbling Bubbling Bubbling Bubbling Swirling Swirling Swirling Swirling
1 2 3 4 5 6 7 8 9 10	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600 45.600 51.900 60.500 70.800	ss orifice Reverse mmH₂O 14.800 19.300 24.100 29.500 34.900 39.600 45.900 51.600 60.100 70.800	Superfice Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553 1.666 1.777 1.919 2.076	l Velocity Reverse <i>m/sec</i> 0.949 1.084 1.211 1.340 1.458 1.553 1.672 1.772 1.913 2.076	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000 22.800 25.700 29.500 33.900	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700 62.300 65.500 69.100 73.500	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500 62.400 65.100 73.500	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700 39.500 39.800 39.600 39.600	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500 39.600 39.400 39.300 39.600		T2	T3		Incipient Bubbling Bubbling Bubbling Swirling Swirling Swirling Swirling Swirling Swirling
1 2 3 4 5 6 7 8 9 10 11	ΔP acros Forward mmH ₂ O 15.200 19.000 24.700 30.200 35.300 39.600 45.600 51.900 60.500 70.800 79.600	ss orifice Reverse mmH ₂ O 14.800 19.300 24.100 29.500 34.900 39.600 45.900 51.600 60.100 70.800 80.000	Superfice Forward m/sec 0.962 1.075 1.226 1.356 1.466 1.553 1.666 1.777 1.919 2.076 2.201	l Velocity Reverse <i>m/sec</i> 0.949 1.084 1.211 1.340 1.458 1.553 1.672 1.772 1.913 2.076 2.207	ΔP across distributor mmH ₂ O 8.500 10.100 12.800 15.800 17.700 20.000 22.800 25.700 29.500 33.900 38.600	Forward mmH ₂ O 48.800 51.100 53.300 55.500 57.700 59.700 62.300 65.500 69.100 73.500 77.600	Reverse mmH ₂ O 48.000 51.300 52.900 55.100 57.500 59.500 62.400 65.100 73.500 73.500	Forward mmH ₂ O 40.300 41.000 40.500 39.700 40.000 39.700 39.500 39.800 39.600 39.600 39.000	Reverse mmH ₂ O 39.500 41.200 40.100 39.300 39.800 39.500 39.600 39.400 39.300 39.600 39.400 39.000		T2	T3		Incipient Bubbling Bubbling Bubbling Swirling Swirling Swirling Swirling Swirling Swirling Swirling

Shape: Spherical Size: d=2.7mm Mass: 1500g Inclination: 10deg Overlap: 18deg

	ΔP acros	s orifice	Superfica	al Velocity		ΔP across d	istributor with particle	ΔP acr	oss bed		SI	ugging Ti	me		
Data No.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Tavg	Observation
Data No.	mmH ₂ O	mmH ₂ O	m/sec	m/sec	mmH ₂ O	mmH ₂ O	mmH ₂ O	mmH ₂ O	mmH ₂ O	s	s	s	s	s	Observation
1	15.000	14.900	0.956	0.952	9.000	19.800	18.900	10.800	9.900						Incipient
2	17.700	18.100	1.038	1.050	10.500	21.200	21.500	10.700	11.000						Start bubbling
3	20.700	21.000	1.123	1.131	12.100	22.700	22.900	10.600	10.800	1.100	1.030	1.080	098	1.070	Slugging
4	23.800	23.900	1.204	1.206	13.600	24.600	24.400	11.000	10.800	1.310	1.360	1.280	1.260	1.303	Slugging
5	26.900	26.900	1.280	1.280	15.200	26.400	26.100	11.200	10.900	1.720	1.620	1.700	1.600	1.660	Slugging
6	29.900	30.000	1.349	1.351	16.600	27.800	27.800	11.200	11.200	1.850	1.820	1.820	1.860	1.838	Slugging
7	35.100	35.000	1.462	1.460	19.200	30.300	30.300	11.100	11.100	2.430	2.310	2.340	2.450	2.383	Slugging
8	40.300	40.300	1.566	1.566	21.700	33.000	32.900	11.300	11.200	2.610	2.670	2.590	2.670	2.635	Slugging
9	45.100	44.900	1.657	1.653	24.200	35.400	35.100	11.200	10.900	3.110	3.720	3.100	3.280	3.303	Slugging
10	49.800	50.400	1.741	1.752	26.700	37.600	38.000	10.900	11.300		Mi	nor slugg	ing		Slugging
11	55.400	55.000	1.836	1.830	29.200	40.600	40.400	11.400	11.200						Swilring
12	60.200	59.800	1.914	1.908	31.600	43.000	42.800	11.400	11.200						Swilring
13	67.600	67.400	2.029	2.026	35.200	46.500	46.400	11.300	11.200						Swilring
14	74.900	75.200	2.135	2.140	38.900	50.200	50.400	11.300	11.500						Swilring
15	82.800	82.900	2.245	2.246	42.400	54.500	54.600	12.100	12.200						Swilring
16	89.700	90.000	2.337	2.341	46.200	58.200	58.000	12.000	11.800						Swilring
17	100.300	100.200	2.471	2.470	51.000	63.600	63.500	12.600	12.500						Swilring
18	110.000	110.200	2.588	2.590	55.900	68.400	68.700	12.500	12.800						Swilring
19	124.900	125.500	2.757	2.764	63.000	76.600	76.600	13.600	13.600						Swilring
	139.700	139.800	2.916	2.917	70.000	83.900	83.800	13.900	13.800						Swilring
20										-					
20 21	155.000	-	3.072	-	77.000	91.000	-	14.000	-						Entrain
21	155.000	-	3.072	-	77.000		-		-						
21	155.000 rical Size: d=3.9m	- m Mass: 1000g	3.072 nclination: 10d	- eg Overlap: 18	77.000	91.000		14.000			ci				
21 Shape: Sphe	155.000 rical Size: d=3.9m ΔP acros	m Mass: 1000g	3.072 nclination: 10d Superfica	eg Overlap: 18 al Velocity	77.000	91.000 ΔP across d	istributor with particle	14.000 ΔP acr	oss bed			ugging Ti	1	Taug	Entrain
21	155.000 rical Size: d=3.9m ΔP acros Forward	- m Mass: 1000g s orifice Reverse	3.072 nclination: 10d Superfica Forward	- eg Overlap: 18 al Velocity Reverse	77.000 deg ΔP across distributor	91.000 ΔP across d Forward	istributor with particle Reverse	14.000 ΔP acro Forward	oss bed Reverse	T1	T2	T3	T4	Tavg	
21 Shape: Sphe Data No.	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O	m Mass: 1000g s orifice Reverse mmH ₂ O	3.072 nclination: 10d Superfica Forward <i>m/sec</i>	eg Overlap: 18 al Velocity Reverse m/sec	77.000 deg ΔP across distributor mmH ₂ O	91.000 ΔP across d Forward mmH ₂ O	istributor with particle Reverse mmH ₂ O	14.000 ΔP acm Forward mmH ₂ O	oss bed Reverse mmH ₂ O	T1 5			1	Tavg S	Entrain Observation
21 Shape: Sphe Data No. 1	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000	− m Mass: 1000g s orifice Reverse mmH ₂ O 18.000	3.072 nclination: 10d Superfica Forward <i>m/sec</i> 1.047	- eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047	77.000 deg ΔP across distributor mmH ₂ O 10.500	91.000 ΔP across d Forward <i>mmH</i> ₂ O 32.500	istributor with particle Reverse <i>mmH</i> ₂ O 31.600	14.000 ΔP acro Forward <i>mmH</i> ₂ O 22.000	oss bed Reverse mmH ₂ O 21.100		T2	T3	T4	-	Entrain Observation Incipient
21 Shape: Sphe Data No. 1 2	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000	- m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400	3.072 nclination: 10d Superfica Forward <i>m/sec</i> 1.047 1.131	- eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141	77.000 deg ΔP across distributor <i>mmH</i> ₂ O 10.500 12.100	91.000 ΔP across d Forward mmH 20 32.500 34.500	istributor with particle Reverse mmH ₂ O 31.600 34.500	<u>Δ</u> P acro Forward <u>mmH₂O</u> 22.000 22.400	oss bed Reverse mmH ₂ O 21.100 22.400		T2	T3	T4	-	Entrain Observation Incipient Start bubbling
21 Shape: Sphe Data No. 1	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000 24.000	m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700	3.072 nclination: 10d Superfica Forward <i>m/sec</i> 1.047 1.131 1.209	- eg Overlap: 18 al Velocity Reverse m/sec 1.047 1.141 1.201	77.000 deg ΔP across distributor <i>mmH</i> ₂ O 10.500 12.100 13.600	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700	ΔP acro Forward mmH ₂ O 22.000 22.400 22.500	Reverse mmH ₂ O 21.100 22.400 22.100		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Start bubbling
21 Shape: Sphe Data No. 1 2 3 4	155.000 rical Size: d=3.9m ΔP acros Forward mmH 20 18.000 21.000 24.000 26.600	- Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700 26.800	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272	- eg Overlap: 18 al Velocity Reverse m/sec 1.047 1.141 1.201 1.277	77.000 deg ΔP across distributor mmH 2 0 10.500 12.100 13.600 15.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200	14.000 ΔP acr. Forward mmH ₂ O 22.000 22.400 22.500 21.900	Reverse mmH ₂ O 21.100 22.400 22.100 22.000		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Start bubbling Bubbling
21 Shape: Sphe Data No. 1 2 3 4 5	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000	m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351	- eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800	14.000 ΔP acr Forward mmH₂O 22.000 22.400 22.500 21.900 22.400	Reverse mmH ₂ O 21.100 22.400 22.100 22.000 22.200		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Start bubbling Bubbling Bubbling
21 Shape: Sphe Data No. 1 2 3 4	155.000 rical Size: d=3.9m ΔP acros Forward mmH 20 18.000 21.000 24.000 26.600	- Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700 26.800 30.000	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272	- eg Overlap: 18 al Velocity Reverse m/sec 1.047 1.141 1.201 1.277	77.000 deg ΔP across distributor mmH 2 0 10.500 12.100 13.600 15.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200	14.000 ΔP acr. Forward mmH ₂ O 22.000 22.400 22.500 21.900	Reverse mmH ₂ O 21.100 22.400 22.100 22.000		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000	- Mass: 1000g sorifice Reverse mmH₂O 18.000 21.400 23.700 26.800 30.000 34.600	3.072 nclination: 10d Superfice Forward m/sec 1.047 1.131 1.209 1.272 1.351 1.460 1.557	- eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.400 22.100	Reverse mmH20 21.100 22.400 22.100 22.000 22.000 21.900		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling Bubbling
21 Shape: Sphe Data No. 1 2 3 4 5 6	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800	m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700 26.800 30.000 34.600 40.300	3.072 nclination: 10d Superfice Forward m/sec 1.047 1.131 1.209 1.272 1.351 1.460	eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700	91.000 ΔP across d Forward 32.500 34.500 36.100 37.100 39.000 41.300 43.700	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.100 22.000	Reverse mmH20 21.100 22.400 22.100 22.000 22.200 21.900 22.300		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 8	155.000 rical Size: d=3.9m ΔP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 30.000 35.000 39.800 44.800	m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300	3.072 nclination: 10d Superfice Forward m/sec 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651	eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200	91.000 ΔP across d Forward 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.100 22.000 22.100 22.100 22.800	Reverse mmH20 21.100 22.400 22.100 22.000 22.200 21.900 22.300 22.300		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling Bubbling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 8 9	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 35.000 39.800 44.800 50.300	m Mass: 1000g s orifice Reverse mmH ₂ O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300 50.300	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750	eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750	77.000 deg ΔP across distributor <i>mmH</i> ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700	91.000 ΔP across d Forward 32.500 34.500 36.100 37.100 39.000 41.300 41.300 43.700 46.000 48.700	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000	ΔP acro Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.100 22.100 22.000 21.800 22.000	Reverse mmH ₂ O 21.100 22.400 22.100 22.000 22.200 21.900 22.300 22.300 22.300 22.300		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 7 8 9 9 10	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 35.000 39.800 44.800 50.300 54.900		3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828	eg Overlap: 18 Al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600	ΔP acro Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.000 22.000 22.000 22.000 22.000 22.000 22.000 21.800 22.000 22.400	Reverse mmH ₂ O 21.100 22.400 22.000 22.000 22.300 22.300 22.300 22.300 22.300 22.400		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 7 8 9 10 11	155.000 rical Size: d=3.9m ΔP acros Forward mmH 20 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000	m Mass: 1000g s orifice mmH ₂ O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300 50.300 55.300 60.100	3.072 nclination: 10d Superfice Forward 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828 1.911	- eg Overlap: 18 eg Overlap: 18 l Velocity Reverse m/sec 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000	Reverse mmH ₂ O 21.100 22.400 22.000 22.200 21.900 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.400 22.200		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 8 9 10 11 11 12	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000 67.800	m Mass: 1000g s orifice Reverse mmH₂O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300 55.300 60.100 67.500	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828 1.911 2.032	- eg Overlap: 18 A Velocity Reverse m/sec 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600 57.300	istributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800 57.500	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.100	Reverse mmH ₂ O 21.100 22.400 22.000 22.200 21.900 22.300 22.300 22.400 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300 22.300		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 5 6 7 7 8 9 9 10 11 11 12 13	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000 67.800 75.300		3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828 1.911 2.032 2.141	- eg Overlap: 18 Al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027 2.137	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600 57.300 61.200	Stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800 57.500 61.300	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 22.400 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.100 22.000 22.100 22.300	Reverse mmH20 21.100 22.400 22.000 22.000 22.300 22.300 22.400 22.300 22.300 22.400 22.300 22.300 22.400 22.400 22.400		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling
21 biape: Sphe Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000 67.800 75.300 82.500		3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828 1.911 2.032 2.141 2.241	- eg Overlap: 18 A Velocity Reverse m/sec 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027 2.137 2.245	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600 57.300 61.200	Stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800 57.500 61.300 65.400	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 22.400 22.000	Reverse mmH20 21.100 22.400 22.000 22.000 22.300 22.300 22.400 22.300 22.300 22.400 22.300 22.300 22.400 22.300 22.300 22.400 23.000		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling
21 Shape: Sphe Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	155.000 AP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000 67.800 75.300 82.500 89.800		3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.351 1.460 1.557 1.651 1.750 1.828 1.911 2.032 2.141 2.241 2.338	- eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027 2.137 2.245 2.345	77.000 deg ΔP across distributor mmH₂O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600 57.300 61.200 65.000 68.700	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800 57.500 61.300 65.400 69.300	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 22.400 22.000 22.400 22.000	Reverse mmH20 21.100 22.400 22.100 22.000 22.000 22.300 22.300 22.400 22.300 22.400 22.300 22.400 22.300 22.400 22.300 22.300 22.300 22.300 22.300 22.300 23.100		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Swirling Swirling Swirling
21 biape: Sphe Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	155.000 Γογματος Γογμα Γογματος Γογματος Γογματος Γογματος Γογματος Γογματος	Imm Mass: 1000g Imm sorifice Reverse mmH₂O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300 50.300 55.300 60.100 67.500 67.500 82.800 90.300 100.000 100.000 100.000	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.351 1.460 1.557 1.651 1.750 1.828 1.911 2.032 2.141 2.238 2.465	eg Overlap: 18 Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027 2.137 2.245 2.345 2.467	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200 51.000	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 43.700 46.000 48.700 51.600 53.600 57.300 61.200 65.000 68.700 73.900	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 49.000 51.600 53.800 57.500 61.300 65.400 69.300 74.300	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.400 22.000 22.400 22.000	Reverse mmH ₂ O 21.100 22.400 22.100 22.000 22.000 22.300 22.300 22.400 22.300 22.300 22.400 22.300 22.300 22.300 22.300 22.300 22.300 22.300 23.300 23.100 23.300		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Swirling Swirling Swirling Swirling
21 shape: Sphe Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	155.000 ΔP acros Forward mmH ₂ O 18.000 21.000 24.000 26.600 30.000 35.000 39.800 44.800 50.300 54.900 60.000 67.800 75.300 82.500 89.800 99.800 109.700	m Mass: 1000g I s orifice Reverse mmH₂O 18.000 21.400 23.700 26.800 30.000 34.600 40.300 45.300 50.300 55.300 60.100 67.500 75.000 82.800 90.300 100.000 110.100 100.000	3.072 nclination: 10d Superfice Forward <i>m/sec</i> 1.047 1.131 1.209 1.272 1.460 1.557 1.651 1.750 1.828 1.911 2.032 2.141 2.338 2.465 2.584	eg Overlap: 18 al Velocity Reverse <i>m/sec</i> 1.047 1.141 1.201 1.277 1.351 1.451 1.566 1.661 1.750 1.835 1.913 2.027 2.137 2.245 2.345 2.467 2.589	77.000 deg ΔP across distributor mmH ₂ O 10.500 12.100 13.600 15.200 16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200 51.000 55.900	91.000 ΔP across d Forward mmH ₂ O 32.500 34.500 36.100 37.100 39.000 41.300 41.300 43.700 46.000 48.700 51.600 53.600 57.300 61.200 65.000 68.700 73.900	stributor with particle Reverse mmH ₂ O 31.600 34.500 35.700 37.200 38.800 41.100 44.000 46.500 51.600 53.800 57.500 61.300 65.400 69.300 74.300 79.400	ΔP acr Forward mmH ₂ O 22.000 22.400 22.500 21.900 22.100 22.000 22.000 22.400 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.000 22.500 22.500 22.900 23.000	Reverse mmH ₂ O 21.100 22.400 22.100 22.000 22.000 22.300 22.300 22.300 22.300 22.300 22.300 22.300 23.00 23.00 23.000 23.000 23.000 23.000 23.000 23.000 23.000 23.000		T2	T3	T4	-	Entrain Observation Incipient Start bubbling Bubbling Bubbling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling Swirling Swirling Swirling Swirling Swirling

