Hydrodynamic Behavior of Geldart particles type B and D in semi circular fluidized bed

By

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CERTIFICATION OF APPROVAL

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Geldart particles type B and D range from 100 μm and more. Green bean, urea and rice will be experiment material because it has size over than 100 μm. Due to that, experimental work will focus on hydrodynamic behavior of Geldart particles where bubble diameter, bed expansion and minimum fluidizing air velocity will be study. Semi-circular fluidized bed will be the experiment equipment. Result from the experiment will be compared in graph with different colour line that indicate different dimaeter of material.

To capture hydrodynamic behavior of bubble, high speed camera, SONY XC 75CE CCD will be used and put in front of the fluidized bed. Image analysis software was used to analyse the image captured via the high speed camera. Pictures taken with the high speed camera will be set to 200 pps, exposure 4997.25 and resolution 1280 x 720.

ACKNOWLEDGEMENT

First and foremost, thank you to Allah S.W.T for the time and guidance that He gave to me to complete this final year project that consume one year to complete. Allah the most merciful and compassionate. All praise to the Almighty.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Geldart's particle was introduced by Professor D. Geldart that proposed powders were grouping according to the "Geldart Groups". The groups are defined based on diagram of solid-fluid density difference and particle size.

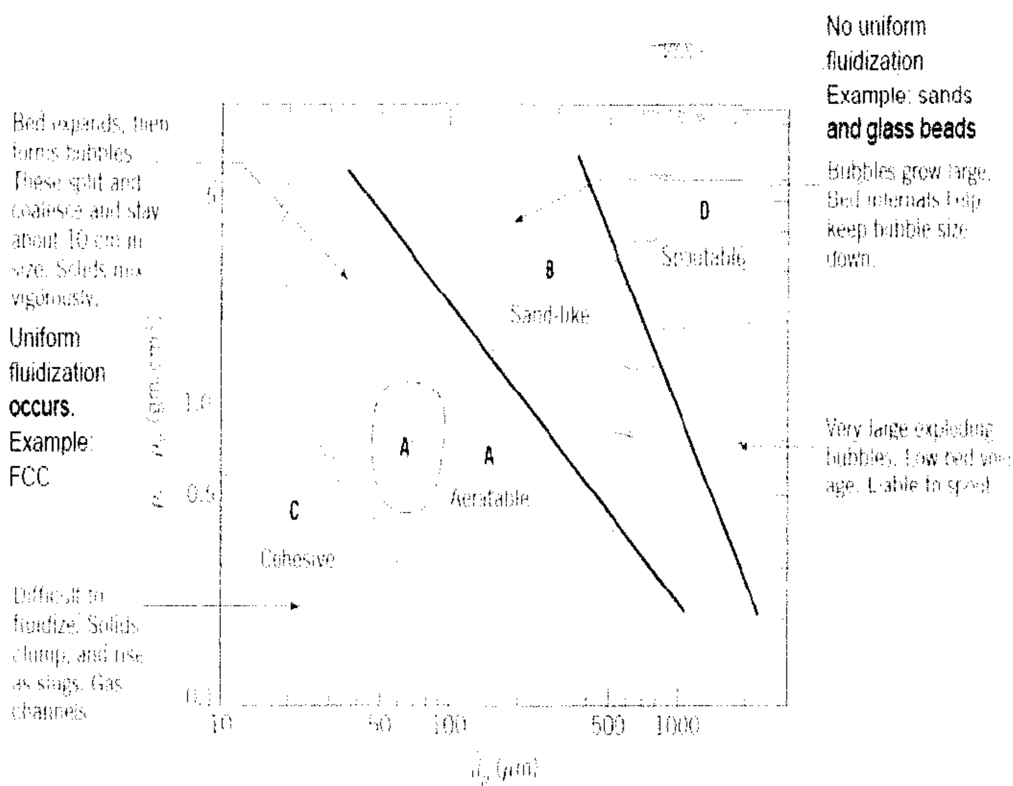

Figure 1.1: Classification of Geldart particles

From the picture above it is clearly shown there are four types of Geldart's group namely Geldart's C particle, Geldart's A particle, Geldart's B particle and Geldart's D particle which arranged according to their respective particle sizes.

Group C particles is cohesive. It's difficult to fluidized and channeling can occurs. Interparticle forces greatly affect the fluidization behavior of these powders. Mechanical powder compaction prior to fluidization greatly affected the fluidization behavior of the powder, even after the powder had been fully fluidized for a while. Saturating the fluidization air with humidity reduced the formation of agglomerates and greatly improved the fluidization quality. The water molecules adsorbed on the particle surface presumably reduced the van der Waals forces. Range of particle's diameter is from 0-30μm. Flour and cement are examples for this group.

Group A is aeratable and been characterized by a small d_p and small p_p. Large bed expansion occur before bubbling starts. Gross circulation of powder even if only a few bubbles are present. In the emulsion phase, large gas backmixing can happen. Rate at which gas is exchanged between the bubbles and the emulsion is high. Bubble size can be reduced by either using a wider particle size distribution or reducing the average particle diameter. The particle's diameter range for this group is between 30-100 μm. Example for group A is milk flour .

Group B is bubbling and solids recirculation rates are smaller. Less gas back mixing in the emulsion phase. Rate at which gas is exchanged between bubbles and emulsion is smaller. Bubble size is almost independent of the mean particle diameter and the width of the particle size distribution. For this group there is no observable maximum bubble size. Particle's diameter range is around 100-1000 μm and sand can be example for group B.

Group D is spoutabe. Bubbles coalesce rapidly and flow to large size. Bubbles rise more slowly than the rest of the gas percolating through the emulsion. The dense phase has a low voidage. Range of particle diameter for this particular group is over than 1000 μm. For group D coffee bean and wheat are the examples.

For this research, only particles that fall into Group B and D (coarse particles) will be study in the circular and semi-circular fluidized bed. The particles that will be taken into consideration to be use during the experiment are urea, rice and green bean. Urea, a white crystalline solid is one of the most important component in agricultural industry. With current technology, urea is manufactured as granules. It is added to the soil to release nutrients necessary for plant to growth. Use of conventional fertilizers may lead to concentration levels that are too high for effective action. According to Kiran J.K et al [1] mention that high concentration may produce undesirable side effects in the target area, which could lead to crop damage, or in the surrounding environment . To increase effectiveness of fertilizers and avoid environmental risk, Slow-release fertilizers (SFR) is used. According to Tzika.M et al [2] mention that Slow-release fertilizers (SFR) have been recently been developed aiming at retarding the release rate of the nutrients to the ground. For rice and green bean, it is very familiar to the cooking world where many dishes can be create using this two ingredients.

1.2 PROBLEM STATEMENT

Fluidized beds are very significant to the industrial world which include pharmaceutical industry, chemical and petrochemical industry, combustion or pyrolysis, for advance material such as silicon production and nano carbon tubes. There are plenty types of fluidized bed in the industry that being classified by their flow behavior. Among examples of fluidized bed are Wurster fluidized bed, Swirling fluidized bed and pressurized fluidized bed but for this research semi-circular fluidized reactor will be use.

This research was carried out to study the hydrodynamic behavior of Geldart particles group B and D in the semi-circular fluidized bed reactor. During fluidization, bubble formation inside the reactor will be observed. It is important to examine bubble formation in the fluidized bed to increase the efficiency of contact between gas and solids.

According Sobrino. C et al [6] due mention that it is important task to control the bubble size to avoid large and fast bubbles that by-pass the bed and increase the elutriation. Bubble characteristics such as bubble size, shape or ascending velocity are important parameters that had been extensively study in the past.

This project is very significant because result from this study can be use by industry to improve the efficiency of fluidized bed in their plant especially semi circular fluidized bed. Despite that, bubbles behavior in semi-circular type of fluidized bed that involve Geldart particles group B and D can be known.In a nutshell, via this study can identify hydrodynamic behavior of Geldart particles group B and D

1.3 OBJECTIVES AND SCOPE OF STUDY

The research will study about the hydrodynamic behavior of the Geldart's particle group B and D where objectives of the project are stated below:

1. To obtain minimum fluidizing air velocity in semi circular fluidized bed

2. To determine effect of pressure to the bed expansion of semi circular fluidized bed

3. To study effect of different particles (Geldart's B and D) to the bubble diameter in the semi circular fluidized bed.

CHAPTER 2

LITERATURE REVIEW

2.1 FLUIDIZED BED

Fluidized bed is commonly use in chemical industry for a various process such as coating, drying, granulation, combustion oxidation and chlorination. Flow behaviors in the fluidized bed solely depend on result of fluid-particle and particle-particle interaction. Hilal. N (2004) said that characteristic of fluidized bed depend upon the behavior of gas bubbles that generated near the distributor and rise through the growing in size and becoming fewer by coalescence.

According to Li.H et al (2003) mention that the fluidization can be divided into two classes which are aggregative fluidization and particulate fluidization. Aggregative fluidization appears in gas-solids system where the particle distribution in the gas is not uniform. Gas bubbles and solids agglomerate did exist. Heat and mass transfer rate are low due to contact between gas and solids is not good.

Meanwhile particulate fluidization appears in liquid-solids systems where this type of fluidization has more uniform particles distribution in the liquid and bubbles and agglomerates do not form. Liquid and solids contact are very good and thus result in high heat and mass transfer rate.According to Singh R.K et al (2005) mention that particulate fluidization exists between minimum fluidization velocity and minimum bubbling velocity. Minimum bubbling velocity is the superficial gas velocity at which first bubble first appear.