Shape: Spherical Size: d=3.9mm Mass: 500g Inclination: 10deg Overlap: 18deg

Shape: Sphe	erical Size: d=3.9m	nm Mass: 1500g I	Inclination: 10d	leg Overlap: 18	deg										
	ΔP acros	ss orifice	Superfica	al Velocity	ΔP across distributor	ΔP across di	stributor with particle	ΔP acro	oss bed		Slu	ugging Tir	ne		
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	s	s	s	s	s	
1	17.900	18.300	1.044	1.055	10.500	41.500	39.400	31.000	28.900						Incipient
2	21.100	20.800	1.133	1.125	12.100	44.700	43.200	32.600	31.100						Fluidization
3	23.700	24.200	1.201	1.214	13.600	46.000	46.200	32.400	32.600						Start Bubbling
4	26.900	27.200	1.280	1.287	15.200	47.200	47.200	32.000	32.000						Start Bubbling
5	30.000	30.200	1.351	1.356	16.600	48.600	48.800	32.000	32.200						Start Bubbling
6	35.000	35.000	1.460	1.460	19.200	51.000	51.000	31.800	31.800						Bubbling
7	39.900	39.800	1.558	1.557	21.700	53.000	53.200	31.300	31.500						Bubbling
8	45.100	44.900	1.657	1.653	24.200	55.900	55.800	31.700	31.600						Bubbling
9	49.900	49.900	1.743	1.743	26.700	57.900	58.200	31.200	31.500						Bubbling
10	55.200	55.400	1.833	1.836	29.200	60.300	60.500	31.100	31.300						Bubbling+ Swrling
11	60.000	60.300	1.911	1.916	31.600	62.600	63.000	31.000	31.400						Bubbling+ Swrling
12	67.700	67.800	2.030	2.032	35.200	66.500	66.500	31.300	31.300						Bubbling+ Swrling
13	74.700	74.900	2.132	2.135	38.900	70.000	70.100	31.100	31.200						Bubbling+ Swrling
14	82.500	82.500	2.241	2.241	42.400	74.200	74.000	31.800	31.600						Bubbling+ Swrling
15	90.300	90.300	2.345	2.345	46.200	77.700	77.800	31.500	31.600						Bubbling+ Swrling
16	100.000	99.800	2.467	2.465	51.000	82.700	82.600	31.700	31.600						Bubbling+Swrling
17	110.200	110.000	2.590	2.588	55.900	88.400	88.400	32.500	32.500						Bubbling+ Swrling
18	124.700	125.300	2.755	2.762	63.000	95.900	96.000	32.900	33.000						Jumping
19	140.200	140.000	2.921	2.919	70.000	103.600	103.300	33.600	33.300						Jumping
20	155.000	-	3.072	-	77.000	111.300	-	34.300	-						Jumping
Shape: Sphe	erical Size: d=3.9n			* '	deg					1					
		ss orifice		al Velocity	ΔP across distributor		stributor with particle		oss bed			ugging Tir		1	
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH ₂ O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH ₂ O	mmH ₂ O	mmH ₂ O	S	s	S	S	S	
1	20.800	21.300	1.125	1.139	12.100	54.800	50.000	42.700	37.900						Incipient
2	24.200	23.800	1.214	1.204	13.600		501000	IEI700							
3	26.700	26.900	1.275			59.100	53.800	45.500	40.200						Fluidization
4	29.800	20 700		1.280	15.200	59.100 56.500		45.500 41.300	40.200 40.200						Fluidization Start bubbling
5		29.700	1.347	1.345	16.600		53.800	45.500							
	35.300	35.100				56.500	53.800 55.400	45.500 41.300	40.200						Start bubbling
6	35.300 40.100		1.347	1.345	16.600	56.500 57.900	53.800 55.400 57.800	45.500 41.300 41.300	40.200 41.200						Start bubbling Start bubbling
7		35.100	1.347 1.466 1.562 1.655	1.345 1.462 1.557 1.661	16.600 19.200	56.500 57.900 60.300 62.500 64.900	53.800 55.400 57.800 60.200	45.500 41.300 41.300 41.100 40.800 40.700	40.200 41.200 41.000						Start bubbling Start bubbling Start bubbling
	40.100	35.100 39.800	1.347 1.466 1.562	1.345 1.462 1.557	16.600 19.200 21.700	56.500 57.900 60.300 62.500	53.800 55.400 57.800 60.200 62.300	45.500 41.300 41.300 41.100 40.800	40.200 41.200 41.000 40.600						Start bubbling Start bubbling Start bubbling Bubbling
7	40.100 45.000	35.100 39.800 45.300	1.347 1.466 1.562 1.655	1.345 1.462 1.557 1.661	16.600 19.200 21.700 24.200	56.500 57.900 60.300 62.500 64.900	53.800 55.400 57.800 60.200 62.300 64.800	45.500 41.300 41.300 41.100 40.800 40.700	40.200 41.200 41.000 40.600 40.600						Start bubbling Start bubbling Start bubbling Bubbling Bubbling
7 8	40.100 45.000 49.700	35.100 39.800 45.300 49.800	1.347 1.466 1.562 1.655 1.739	1.345 1.462 1.557 1.661 1.741	16.600 19.200 21.700 24.200 26.700	56.500 57.900 60.300 62.500 64.900 67.200	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700	45.500 41.300 41.300 41.100 40.800 40.700 40.500	40.200 41.200 41.000 40.600 40.600 40.300						Start bubbling Start bubbling Start bubbling Bubbling Bubbling Bubbling
7 8 9 10 11	40.100 45.000 49.700 55.400 60.000 67.800	35.100 39.800 45.300 49.800 55.400 60.000 67.500	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300	45.500 41.300 41.300 40.800 40.700 40.500 40.400 40.100 40.500	40.200 41.200 40.600 40.600 40.300 40.300 40.300 40.100						Start bubbling Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling
7 8 9 10	40.100 45.000 49.700 55.400 60.000	35.100 39.800 45.300 49.800 55.400 60.000	1.347 1.466 1.562 1.655 1.739 1.836 1.911	1.345 1.462 1.557 1.661 1.741 1.836 1.911	16.600 19.200 21.700 24.200 26.700 29.200 31.600	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700	45.500 41.300 41.300 40.800 40.700 40.500 40.400 40.100	40.200 41.200 40.600 40.600 40.300 40.300 40.300 40.100						Start bubbling Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling
7 8 9 10 11 12 13	40.100 45.000 49.700 55.400 60.000 67.800 75.400 82.600	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200 82.300	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.142 2.242	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 79.200 83.200	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100 82.400	45.500 41.300 41.300 41.100 40.800 40.700 40.500 40.400 40.500 40.500 40.300 40.800	40.200 41.200 41.000 40.600 40.600 40.300 40.300 40.100 40.100 40.200 40.000						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling Bubbling + Swirling
7 8 9 10 11 12 13 14	40.100 45.000 49.700 55.400 60.000 67.800 75.400	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.142 2.242 2.337	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238 2.338	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 79.200	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100	45.500 41.300 41.300 40.800 40.700 40.500 40.400 40.400 40.500 40.300	40.200 41.200 40.600 40.600 40.300 40.300 40.100 40.100 40.200						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling
7 8 9 10 11 12 13	40.100 45.000 49.700 55.400 60.000 67.800 75.400 82.600	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200 82.300	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.142 2.242	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238 2.338 2.465	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 79.200 83.200	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100 82.400	45.500 41.300 41.300 41.100 40.800 40.700 40.500 40.400 40.500 40.500 40.300 40.800	40.200 41.200 41.000 40.600 40.600 40.300 40.300 40.100 40.100 40.200 40.000						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling Bubbling + Swirling Bubbling + Swirling
7 8 9 10 11 12 13 14	40.100 45.000 49.700 55.400 60.000 67.800 75.400 82.600 89.700	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200 82.300 89.800	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.142 2.242 2.337	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238 2.338	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 75.700 79.200 83.200 86.400	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100 82.400 86.100	45.500 41.300 41.300 41.100 40.800 40.700 40.500 40.400 40.100 40.500 40.500 40.300 40.800 40.200	40.200 41.200 40.600 40.600 40.300 40.300 40.100 40.100 40.100 40.000 39.900						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling Bubbling + Swirling
7 8 9 10 11 12 13 14 15	40.100 45.000 49.700 55.400 60.000 67.800 75.400 82.600 89.700 99.700	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200 82.300 89.800 99.800	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.142 2.242 2.337 2.464 2.589 2.758	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238 2.338 2.465 2.590 2.762	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200 51.000	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 75.700 79.200 83.200 86.400 91.800 97.000 104.400	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100 82.400 86.100 91.400	45.500 41.300 41.300 41.100 40.800 40.700 40.500 40.400 40.500 40.500 40.300 40.800 40.800	40.200 41.200 41.000 40.600 40.600 40.300 40.300 40.100 40.100 40.200 40.200 39.900 40.400						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling Bubbling + Swirling Bubbling + Swirling
7 8 9 10 11 12 13 14 15 16	40.100 45.000 55.400 60.000 67.800 75.400 82.600 89.700 99.700 110.100	35.100 39.800 45.300 49.800 55.400 60.000 67.500 75.200 82.300 89.800 99.800 110.200	1.347 1.466 1.562 1.655 1.739 1.836 1.911 2.032 2.242 2.337 2.464 2.589	1.345 1.462 1.557 1.661 1.741 1.836 1.911 2.027 2.140 2.238 2.338 2.465 2.590	16.600 19.200 21.700 24.200 26.700 29.200 31.600 35.200 38.900 42.400 46.200 51.000 55.900	56.500 57.900 60.300 62.500 64.900 67.200 69.600 71.700 75.700 79.200 83.200 88.400 91.800 97.000	53.800 55.400 57.800 60.200 62.300 64.800 67.000 69.500 71.700 75.300 79.100 82.400 86.100 91.400 96.700	45.500 41.300 41.300 40.800 40.700 40.500 40.500 40.000 40.500 40.300 40.800 40.200 40.800 41.100	40.200 41.200 40.600 40.600 40.300 40.300 40.100 40.100 40.200 40.000 39.900 40.400 40.800						Start bubbling Start bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bottom swirling Bottom swirling Bubbling + Swirling Bubbling + Swirling Bubbling + Swirling