Sobrino C.et al(2007) had conducted an experiment which involve fluidization of Group B particles with a rotating distributor. Fluidization sometimes difficult to achieve due to the agglomeration or cohesion between particles. Despite that, defluidization or non-uniform fluidization may occur sometimes.

Despite the agglomeration problems, some researchers due suggest few solutions. Sobrino.C et al(2007) suggested vibrated bed where better mixing between gas and particles can be achieved. Li.H et al(2003) mention two groups of method (1) particle and fluid design and (2) external force field, internals and configuration design. This two method can increase the reaction efficiency of gas-solids fluidization.

2.2 MINIMUM AIR-FLUIDIZATION VELOCITY

Minimum fluidization velocity U_{mf} is the velocity at which fluidization start to begin. According to Lim K.S et al(1995), minimum fluidization velocity is based on the balance of pressure drops required to support the weight minus buoyancy acting on the particles at the point of minimum fluidization. Based on the Ergun's equation, minimum fluidization velocity U_{mf} is calculated using the equation below:

$$Re_{mf} = \sqrt{C_1^2 + C_2 Ar} - C_1$$

$$Re_{mf} = (\rho_G \, d_p \, U_{mf}) / \mu_G$$

$$Ar = (\rho_G \, \Delta p \, g \, d_p^3) / \mu_G^2$$

Where $\Delta p = (\rho_p - \rho_G)$ is the pressure drop, ρ_p is the particle density, ρ_G is the gas density, d_p is the particle diameter , μ_G is the gas viscosity, U_{mf} is the minimum fluidization velocity, Re_{mf} is the Reynolds number Ar is the Archimedes number and C_1, C_2 is the particle shape dependant and species dependant.

Besides the equation mentioned earlier, minimum fluidization velocity U_{mf}, also can be found using Ergun's equation directly by substituting superficial fluid velocity with U_{mf} and the pressure drop across the bed is equal to the effective weight per unit area of the particles at the point of incipient fluidization as per below:

$$\frac{\Delta P}{L} = 150\frac{(1-\varepsilon_{mf})^2}{{\varepsilon_{mf}}^3}\frac{\mu U_{mf}}{(\emptyset_s d_p)^2} + 1.75\frac{(1-\varepsilon_{mf})}{\varepsilon_{mf}^3}\frac{\rho_g U_{mf}^2}{\emptyset_s d_p}$$

Where ΔP is equal to the bed weight per unit cross-sectional area, and the particle sphericity, $\emptyset_s$ is defined as the surface area of a volume equivalent sphere divided by the particle's surface area. When applying the Ergun equation, one has to know the minimum fluidization voidage, ε_{mf} although it is frequently an unknown.

Other than Ergun's equation, one of the more widely used correlations to predict U_{mf} is the Wen and Yu Correlation (1966). The simplified form of the Wen and Yu correlation is :

$$Ar = 1650Re_{p,mf} + 24.5(Re_{p,mf})^2$$

Above equation can be rearranged to form equation below. This form expresses U_{mf} in terms of known system parameters.

$$\boxed{U_{mf} = \frac{\mu}{\rho_g d_p}\left[\frac{(33.7)^{0.5} + 0.0408 d_p^3\,\rho_g(\rho_p - \rho_g)g}{\mu^2}\right]^{0.5}}$$

Where Ar is Archimedes number, Re is Reynold's number, μ is air viscosity, ρ_g is gas density, d_p is particle diameter, g is gravity 9.81 m/s and ρ_p is particle density.

The effect of temperature and pressure on U_{mf} is strongly influenced by particle size. For small particles $(Re_{p,mf} < 20)$, the simplified Wen and Yu Equation reduces to:

$$U_{mf} = \frac{d_p^2(\rho_p - \rho_g)g}{1650\mu}$$

For large particles $((Re_{p,mf} > 1000)$,

$$U_{mf} = \frac{d_p(\rho_p - \rho_p)g}{24.5\rho_g}$$

Rang R. Pattipati and C.Y. Wen (1981) said that the minimum fluidization velocity decreases with increasing temperature for small particles. They also mention that for small particles and at high temperature, the viscous forces are dominant. However, for larger particles, kinetic forces are dominant compared to viscous force.

According to Vojtěch V. et al (1966), a fixed bed is a layer of particles which rest on one another and do not move relative to one another or relative to the walls of the container. On the other hand, moving bed is a layer of particles moving as a whole under the action of gravity. After reach fluidization state, the volume of the bed is somewhat larger than the volume of the fixed layer. Thus, the bed is said to be expand. If we further increases the velocity of the fluid, the bed continues to expand, the height of the bed increases. However, the concentration of particles per unit volume of the bed decrease.

Once the minimum fluidization velocity can be obtain, the next stage can be proceed where velocity will be increase gradually and the effects to bubble formation will be record. Air fluidization velocity very important parameter. Moderate air fluidization velocities can give uniform bubble formation since the particles will follow regular flow trajectories while their respective collision rate was negligible.

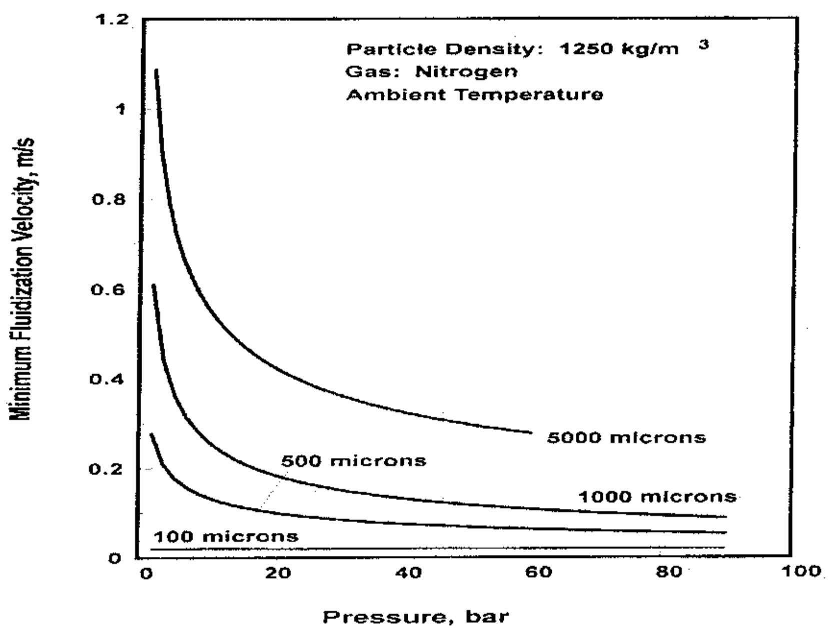

Figure 2.2.1: Effect of pressure versus minimum fluidization velocity (Rowe et al 1984)

Based on Figure 2.2.1, experiment conducted by Rowe at al(1984) had shown that the minimum fluidization velocity will decrease when pressure increase. The heavier particles 5000 microns, 1000 microns and 500 shown very much decrease in minimum fluidization velocity when pressure increase while the lighter particles 100microns do not shown very much decrease. Increment in pressure do not affect significantly the minimum fluidization velocity for lighter particles.

Tzika. M et al (2003) has conducted experiments with the effect of the air-fluidization velocity. The air fluidization velocity was varied by moving the position of the flap at the air outlet. At position 0 (completely open flap) the velocity of the air was the lowest. As the flap was gradually shut 35 %, 45% and 60%, it gave different results. When air fluidization velocity was very low (flap position of 35%) the granules did not follow a uniform flow trajectory, while frequency granules entered coating zone significantly reduced. This resulted in the formation of a quite thin, nonuniform coating. For air-fluidization at high velocity (flap position of 60%), the granules entered coating zone more often and granule's mean residence time in the coating zone per pass was reduced. Hence it result in poor coating quality.

According to Sidorenko. I et al (2004) mention that in industrial practice fluidized bed reactors are mostly operated at superficial gas velocities well above the minimum fluidization veloctities. Therefore, the minimum fluidization velocity is not very applicable in the industry.

2.3 BED EXPANSION

Bed expansion in semi-circular fluidized bed depends largely on the size of the fluidized bed. Particles distribution in the gas is not uniform hence exist gas bubbles and solid particles agglomerates. This affect the heat and mass transfer rate where it becomes low. Several researchers have proposed several correlations to predict bed expansion such as two-phase theory, growth of the bubbles and via correlation of experimental data.

In the study of L.lop M.F et al (1999), bed expansion has influence on the residence time in a chemical reactor, bubble growth, mass transfer phenomena and can determine the height of any heat exchange equipment.

Few experiments had been conducted by researchers about bed expansion in the fluidized bed. Experiment conducted by Kawabata et al (1981) shows that the expansion increased with pressure for Geldart B from the observation of bubble diameter and velocity in bed.

Experiment conducted by Hilal. N (2004) study the effect of particle bed depth. The dimensionless bed density for 325 μm Diakon particles is given for bed depths of 200,300,400 and 500 mm in the 290 mm diameter bed. From the experiment, Hilal. N (2004) notice that the difference of particles depth at difference level is smalls and not systematic.