Shape: Spherical Size: d=3.9mm Mass: 1500g Inclination: 10deg Overlap: 18deg

	AP acros	ss orifice	Suporfice	l Velocity		ΔP across distribut	or with narticle	AP acre	oss bed		s	ugging Ti	me		
.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Teure	
Data No.	mmH ₂ O	mmH ₂ O	m/sec	m/sec	mmH ₂ O	mmH ₂ O	mmH ₂ O	mmH ₂ O	mmH ₂ O	5	12 S	5	14 S	Tavg s	Observation
1	-	=	-	-	-	-	-	-	10.400	3	3	3	3	3	Inciniont
1	9.800 12.900	10.200	0.772	0.788	5.700	16.400	16.100	10.700	10.400						Incipient
3	15.900	13.100 16.100	0.886	0.893	7.400 8.900	18.500 20.300	18.300 20.100	11.100 11.400	11.200						Bubbling Bubbling
4	18.800	19.000	1.070	1.075	10.400	21.800	21.800	11.400	11.200	1.530	1.450	1.410	1.400	1.448	Slugging
5	21.900	22.000	1.155	1.075	11.800	23.500	23.600	11.400	11.400	1.530	1.450	1.410	1.400	1.448	
6	24.900	25.000	1.135	1.137	13.400	24.900	25.000	11.500	11.600	1.820	1.910	1.890	1.750	1.898	Slugging Slugging
7	30.000	30.500	1.251	1.254	15.800	27.500	23.000	11.700	12.000	2.400	2.410	2.410	2.420	2.410	Slugging
8	35.000	34.900	1.351	1.458	13.800	29.900	29.700	11.900	11.700	2.400	2.780	2.410	2.740	2.410	Slugging
9	39.800	39.900	1.400	1.458	20.400	31.700	31.800	11.300	11.400	2.070	2.780	2.700	2.740	2.723	Swirling
10	45.200	45.300	1.659	1.661	22.700	34.000	34.100	11.300	11.400						Swirling
10	50.000	49.800	1.745	1.741	25.000	36.400	36.200	11.400	11.400						Swirling
12	55.300	55.500	1.835	1.838	27.300	39.000	38.900	11.700	11.600						Swirling
13	60.200	60.500	1.000	1.000	29.600	41.400	41.300	11.800	11.700						Swirling
13	69.900	69.600	2.063	2.058	34.000	46.000	46.000	12.000	12.000						Swirling
15	79.900	79.900	2.205	2.205	38.300	51.000	51.400	12.700	13.100						Swirling
16	90.000	90.400	2.341	2.346	43.000	55.600	56.300	12.600	13.300						Swirling
10	99.600	100.200	2.462	2.470	47.600	60.300	61.000	12.700	13.400						Swirling
	110.300	110.500	2.591	2.594	51.600	65.700	65.700	14.100	14.100						Swirling
18					51,000		001700	111100	111100						
18 19	120.200	-	2.705	-	56.500	70.600	-	14.100	-						Entrain
				-	56.500	70.600	-	14.100	-						Entrain
19		-	2.705			70.600	-	14.100	-						Entrain
19	120.200 ular Size: L/D=1.30	-	2.705	g Overlap: 18	deg	70.600 ΔP across distribute			- oss bed		SI	ugging Ti	me		Entrain
19	120.200 ular Size: L/D=1.30	- 6 Mass: 1000g Ind	2.705 clination: 10de	g Overlap: 18						T1	SI T2	ugging Tir T3	ne T4	Tavg	Entrain Observation
19 Shape: Irreg	120.200 ular Size: L/D=1.30 ΔP acros	- 6 Mass: 1000g Inc ss orifice	2.705 clination: 10de Superfica	g Overlap: 18 I Velocity	deg	ΔP across distribut	or with particle	ΔP acro	oss bed	T1 5				Tavg s	
19 Shape: Irreg	120.200 ular Size: L/D=1.30 ΔP acros Forward	- 6 Mass: 1000g Inc ss orifice Reverse	2.705 clination: 10de Superfica Forward	g Overlap: 18 I Velocity Reverse	ideg ΔP across distributor	ΔP across distribut	or with particle Reverse	ΔP acro Forward	oss bed Reverse		T2	T3	T4		
19 Shape: Irreg Data No.	120.200 ular Size: L/D=1.30 ΔP acros Forward mmH ₂ O	- 6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O	2.705 lination: 10de Superfica Forward <i>m/sec</i>	g Overlap: 18 I Velocity Reverse <i>m/sec</i>	deg ΔP across distributor mmH₂O	ΔP across distribute Forward mmH ₂ O	or with particle Reverse mmH ₂ O	ΔP acro Forward mmH ₂ O	oss bed Reverse mmH ₂ O		T2	T3	T4		Observation
19 Shape: Irreg Data No. 1	120.200 ular Size: L/D=1.30 ΔP acros Forward mmH 20 12.900	- 6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893	sdeg ΔP across distributor mmH ₂ O 7.400	ΔP across distribut Forward mmH ₂ O 29.000	or with particle Reverse mmH ₂ O 27.900	ΔP acro Forward mmH ₂ O 21.600	oss bed Reverse mmH ₂ O 20.500		T2	T3	T4		Observation Incipient
19 Shape: Irreg Data No. 1 2	120.200 ular Size: L/D=1.30 ΔP acros Forward mmH ₂ O 12.900 15.900	- 6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990	deg ΔP across distributor mmH ₂ O 7.400 8.900	ΔP across distribut Forward mmH ₂ O 29.000 30.900	or with particle Reverse mmH ₂ O 27.900 29.900	ΔP acro Forward mmH 20 21.600 22.000	Reverse mmH ₂ O 20.500 21.000		T2	T3	T4		Observation Incipient Bubbling
19 Shape: Irreg Data No. 1 2 3	120.200 ular Size: L/D=1.31 ΔP across Forward mmH 20 12.900 15.900 19.200	6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500	2.705 clination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090	ideg ΔP across distributor <i>mmH</i> ₂ <i>O</i> 7.400 8.900 10.400	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700	or with particle Reverse mmH ₂ O 27.900 29.900 32.000	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300	Reverse mmH ₂ O 20.500 21.000 21.600		T2	T3	T4		Observation Incipient Bubbling Bubbling
19 Shape: Irreg Data No. 1 2 3 4	120.200 ular Size: L/D=1.31 ΔP acros Forward mmH 20 12.900 15.900 19.200 22.000	6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400	2.705 clination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168	ideg ΔP across distributor <i>mmH</i> ₂ <i>O</i> 7.400 8.900 10.400 11.800	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100	or with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300	ΔP acre Forward mmH ₂ O 21.600 22.000 22.300 22.300	Reverse mmH ₂ O 20.500 21.000 21.600 21.500		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling
19 Shape: Irreg Data No. 1 2 3 4 5	120.200 Jlar Size: L/D=1.30 AP acros Forward <i>mmH</i> ₂ 0 12.900 19.200 22.000 25.100	- 6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400 24.800	2.705 lination: 10de Superfica Forward 0.886 0.984 1.081 1.157 1.236	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229	ideg ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500	or with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.300 22.100	Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Bubbling
19 Shape: Irreg Data No. 1 2 3 4 5 6	120.200 Jlar Size: L/D=1.30 AP acros Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800	6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800	or with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700	ΔP acre Forward mmH ₂ O 21.600 22.000 22.300 22.300 22.100 22.000	Dess bed Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100 20.900		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Bubbling Slow Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7	120.200 μlar Size: L/D=1.30 AP acros Forward mmH₂O 12.900 15.900 19.200 22.000 25.100 29.800 34.900	6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400 24.800 30.100 34.500	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458	g Overlap: 18 I Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 18.000	ΔP across distribute Forward <i>mmH</i> ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100	r with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700 38.700	ΔP acro Forward <i>mmH</i> ₂ O 21.600 22.000 22.300 22.300 22.100 22.000 22.100	Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100 20.900 20.700		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8	120.200 μlar Size: L/D=1.30 Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000	6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.560	g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400	ΔP across distribute Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400	r with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100	ΔP acro Forward mmH ₂ O 21.600 22.300 22.300 22.100 22.100 22.000 22.100	Reverse mmH20 20.500 21.000 21.600 21.500 21.100 20.900 20.700		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8 9	120.200 μlar Size: L/D=1.30 ΔP across Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 45.000	6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.560 1.655	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562 1.648	ΔP across distributor mmH₂O 7.400 8.900 10.400 13.400 15.800 18.000 20.400 22.700	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100	r with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.100 22.000 22.100 22.000 22.000 21.400	Bess bed Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100 20.900 20.700 20.700 20.500		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 7 8 9 10	120.200 μlar Size: L/D=1.30 ΔP across Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 45.000 50.400	6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700	2.705 Clination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.560 1.655 1.752	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.552 1.648 1.739	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400 22.700 25.000	ΔP across distribute Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 46.600	or with particle Reverse mmH 20 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.100 22.100 22.100 22.000 21.400 21.600	Reverse mmH 20 20.500 21.000 21.600 21.500 21.100 20.700 20.700 20.700 20.500 20.700 20.700 20.700 20.700 20.700		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 7 8 9 9 10 11	120.200 ular Size: L/D=1.30 Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 40.000 50.400 55.000	- 6 Mass: 1000g Inc ss orifice Reverse mmH ₂ O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700 54.700	2.705 Clination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.550 1.655 1.752 1.830	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562 1.648 1.739 1.825	ΔP across distributor mmH₂O 7.400 8.900 10.400 13.400 15.800 18.000 20.400 22.700 25.000 27.300	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 46.600 48.600	or with particle Reverse mmH 20 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200 45.700 48.200	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.100 22.100 22.100 22.000 22.100 22.000 21.400 21.600 21.300	Reverse mmH 2 O 20.500 21.000 21.600 21.500 21.000 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.900		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Subbling Subbling Swirling Swirling Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8 9 10 11 11 12	120.200 Jlar Size: L/D=1.30 AP acros Forward <i>mmH</i> ₂ 0 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 45.000 50.400 55.000 59.800	- 6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700 59.700	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.560 1.655 1.655 1.655 1.830 1.908	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562 1.668 1.739 1.825 1.906	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 20.400 22.700 25.000 27.300 29.600	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 44.600 48.600 50.500	or with particle Reverse mmH 2 0 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200 45.700 48.200 50.700	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.100 22.100 22.000 22.100 22.000 22.100 22.000 22.100 22.000 21.400 21.600 21.300 20.900	Reverse mmH 2 O 20.500 21.000 21.600 21.500 21.000 20.700 20.700 20.500 20.700 20.500 20.700 20.700 20.700 20.700 20.900 21.100		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Bubbling Subbling Subbling Swirling Swirling Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13	120.200 Jlar Size: L/D=1.30 AP acros Forward mmH ₂ 0 12.900 15.900 22.000 25.100 29.800 34.900 40.000 45.000 50.400 55.000 59.800 64.700	- 6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700 54.700 59.700 64.900	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.157 1.236 1.347 1.458 1.560 1.655 1.752 1.752 1.830 1.908 1.985	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562 1.648 1.739 1.825 1.906 1.988	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 20.400 22.700 25.000 27.300 29.600 31.700	ΔP across distribut Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 44.100 44.600 50.500 53.300	or with particle Reverse mmH 2 0 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200 45.700 48.200 50.700 53.400	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.300 22.000 22.000 22.100 22.000 22.100 22.000 21.400 21.600 21.600	Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.000 20.700 20.700 20.500 20.700 20.700 20.700 20.900 21.100 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14	120.200 Jlar Size: L/D=1.30 AP acros Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 55.000 59.800 64.700 70.300	- 6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700 54.700 59.700 64.900 70.000	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.081 1.236 1.347 1.458 1.560 1.655 1.752 1.752 1.830 1.908 1.985 2.069	g Overlap: 18 g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.229 1.354 1.449 1.562 1.648 1.739 1.825 1.906 1.988 2.064	ΔP across distributor mmH₂O 7.400 8.900 10.400 11.800 13.400 15.800 20.400 22.700 25.000 27.300 29.600 31.700 34.000	ΔP across distribute Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 46.600 48.600 50.500 53.300 56.100	mith particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200 45.700 50.700 53.400 56.000	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.300 22.100 22.000 22.100 22.000 21.400 21.600 21.600 20.900 21.600	Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100 20.700 20.700 20.500 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.900 21.100 21.700 22.000		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling
19 Shape: Irreg Data No. 1 2 3 4 5 6 7 8 9 10 11 11 12 13 14 15	120.200 Jlar Size: L/D=1.30 AP acros Forward mmH ₂ O 12.900 15.900 19.200 22.000 25.100 29.800 34.900 40.000 55.000 59.800 64.700 70.300 79.900	6 Mass: 1000g Inc ss orifice Reverse mmH₂O 13.100 16.100 19.500 22.400 24.800 30.100 34.500 40.100 44.600 49.700 54.700 59.700 64.900 70.000 80.000	2.705 lination: 10de Superfica Forward <i>m/sec</i> 0.886 0.984 1.081 1.081 1.157 1.236 1.347 1.458 1.560 1.655 1.752 1.830 1.908 1.908 1.908 2.069 2.205	g Overlap: 18 Velocity Reverse <i>m/sec</i> 0.893 0.990 1.090 1.168 1.168 1.229 1.354 1.449 1.562 1.648 1.739 1.825 1.906 1.998 2.064 2.207	ΔP across distributor mmH₂O 7.400 8.900 10.400 13.400 13.400 15.800 20.400 22.700 25.000 27.300 29.600 31.700 34.000 38.300	ΔP across distribute Forward mmH ₂ O 29.000 30.900 32.700 34.100 35.500 37.800 40.100 42.400 44.100 46.600 48.600 50.500 53.300 56.100 61.200	r with particle Reverse mmH ₂ O 27.900 29.900 32.000 33.300 34.500 36.700 38.700 41.100 43.200 45.700 48.200 50.700 53.400 56.000 61.200	ΔP acro Forward mmH ₂ O 21.600 22.000 22.300 22.300 22.100 22.000 22.100 22.000 21.600 21.600 21.600 21.600 21.600 22.100 22.000	Reverse mmH ₂ O 20.500 21.000 21.600 21.500 21.100 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.700 20.900 21.700 22.000		T2	T3	T4		Observation Incipient Bubbling Bubbling Bubbling Slow Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling Swirling

Shape: Irregular Size: L/D=1.36 Mass: 500g Inclination: 10deg Overlap: 18deg

	ΔP acros	ss orifice	Superfica	l Velocity	ΔP across distributor	ΔP across distribute	or with particle	ΔP acr	oss bed		SI	ugging Ti	me		
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	5	5	s	s	s	
1	13.000	12.900	0.890	0.886	7.400	38.900	36.800	31.500	29.400						Incipient
2	15.800	16.000	0.981	0.987	8.900	40.400	38.400	31.500	29.500						Bubbling
3	18.700	18.700	1.067	1.067	10.400	41.600	39.800	31.200	29.400						Bubbling
4	22.000	22.100	1.157	1.160	11.800	43.000	41.500	31.200	29.700						Bubbling
5	25.100	25.100	1.236	1.236	13.400	44.300	42.800	30.900	29.400						Bottom swirling
6	30.200	30.200	1.356	1.356	15.800	46.800	45.000	31.000	29.200						Bottom swirling
7	34.900	34.800	1.458	1.455	18.000	48.700	46.900	30.700	28.900						Bottom swirling
8	39.800	40.000	1.557	1.560	20.400	50.700	49.200	30.300	28.800						Bottom swirling
9	44.600	44.700	1.648	1.650	22.700	53.100	51.400	30.400	28.700						Bottom swirling
10	49.800	50.300	1.741	1.750	25.000	55.500	54.400	30.500	29.400						Bottom swirling
11	55.200	55.200	1.833	1.833	27.300	57.700	56.600	30.400	29.300						Bottom swirling
12	60.000	60.300	1.911	1.916	29.600	60.000	59.200	30.400	29.600						Bottom swirling
13	70.000	69.900	2.064	2.063	34.000	64.700	64.400	30.700	30.400						Bottom swirling
14	79.600	80.000	2.201	2.207	38.300	69.500	69.400	31.200	31.100						Entrain
15	90.200	90.400	2.343	2.346	43.000	75.000	74.900	32.000	31.900						Entrain
16	99.800	-	2.465	-	47.600	79.900	-	32.300	-						Entrain
Shane: Irreg	ular Size: L/D=1.30	6 Marci 2000g Inc		- 0	ale a										
snape. meg	alui 5120. L/D=1.50	e iviass. 2000g ITIC	clination: 10de	g Overlap: 18	ueg										
Shape. meg		ss orifice		l Velocity		ΔP across distribute	or with particle	ΔP acr	oss bed		SI	ugging Ti	me		
Data No.		<u> </u>			ΔP across distributor	ΔP across distribut Forward	or with particle Reverse	ΔP acro Forward	oss bed Reverse	T1	SI T2	ugging Ti T3	me T4	Tavg	Observation
	ΔP acros	ss orifice	Superfica	l Velocity					1	T1 5	1		1	Tavg s	Observation
	ΔP acros Forward	ss orifice Reverse	Superfica Forward	l Velocity Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse		T2	T3	T4		Observation Incipient
Data No.	ΔP acros Forward mmH ₂ O	ss orifice Reverse mmH ₂ O	Superfica Forward <i>m/sec</i>	l Velocity Reverse <i>m/sec</i>	ΔP across distributor mmH ₂ O	Forward mmH ₂ O	Reverse mmH₂O	Forward mmH ₂ O	Reverse mmH ₂ O		T2	T3	T4		
Data No.	ΔP acros Forward mmH ₂ O 12.800	ss orifice Reverse mmH ₂ O 12.700	Superfica Forward <i>m/sec</i> 0.883	Velocity Reverse <i>m/sec</i> 0.879	ΔP across distributor mmH ₂ O 7.400	Forward <i>mmH</i> ₂ <i>O</i> 46.300	Reverse mmH₂O 44.000	Forward <i>mmH</i> ₂ <i>O</i> 38.900	Reverse mmH ₂ O 36.600		T2	T3	T4		Incipient
Data No.	ΔP acros Forward mmH ₂ O 12.800 16.300	ss orifice Reverse mmH₂O 12.700 16.300	Superfica Forward m/sec 0.883 0.996	Velocity Reverse m/sec 0.879 0.996	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 7.400 8.900	Forward mmH ₂ O 46.300 48.500	Reverse mmH ₂ O 44.000 47.100	Forward mmH ₂ O 38.900 39.600	Reverse mmH ₂ O 36.600 38.200		T2	T3	T4		Incipient Bubbling
Data No.	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100	Reverse mmH ₂ O 12.700 16.300 19.200	Superfica Forward m/sec 0.883 0.996 1.078	Velocity Reverse m/sec 0.879 0.996 1.081	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 7.400 8.900 10.400	Forward mmH ₂ O 46.300 48.500 49.800	Reverse mmH ₂ O 44.000 47.100 48.800	Forward mmH₂O 38.900 39.600 39.400	Reverse mmH ₂ O 36.600 38.200 38.400		T2	T3	T4		Incipient Bubbling Bubbling
Data No.	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000	ss orifice Reverse mmH ₂ O 12.700 16.300 19.200 22.000	Superfica Forward m/sec 0.883 0.996 1.078 1.157	Velocity Reverse <i>m/sec</i> 0.879 0.996 1.081 1.157	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800	Forward mmH ₂ O 46.300 48.500 49.800 51.300	Reverse mmH ₂ O 44.000 47.100 48.800 50.100	Forward mmH ₂ O 38.900 39.600 39.400 39.500	Reverse mmH ₂ O 36.600 38.200 38.400 38.300		T2	T3	T4		Incipient Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200	ss orifice Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400	Superfica Forward m/sec 0.883 0.996 1.078 1.157 1.239	Velocity Reverse <i>m/sec</i> 0.879 0.996 1.081 1.157 1.243	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500	Forward mmH ₂ O 38.900 39.600 39.400 39.500 39.100	Reverse mmH_2O 36.600 38.200 38.400 38.300 38.100		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200	Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800	Superfica Forward 0.883 0.996 1.078 1.157 1.239 1.356	Velocity Reverse <i>m/sec</i> 0.879 0.996 1.081 1.157 1.243 1.347	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400	Forward mmH ₂ O 38.900 39.600 39.400 39.500 39.100 39.100	Reverse mmH20 36.600 38.200 38.400 38.300 38.100 37.600		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6 7	ΔP acros Forward mmH₂O 12.800 16.300 19.100 22.000 25.200 30.200 34.700	mmH20 12.700 16.300 19.200 22.000 25.400 29.800 34.700	Superfica Forward <i>m/sec</i> 0.883 0.996 1.078 1.157 1.239 1.356 1.453	Velocity Reverse <i>m/sec</i> 0.879 0.996 1.081 1.157 1.243 1.347 1.453	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900 57.000	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700	Forward mmH ₂ O 38.900 39.600 39.400 39.500 39.100 39.100 39.000	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.700		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Bubbling Two-layer
Data No. 1 2 3 4 5 6 7 8	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200 34.700 39.600	ss orifice Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200	Superfica Forward 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.553	Velocity Reverse 0.879 0.996 1.081 1.157 1.243 1.347 1.453 1.564	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300	Forward mmH ₂ O 38.900 39.600 39.400 39.500 39.100 39.100 39.000 38.300	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.900		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer
Data No. 1 2 3 4 5 6 7 8 9	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200 30.200 34.700 39.600 44.700	ss orifice Reverse mmH 20 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200 45.400	Superfica Forward 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.553 1.650	I Velocity Reverse <i>m/sec</i> 0.879 0.996 1.081 1.157 1.243 1.347 1.453 1.564 1.662	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400 22.700	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700 61.100	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300 61.000	Forward mmH ₂ O 38.900 39.600 39.500 39.100 39.100 39.100 39.000 38.300 38.400	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.900 38.300		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer Two-layer
Data No. 1 2 3 4 5 6 7 8 9 10	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200 34.700 39.600 44.700 49.800	ss orifice Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200 45.400 49.800	Superfica Forward <i>m/sec</i> 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.553 1.650 1.741	Velocity Reverse m/sec 0.879 0.996 1.081 1.157 1.243 1.347 1.554 1.662 1.741	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400 22.700 25.000	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700 61.100 63.200	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300 61.000 63.000	Forward mmH ₂ O 38.900 39.600 39.500 39.100 39.100 39.000 38.300 38.400 38.200	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.700 37.900 38.300 38.000		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer Two-layer Two-layer
Data No. 1 2 3 4 5 6 7 7 8 9 10 11	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200 34.700 39.600 44.700 49.800 54.900	ss orifice Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200 45.400 49.800 55.000	Superfica Forward <i>m/sec</i> 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.650 1.741 1.828	Velocity Reverse m/sec 0.879 0.996 1.081 1.157 1.243 1.347 1.564 1.662 1.741 1.830	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400 22.700 25.000 27.300	Forward mmH₂O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700 61.100 63.200 65.700	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300 61.000 63.000 65.500	Forward mmH ₂ O 38.900 39.600 39.400 39.100 39.100 39.000 38.300 38.400 38.400 38.400	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.700 37.900 38.300 38.000 38.200		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer Two-layer Two-layer Two-layer
Data No. 1 2 3 4 5 6 7 7 8 9 10 11 12	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 30.200 34.700 39.600 44.700 49.800 54.900 60.400	Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200 45.400 49.800 55.000 60.000	Superfica Forward <i>m/sec</i> 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.553 1.650 1.741 1.828 1.917	Velocity Reverse m/sec 0.879 0.996 1.081 1.157 1.243 1.347 1.453 1.564 1.564 1.564 1.741 1.830 1.911	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 15.800 18.000 20.400 22.700 22.700 25.000 27.300 29.600	Forward mmH₂O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700 61.100 63.200 65.700 68.100	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300 61.000 63.000 65.500 67.400	Forward mmH ₂ O 38.900 39.400 39.500 39.100 39.100 39.000 38.300 38.400 38.200 38.400 38.500	Reverse mmH ₂ O 36.600 38.200 38.400 38.300 38.100 37.600 37.700 37.900 38.300 38.300 38.200 37.900 38.200 38.200 37.800		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer Two-layer Two-layer Two-layer Two-layer Two-layer
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13	ΔP acros Forward mmH ₂ O 12.800 16.300 19.100 22.000 25.200 30.200 34.700 39.600 44.700 49.800 54.900 60.400 64.800	Reverse mmH ₂ O 12.700 16.300 19.200 22.000 25.400 29.800 34.700 40.200 45.400 49.800 55.000 60.000 65.300	Superfica Forward <i>m/sec</i> 0.883 0.996 1.078 1.157 1.239 1.356 1.453 1.553 1.650 1.741 1.828 1.917 1.986	Velocity Reverse m/sec 0.879 0.996 1.081 1.157 1.243 1.347 1.453 1.564 1.741 1.830 1.911	ΔP across distributor mmH ₂ O 7.400 8.900 10.400 11.800 13.400 13.400 20.400 22.700 22.700 22.700 25.000 27.300 29.600 31.700	Forward mmH ₂ O 46.300 48.500 49.800 51.300 52.500 54.900 57.000 58.700 61.100 63.200 65.700 68.100 70.500	Reverse mmH ₂ O 44.000 47.100 48.800 50.100 51.500 53.400 55.700 58.300 61.000 63.000 65.500 67.400 70.100	Forward mmH ₂ O 38.900 39.600 39.100 39.100 39.100 38.000 38.400 38.200 38.400 38.500 38.800	Reverse mmH20 36.600 38.200 38.400 38.300 38.100 37.600 37.700 37.900 38.300 38.200 38.200 38.200 37.800 38.400		T2	T3	T4		Incipient Bubbling Bubbling Bubbling Bubbling Bubbling Two-layer Two-layer Two-layer Two-layer Two-layer Two-layer Two-layer

Shape: Irregular Size: L/D=1.36 Mass: 1500g Inclination: 10deg Overlap: 18deg

	ΔP acros	ss orifice	Superfica	al Velocity		ΔP across distribut	or with particle	ΔP acr	oss bed			Slugging	Time		
ata No.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Tavg	Observation
	mmH ₂ O	mmH ₂ O	m/sec	m/sec	mmH₂O	mmH ₂ O	mmH ₂ O	mmH ₂ O	mmH ₂ O	s	s	s	5	s	Observation
1	12.900	13.300	0.886	0.900	8.100	16.700	17.800	8.600	9.700	-	-	-		-	Incipient
2	15.800	15.900	0.981	0.984	9.600	20.700	20.500	11.100	10.900						Start swirling
3	19.000	18.900	1.075	1.073	11.300	22.300	22.300	11.000	11.000	1.040	0.980	0.980	0.890	0.973	Slugging
4	21.800	22.200	1.152	1.162	12.900	23.500	23.700	10.600	10.800	1.540	1.530	1.680	1.570	1.580	Slugging
5	25.000	24.800	1.234	1.229	14.500	25.200	25.200	10.700	10.700	1.840	1.800	1.730	1.880	1.813	Slugging
6	29.800	30.000	1.347	1.351	16.900	28.000	28.000	11.100	11.100	2.330	2.400	2.240	2.320	2.323	Slugging
7	34.900	35.300	1.458	1.466	19.300	30.800	30.900	11.500	11.600	2.520	2.600	2.530	2.520	2.543	Slugging
8	39.800	40.200	1.557	1.564	22.000	33.800	33.800	11.800	11.800	2.580	2.660	2.640	2.640	2.630	Slugging
9	45.300	45.400	1.661	1.662	24.300	36.000	36.200	11.700	11.900						Swirling
10	50.100	50.400	1.746	1.752	26.900	38.500	39.000	11.600	12.100						Swirling
11	55.200	55.200	1.833	1.833	29.500	41.100	41.600	11.600	12.100						Swirling
12	60.000	59.900	1.911	1.910	31.500	44.500	44.200	13.000	12.700						Swirling
13	67.500	67.500	2.027	2.027	35.500	48.300	48.100	12.800	12.600						Swirling
14	74.900	74.900	2.135	2.135	39.000	51.600	51.700	12.600	12.700						Swirling
15	82.500	82.400	2.241	2.240	43.100	55.600	55.600	12.500	12.500						Swirling
16	90.000	89.900	2.341	2.339	46.000	57.800	60.000	11.800	14.000						Swirling
17	100.200	100.300	2.470	2.471	51.000	65.400	65.600	14.400	14.600						Jumping
18	109.800	109.900	2.585	2.586	56.100	70.600	70.500	14.500	14.400						Jumping
19	120.000	-	2.703	-	61.100	75.100	-	14.000	-						Entrain
		00. 14 1000			10-1										
Shape: Irre	÷ .	2.00 Mass: 1000g			18deg				are he d			Clugging	Times		
	ΔP acros	ss orifice	Superfica	al Velocity	18deg ΔP across distributor	ΔP across distribut	· ·	ΔP acr	oss bed	T1		Slugging		Taura	
•	ΔP acros Forward	ss orifice Reverse	Superfica Forward	al Velocity Reverse	ΔP across distributor	ΔP across distribut Forward	Reverse	ΔP acro Forward	Reverse	T1	T2	T3	T4	Tavg	
Data No.	ΔP acros Forward mmH ₂ O	ss orifice Reverse mmH ₂ O	Superfica Forward <i>m/sec</i>	al Velocity Reverse <i>m/sec</i>	ΔP across distributor mmH_2O	ΔP across distribut Forward mmH ₂ O	Reverse mmH ₂ O	ΔP acro Forward mmH ₂ O	Reverse mmH ₂ O	T1 5				Tavg s	Observation
Data No.	ΔP acros Forward mmH ₂ O 19.200	ss orifice Reverse mmH ₂ O 18.800	Superfice Forward <i>m/sec</i> 1.081	Reverse <i>m/sec</i> 1.070	ΔP across distributor mmH ₂ O 11.300	ΔP across distribut Forward mmH ₂ O 33.400	Reverse mmH ₂ O 31.700	ΔP acro Forward mmH ₂ O 22.100	Reverse mmH ₂ O 20.400		T2	T3	T4		Observation Incipient
Data No.	ΔP acros Forward mmH ₂ O 19.200 21.800	ss orifice Reverse mmH ₂ O 18.800 22.300	Superfica Forward m/sec 1.081 1.152	Image: Velocity Reverse m/sec 1.070 1.165	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 11.300 12.900	ΔP across distribut Forward mmH ₂ O 33.400 34.500	Reverse mmH₂O 31.700 34.700	ΔP acro Forward mmH ₂ O 22.100 21.600	Reverse mmH ₂ O 20.400 21.800		T2	T3	T4		Observation Incipient Start bubbling
Data No.	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200	Superfice Forward m/sec 1.081 1.152 1.239	Velocity Reverse m/sec 1.070 1.165 1.239	ΔP across distributor <i>mmH</i> ₂ O 11.300 12.900 14.500	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000	Reverse mmH ₂ O 31.700 34.700 36.000	ΔP acro Forward mmH ₂ 0 22.100 21.600 21.500	Reverse mmH ₂ O 20.400 21.800 21.500		T2	T3	T4		Observation Incipient Start bubbling Bubbling
Data No.	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200 29.900	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000	Superfica Forward m/sec 1.081 1.152 1.239 1.349	Velocity Reverse m/sec 1.070 1.165 1.239 1.351	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700	Reverse mmH₂O 31.700 34.700 36.000 38.600	ΔP acro Forward 22.100 21.600 21.500 21.800	Reverse mmH₂O 20.400 21.800 21.500 21.700		T2	T3	T4		Observation Incipient Start bubbling Bubbling Bubbling
Data No. 1 2 3 4 5	ΔP acro Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300	Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400	Superfica Forward m/sec 1.081 1.152 1.239 1.349 1.466	Al Velocity Reverse m/sec 1.070 1.165 1.239 1.351 1.468	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300	ΔP acro Forward 22.100 21.600 21.500 21.800 22.300	Reverse mmH₂O 20.400 21.800 21.500 21.700 22.000	5	T2 s	T3 <i>s</i>	T4 5	S	Observation Incipient Start bubbling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6	ΔP acro Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600	Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800	Superfice Forward m/sec 1.081 1.152 1.239 1.349 1.466 1.553	al Velocity Reverse m/sec 1.070 1.165 1.239 1.351 1.468 1.557	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900	Reverse mmH20 20.400 21.800 21.500 21.700 22.000 21.200	s	T2 s 2.680	T3 <i>s</i> 2.600	T4 5 2.680	s 2.353	Observation Incipient Start bubbling Bubbling Bubbling Bubbling Slugging
Data No. 1 2 3 4 5 6 7	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900	Reverse mmH20 18.800 22.300 25.200 30.000 35.400 39.800 45.100	Superfict Forward m/sec 1.081 1.152 1.239 1.349 1.466 1.553 1.653	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 22.300 22.400	Reverse mmH20 20.400 21.800 21.500 21.700 22.000 21.200 22.200	s 1.450 1.440	T2 s 2.680 2.980	T3 <i>s</i> 2.600 2.970	T4 <i>s</i> 2.680 2.890	s 2.353 2.570	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging
Data No. 1 2 3 4 5 6 7 8	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000	Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200	Superfict Forward m/sec 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.748	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 22.400	Reverse mmH20 20.400 21.800 21.500 21.700 22.000 21.200 22.200 21.700	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010	T3 s 2.600 2.970 3.110	T4 <i>s</i> 2.680 2.890 3.140	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000	Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.653 1.653 1.745 1.830	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.657 1.748 1.835	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.800 21.600	Reverse mmH20 20.400 21.800 21.500 21.700 22.000 21.200 22.200 21.700 22.800 21.700 22.200 21.700	s 1.450 1.440	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	s 2.353 2.570	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8	ΔP acros Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 55.000 60.100	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800	Superfict Forward m/sec 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.748 1.835 1.908	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.800 21.600 22.200	Reverse mmH20 20.400 21.800 21.500 21.700 22.000 21.200 22.200 21.700	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10	ΔP acro Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000 60.100 67.300	Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800 67.600	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.653 1.745 1.830 1.913 2.024	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.657 1.748 1.835	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500 57.900	ΔP acm Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.800 21.600 22.200 22.400	Reverse mmH ₂ O 20.400 21.800 21.700 22.000 21.700 22.200 21.700 21.700 22.000 21.800 22.000	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12	ΔP acro Forward mmH 2 0 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000 60.100 67.300	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.653 1.653 1.745 1.830 1.913	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.748 1.835 1.908 2.029	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500 39.000	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900 62.400	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500 57.900 61.900	ΔP acm Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.600 21.600 22.200 22.400 23.400	Reverse mmH ₂ O 20.400 21.800 21.700 22.000 21.200 21.700 22.000 21.800 22.000 21.800 22.400 22.400 22.900	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging
Data No.	ΔP acros Forward mmH 2 0 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000 60.100 67.300 75.300 82.700	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800 67.600 75.300 82.500	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745 1.830 1.913 2.024 2.141 2.244	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.748 1.908 2.029 2.141 2.241	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500 39.000 43.100	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900 62.400 66.500	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500 57.900 61.900 65.800	ΔP acm Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.600 22.200 22.400 22.400 23.400	Reverse mmH20 20.400 21.800 21.700 22.000 21.200 21.700 22.200 21.700 22.000 21.000 22.000 21.200 22.200 21.200 22.200 22.200 22.400 22.900 22.700	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Swirling Swirling
Data No. 1 2 3 4 5 6 7 8 9 10 11 12	ΔP acro Forward mmH 2 0 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000 60.100 67.300	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800 67.600 75.300	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745 1.830 1.913 2.024 2.141	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.748 1.835 1.908 2.029 2.141	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500 39.000	ΔP across distribut Forward mmH ₂ O 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900 62.400	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500 57.900 61.900	ΔP acm Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.600 21.600 22.200 22.400 23.400	Reverse mmH20 20.400 21.800 21.700 22.000 21.200 21.700 22.200 21.700 22.000 21.700 22.000 21.700 22.000 22.000 22.000 22.000 22.000 22.700 23.200	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14	ΔP acro: Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 55.000 60.100 67.300 75.300 82.700 89.900	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 55.300 55.300 59.800 67.600 75.300 82.500 89.800	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745 1.830 1.913 2.024 2.141 2.244 2.339	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.748 1.835 1.835 1.908 2.029 2.141 2.241 2.338	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500 39.000 43.100 46.000	ΔP across distribut Forward mmH20 33.400 34.500 36.000 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900 62.400 66.500 69.200	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 57.900 61.900 65.800 69.200	ΔP acro Forward mmH ₂ O 22.100 21.600 21.800 21.800 22.300 21.900 22.400 21.600 22.400 21.600 22.400 23.400 23.400 23.400 23.200	Reverse mmH20 20.400 21.800 21.700 22.000 21.200 21.700 22.200 21.700 22.000 21.000 22.000 21.200 22.200 21.200 22.200 22.200 22.400 22.900 22.700	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Swirling Swirling Swirling Swirling
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	ΔP acro: Forward mmH ₂ O 19.200 21.800 25.200 29.900 35.300 39.600 44.900 50.000 55.000 60.100 67.300 75.300 82.700 89.900 100.300	ss orifice Reverse mmH ₂ O 18.800 22.300 25.200 30.000 35.400 39.800 45.100 50.200 55.300 59.800 67.600 75.300 82.500 89.800 100.000	Superfic: Forward <i>m/sec</i> 1.081 1.152 1.239 1.349 1.466 1.553 1.653 1.745 1.830 1.913 2.024 2.141 2.244 2.339 2.471	al Velocity Reverse <i>m/sec</i> 1.070 1.165 1.239 1.351 1.468 1.557 1.657 1.748 1.835 1.908 2.029 2.141 2.241 2.338 2.467	ΔP across distributor mmH ₂ O 11.300 12.900 14.500 16.900 19.300 22.000 24.300 26.900 29.500 31.500 35.500 39.000 43.100 46.000 51.000	ΔP across distribut Forward mmH ₂ O 33.400 34.500 34.500 38.700 41.600 43.900 46.700 48.700 51.100 53.700 57.900 62.400 66.500 69.200 75.000	Reverse mmH ₂ O 31.700 34.700 36.000 38.600 41.300 43.200 46.500 48.600 51.300 53.500 57.900 61.900 65.800 69.200 74.800	ΔP acro Forward mmH ₂ O 22.100 21.600 21.500 21.800 22.300 21.900 22.400 21.600 22.200 22.400 22.400 23.400 23.400 23.400 23.400	Reverse mmH20 20,400 21.800 21.700 22,000 21.700 22,200 21.700 22,000 21.700 22,000 21.700 22,000 22,000 22,400 22,900 22,700 23,200 23,800	s 1.450 1.440 1.640	T2 s 2.680 2.980 3.010 3.170	T3 s 2.600 2.970 3.110 3.230	T4 5 2.680 2.890 3.140 3.090	2.353 2.570 2.725	Observation Incipient Start bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Swirling Swirling Swirling