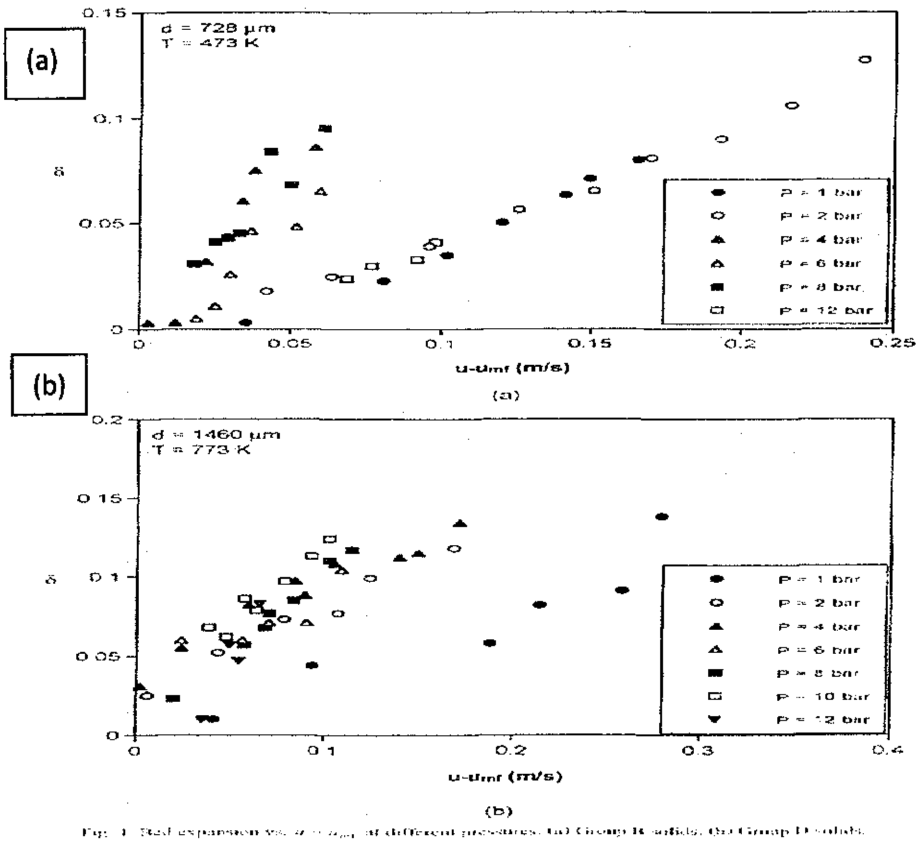

Figure 2.3.1: Bed expansion versus minimum fluidization at different pressure (a) Group B solids (b) Group D solids (Schweinzer and Molerus 1987)

Figure 2.3.1 above shown the bed expansion at different pressure for group B and group D solids. Schweinzer and Molerus(1987) observed that bubble fraction therefore bed expansion was not significantly influenced by pressure for Group B particles, nevertheless by analyzing the visible flow of bubbles as well as bubble diameter and velocity,it can be concluded that bed expansion increased with pressure for particles belonging to groups B and D.

2.4 EFFECT OF DIFFERENT PARTICLES

In the experiment, different particles will be used namely rice with Dp 0.34mm, green bean with Dp 2.71mm and urea with Dp 3.35mm. Experiment will be conducted in semi-fluidized bed.

Sidorenko. I. et al (2004) mention that particles size do bring effect to the minimum fluidization velocity and pressure. The result from the experiment did show a decrease in the minimum fluidization velocity with increasing pressure for particles larger than 100 μm (Geldart particles type B and D).

Hilal.N (2004) found only certain type of particles types can be effectively fluidized. Isometric particles smaller than 10 μm display cohesive properties that usually prevent uniform fluidization while particles in the range of 10 -100 μm of low density fluidized in a particulate manner of the minimum velocity of fluidization.

According to Tao Zhou et al (1999) mention that fluidized bed characteristic really get affected by the size of the particles which the smaller particles size, bigger inter-particle force therefore the worse fluidized behavior.

CHAPTER 3

METHODOLOGY

3.1 PROCEDURE

The overall methodology of this study are divided into three parts which are

i. Apparatus setup
ii. Experimental procedure
iii. Experimental matrix

3.1.1 Apparatus setup

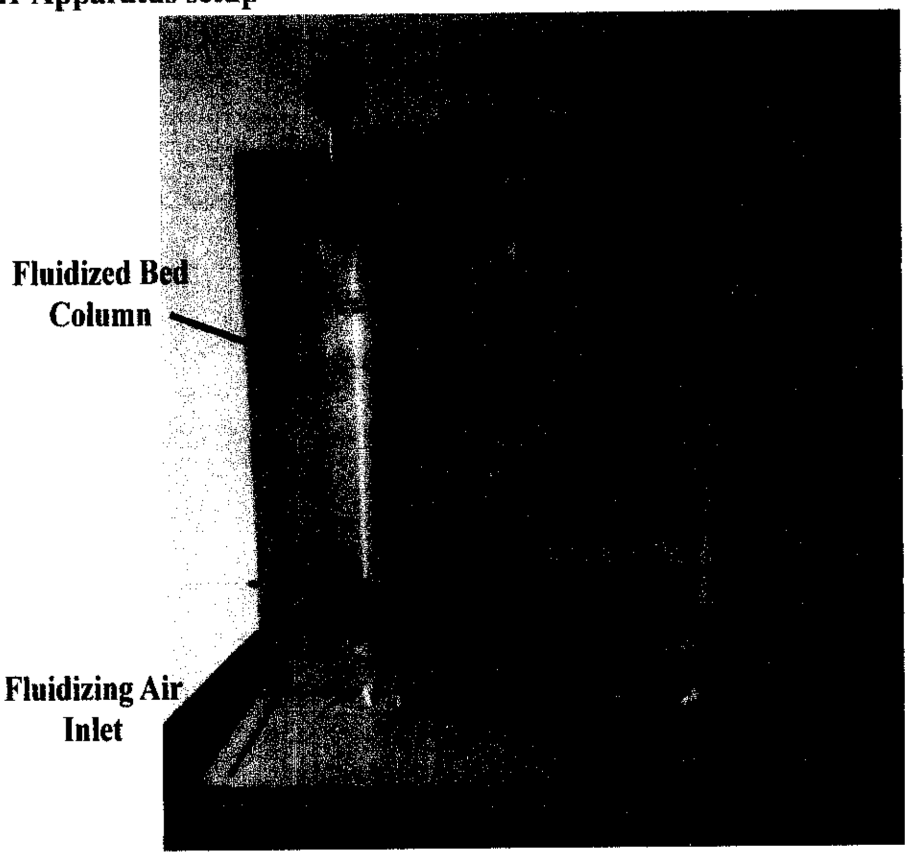

Figure 3.1 : Fluidized bed circular and semi-circular

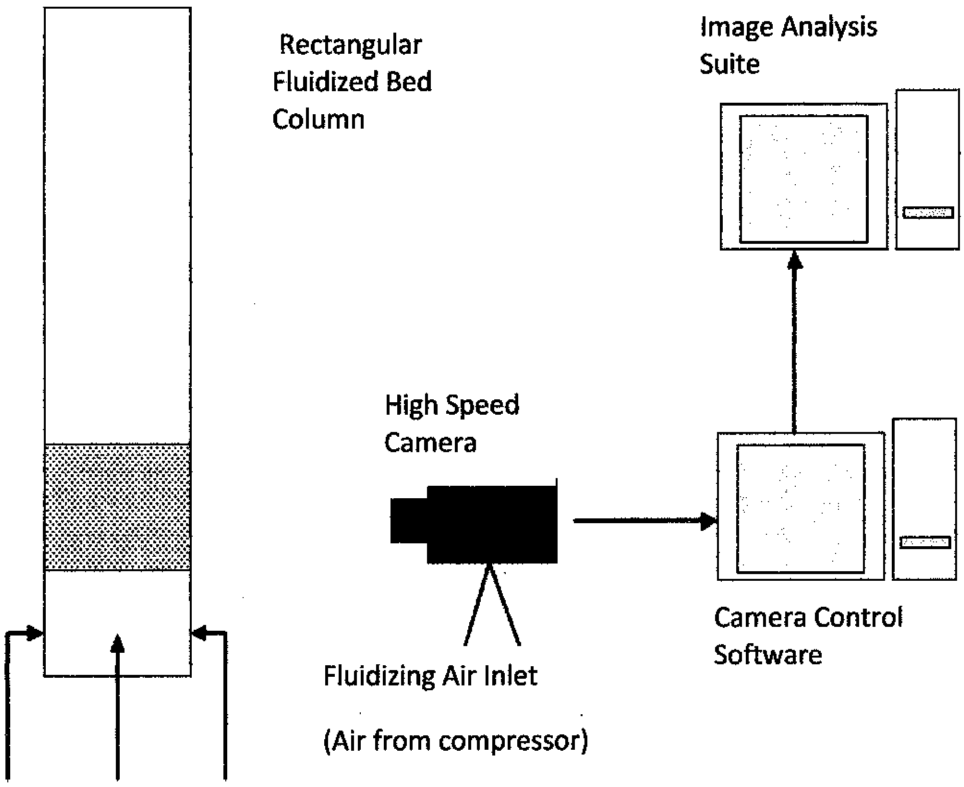

Figure 3.2 : Experiment set up used in the video imaging through the rectangular column (Ganeshkumar Subramaniam,2003)

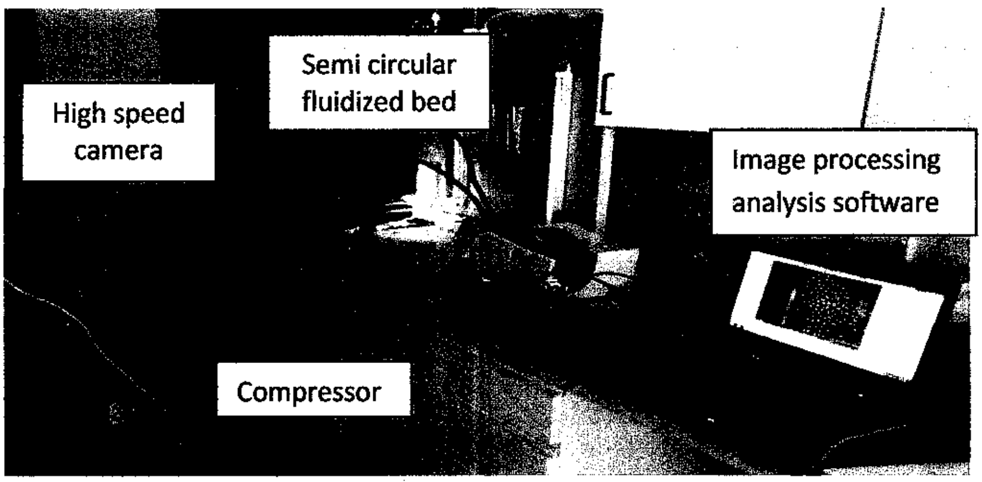

Figure 3.3: Experiment set up with high speed camera,SONY XC 75CE CCD with setting 200 frames per second, exposure 4997.5 and resolution 1280 X 720

3.1.2 Experimental Procedure

The experiment consist of a semi-circular column with 50 cm height and 5.7cm in diameter, a syringe and air compressor to provide the fluidizing medium (gas) to establish required superficial gas velocity, and camera Sony XC 75CE CCD, Sony Inc.

The distributor plates are made from wire mash tray with pore size of 20 μm and a fractional free area of 60%. Granular urea, green bean and rice are used as the Geldart's particles. The particles are divided into Geldart's particles specification such as, Geldart B, and Geldart D. The bubble formation of the particles in the fluidized bed is investigated by changing the pressure and particles sizes.

The experiment set up is according to figure 3.2 and figure 3.3. Fill the semi circular fluidized bed with one type of Geldart particle. Measure the bed height and the value is the initial bed height. Air from compressor was feed to the rectangular shape plenum which located beneath the distributor plate. Let the air flow for five minutes and the take the inlet pressure and outlet pressure. The process was recorded by using high speed camera at 200 frames per second. High speed camera was placed in front of the fluidized bed to capture the dynamic images. Save the images captured and analyze. The fluidizing air from the compressor flows into the fluidized bed through the bottom plate and fluidized the particles by overcoming the centrifugal force. Fluidized bed must be in line with the camera lens in order to capture the fluidization images.

The air flow rates will be increase to get increment in pressure. The bed height was adjusted by removing or adding Geldart particles to or from the bed to get the desired bed height. The experiment was repeated with different Geldart particles. To study effect of pressure to bed expansion, the bed height was fixed with 10cm with increment in pressure 0.5 bar, 0.7 bar, 0.9 bar and 1.1 bar. To study effect of different particles to bubble diameter, the bed height was 10cm, 20cm and 30cm for each pressure different.

Voidage measurements were obtained in a given region of interest of the bed using a single CCD camera mounted perpendicular to the flat front face of the bed. A shutter of 0.1 ms was used in order to obtain crisp, blur-free images. The software counted the number of tablets in the FOV automatically. To convert the number count to a voidage, the depth of field, DOF, of the camera and lens system had to be found.

The DOF was obtained by calibration and using this value with the known volume of tablets in a given volume of bed, the local void volume in the bed was calculated. (Subramaniam, 2003). All steps are repeated using different atomizing air pressure, different Geldart's particles group, different fluidized column and different type of distributor. The results are compared and analyzed.

3.1.3 Experimental Matrix

Experiments	Type of Fluidized Bed Column	Type of Particle	Fluidizing Air Pressure (bar)	Initial Bed Height (cm)
Effect of pressure to bed expansion				
Run 1	Semi-Circular	Geldart's B & D	0.5	10
Run 2			0.7	10
Run 3			0.9	10
Run 4			1.1	10
Effect of different particles to bubble diameter				
Run 5	Semi-Circular	Geldart's B & D	0.5	10
Run 6			0.5	20
Run 7			0.5	30
Run 8			0.7	10
Run 9			0.7	20
Run 10			0.7	30
Run 11			0.9	10
Run 12			0.9	20
Run 13			0.9	30
Run 14			1.1	10
Run 15			1.1	20
Run 16			1.1	30

Table 3.1: Detailed condition of each experimental run. The results are then compared and analyzed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Minimum fluidization velocity,U_{mf}

Minimum fluidization velocity can be find via calculation and few information need to be fill in the equation. At 1 bar and room temperature, 22C.*Density of air =1.199 kg/m3.*Viscosity of air = 1.825 X 10^-5.Volume semi circular = 127.58 cm^3.Diameter semi circular fluidized bed = 5.7cm, Length semi circular fluidized bed = 50cm

	Urea	**Green Bean**	**Rice**
Particle diameter,Dp	3.35mm	2.71mm	0.34mm
Weight(kg)	0.4	0.35	0.22
Density (kg/cm^3)	3135	2743	1724

Table 4.1: Density of air at room temperature but different pressure

Pressure (bar)	**Air density (kg/m^3)**
0.5	1.9414
0.7	2.178
0.9	2.452
1.1	2.712

* value of air density and viscosity is based on
http://www.engineeringtoolbox.com/air-temperature-pressure-density-d_771.html

By using Wen and Yu equation, Umf can be calculated.

$$U_{mf} = \frac{\mu}{\rho_g d_p} [\frac{(33.7)^{0.5} + 0.0408 d_p^3\ \rho_g(\rho_p - \rho_g)g}{\mu^2}]^{0.5}$$

Simplified version Wen and Yu equation

For small particles (Re <20)

$$U_{mf} = \frac{d_p^2(\rho_p - \rho_g)g}{1650\mu}$$

For large particles (Re >1000)

$$U_{mf} = \frac{d_p(\rho_p - \rho_g)g}{24.5\rho_g}$$

Table 4.2: Minimum fluidization of Dp 0.34mm,2.71mm,3.35mm at different pressure.

Pressure(bar)	U_{mf} for Dp 3.35mm (m/s)	U_{mf} for Dp 2.71mm (m/s)	U_{mf} for Dp 0.34mm (m/s)
0.5	1.47	1.24	0.35
0.7	1.38	1.16	0.33
0.9	1.38	1.10	0.31
1.1	1.24	1.05	0.29

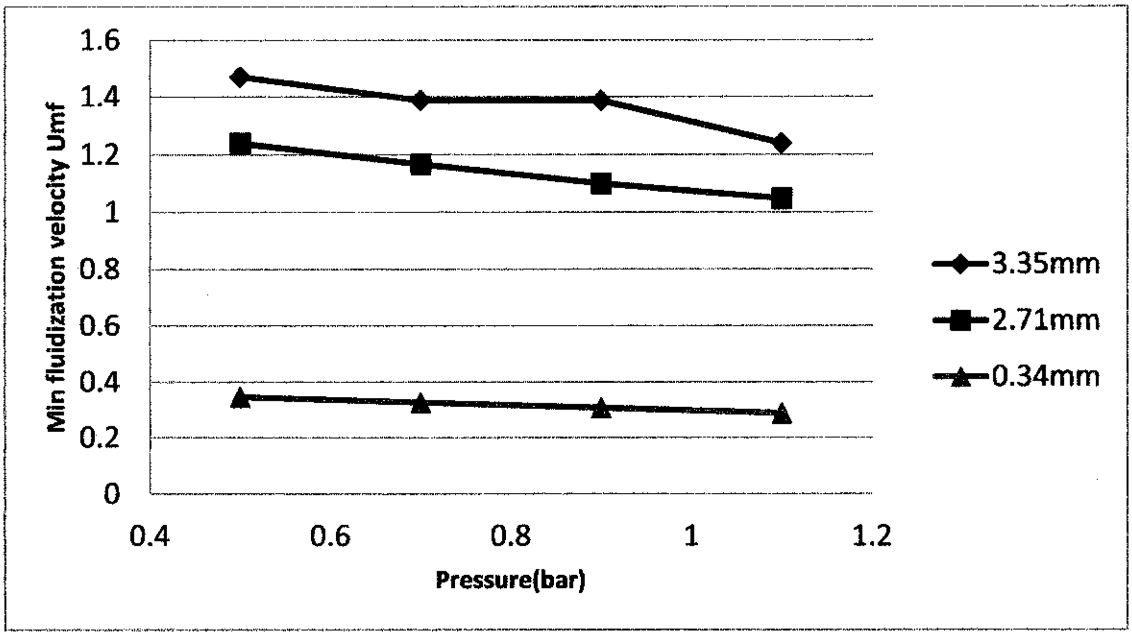

Figure 4.1: Min fluidization,U_{mf} versus pressure for Dp 0.34mm,2.71mm,3.35mm

Effect of pressure and temperature on minimum fluidization velocity, U_{mf} largely depend upon particle size. From Figure 4.1, it can be seen that increasing system pressure causes U_{mf} to decrease for particle size greater than 100 μm. Materials of this size are essentially Geldart Group B and D. For large particles, the Wen and Yu equation predicts that U_{mf} should vary as $(\frac{1}{\rho_g})^{0.5}$. Therefore, U_{mf} should decrease with pressure for large particles.

4.2 Effect of pressure to the bed expansion

The results are shown in table below. Bed height before the experiment is fix which is 10 cm.

Table 4.3: Bed expansion for Dp = 0.34 mm.