Shape: Irregular Size: L/D=2.00 Mass: 500g Inclination: 10deg Overlap: 18deg

snape. In	egular Size: L/D=2	-	1		10005						al			
Data No.		ss orifice		al Velocity	ΔP across distributor	ΔP across distribut	or with particle		oss bed			ng Time	r	-
	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	\$	s	s	s	
1	18.900	19.100	1.073	1.078	11.300	43.700	38.900	32.400	27.600					Fluidized
2	22.200	22.200	1.162	1.162	12.900	44.500	42.000	31.600	29.100					Start bubbling
3	24.900	24.600	1.231	1.224	14.500	45.600	45.000	31.100	30.500					Bubbling
4	29.900	29.900	1.349	1.349	16.900	47.700	47.400	30.800	30.500					Bubbling
5	35.000	35.000	1.460	1.460	19.300	50.000	50.300	30.700	31.000					Bubbling
6	39.900	40.200	1.558	1.564	22.000	52.500	51.900	30.500	29.900					Slugging
7	45.300	45.300	1.661	1.661	24.300	55.100	54.600	30.800	30.300					Bottom swirling
8	49.800	50.200	1.741	1.748	26.900	57.500	56.900	30.600	30.000					Bottom swirling
9	54.900	55.300	1.828	1.835	29.500	60.200	59.700	30.700	30.200					Bottom swirling
10	60.000	60.200	1.911	1.914	31.500	62.800	62.700	31.300	31.200					Bottom swirling
11	67.400	67.400	2.026	2.026	35.500	66.400	66.300	30.900	30.800					Jumping
12	75.000	75.000	2.137	2.137	39.000	70.900	70.500	31.900	31.500					Jumping
13	82.500	82.500	2.241	2.241	43.100	74.600	74.300	31.500	31.200					Jumping
14	90.400	90.400	2.346	2.346	46.000	78.500	78.000	32.500	32.000					Jumping
15	100.300	100.300	2.471	2.471	51.000	83.200	83.000	32.200	32.000					Jumping
16	110.000	110.200	2.588	2.590	56.100	89.300	88.400	33.200	32.300					Jumping
17	120.300	-	2.706	-	61.100	93.400	-	32.300	-					Jumping
Shape: Irre	egular Size: L/D=2	2.00 Mass: 2000g	Inclination: 10	deg Overlap:	18deg									
Data No.	ΔP acros	ss orifice	Superfica	al Velocity	ΔP across distributor	ΔP across distribut	tor with particle	ΔP acr	oss bed		Sluggir	ng Time		
Data NO.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH ₂ O	mmH₂O	s	s	s	s	
1	22.300	21.900	1.000	1.018	12.900	51.200	49.000	38.300	36.100					Fluidized
2	24.900	25.000	1.231	1.234	14.500	54.600	54.600	40.100	40.100					Bottom swirling
3	30.000	29.900	1.351	1.349	16.900	56.800	56.800	39.900	39.900					Bottom swirling
4	34.700	35.200	1.453	1.464	19.300	58.800	58.900	39.500	39.600					Bottom swirling
5	39.900	40.300	1.558	1.566	22.000	60.500	59.900	38.500	37.900					Bottom swirling
6	45.000	44.900	1.655	1.653	24.300	62.800	62.000	38.500	37.700					Bottom swirling
7	50.300	50.000	1.750	1.745	26.900	65.700	64.800	38.800	37.900					Bottom swirling
8	55.200	55.300	1.833	1.835	29.500	68.400	68.000	38.900	38.500					Bottom swirling
	60.200	60.000	1.914	1.911	31.500	70.800	70.200	39.300	38.700					Bottom swirling
9	00.200	1		2.032	35.500	74.700	74.700	39.200	39.200	1				Bottom swirling
9 10	67.500	67.800	2.027	2.052			1	20 700	39.100	1	1	1	Î.	-
		67.800 74.900	2.027	2.135	39.000	78.700	78.100	39.700	39.100					Bottom swirling
10	67.500				39.000 43.100	78.700 82.700	78.100 82.100	39.700	39.000					Bottom swirling
10 11	67.500 75.000	74.900	2.137	2.135										0
10 11 12	67.500 75.000 82.500	74.900 82.500	2.137 2.241	2.135 2.241	43.100	82.700	82.100	39.600	39.000					Bottom swirling

Shape: Irregular Size: L/D=2.00 Mass: 1500g Inclination: 10deg Overlap: 18deg

Shape: Cyli				8											
	ΔP across orifice		Superfical Velocity		ΔP across distributor	ΔP across distributor with particle		ΔP across bed		Slugging Time				1	
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	s	s	s	5	s	
1	6.100	6.200	0.609	0.614	4.000	11.600	6.300	7.600	2.300						Incipient
2	8.900	9.300	0.736	0.752	5.700	15.300	9.200	9.600	3.500						Incipient
3	12.300	12.300	0.865	0.865	7.300	17.700	11.600	10.400	4.300						Massing
4	15.300	14.800	0.965	0.949	9.000	17.700	13.600	8.700	4.600						Massing
5	19.800	20.400	1.098	1.114	11.600	18.000	18.300	6.400	6.700						Massing
6	24.900	25.200	1.231	1.239	14.200	24.100	23.700	9.900	9.500						Massing
7	30.000	30.000	1.351	1.351	16.700	27.200	26.900	10.500	10.200	7.140	7.250	7.160	7.210	7.190	Slugging
8	34.800	35.300	1.455	1.466	19.300	29.900	30.200	10.600	10.900	6.220	6.210	6.230	6.220	6.220	Slugging
9	40.100	39.900	1.562	1.558	21.800	32.800	32.600	11.000	10.800	5.640	5.560	5.620	5.590	5.603	Slugging
10	44.800	45.200	1.651	1.659	24.300	35.600	35.600	11.300	11.300	5.530	5.480	5.520	5.530	5.515	Slugging
11	50.200	49.800	1.748	1.741	26.800	38.300	38.000	11.500	11.200	5.120	5.210	5.150	5.170	5.163	Slugging
12	55.400	55.300	1.836	1.835	29.200	41.200	41.200	12.000	12.000						Swirling
13	60.300	60.000	1.916	1.911	31.800	43.900	43.800	12.100	12.000						Swirling
14	65.200	65.000	1.992	1.989	34.100	46.400	46.400	12.300	12.300						Swirling
15	70.000	69.800	2.064	2.061	36.600	49.000	48.800	12.400	12.200						Swirling
16	79.800	80.000	2.204	2.207	41.200	53.900	53.900	12.700	12.700						Swirling
17	89.700	90.300	2.337	2.345	46.400	59.100	59.200	12.700	12.800						Jumping
18	105.000	105.300	2.528	2.532	53.600	66.500	66.800	12.900	13.200						Entrain
19	120.200	-	2.705	-	60.800	74.200	-	13.400							Entrain
Shape: Cyli	ndrical Size: L/D=1	1.28 Mass: 1000g	Inclination: 100	leg Overlap: 1	L8deg										
	ΔP acros	ss orifice	Superfica	Velocity	ΔP across distributor	ΔP across distribut	or with particle	ΔP acro	oss bed			ugging Tir	me	•	
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH₂O		,										5	
1	12,000		m/sec	m/sec	mmH ₂ O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	5	5	5	5	3	
2	12.000	12.000	0.855	0.855	7.300	28.400	22.500	<i>mmH</i> ₂ <i>O</i> 21.100	mmH ₂ O 15.200	S	S	S	S	3	Incipient
2	12.000	_	-	-		=	-	_	=	5	S	S	S	3	Incipient Bubbling
2		12.000	0.855	0.855	7.300	28.400	22.500	21.100	15.200	5	S	S	S	3	
	15.200	12.000 15.000	0.855 0.962	0.855 0.956	7.300 9.000	28.400 31.800	22.500 26.500	21.100 22.800	15.200 17.500	S	\$ 	\$ 	5	3	Bubbling
3	15.200 20.200	12.000 15.000 20.200	0.855 0.962 1.109	0.855 0.956 1.109	7.300 9.000 11.600	28.400 31.800 34.600	22.500 26.500 30.900	21.100 22.800 23.000	15.200 17.500 19.300	<u>s</u>	<u>s</u>	S	<u>s</u>		Bubbling Bubbling
3 4	15.200 20.200 25.000	12.000 15.000 20.200 25.200	0.855 0.962 1.109 1.234	0.855 0.956 1.109 1.239	7.300 9.000 11.600 14.200	28.400 31.800 34.600 35.200	22.500 26.500 30.900 33.900	21.100 22.800 23.000 21.000	15.200 17.500 19.300 19.700	s	s 2.460	s 2.420	s 2.410	2.458	Bubbling Bubbling Bubbling
3 4 5	15.200 20.200 25.000 30.000	12.000 15.000 20.200 25.200 30.000	0.855 0.962 1.109 1.234 1.351	0.855 0.956 1.109 1.239 1.351	7.300 9.000 11.600 14.200 16.700 19.300 21.800	28.400 31.800 34.600 35.200 39.000 41.900 45.000	22.500 26.500 30.900 33.900 38.500	21.100 22.800 23.000 21.000 22.300	15.200 17.500 19.300 19.700 21.800 21.500 22.100		2.460	2.420 2.750	2.410 2.770	2.458 2.723	Bubbling Bubbling Bubbling Bubbling
3 4 5 6	15.200 20.200 25.000 30.000 35.100	12.000 15.000 20.200 25.200 30.000 35.000	0.855 0.962 1.109 1.234 1.351 1.462	0.855 0.956 1.109 1.239 1.351 1.460	7.300 9.000 11.600 14.200 16.700 19.300	28.400 31.800 34.600 35.200 39.000 41.900	22.500 26.500 30.900 33.900 38.500 40.800	21.100 22.800 23.000 21.000 22.300 22.600	15.200 17.500 19.300 19.700 21.800 21.500	2.540	2.460	2.420	2.410	2.458	Bubbling Bubbling Bubbling Bubbling Slugging
3 4 5 6 7 8 9	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800	28.400 31.800 35.200 39.000 41.900 45.000 48.000 50.600	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200	21.100 22.800 23.000 21.000 22.300 22.600 23.200 23.700 23.800	15.200 17.500 19.300 19.700 21.800 21.500 22.100 22.800 23.400	2.540 2.650 2.890 2.890	2.460 2.720 2.920 3.010	2.420 2.750 2.950 2.950	2.410 2.770 2.900 2.980	2.458 2.723 2.915 2.958	Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging
3 4 5 6 7 8 9 10	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200	28.400 31.800 34.600 35.200 39.000 41.900 45.000 48.000 50.600 52.600	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400	15.200 17.500 19.300 19.700 21.800 21.500 22.800 23.400 23.300	2.540 2.650 2.890 2.890 3.010	2.460 2.720 2.920 3.010 3.073	2.420 2.750 2.950 2.950 3.000	2.410 2.770 2.900 2.980 3.050	2.458 2.723 2.915 2.958 3.033	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging
3 4 5 6 7 8 9	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800	28.400 31.800 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600	21.100 22.800 23.000 21.000 22.300 22.600 23.200 23.700 23.800	15.200 17.500 19.300 19.700 21.800 21.500 22.100 22.800 23.400	2.540 2.650 2.890 2.890	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging
3 4 5 6 7 8 9 10 11 12	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833 1.916 1.992	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100	28.400 31.800 35.200 39.000 41.900 45.000 50.600 52.600 56.000 59.700	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100	21.100 22.800 23.000 21.000 22.300 22.600 23.200 23.700 23.800 23.400 24.200 25.600	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.300 23.800 24.000	2.540 2.650 2.890 2.890 3.010	2.460 2.720 2.920 3.010 3.073	2.420 2.750 2.950 2.950 3.000	2.410 2.770 2.900 2.980 3.050	2.458 2.723 2.915 2.958 3.033	Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging
3 4 5 7 8 9 10 11 12 13	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.752 1.833 1.916 1.992 2.064	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600	28.400 31.800 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000 59.700 60.800	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 55.600 55.600 58.100 61.100	21.100 22.800 23.000 21.000 22.300 22.600 23.200 23.700 23.800 23.400 24.200 25.600 24.200	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.800 23.800 24.000 24.500	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging
3 4 5 7 8 9 10 11 12 13 14	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000 79.900	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 79.800	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833 1.916 1.992 2.064 2.205	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600 41.200	28.400 31.800 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000 59.700 60.800 66.000	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400 24.200 25.600 24.200 24.800	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.800 23.800 24.000 24.500 24.600	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Swirling
3 4 5 6 7 8 9 10 11 12 13 14 15	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000 79.900 90.000	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 79.800 89.700	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833 1.916 1.992 2.064 2.205 2.341	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204 2.337	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600 41.200	28.400 31.800 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000 59.700 60.800 66.000 70.800	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800 70.200	21.100 22.800 23.000 21.000 22.300 22.600 23.200 23.200 23.700 23.400 24.200 24.200 24.200 24.800 24.400	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.800 23.800 24.000 24.600 23.800	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Sugging Sugging Sugging Swirling Swirling
3 4 5 6 7 8 9 10 11 12 13 14 15 16	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000 79.900 90.000 100.100	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 79.800 89.700 99.900	0.855 0.962 1.109 1.234 1.351 1.462 1.552 1.655 1.752 1.833 1.916 1.992 2.064 2.205 2.341 2.468	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204 2.337 2.466	7.300 9.000 11.600 14.200 16.700 19.300 24.300 24.300 26.800 29.200 31.800 34.100 36.600 41.200 46.400 51.000	28.400 31.800 34.600 35.200 39.000 41.900 45.000 50.600 52.600 52.600 56.000 59.700 60.800 66.000 70.800 75.400	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800 70.200 75.300	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400 24.200 24.200 24.200 24.800 24.400	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.300 23.800 24.500 24.500 24.500 23.800 24.500	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Sugging Sugging Sugging
3 4 5 6 7 8 9 10 11 12 12 13 14 15 16 17	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000 79.900 90.000 100.100	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 70.300 79.800 89.700 99.900 109.900	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833 1.916 1.992 2.064 2.205 2.341 2.468 2.591	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204 2.337 2.466 2.586	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600 41.200 46.400 51.000	28.400 31.800 34.600 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000 59.700 60.800 66.000 70.800 75.400 81.900	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800 70.200 75.300 81.200	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400 24.200 24.200 24.200 24.800 24.400 24.400 24.400	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.300 23.800 24.600 24.600 24.600 23.800 24.600 24.300 24.300	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Sugging Swirling Swirling Swirling Swirling
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	15.200 20.200 25.000 30.000 35.100 40.100 45.000 55.200 60.300 65.200 70.000 79.900 90.000 100.100 110.300	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 79.800 89.700 99.900 109.900 120.200	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.752 1.833 1.916 1.992 2.064 2.205 2.341 2.468 2.591 2.705	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204 2.337 2.466 2.586 2.705	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600 41.200 46.400 51.000 55.700 65.600	28.400 31.800 34.600 35.200 39.000 41.900 45.000 50.600 52.600 52.600 59.700 60.800 66.000 70.800 75.400 81.900 86.600	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800 70.200 75.300 81.200 86.300	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400 24.200 24.200 24.800 24.400 24.400 24.400 26.200 21.000	15.200 17.500 19.300 21.800 21.500 22.800 23.400 23.300 23.800 24.000 24.500 24.600 23.800 24.600 23.800 24.300 25.500 20.700	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Sugging Swirling Swirling Swirling
3 4 5 6 7 8 9 10 11 12 12 13 14 15 16 17	15.200 20.200 25.000 30.000 35.100 40.100 45.000 50.400 55.200 60.300 65.200 70.000 79.900 90.000 100.100	12.000 15.000 20.200 25.200 30.000 35.000 40.400 44.900 50.400 55.200 360.000 65.000 70.300 70.300 79.800 89.700 99.900 109.900	0.855 0.962 1.109 1.234 1.351 1.462 1.562 1.655 1.752 1.833 1.916 1.992 2.064 2.205 2.341 2.468 2.591	0.855 0.956 1.109 1.239 1.351 1.460 1.568 1.653 1.752 1.833 4.681 1.989 2.069 2.204 2.337 2.466 2.586	7.300 9.000 11.600 14.200 16.700 19.300 21.800 24.300 26.800 29.200 31.800 34.100 36.600 41.200 46.400 51.000	28.400 31.800 34.600 35.200 39.000 41.900 45.000 48.000 50.600 52.600 56.000 59.700 60.800 66.000 70.800 75.400 81.900	22.500 26.500 30.900 33.900 38.500 40.800 43.900 47.100 50.200 52.500 55.600 58.100 61.100 65.800 70.200 75.300 81.200	21.100 22.800 23.000 21.000 22.300 23.200 23.200 23.700 23.800 23.400 24.200 24.200 24.200 24.800 24.400 24.400 24.400	15.200 17.500 19.300 21.800 21.500 22.100 22.800 23.400 23.300 23.800 24.600 24.600 24.600 23.800 24.600 24.300 24.300	2.540 2.650 2.890 2.890 3.010 2.920	2.460 2.720 2.920 3.010 3.073 2.910	2.420 2.750 2.950 2.950 3.000 2.920	2.410 2.770 2.900 2.980 3.050 2.910	2.458 2.723 2.915 2.958 3.033 2.915	Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Sugging Sugging Swirling Swirling Swirling Swirling