Pressure (bar)			**Expended bed height (cm)**
Inlet	**Outlet**	**Δ P**	
0.5	0.11	0.39	19
0.7	0.10	0.6	21
0.9	0.12	0.78	27
1.1	0.21	0.89	34

Table 4.4 : Bed expansion for Dp = 2.71 mm

Pressure (bar)			**Expended bed height (cm)**
Inlet	**Outlet**	**Δ P**	
0.5	0.09	0.41	17
0.7	0.1	0.6	20
0.9	0.11	0.79	25
1.1	0.15	0.95	32

Table 4.5: Bed expansion for Dp = 3.35 mm

Pressure (bar)			**Expended bed height (mm)**
Inlet	**Outlet**	**Δ P**	
0.5	0.1	0.4	13
0.7	0.11	0.59	22
0.9	0.12	0.78	24
1.1	0.16	0.94	26

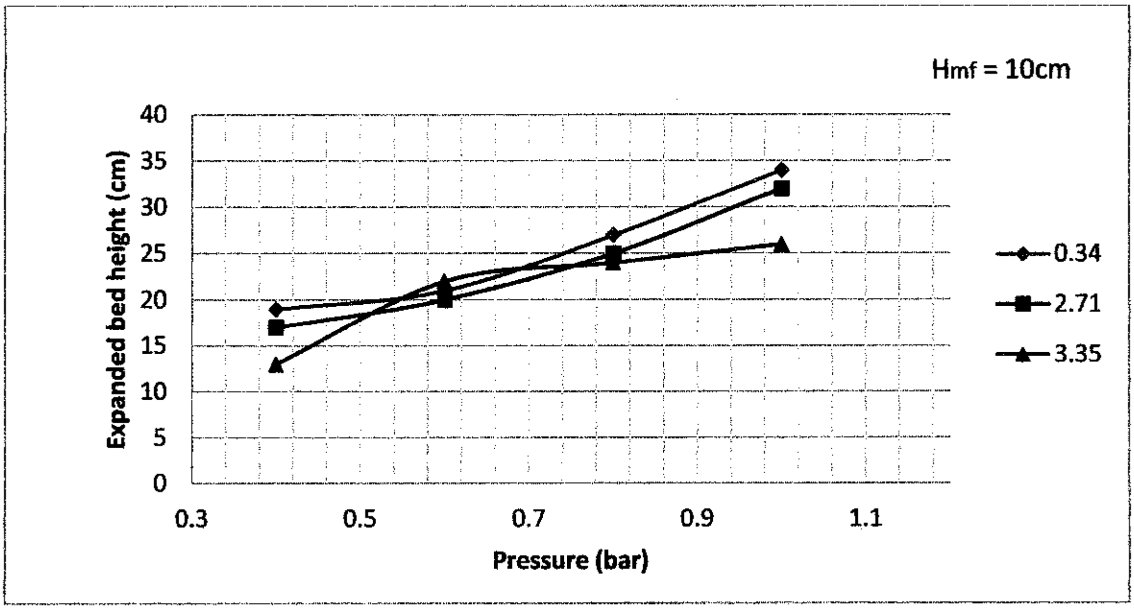

Figure 4.2 : Expended bed height versus pressure (bar) for particles diameter 0.34mm,2.71mm and 3.35mm, **Hmf** =10cm

Based from the Figure 4.2, the result clearly shown that the bed expansion is increase with the increasing of pressure but bed expansion will decrease if heavier particles is used. Bed expansion for particles size 3.35mm and 2.71mm are shorter than 0.34mm. The bed new height decreased with the particle size.

4.2 Effect of different particles to the bubble diameter

Table 4.6: Bubble diameter for Dp = 0.34 mm

Pressure			Initial Bed Height	Bubble
Inlet	**Outlet**	**Δ P**	**(cm)**	**diameter(cm)**
0.5	0.12	0.38	10	3.2
	0.125	0.375	20	2.7
	0.12	0.38	30	4.4
0.7	0.16	0.54	10	2.9
	0.18	0.52	20	3.5
	0.17	0.53	30	4.0
0.9	0.18	0.72	10	2.6
	0.2	0.7	20	4
	0.19	0.71	30	6.0
1.1	0.2	0.9	10	1.5
	0.22	0.88	20	3.2
	0.21	0.89	30	6.2

Table 4.7: Bubble diameter for Dp = 2.71mm

Pressure			Initial Bed Height	Bubble
Inlet	**Outlet**	**Δ P**	**(cm)**	**diameter(cm)**
0.5	0.12	0.38	10	2.9
	0.125	0.375	20	3.0
			30	4.1
0.7	0.16	0.54	10	2.7
	0.18	0.52	20	3.2
			30	3.9
0.9	0.18	0.72	10	3.1
	0.2	0.7	20	3.5
			30	5.2
1.1	0.2	0.9	10	2.4
	0.22	0.88	20	2.5
			30	5.4

Table 4.8: Bubble diameter for Dp = 3.35mm

Pressure			Initial Bed Height (cm)	Bubble diameter(cm)
Inlet	**Outlet**	**Δ P**		
0.5	0.12	0.38	10	2.5
	0.125	0.375	20	2.7
	0.18	0.32	30	3.9
0.7	0.16	0.54	10	2.5
	0.18	0.52	20	2.9
	0.16	0.54	30	4.2
0.9	0.18	0.72	10	2.6
	0.2	0.7	20	3.2
	0.18	0.72	30	6.5
1.1	0.2	0.9	10	2.7
	0.22	0.88	20	1.5
	0.19	0.91	30	5.2

The graph of bubble diameter at certain height above air distributor for Dp 0.34mm,2.71mm,3.35mm with pressure 0.3,0.5,0.7 and 0.9 bar are shown in Fig. 4.3,Fig 4.4,Fig 4.5 and Fig 4.6 below

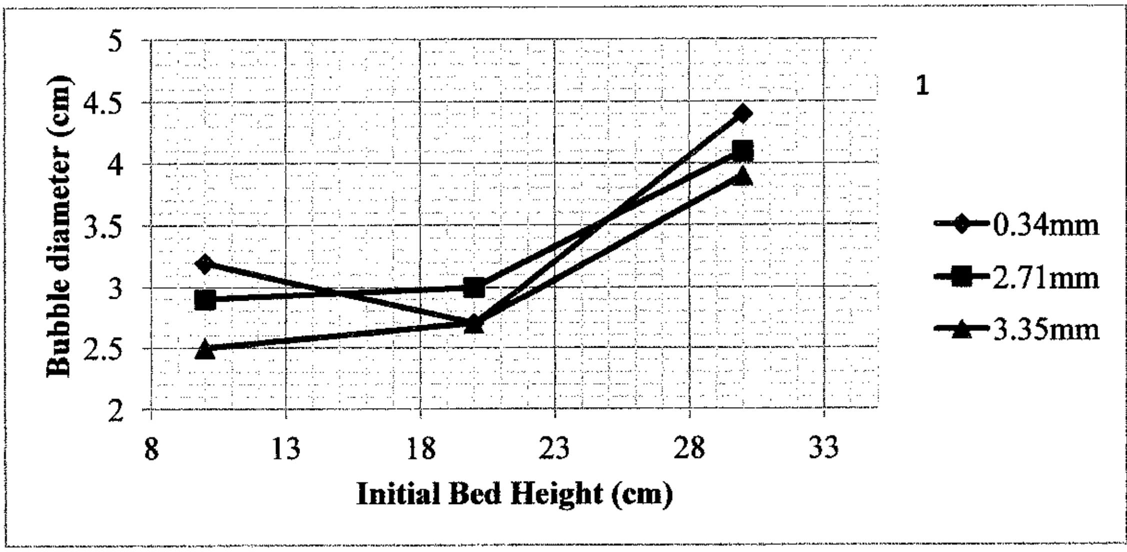

Figure 4.3 : Bubble diameter(cm) versus height for Dp 0.35mm,2.71mm,3.35mm at pressure **0.3 bar** , H_{mf} = 10cm,20cm,30cm

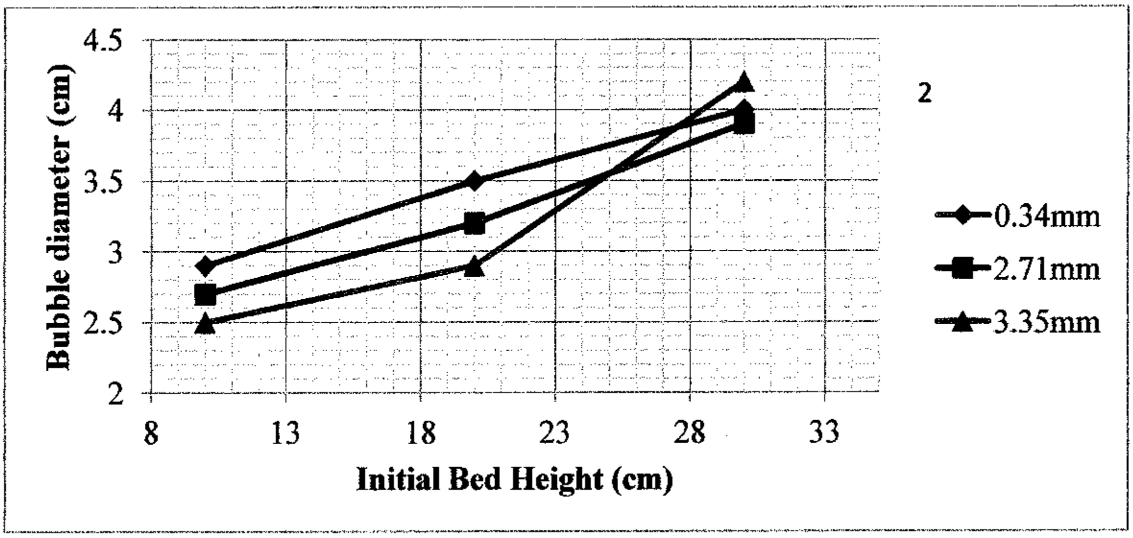

Figure 4.4 : Bubble diameter(cm) versus height for Dp0.34mm, 2.71mm,3.35mm at

pressure **0.5 bar**,H_{mf} =10cm, 20cm,30cm

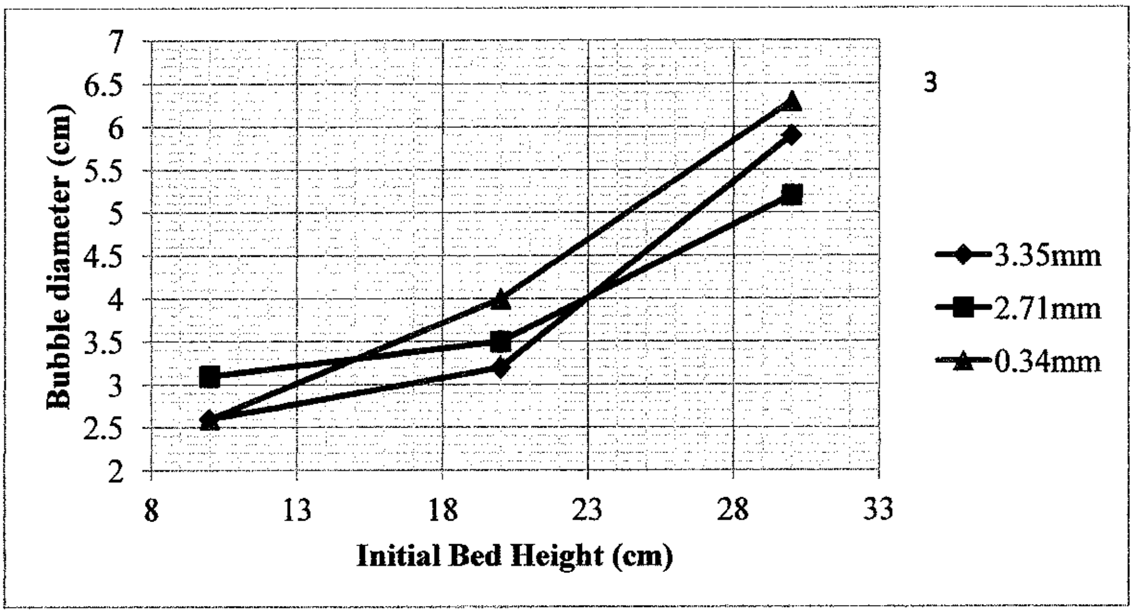

Figure 4.5 : Bubble diameter(cm) versus height for Dp 0.34mm, 2.71mm, 3.35mm at pressure **0.7 bar**, H_{mf} = 10cm,20cm,30cm

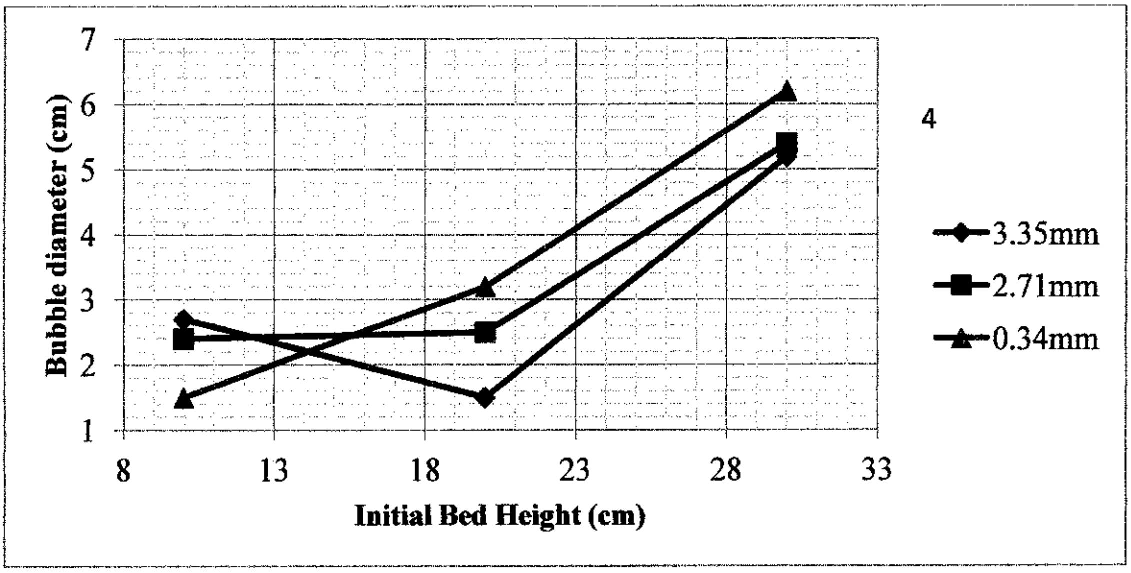

Figure 4.6: Bubble diameter(cm) versus height for Dp 0.34mm,2.71mm,3.35mm at pressure **0.9bar**, H_{mf}=10cm,20cm,30cm

The graph shown above indicate relation between different particles and its effect to the bubble diameter at different pressure namely 0.3 bar, 0.5 bar, 0.7 bar and 0.9 bar. Based on Fig. 4.3,Fig 4.4, Fig.4.5 and Fig 4.6, it can be concluded that particle size with Dp 0.34 mm show bubble size that is bigger than 2.71mm and 3.35mm. Smaller particles will form larger bubbles diameter.

As the height above air distributor increase, as can be seen from above graph, particles with Dp 0.34mm still predominates the graph that form large bubbles and then followed by Dp 2.71mm and Dp 3.35mm. Large particles will have larger void friction in packed bed column and thus affect the bubble diameter where the bubble diameter is happening to be smaller.

The graph of bubble diameter versus pressure can be seen below in Fig 4.7, Fig 4.8 and Fig 4.9 for Dp 0.34mm, 2.71mm and 3.35mm with initial bed height 10cm,20cm and 30cm.

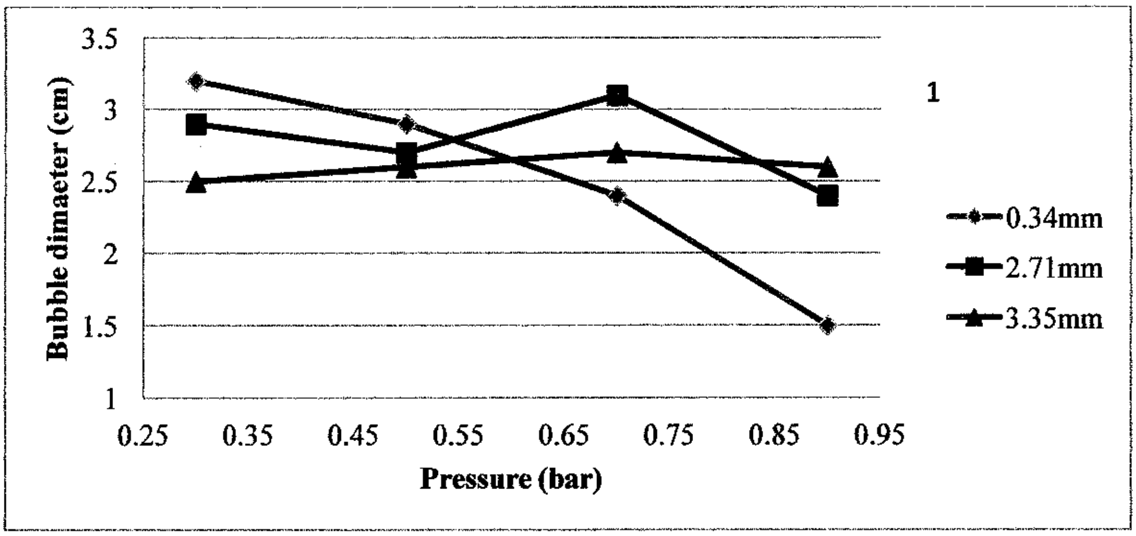

Figure 4.7: Bubble diameter(cm) versus pressure for Dp 0.34mm,2.71mm,3.35mm at H_{mf}=**10cm**

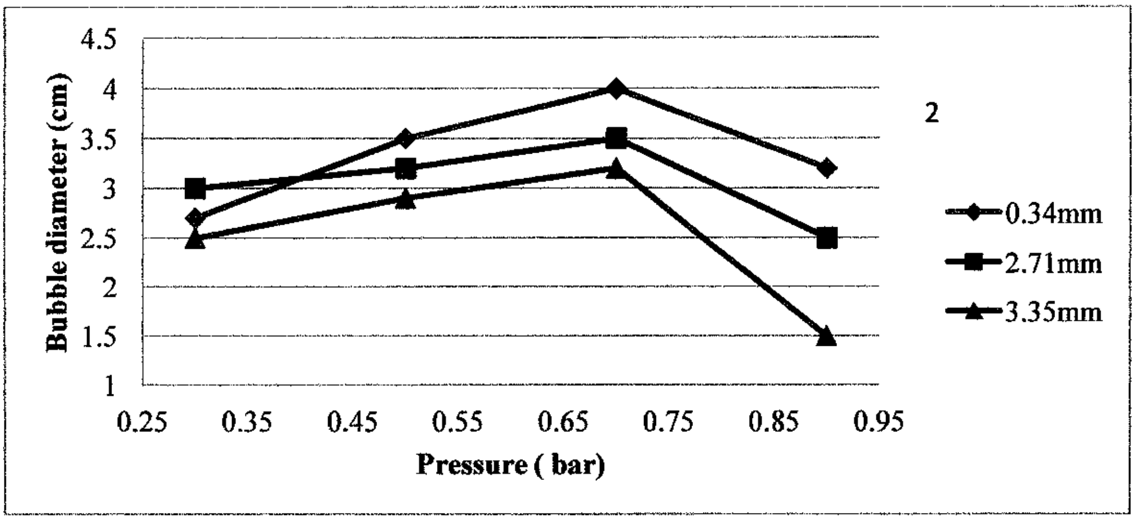

Figure 4.8: Bubble diameter(cm) versus pressure for Dp 0.34mm,2.71mm,3.35mm at H_{mf}=**20cm**