Shape: Cylindrical Size: L/D=1.28 Mass: 500g Inclination: 10deg Overlap: 18deg

ndrical Size: L/D=1	1.28 Mass: 1500g	inclination: 100	leg Overlap: 1	ladeg										
ΔP across orifice		Superfical Velocity		AD across distributor	ΔP across distributor with particle		ΔP acro	Slugging Time						
Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH ₂ O	mmH₂O	mmH₂O	s	s	5	5	s	
11.800	12.400	0.848	0.869	7.300	31.300	30.700	24.000	23.400						Incipient
15.100	15.400	0.959	0.968	9.000	38.300	36.700	29.300	27.700						Incipient
20.300	20.100	1.112	1.106	11.600	41.900	41.300	30.300	29.700						Bubbling
24.900	25.300	1.231	1.241	14.200	44.900	45.100	30.700	30.900						Bubbling
30.100	30.300	1.354	1.358	16.700	48.600	48.800	31.900	32.100						Bubbling
35.300	35.400	1.466	1.468	19.300	53.000	52.800	33.700	33.500						Bubbling
40.300	39.800	1.566	1.557	21.800	56.100	55.600	34.300	33.800	1.950	1.980	1.910	1.920	1.940	Slugging
44.800	44.800	1.651	1.651	24.300	58.700	58.300	34.400	34.000	1.970	1.990	2.010	1.950	1.980	Slugging
50.100	50.300	1.746	1.750	26.800	61.300	61.400	34.500	34.600	2.090	2.140		2.120	2.130	Slugging
55.100	55.300	1.831	1.835	29.200	64.600	64.600	35.400	35.400		2.170				Slugging
														Slugging
									-					Slugging
														Slugging
									2.520				2.500	Slugging
										Mi	nor Slugg	ing	r	Slugging
														Jumping
		-												Jumping
	129.900													Entrain
139.800	-	2.917	-	70.300	108.000	-	37.700	-						Entrain
	_			.80eg		on with norticle	AD com	aaa haad		ci.	unaina Ti			
	1		· ·	ΔP across distributor				r	T1				Tours	
				mmH 0					-				-	Observation
-	=	-		•	=	=	-	-	3	3	3	3	3	
														Incipient
														Incipient
														Start bubbling
									-					Bubbling Bubbling
									-					
														Bubbling Bubbling
									0.670	0.760	0.640	0.770		Slugging
														Slugging
54.800	55.000	1.732	1.830	29.200	73.900	74.000	44.700	44.200	1.520	1.580	1.610	1.650		Slugging
						74.000	44.700	44.000	1.520	1.500				
						76 300	44 700	44 500	1 850	1 890	1 850	1 880		
60.000	60.000	1.911	1.911	31.800	76.500	76.300 78.700	44.700 44.600	44.500 44.600	1.850	1.890	1.850	1.880		Slugging
60.000 65.300	60.000 65.300	1.911 1.994	1.911 1.994	31.800 34.100	76.500 78.700	78.700	44.600	44.600	1.850 1.830	1.790	1.750	1.880 1.740		Slugging
60.000 65.300 69.800	60.000 65.300 70.200	1.911 1.994 2.061	1.911 1.994 2.067	31.800 34.100 36.600	76.500 78.700 81.000	78.700 81.300	44.600 44.400	44.600 44.700		1.790 Minor s	1.750 lugging			Slugging Slugging
60.000 65.300 69.800 79.700	60.000 65.300 70.200 80.300	1.911 1.994 2.061 2.203	1.911 1.994 2.067 2.211	31.800 34.100 36.600 41.200	76.500 78.700 81.000 85.800	78.700 81.300 85.800	44.600 44.400 44.600	44.600 44.700 44.600		1.790	1.750 lugging			Slugging Slugging Slugging
60.000 65.300 69.800 79.700 89.800	60.000 65.300 70.200 80.300 89.800	1.911 1.994 2.061 2.203 2.338	1.911 1.994 2.067 2.211 2.338	31.800 34.100 36.600 41.200 46.400	76.500 78.700 81.000 85.800 91.200	78.700 81.300 85.800 91.000	44.600 44.400 44.600 44.800	44.600 44.700 44.600 44.600		1.790 Minor s	1.750 lugging			Slugging Slugging Slugging Jumping
60.000 65.300 69.800 79.700 89.800 99.800	60.000 65.300 70.200 80.300 89.800 100.400	1.911 1.994 2.061 2.203 2.338 2.465	1.911 1.994 2.067 2.211 2.338 2.472	31.800 34.100 36.600 41.200 46.400 51.000	76.500 78.700 81.000 85.800 91.200 95.800	78.700 81.300 85.800 91.000 96.000	44.600 44.400 44.600 44.800 44.800	44.600 44.700 44.600 44.600 45.000		1.790 Minor s	1.750 lugging			Slugging Slugging Slugging Jumping Jumping
60.000 65.300 69.800 79.700 89.800	60.000 65.300 70.200 80.300 89.800	1.911 1.994 2.061 2.203 2.338	1.911 1.994 2.067 2.211 2.338	31.800 34.100 36.600 41.200 46.400	76.500 78.700 81.000 85.800 91.200	78.700 81.300 85.800 91.000	44.600 44.400 44.600 44.800	44.600 44.700 44.600 44.600		1.790 Minor s	1.750 lugging			Slugging Slugging Slugging Jumping
	ΔP acros Forward mmH ₂ O 11.800 15.100 20.300 24.900 30.100 35.300 40.300 44.800 50.100 55.100 60.300 65.000 70.200 79.800 90.200 99.700 114.800 130.100 139.800 99.700 114.800 139.800 90.200 99.700 114.800 130.100 139.800 90.200 99.700 114.800 130.100 139.800 90.200 90.200 90.200 91.14.800 130.100 139.800 12.200 15.000 20.300 24.700 30.000 35.200 39.900 45.300 50.400	ΔP across orifice Forward Reverse mmH ₂ O mmH ₂ O 11.800 12.400 15.100 15.400 20.300 20.100 24.900 25.300 30.100 30.300 35.300 35.400 40.300 39.800 44.800 44.800 50.100 55.300 60.300 60.000 65.000 65.000 70.200 70.100 79.800 80.300 90.200 90.000 99.700 99.800 114.800 114.700 130.100 129.900 139.800 - ndrical Size: L/D=1.28 Mass: 2000g ΔP across orifice Forward Reverse mmH ₂ O 11.900 15.000 14.800 20.300 19.900 24.700 25.100 30.000 35.400 39.900 40.200	ΔP across orifice Superfical Forward Reverse Forward mmH_2O mmH_2O m/sec 11.800 12.400 0.848 15.100 15.400 0.959 20.300 20.100 1.112 24.900 25.300 1.231 30.100 30.300 1.354 35.300 35.400 1.466 40.300 39.800 1.566 44.800 44.800 1.651 50.100 55.300 1.831 60.300 60.000 1.916 65.000 65.000 1.989 70.200 70.100 2.067 79.800 80.300 2.204 90.200 90.000 2.343 99.700 99.800 2.464 114.800 114.700 2.644 130.100 129.900 2.814 139.800 - 2.917 mdrical Size: L/D=1.28 Mass: 2000g Inclination: 10c	ΔP across orifice Superfical Velocity Forward Reverse Forward Reverse mmH ₂ O mmH ₂ O m/sec m/sec 11.800 12.400 0.848 0.869 15.100 15.400 0.959 0.968 20.300 20.100 1.112 1.106 24.900 25.300 1.231 1.241 30.100 30.300 1.354 1.358 35.300 35.400 1.466 1.468 40.300 39.800 1.566 1.557 54.4800 44.800 1.651 1.651 55.100 55.300 1.831 1.835 60.300 60.000 1.916 1.911 65.000 1.989 1.989 1.989 70.200 70.100 2.067 2.066 79.800 80.300 2.204 2.211 90.200 90.800 2.464 2.465 114.800 114.700 2.644 2.642 <td< td=""><td>ΔP across orificeSuperfical Velocity$\Delta P across distributor$ForwardReverseForwardReverse$\Delta P across distributor$mmH $_2$ 0m/secm/secmmL $_2$ 011.80012.4000.8480.8697.30015.10015.4000.9590.9689.00020.30020.1001.1121.10611.60024.90025.3001.2311.24114.20030.10030.3001.3541.35816.70035.30035.4001.4661.46819.30040.30039.8001.5561.55721.80044.80044.8001.6511.65124.30050.10050.3001.7461.75026.80055.10055.3001.8311.83529.20060.30060.0001.9161.91131.80065.00065.0001.9891.98934.10070.20070.1002.0672.06636.60079.80080.3002.2042.21141.20090.20090.8002.4642.46551.000114.800114.7002.6442.64258.200130.100129.9002.8142.81265.600139.800-2.917-70.30099.70099.8002.8620.8517.30015.00014.8000.9560.9499.000130.100129.9002.8142.81265.600139.800-2.917</td></td<> <td>ΔP across orifice Superfical Velocity ΔP across distributor ΔP across distributor mmH₂O mmH₂O m/sec m/sec m/sec mmH₂O mmH₂O 11.800 12.400 0.848 0.869 7.300 31.300 24.900 25.300 1.112 1.106 11.600 44.900 33.300 33.300 1.354 1.358 16.700 48.600 35.300 35.400 1.466 1.468 19.300 53.000 44.800 44.800 1.651 24.300 58.700 56.100 44.800 1.651 1.451 24.300 58.700 56.100 44.800 1.651 1.750 26.800 61.300 55.100 50.100 50.300 1.746 1.750 26.800 65.000 66.700 65.000 65.000 1.989 1.989 34.100 66.400 50.000 79.800 80.300 2.204 2.211 41.200 76.900 90.200</td> <td>ΔP across orifice Superfical Velocity ΔP across distributor ΔP across distributor ΔP across distributor mmH₂O mmH₂O mMs mmH₂O mmH₂O mmH₂O mmH₂O 11.800 12.400 0.848 0.869 7.300 31.300 30.700 15.100 15.400 0.959 0.968 9.000 38.300 36.700 24.900 25.300 1.231 1.241 14.200 44.900 45.100 30.100 30.300 1.554 1.358 16.700 48.600 48.800 40.300 39.800 1.566 1.557 21.800 56.100 55.600 44.800 44.800 1.651 1.651 24.300 58.700 58.300 55.100 55.300 1.831 1.835 29.200 64.600 64.600 65.000 1.989 34.100 69.400 69.200 70.200 70.100 2.067 2.066 36.600 72.900 72.100 79.200 90.</td> <td>ΔP across orifice Superfical Velocity Forward ΔP across distributor ΔP across distributor ΔP across distributor with particle ΔP across distributor with particle ΔP across distributor with particle AP across distributor with particle Forward 11800 112400 0.848 0.869 7.300 31.300 30.700 24.000 20.300 20.100 1.121 1.106 11.600 44.900 45.100 30.300 20.300 23.300 1.334 1.358 16.700 48.600 48.800 31.900 33.300 35.400 1.666 1.458 19.300 55.100 55.800 33.300 34.400 50.100 55.300 1.831 1.835 23.200 64.600 64.600 34.900 66.300 60.300 1.989 1.989 34.100 66.700 36.300 72.0</td> <td>AP across office Superfical Velocity AP across distributor ΔA across distributor AD across distributor A</td> <td>AP across office Superficial Velocity Forward AP across distributor AP across distributor with particle Derossed T1 mmH_0 mmH_0 ms/sec ms/sec mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 stand stand</td> <td>ΔP across office Superfical Velocity Forward Pacross distributor ΔP across distributor ΔP across distributor MP across held SI forward Reverse Forward Reverse mmH 20 23.00 23.00 23.00 23.00 27.00 23.00 33.00 33.00 30.00 30.00 30.00 30.00 27.00 23.00 23.00 23.00 23.00 23.00 23.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 32.00 53.00 53.00 33.00 33.00 15.00 15.00 53.00 13.00 160.00 19.00 33.00 <t< td=""><td>ΔP across ortice Superical Velocity ΔP across distributor ΔP across distributor ΔP across distributor Derivat Reverse Forward Reverse Ti Ti< Ti< Ti< Ti< Ti< Ti< Ti< Ti<</td><td>Φ across office Superifical Velocity forward ΦP across distributor Part of the part of</td><td>Forward Reverse Forward Reverse Forward Reverse Forward Reverse To T2 T3 T4 Tage mmH₂O m</td></t<></td>	ΔP across orificeSuperfical Velocity $\Delta P across distributor$ ForwardReverseForwardReverse $\Delta P across distributor$ mmH $_2$ 0m/secm/secmmL $_2$ 011.80012.4000.8480.8697.30015.10015.4000.9590.9689.00020.30020.1001.1121.10611.60024.90025.3001.2311.24114.20030.10030.3001.3541.35816.70035.30035.4001.4661.46819.30040.30039.8001.5561.55721.80044.80044.8001.6511.65124.30050.10050.3001.7461.75026.80055.10055.3001.8311.83529.20060.30060.0001.9161.91131.80065.00065.0001.9891.98934.10070.20070.1002.0672.06636.60079.80080.3002.2042.21141.20090.20090.8002.4642.46551.000114.800114.7002.6442.64258.200130.100129.9002.8142.81265.600139.800-2.917-70.30099.70099.8002.8620.8517.30015.00014.8000.9560.9499.000130.100129.9002.8142.81265.600139.800-2.917	ΔP across orifice Superfical Velocity ΔP across distributor ΔP across distributor mmH ₂ O mmH ₂ O m/sec m/sec m/sec mmH ₂ O mmH ₂ O 11.800 12.400 0.848 0.869 7.300 31.300 24.900 25.300 1.112 1.106 11.600 44.900 33.300 33.300 1.354 1.358 16.700 48.600 35.300 35.400 1.466 1.468 19.300 53.000 44.800 44.800 1.651 24.300 58.700 56.100 44.800 1.651 1.451 24.300 58.700 56.100 44.800 1.651 1.750 26.800 61.300 55.100 50.100 50.300 1.746 1.750 26.800 65.000 66.700 65.000 65.000 1.989 1.989 34.100 66.400 50.000 79.800 80.300 2.204 2.211 41.200 76.900 90.200	ΔP across orifice Superfical Velocity ΔP across distributor ΔP across distributor ΔP across distributor mmH ₂ O mmH ₂ O mMs mmH ₂ O mmH ₂ O mmH ₂ O mmH ₂ O 11.800 12.400 0.848 0.869 7.300 31.300 30.700 15.100 15.400 0.959 0.968 9.000 38.300 36.700 24.900 25.300 1.231 1.241 14.200 44.900 45.100 30.100 30.300 1.554 1.358 16.700 48.600 48.800 40.300 39.800 1.566 1.557 21.800 56.100 55.600 44.800 44.800 1.651 1.651 24.300 58.700 58.300 55.100 55.300 1.831 1.835 29.200 64.600 64.600 65.000 1.989 34.100 69.400 69.200 70.200 70.100 2.067 2.066 36.600 72.900 72.100 79.200 90.	ΔP across orifice Superfical Velocity Forward ΔP across distributor ΔP across distributor ΔP across distributor with particle ΔP across distributor with particle ΔP across distributor with particle AP across distributor with particle Forward 11800 112400 0.848 0.869 7.300 31.300 30.700 24.000 20.300 20.100 1.121 1.106 11.600 44.900 45.100 30.300 20.300 23.300 1.334 1.358 16.700 48.600 48.800 31.900 33.300 35.400 1.666 1.458 19.300 55.100 55.800 33.300 34.400 50.100 55.300 1.831 1.835 23.200 64.600 64.600 34.900 66.300 60.300 1.989 1.989 34.100 66.700 36.300 72.0	AP across office Superfical Velocity AP across distributor ΔA across distributor AD across distributor A	AP across office Superficial Velocity Forward AP across distributor AP across distributor with particle Derossed T1 mmH_0 mmH_0 ms/sec ms/sec mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 mmH_0 stand stand	ΔP across office Superfical Velocity Forward Pacross distributor ΔP across distributor ΔP across distributor MP across held SI forward Reverse Forward Reverse mmH 20 23.00 23.00 23.00 23.00 27.00 23.00 33.00 33.00 30.00 30.00 30.00 30.00 27.00 23.00 23.00 23.00 23.00 23.00 23.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 33.00 32.00 53.00 53.00 33.00 33.00 15.00 15.00 53.00 13.00 160.00 19.00 33.00 <t< td=""><td>ΔP across ortice Superical Velocity ΔP across distributor ΔP across distributor ΔP across distributor Derivat Reverse Forward Reverse Ti Ti< Ti< Ti< Ti< Ti< Ti< Ti< Ti<</td><td>Φ across office Superifical Velocity forward ΦP across distributor Part of the part of</td><td>Forward Reverse Forward Reverse Forward Reverse Forward Reverse To T2 T3 T4 Tage mmH₂O m</td></t<>	ΔP across ortice Superical Velocity ΔP across distributor ΔP across distributor ΔP across distributor Derivat Reverse Forward Reverse Ti Ti< Ti< Ti< Ti< Ti< Ti< Ti< Ti<	Φ across office Superifical Velocity forward ΦP across distributor Part of the part of	Forward Reverse Forward Reverse Forward Reverse Forward Reverse To T2 T3 T4 Tage mmH ₂ O m