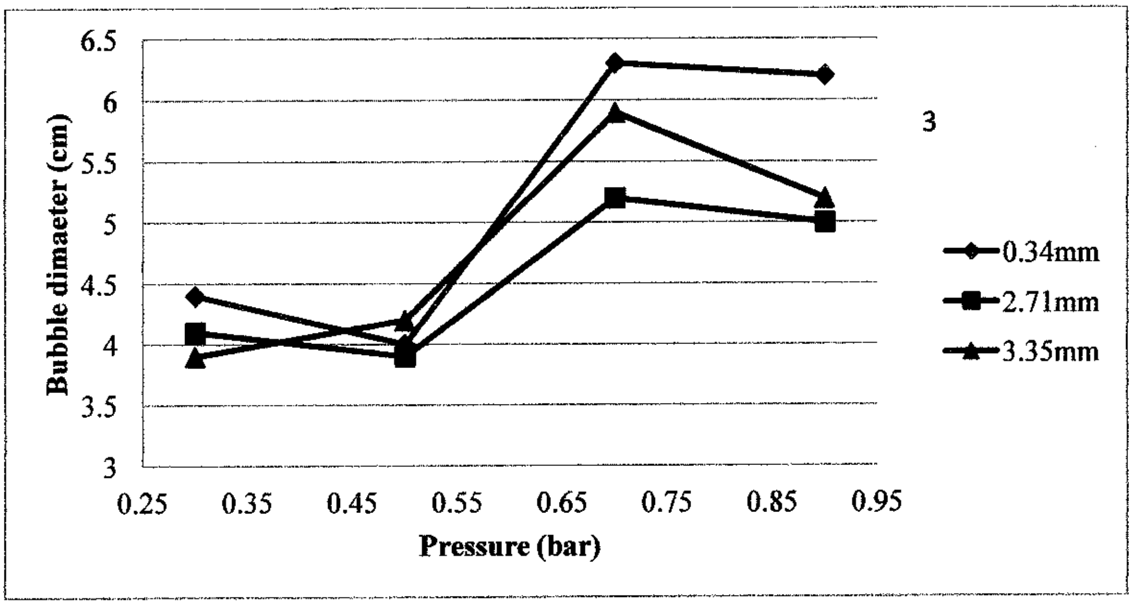

Figure 4.9:Bubble diameter(cm) versus pressure for Dp 0.34mm,2.71mm,3.35mm for H_{mf}=**30cm.**

Based on Fig 4.7, Fig 4.8 and Fig 4.9, as the pressure increase the bubble diameter will increase gradually until certain pressure where bubble diameter is maximum and after that bubble diameter will decrease even though pressure is increasing. From the graph can be seen that bubble diameter is increasing when pressure increase from 0.3 bar to 0.5 bar to 0.7 bar. After 0.7 bar, bubble diameter decrease even though pressure increase at 0.9 bar. Particles with Dp 0.34mm still predominates the graph that create large bubble. This is because smaller particles have smaller void friction that enable air to form larger bubbles.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

High speed camera was used in the experiment because it can captured fast moving particles via high shutter speed feature. Characteristic bubble formation in the fluidized bed can be study via pictures taken via high speed camera.

Minimum fluidization velocity U_{mf} depend on particle size. For large particles, the Wen and Yu equation predicts that U_{mf} should vary as $(\frac{1}{\rho_g})^{0.5}$. Therefore, U_{mf} should decrease with pressure for large particles. Result from experiment also shown that as the pressure increase, minimum fluidization velocity will decrease.

For expended bed height, the result shown that pressure did not play significant effect to the bed height. As particles diameter increase the expended bed height will increase as well. Bed expansion for particles size 3.35mm and 2.71mm are shorter than 0.34mm. The bed new height decreased with the particle size.

Smaller particles will form larger bubbles diameter. As the height above air distributor increase, as can be seen from the experiment result, particles with Dp 0.34mm still predominates the graph that form large bubbles and then followed by Dp 2.71mm and Dp 3.35mm. Large particles will have larger void friction in packed bed column and thus affect the bubble diameter where the bubble diameter is happening to be smaller.

The result show as the pressure increase the bubble diameter will increase gradually until certain pressure where bubble diameter is maximum and after that bubble diameter will decrease even though pressure is increasing. Smaller particles will create large bubbles diameter because smaller particles have smaller void friction that easily trap air and form big bubbles.

5.2 Recommendation

The air flow at the plenum before enter fluidized bed is not center. Thus this result the bubble formation to form at the side of the fluidized bed and not in the middle fluidized bed. To cater this problem, the air tube that connected to the plenum was cut shorter and the length of air tube inside the plenum was made uniform.

Fluidized bed need to be repaired since the small light behind the fluidized bed cannot be used. Extra lighting was used to complete the experiment. Fluidized bed need to be install with temperature indicator to monitor inlet air temperature from the compressor.

Column can be vary by changing the column shape to circular, rectangular or triangle shape to examine the bubble characteristic inside those columns. More column shape provides more information for bubble characteristic inside the column.

The data for bubble diameter and bed expansion should be repeat at least three times to get more reliable and consistent values.

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Gauthier, D., Zerguerras, S., & Flamant, G. (1999). Influence of the particle size distribution of powders on the velocities of minimum and complete fluidization. *Chemical Engineering Journal, 74*(3), 181-196. doi: 10.1016/S1385-8947(99)00075-3

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APPENDIX

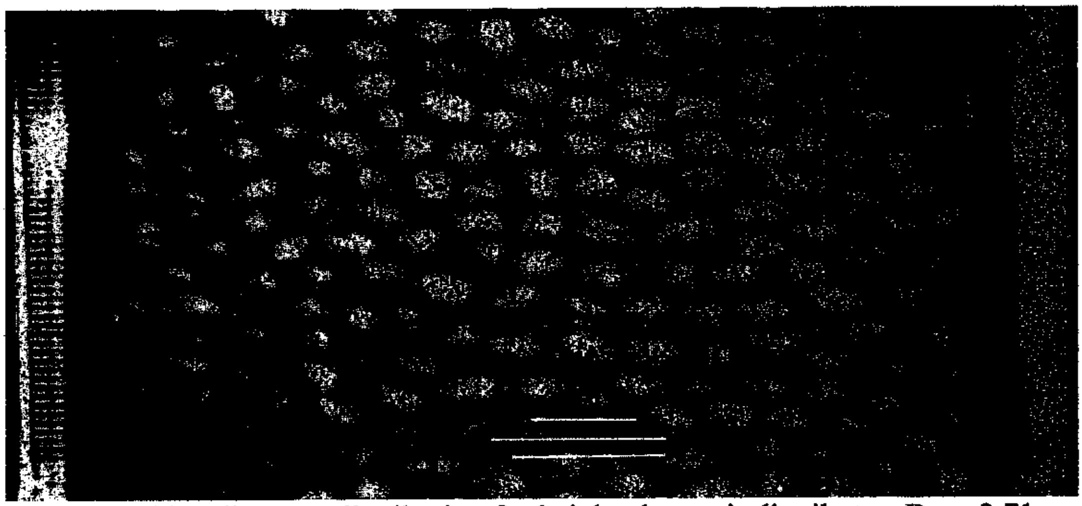

Figure 1: Bubble diameter distribution for height above air distributor, Dp = 2.71mm, Pressure =0.3 bar, H_{mf} = 10cm

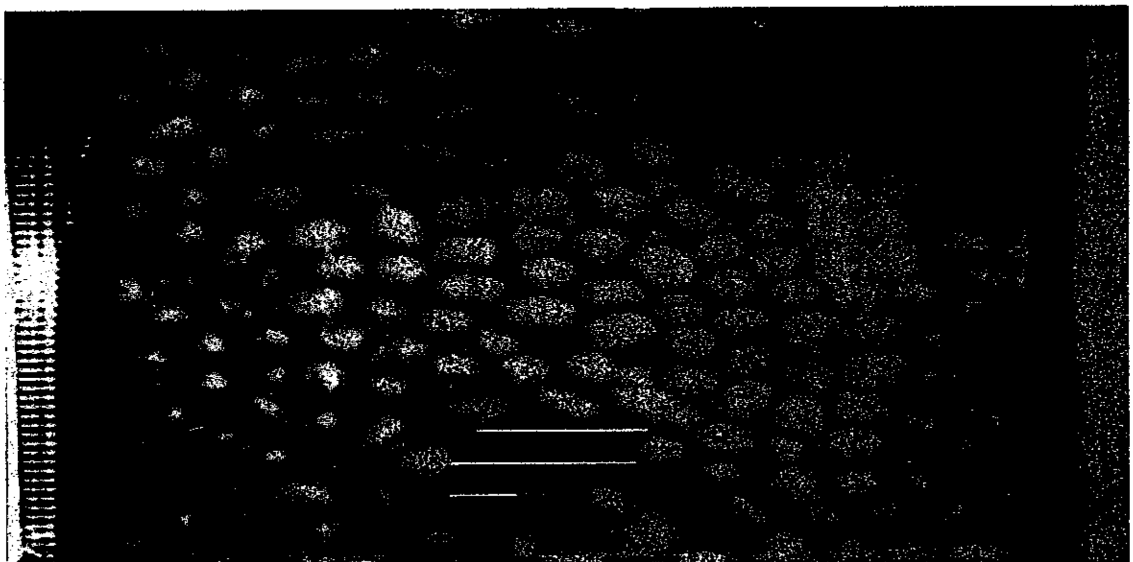

Figure 2 : Bubble diameter distribution for height above air distributor,Dp = 2.71mm Pressure = 0.3 bar H_{mf} = 20cm