Shape: Cylindrical Size: L/D=1.28 Mass: 1500g Inclination: 10deg Overlap: 18deg

	indrical Size: L/D	-											_		
	ΔP across orifice		Superfical Velocity		ΔP across distributor	ΔP across distributor with particle		ΔP acro	Slugging Time						
Data No.	Forward	Reverse	Forward	Reverse		Forward	Reverse	Forward	Reverse	T1	T2	T3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH ₂ O	mmH₂O	mmH ₂ O	s	s	s	s	s	
1	12.300	12.500	0.865	0.872	7.100	16.400	11.000	9.300	3.900						Fluidizatior
2	14.900	15.000	0.952	0.956	8.300	19.100	13.000	10.800	4.700						Fluidizatio
3	18.100	18.600	1.050	1.064	9.900	21.200	15.700	11.300	5.800						Fluidizatio
4	20.900	20.400	1.128	1.114	10.800	23.000	17.000	12.200	6.200						Channelin
5	24.800	24.800	1.229	1.229	12.900	25.000	20.300	12.100	7.400						Channelin
6	29.000	29.400	1.329	1.338	15.100	25.900	23.600	10.800	8.500						Channelin
7	33.800	33.900	1.434	1.437	16.700	27.300	27.000	10.600	10.300						Bubbling
8	38.300	38.700	1.527	1.535	19.000	29.100	29.100	10.100	10.100	7.400	7.860	7.410	7.900	7.643	Slugging
9	42.100	41.600	1.601	1.591	20.700	30.900	30.500	10.200	9.800	8.950	8.830	9.180	8.480	8.860	Slugging
10	45.900	45.900	1.672	1.672	22.300	32.600	32.600	10.300	10.300	7.480	7.480	7.830	7.860	7.663	Slugging
11	49.700	50.300	1.739	1.750	24.000	34.500	34.800	10.500	10.800	7.280	6.900	6.920	7.370	7.118	Slugging
12	55.100	55.600	1.831	1.840	26.500	37.200	37.500	10.700	11.000	6.340	6.400	6.390	6.140	6.318	Slugging
13	59.400	60.400	1.902	1.917	28.200	39.400	39.900	11.200	11.700	6.090	5.780	5.760	5.920	5.888	Slugging
14	65.000	65.400	1.989	1.995	30.600	42.100	42.500	11.500	11.900	5.980	5.910	6.080	5.920	5.973	Slugging
15	70.000	69.600	2.064	2.058	32.600	44.700	44.400	12.100	11.800	5.220	5.350	5.710	5.550	5.458	Slugging
16	75.100	75.300	2.138	2.141	34.700	47.100	47.100	12.400	12.400						Swirling
17	85.000	85.600	2.275	2.283	39.200	51.800	52.000	12.600	12.800						Swirling
18	95.000	95.000	2.405	2.405	43.500	56.300	56.000	12.800	12.500						Swirling
19	105.100	105.100	2.529	2.529	47.900	60.900	60.600	13.000	12.700						Swirling
20	115.400	115.800	2.650	2.655	52.200	65.900	66.800	13.700	14.600						Swirling
21	125.100	125.400	2.760	2.763	56.300	70.000	71.400	13.700	15.100						Swirling
22	134.900	135.300	2.866	2.870	60.500	74.700	75.500	14.200	15.000						Swirling
23	145.000	-	2.800	-	64.900	80.200	80.200	15.300	-						Jumping
nape: Cyl	indrical Size: L/D	=4.10 Mass: 1000g	Inclination:	10deg Overla	p: 18deg										
ape: Cyl		=4.10 Mass: 1000g		-		ΔP across distribu	tor with particle	ΔP acro	oss bed		Sli	ugging Ti	me		
		s orifice		10deg Overla al Velocity Reverse	p: 18deg ΔP across distributor	ΔP across distribu Forward	· ·	ΔP acro Forward		T1				Tavg	Observatio
	ΔP acros Forward	ss orifice Reverse	Superfica Forward	al Velocity Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse		T2	T3	T4	Tavg s	Observatio
ata No.	ΔP acros Forward mmH ₂ O	s orifice Reverse mmH ₂ O	Superfica Forward <i>m/sec</i>	al Velocity Reverse <i>m/sec</i>	ΔP across distributor mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	T1 5				Tavg s	
ata No.	ΔP acros Forward mmH ₂ O 20.000	ss orifice Reverse <i>mmH</i> ₂ O 20.800	Superfica Forward <i>m/sec</i> 1.103	Al Velocity Reverse <i>m/sec</i> 1.125	ΔP across distributor mmH ₂ O 10.800	Forward mmH ₂ O 25.100	Reverse mmH ₂ O 23.900	Forward <i>mmH</i> ₂ <i>O</i> 14.300	Reverse mmH ₂ O 13.100		T2	T3	T4	-	Fluidizatio
ata No.	ΔP acros Forward <i>mmH</i> ₂ O 20.000 24.600	ss orifice Reverse mmH ₂ O 20.800 24.600	Superfica Forward m/sec 1.103 1.224	Al Velocity Reverse <i>m/sec</i> 1.125 1.224	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 10.800 12.900	Forward mmH ₂ O 25.100 29.700	Reverse mmH₂O 23.900 27.200	Forward mmH ₂ O 14.300 16.800	Reverse mmH ₂ O 13.100 14.300		T2	T3	T4	-	Fluidizatio Channelir
ata No.	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500	Superfica Forward m/sec 1.103 1.224 1.338	Al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 10.800 12.900 15.100	Forward mmH ₂ O 25.100 29.700 34.500	Reverse mmH ₂ O 23.900 27.200 31.400	Forward mmH ₂ O 14.300 16.800 19.400	Reverse mmH ₂ O 13.100 14.300 16.300		T2	T3	T4	-	Fluidizatio Channelin Channelin
1 2 3 4	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400	Superfica Forward m/sec 1.103 1.224 1.338 1.424	A Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 10.800 12.900 15.100 16.700	Forward mmH ₂ O 25.100 29.700 34.500 37.700	Reverse mmH ₂ O 23.900 27.200 31.400 34.700	Forward mmH ₂ O 14.300 16.800 19.400 21.000	Reverse mmH ₂ O 13.100 14.300 16.300 18.000		T2	T3	T4	-	Fluidizatio Channelin Channelin Channelin
ata No. 1 2 3 4 5	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400	Superfica Forward m/sec 1.103 1.224 1.338 1.424 1.537	Al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 19.000	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800	Forward mmH ₂ O 14.300 16.800 19.400 21.000 22.300	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800		T2	T3	T4	-	Fluidizatio Channelir Channelir Channelir Bubbling
ata No. 1 2 3 4 5 6	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800	Superfice Forward 1.103 1.224 1.338 1.424 1.537 1.608	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 19.000 20.700	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400	Forward mmH ₂ O 14.300 16.800 19.400 21.000 22.300 21.900	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700	S	T2 s	T3 s	T4 5	S	Fluidizatio Channelir Channelir Channelir Bubbling Bubbling
1 2 3 4 5 6 7	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 19.000 20.700 22.300	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100	Forward mmH ₂ O 14.300 16.800 19.400 21.000 22.300 21.900 21.400	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800	5	T2 s 1.210	T3 <i>s</i> 1.280	T4 s 1.350	s	Fluidizatio Channelir Channelir Channelir Bubbling Bubbling Slugging
ata No. 1 2 3 4 5 6 7 8	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500	Superfice Forward m/sec 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800	Forward mmH ₂ O 14.300 16.800 19.400 21.000 22.300 21.900 21.400 20.600	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800	s 1.230 1.980	T2 s 1.210 1.660	T3 s 1.280 1.670	T4 s 1.350 1.960	s 1.268 1.818	Fluidizatic Channelir Channelir Channelir Bubbling Bubbling Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 41.800 46.500 49.500 55.100	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.608 1.608 1.736 1.831	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.525 1.682 1.736 1.831	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000 26.500	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300	s 1.230 1.980 2.040	T2 s 	T3 s 1.280 1.670 2.200	T4 <i>s</i> 1.350 1.960 2.230	s 1.268 1.818 2.140	Fluidizatio Channelin Channelin Channelin Bubbling Bubbling Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.908	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914	ΔP across distributor mmH 20 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 22.400	s 1.230 1.980 2.040 2.350	T2 \$ 1.210 1.660 2.090 2.280	T3 S 1.280 1.670 2.200 2.270	T4 s 1.350 1.960 2.230 2.420	s 1.268 1.818 2.140 2.330	Fluidizatio Channelin Channelin Channelin Bubbling Bubbling Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.681 1.736 1.831 1.908 1.992	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998	ΔP across distributor mmH 2 0 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 44.600 47.900 50.700 53.500	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 22.400 23.000	s 1.230 1.980 2.040 2.350 2.550	T2 \$ 1.210 1.660 2.090 2.280 2.890	T3 S 1.280 1.670 2.200 2.270 2.480	T4 5 1.350 1.960 2.230 2.420 2.690	s 1.268 1.818 2.140 2.330 2.653	Fluidizatio Channelir Channelir Bubbling Bubbling Slugging Slugging Slugging Slugging
1 2 3 4 5 6 7 8 9 10 11 12	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.908 1.992 2.067	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998 2.066	ΔP across distributor mmH 2 0 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600 32.600	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 22.400 23.000	s 1.230 1.980 2.040 2.350 2.550 2.540	T2 <i>s</i> 	T3 5 1.280 1.670 2.200 2.270 2.480 4.610	T4 s 	5 1.268 1.818 2.140 2.330 2.653 3.005	Fluidizatio Channelin Channelin Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 55.100 55.800 65.200 70.200 74.800	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.681 1.736 1.998 1.992 2.067 2.134	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998 2.066 2.140	ΔP across distributor mmH 2 0 10.800 12.900 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400 23.500	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 22.400 23.000 23.600	s 1.230 1.230 2.040 2.350 2.550 2.540 2.640	T2 <i>s</i> 	T3 5 	T4 s 	5 1.268 1.818 2.140 2.330 2.653 3.005 2.633	Fluidizatic Channelin Channelin Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200 84.400	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.736 1.831 1.908 1.992 2.067 2.134 2.268	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400 23.500 24.000	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 22.400 23.000 23.600 23.800	s 1.230 1.980 2.350 2.550 2.550 2.540 2.640 2.950	T2 5 1.210 1.660 2.090 2.280 2.460 2.730 2.730	T3 <i>s</i> 1.280 1.670 2.200 2.480 4.610 2.600 2.830	T4 s 1.350 1.960 2.420 2.690 2.410 2.560 2.920	s 1.268 1.818 2.140 2.330 2.653 3.005 2.633 2.873	Fluidizatic Channelin Channelin Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500 95.200	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200 84.400 94.800	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.908 1.992 2.067 2.134 2.268 2.407	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267 2.402	ΔP across distributor mmH 2 0 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200 68.100	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000 68.000	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400 23.500 24.000	Reverse mmH20 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 23.000 23.200 23.800 24.500	s 1.230 1.230 2.040 2.350 2.550 2.550 2.540	T2 <i>s</i> 	T3 5 	T4 s 	5 1.268 1.818 2.140 2.330 2.653 3.005 2.633	Fluidizati Channelin Channelin Bubblin Bubblin Bubblin Sluggin Sluggin Sluggin Sluggin Sluggin Sluggin Sluggin Sluggin
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500 95.200 105.100	s orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200 84.400 94.800 105.700	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.681 1.736 1.831 1.908 1.908 1.908 2.9067 2.134 2.268 2.407 2.529	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267 2.402 2.537	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200 68.100 73.100	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000 63.000 73.700	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400 23.500 24.000 24.600 25.200	Reverse mmH20 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 23.000 23.600 23.800 24.500 25.800	s 1.230 1.980 2.350 2.550 2.550 2.540 2.640 2.950	T2 5 1.210 1.660 2.090 2.280 2.460 2.730 2.730	T3 <i>s</i> 1.280 1.670 2.200 2.480 4.610 2.600 2.830	T4 s 1.350 1.960 2.420 2.690 2.410 2.560 2.920	s 1.268 1.818 2.140 2.330 2.653 3.005 2.633 2.873	Fluidizati Channelin Channelin Bubblin Bubblin Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500 95.200 105.100 115.500	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200 84.400 94.800 105.700 115.100	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.908 1.992 2.067 2.134 2.468 2.407 2.529 2.652	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267 2.647	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200 68.100 73.100	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000 63.000 73.700 77.800	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 23.400 23.400 23.500 24.000 24.600 25.200	Reverse mmH20 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 23.000 23.600 23.800 24.500 25.800 25.600	s 1.230 1.980 2.350 2.550 2.550 2.540 2.640 2.950	T2 5 1.210 1.660 2.090 2.280 2.460 2.730 2.730	T3 <i>s</i> 1.280 1.670 2.200 2.480 4.610 2.600 2.830	T4 s 1.350 1.960 2.420 2.690 2.410 2.560 2.920	s 1.268 1.818 2.140 2.330 2.653 3.005 2.633 2.873	Fluidizatic Channelin Channelin Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500 95.200 105.100 115.500 125.000	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 46.500 40.500 40.500 60.200 65.600 70.100 75.200 84.400 94.800 94.800 105.700 115.100 125.100	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.736 1.681 1.736 1.831 1.908 1.992 2.067 2.134 2.268 2.067 2.529 2.652 2.758	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.595 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267 2.402 2.537 2.647 2.760	ΔP across distributor mmH 2 0 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 43.500 47.900 52.200 56.300	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200 68.100 73.100 77.600 82.200	Reverse mmH₂O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000 63.000 73.700 77.800 82.300	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 22.900 23.400 23.500 24.000 24.600 25.200 25.400	Reverse mmH ₂ O 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 23.000 23.600 23.800 24.500 25.800 25.600	s 1.230 1.980 2.350 2.550 2.550 2.540 2.640 2.950	T2 5 1.210 1.660 2.090 2.280 2.460 2.730 2.730	T3 <i>s</i> 1.280 1.670 2.200 2.480 4.610 2.600 2.830	T4 s 1.350 1.960 2.420 2.690 2.410 2.560 2.920	s 1.268 1.818 2.140 2.330 2.653 3.005 2.633 2.873	Fluidizatic Channelir Channelir Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging Slugging
ata No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	ΔP acros Forward mmH ₂ O 20.000 24.600 29.400 33.300 38.800 42.500 46.400 49.500 55.100 59.800 65.200 70.200 74.800 84.500 95.200 105.100 115.500	ss orifice Reverse mmH ₂ O 20.800 24.600 29.500 33.400 38.400 41.800 46.500 49.500 55.100 60.200 65.600 70.100 75.200 84.400 94.800 105.700 115.100	Superfice Forward <i>m/sec</i> 1.103 1.224 1.338 1.424 1.537 1.608 1.681 1.736 1.831 1.908 1.992 2.067 2.134 2.468 2.407 2.529 2.652	al Velocity Reverse <i>m/sec</i> 1.125 1.224 1.340 1.426 1.529 1.682 1.736 1.831 1.914 1.998 2.066 2.140 2.267 2.647	ΔP across distributor mmH ₂ O 10.800 12.900 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200	Forward mmH ₂ O 25.100 29.700 34.500 37.700 41.300 42.600 43.700 44.600 47.900 50.700 53.500 56.000 58.200 63.200 68.100 73.100	Reverse mmH ₂ O 23.900 27.200 31.400 34.700 38.800 41.400 44.100 44.800 47.800 50.600 53.600 55.800 58.300 63.000 63.000 73.700 77.800	Forward mmH ₂ O 14.300 16.800 21.000 22.300 21.900 21.400 20.600 21.400 22.500 23.400 23.400 23.500 24.000 24.600 25.200	Reverse mmH20 13.100 14.300 16.300 18.000 19.800 20.700 21.800 20.800 21.300 23.000 23.600 23.800 24.500 25.800 25.600	s 1.230 1.980 2.350 2.550 2.550 2.540 2.640 2.950	T2 5 1.210 1.660 2.090 2.280 2.460 2.730 2.730	T3 <i>s</i> 1.280 1.670 2.200 2.480 4.610 2.600 2.830	T4 s 1.350 1.960 2.420 2.690 2.410 2.560 2.920	s 1.268 1.818 2.140 2.330 2.653 3.005 2.633 2.873	Observation Fluidizatic Channelin Channelin Bubbling Bubbling Slugging Slug

Shape: Cylindrical Size: L/D=4.10 Mass: 500g Inclination: 10deg Overlap: 18deg

Shape: Cyl	indrical Size: L/D	=4.10 Mass: 1500g	Inclination:	10deg Overla	p:18deg										
	ΔP across orifice				A D a supra a distability tau	ΔP across distributor with particle		ΔP acr	Slugging Time						
Data No.	Forward	Reverse	Forward	Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	mmH₂O	mmH₂O	m/sec	m/sec	mmH₂O	mmH₂O	mmH₂O	mmH₂O	mmH₂O	s	s	s	s	s	
1	25.200	25.100	1.239	1.236	12.900	41.000	33.900	28.100	21.000						Fluidization
2	29.000	28.300	1.329	1.313	15.100	46.000	37.200	30.900	22.100						Channeling
3	33.000	33.200	1.417	1.422	16.700	49.400	42.200	32.700	25.500						Channeling
4	38.000	38.400	1.521	1.529	19.000	50.100	47.600	31.100	28.600						Channeling
5	42.500	42.800	1.608	1.614	20.700	52.600	51.600	31.900	30.900						Channeling
6	46.200	46.100	1.677	1.675	22.300	55.100	54.100	32.800	31.800						Bubbling
7	50.000	49.300	1.745	1.732	24.000	57.200	56.000	33.200	32.000						Bubbling
8	55.700	55.800	1.841	1.843	26.500	59.900	59.800	33.400	33.300						Bubbling
9	59.800	59.800	1.908	1.908	28.200	60.600	61.700	32.400	33.500	1.200	1.170	1.230	0.990	1.148	Slugging
10	64.500	65.000	1.981	1.989	30.600	63.000	63.200	32.400	32.600	1.490	1.480	1.350	1.580	1.475	Slugging
11	69.800	69.900	2.061	2.063	32.600	65.600	65.600	33.000	33.000	1.600	1.660	1.650	1.510	1.605	Slugging
12	75.300	75.200	2.141	2.140	34.700	68.600	68.200	33.900	33.500	1.730	1.780	1.710	1.830	1.763	Slugging
13	85.200	85.800	2.277	2.285	39.200	73.800	74.000	34.600	34.800	1.790	1.840	1.730	1.730	1.773	Slugging
14	95.300	94.900	2.409	2.404	43.500	78.800	78.400	35.300	34.900	2.010	2.050	1.860	1.790	1.928	Slugging
15	105.200	105.500	2.531	2.534	47.900	83.800	83.800	35.900	35.900	2.300	1.990	2.030	2.100	2.105	Slugging
16	114.900	115.200	2.645	2.648	52.200	88.300	88.900	36.100	36.700	2.280	2.200	2.230	2.280	2.248	Slugging
17	124.700	124.500	2.755	2.753	56.300	93.000	92.800	36.700	36.500	2.270	2.510	2.310	2.400	2.373	Slugging
18	135.300	135.300	2.870	2.870	60.500	97.200	97.400	36.700	36.900						Swirling
19	144.900	145.300	2.970	2.974	64.900	101.700	102.300	36.800	37.400						Swirling
20	165.300	-	3.172	-	73.100	111.700	-	38.600	-						Swirling
Shape: Cyl	indrical Size: L/D		1		p: 18deg										
	ΔP acros	s orifice	Superfica	al Velocity	p: 18deg ΔP across distributor	ΔP across distribu	•		oss bed			ugging Ti			
Shape: Cyl Data No.	ΔP acros Forward	ss orifice Reverse	Superfica Forward	al Velocity Reverse	ΔP across distributor	Forward	Reverse	Forward	Reverse	T1	T2	Т3	T4	Tavg	Observation
	ΔP acros	s orifice Reverse mmH 20	Superfica	al Velocity	ΔP across distributor mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	Forward mmH ₂ O	Reverse mmH ₂ O	T1 5				Tavg s	Observation
Data No.	ΔP acros Forward	ss orifice Reverse <i>mmH</i> ₂ O 29.400	Superfica Forward	Al Velocity Reverse <i>m/sec</i> 1.338	De across distributor mmH ₂ O 15.100	Forward mmH ₂ O 54.400	Reverse mmH ₂ O 45.200	Forward	Reverse mmH ₂ O 30.100		T2	Т3	T4	-	Observation Fluidization
Data No.	ΔP acros Forward mmH 2 0 30.000 32.900	ss orifice Reverse mmH ₂ O 29.400 32.900	Superfica Forward <i>m/sec</i> 1.351 1.415	Al Velocity Reverse m/sec 1.338 1.415	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 15.100 16.700	Forward mmH ₂ O 54.400 57.800	Reverse mmH ₂ O 45.200 48.900	Forward mmH ₂ O 39.300 41.100	Reverse mmH ₂ O 30.100 32.200		T2	Т3	T4	-	Fluidization Channeling
Data No.	ΔP acros Forward mmH 2 0 30.000 32.900 38.300	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300	Superfica Forward m/sec 1.351 1.415 1.527	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 15.100 16.700 19.000	Forward mmH ₂ O 54.400 57.800 59.300	Reverse mmH 20 45.200 48.900 55.600	Forward mmH ₂ O 39.300 41.100 40.300	Reverse mmH ₂ O 30.100 32.200 36.600		T2	Т3	T4	-	Fluidization
Data No. 1 2 3 4	ΔP acros Forward mmH 2 0 30.000 32.900 38.300 42.400	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500	Superfica Forward m/sec 1.351 1.415 1.527 1.607	Al Velocity Reverse m/sec 1.338 1.415 1.527 1.608	ΔP across distributor <i>mmH</i> ₂ <i>O</i> 15.100 16.700 19.000 20.700	Forward mmH ₂ O 54.400 57.800 59.300 63.000	Reverse mmH ₂ O 45.200 48.900 55.600 60.300	Forward mmH ₂ O 39.300 41.100 40.300 42.300	Reverse mmH₂O 30.100 32.200 36.600 39.600		T2	Т3	T4	-	Fluidization Channeling Channeling Channeling
Data No. 1 2 3 4 5	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500	Superfica Forward m/sec 1.351 1.415 1.527 1.607 1.673	Al Velocity Reverse m/sec 1.338 1.415 1.527 1.608 1.664	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200		T2	Т3	T4	-	Fluidization Channeling Channeling Channeling Channeling
Data No. 1 2 3 4 5 6	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900	Superfica Forward m/sec 1.351 1.415 1.527 1.607 1.673 1.738	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100		T2	Т3	T4		Fluidization Channeling Channeling Channeling Channeling Bubbling
Data No. 1 2 3 4 5	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500	Superfica Forward m/sec 1.351 1.415 1.527 1.607 1.673	Al Velocity Reverse m/sec 1.338 1.415 1.527 1.608 1.664	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000		T2	Т3	T4		Fluidization Channeling Channeling Channeling Channeling
Data No.	ΔP acros Forward mmH₂O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200	Superfice Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.500		T2	Т3	T4		Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6 7 8 9	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.673 1.738 1.830 1.902 1.986	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300	Reverse mmH20 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600		T2	Т3	T4		Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling
Data No.	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.738 1.902 1.986 2.057	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.743 1.914 1.997 2.057	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600 32.600	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400	Reverse mmH 20 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.400 43.800	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.500 43.600		T2 5	T3 5	T4 S		Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6 7 7 8 9 10 11	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 60.200 65.500 69.500 74.600	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.830 1.902 1.986 2.057 2.130	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131	ΔP across distributor mmH ₂ O 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.500 43.000 43.400 43.300 43.800 44.200	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 44.700	S	T2 5	T3 s	T4 S		Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling
Data No. 1 2 3 4 5 6 7 8 9 10 11 12	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500 74.600 85.300	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279	ΔP across distributor mmH ₂ O 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300 43.800 44.200	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 44.700 45.300	s 	T2 5	T3 <i>s</i> nor Slugg 1.370	T4 s	s 	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling
Data No.	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500 74.600 85.300 94.800	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402	ΔP across distributor mmH 2 0 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300 43.800 44.200 45.000	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 44.700 45.300 45.800	s 	T2 5 	T3 <i>s</i>	T4 s	s 	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging
Data No.	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500 74.600 85.300 94.800 105.400	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406 2.531	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533	ΔP across distributor mmH 2 0 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 32.600 34.700 39.200 43.500 47.900	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300 43.800 43.800 44.200 45.000 45.700 46.200	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 45.300 45.800 46.400	s 	T2 s Min 1.330 1.550 1.660	T3 <i>s</i> nor Slugg 1.370 1.740 1.710	T4 s	s 1.310 1.675 1.715	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging
Data No.	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200 114.700	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500 74.600 85.300 94.800 105.400 114.800	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406 2.531 2.642	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533 2.644	ΔP across distributor mmH 2 0 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100 98.300	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300 98.800	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.800 44.200 45.000 45.000 46.100	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 45.300 45.800 46.400 46.600	s 	T2 s Min 1.330 1.550 1.660 1.870	T3 s nor Slugg 1.370 1.740 1.710 1.760	T4 s	s 1.310 1.675 1.715 1.803	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200 114.700 125.400	s orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 49.900 55.300 60.200 65.500 69.500 74.600 85.300 94.800 105.400 114.800 124.900	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406 2.531 2.642 2.763	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533 2.644 2.757	ΔP across distributor mmH ₂ O 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200 56.300	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100 98.300 102.800	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300 98.800 103.100	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300 43.300 44.200 45.000 45.700 46.200 46.500	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 45.300 45.800 46.400 46.800	s 	T2 s Mii 1.330 1.550 1.660 1.870 1.890	T3 s nor Slugg 1.370 1.740 1.710 1.760 1.840	T4 s ing 1.270 1.650 1.760 1.850 2.020	s 1.310 1.675 1.715 1.803 1.975	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200 114.700 125.400 135.600	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 69.900 65.300 60.200 65.500 69.500 74.600 85.300 94.800 105.400 114.800 124.900 135.000	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406 2.531 2.642 2.763 2.873	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533 2.644 2.757 2.867	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200 56.300 60.500	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100 98.300 102.800	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300 98.800 103.100	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.800 44.200 45.000 45.000 46.200 46.100 46.500 47.300	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 43.600 43.600 44.700 45.300 46.400 46.600 47.400	s 	T2 s Min 1.330 1.550 1.660 1.870 1.890 2.040	T3 s	T4 s ing 1.270 1.650 1.760 2.020 2.230	s 1.310 1.675 1.715 1.803 1.975 2.115	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	ΔP acros Forward mmH₂O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200 114.700 125.400 135.600 144.600	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 60.200 65.500 60.200 65.500 69.500 74.600 85.300 94.800 105.400 114.800 124.900 135.000 144.600	Superfice Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.738 1.902 1.986 2.057 2.130 2.271 2.406 2.531 2.531 2.531 2.763 2.873 2.967	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533 2.402 2.533 2.444 2.757 2.867 2.967	ΔP across distributor mmH ₂ O 15.100 16.700 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 43.500 47.900 52.200 56.300 60.500 64.900	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100 98.300 102.800 111.600	Reverse mmH 20 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300 98.800 103.100 107.900 111.600	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.300 43.800 44.200 45.000 45.700 46.200 46.500 47.300 46.700	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.500 43.600 43.600 43.600 43.600 43.600 44.700 45.300 46.400 46.600 46.700 47.400	s 	T2 s Mii 1.330 1.550 1.660 1.870 1.890	T3 s nor Slugg 1.370 1.740 1.710 1.760 1.840	T4 s ing 1.270 1.650 1.760 1.850 2.020	s 1.310 1.675 1.715 1.803 1.975	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging Slugging
Data No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	ΔP acros Forward mmH ₂ O 30.000 32.900 38.300 42.400 46.000 49.600 55.000 59.400 64.800 69.500 74.500 84.700 95.100 105.200 114.700 125.400 135.600	ss orifice Reverse mmH ₂ O 29.400 32.900 38.300 42.500 45.500 69.900 65.300 60.200 65.500 69.500 74.600 85.300 94.800 105.400 114.800 124.900 135.000	Superfic: Forward <i>m/sec</i> 1.351 1.415 1.527 1.607 1.673 1.738 1.830 1.902 1.986 2.057 2.130 2.271 2.406 2.531 2.642 2.763 2.873	al Velocity Reverse <i>m/sec</i> 1.338 1.415 1.527 1.608 1.664 1.743 1.835 1.914 1.997 2.057 2.131 2.279 2.402 2.533 2.644 2.757 2.867	ΔP across distributor mmH ₂ O 15.100 16.700 19.000 20.700 22.300 24.000 26.500 28.200 30.600 32.600 34.700 39.200 43.500 47.900 52.200 56.300 60.500	Forward mmH ₂ O 54.400 57.800 59.300 63.000 64.900 66.500 69.500 71.600 73.900 76.400 78.900 84.200 89.200 94.100 98.300 102.800	Reverse mmH ₂ O 45.200 48.900 55.600 60.300 63.500 66.100 69.500 71.700 74.200 76.200 79.400 84.500 89.300 94.300 98.800 103.100	Forward mmH ₂ O 39.300 41.100 40.300 42.300 42.600 42.500 43.000 43.400 43.800 44.200 45.000 45.000 46.200 46.100 46.500 47.300	Reverse mmH ₂ O 30.100 32.200 36.600 39.600 41.200 42.100 43.000 43.600 43.600 43.600 43.600 43.600 44.700 45.300 46.400 46.600 47.400	s 	T2 s Min 1.330 1.550 1.660 1.870 1.890 2.040	T3 s	T4 s ing 1.270 1.650 1.760 2.020 2.230	s 1.310 1.675 1.715 1.803 1.975 2.115	Fluidization Channeling Channeling Channeling Bubbling Bubbling Bubbling Bubbling Bubbling Bubbling Slugging Slugging Slugging Slugging Slugging

APPENDIX C: PROJECT RECOGNITIONS

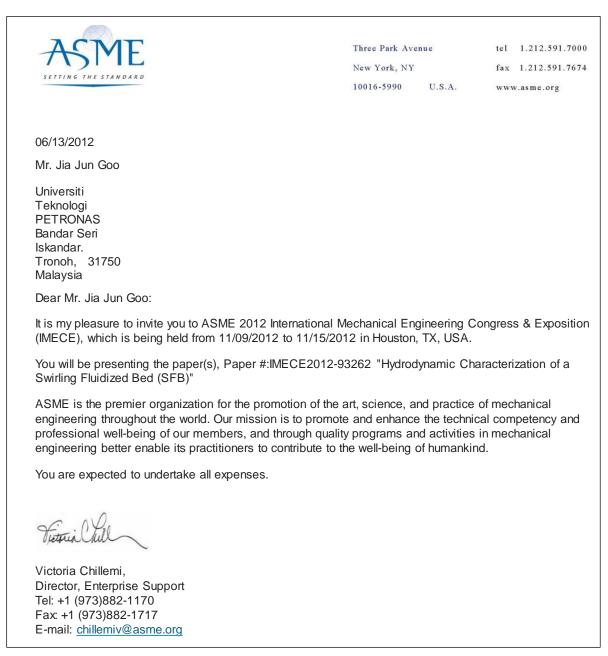
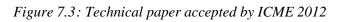


Figure 7.2: Technical paper accepted by ASME Congress 2012

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Ch Hussein Ot	FAKULTI KEJURUTERAAN MEKANIKAL DAN PEMBUATAN Tel: 07-4537701/7703/7707 Faks: 07-4536080
	Rujukan Kami (Our Ref) : UTHM/FKMP/100-36/5/1 Jld 2(215) Rujukan Tuan (Your Ref) : Tarikh : 9 July 2012
goojiajun@gmail.com, vijay@oyl.com.my, ch Dear Prof. /Dr. /Mr. /Mrs. /Miss/Ms. STATUS OF FULL TECHNICAL PAPER SU	IBMITTED FOR 3 rd INTERNATIONAL CONFERENCE ON
MECHANICAL AND MANUFACTURING EN	IGINEERING 2012 (ICME2012)
Paper no.: ICME2012-ID-143 EARLY BIRD REGISTRATION	
Thank you for your full technical paper subm	ission and interest.
The ICME2012 Technical Review Commit following recommendations:	tee has completed the review for your paper and suggested the
Status of technical paper	
Accepted with revision	\checkmark
Accepted	
Publication	
Will be published in the Applied Mechanics Materials Journal (ISSN 1660-9336)	and 🗸



Effect of F	Particle Shape on Bed Pressure Drop in a Swirling Fluidized Bed						
Venkiteswaran, V. K. and Goo, Jia Jun and Chin, Yee Sing and Sulaiman, S. A. and Raghavan, V. R. (2012) Effect of Particle Shape on Bed Pressure Drop in a Swirling Fluidized Bed. In: 3rd International Conference on Production, Energy and Reliability, 12-14 June 2012, Kuala Lumpur.							
PDF Restricted to Repository staff only 77Kb							
	Abstract						
In fluidized bed processes, bed pressure drop is crucial as it determines the pumping power required. However, the physical parameters that influence the bed pressure drop are yet to be fully established. The present work studies the effect of particle shape on bed pressure drop in a swirling fluidized bed. The three different shapes of particle used in the work are; cylindrical, spherical and ellipsoidal, with different bed weights (0.5 kg, 0.75 kg and 1.0 kg). Blades with overlap angle of 9° and blade inclination of 10° were used in this experiment. The results showed an increase in the bed pressure drop with an increase in bed weight for all three particles regardless of shape. Spherical shaped particles were seen to have the highest pressure drop compared to the others due to a smaller exposed surface area.							
Item Type:	Conference or Workshop Item (Paper)						
Subjects:	<u>T Technology > TJ Mechanical engineering and machinery</u>						
	Departments > Mechanical Engineering Mission Oriented Research > Energy						
ID Code:	7740						
Deposited By:	Dr Ir Shaharin A Sulaiman						
Deposited On:	22 Jun 2012 15:05						
Last Modified:	22 Jun 2012 15:05						
	Repository Staff Only: item control page						

Figure: Technical paper published in ICPER 2012 Retrieved August 02, 2012 from eprints.utp.edu.my.



Figure 7.5: Gold medal award in SEDEX 30th, 2012





Certificate for Oral Presentation

Paper Title: Experimental study on the Hydrodynamics of Swirling Pluidized Bed (70124)

This is to certify that <u>Jia Jun</u> <u>Goo</u> from <u>Unversitive Technologi</u> <u>PETEONAS</u>, <u>Malaysia</u> has attended, and delivered an oral presentation in the 2012 International Conference on Mechanical and Electrical Technology (ICMET 2012) held in Kuala Lumpur, Malaysia during July 24-26, 2012.



Figure 7.6: Technical paper published in ICMET 2012

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