Figure 3 : Bubble diameter distribution for height above air distributor, Dp = 2.71mm
Pressure = 0.3 bar H_{mf} = 30cm

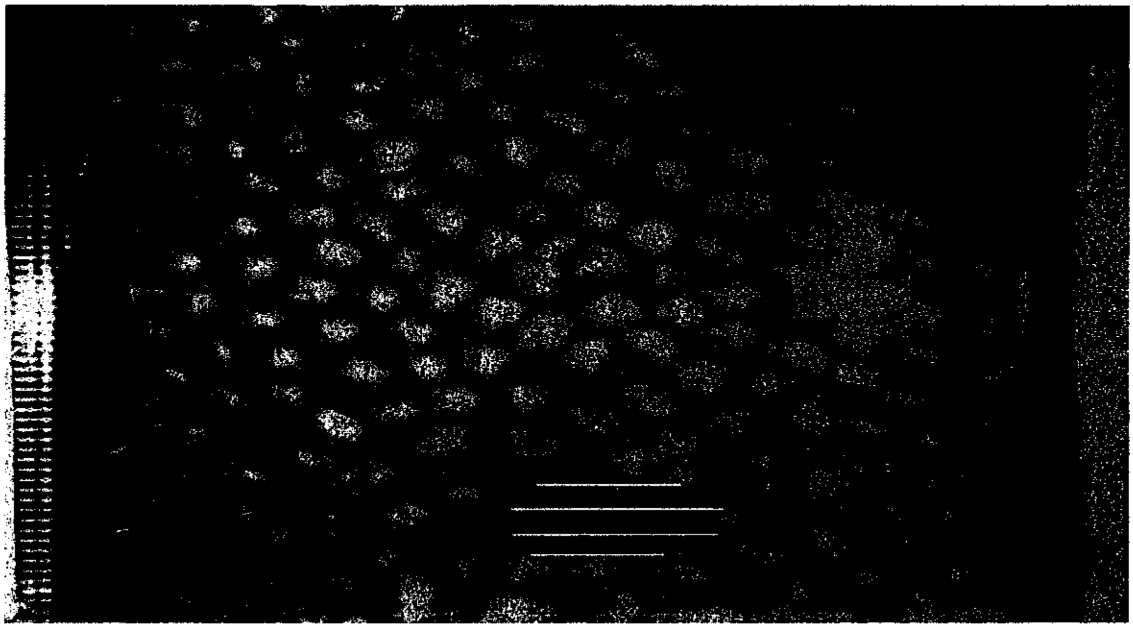

Figure 4 : Bubble diameter distribution for height above air distributor, Dp = 2.71mm
Pressure = 0.5 bar, H_{mf} = 10cm

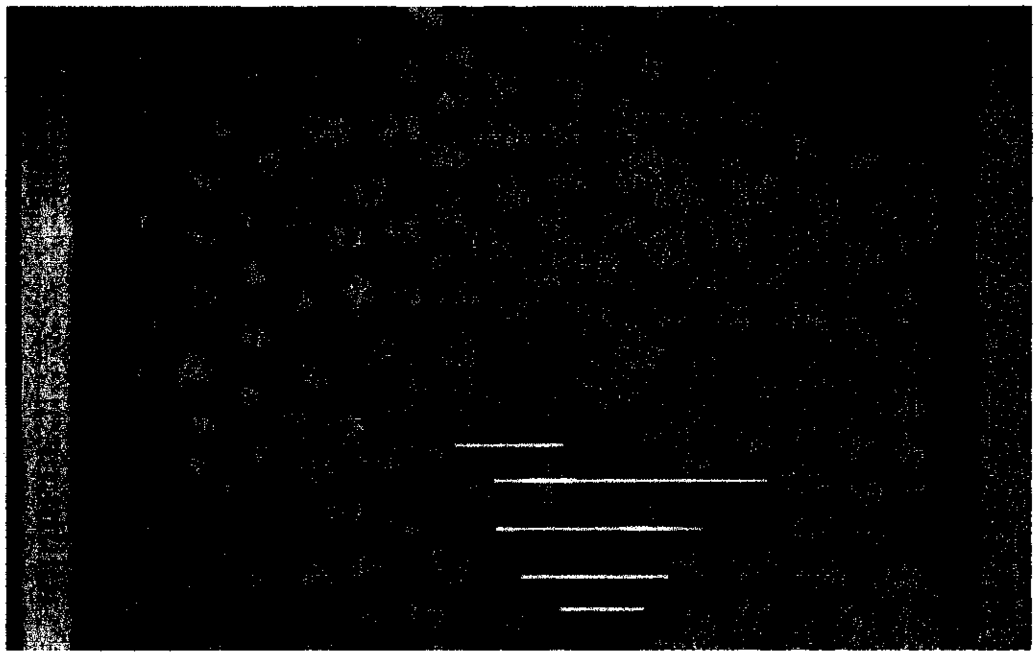

Figure 5 : Bubble diameter distribution for height above air distributor, Dp = 2.71mm
Pressure= 0.5 bar, H_{mf} = 20cm

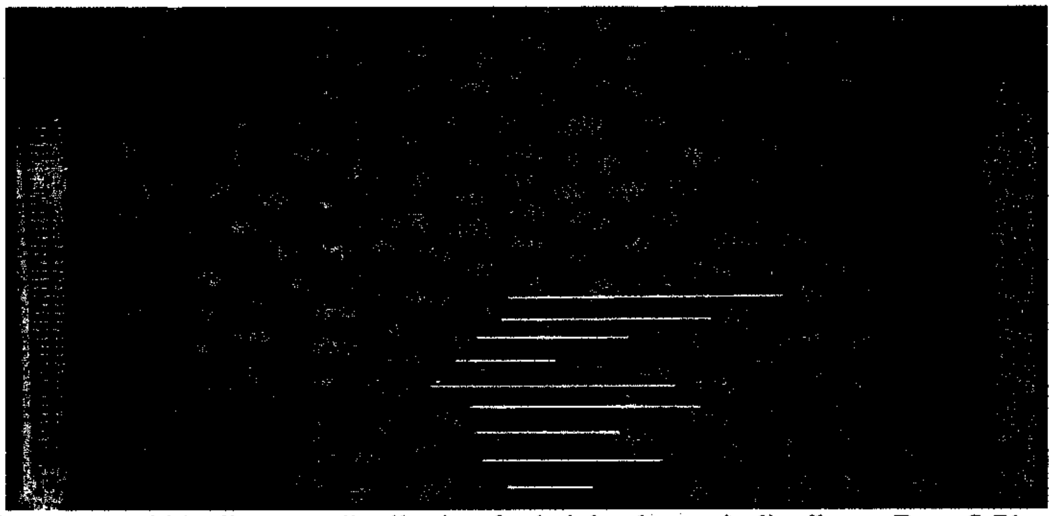

Figure 6 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.5 bar, H_{mf} = 30cm

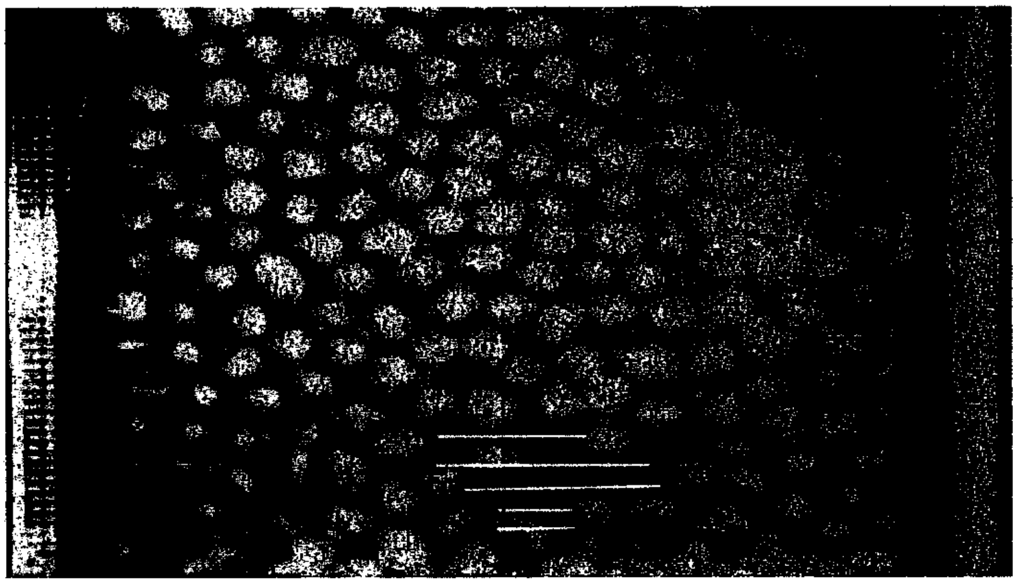

Figure 7 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.7 bar, H_{mf} = 10cm

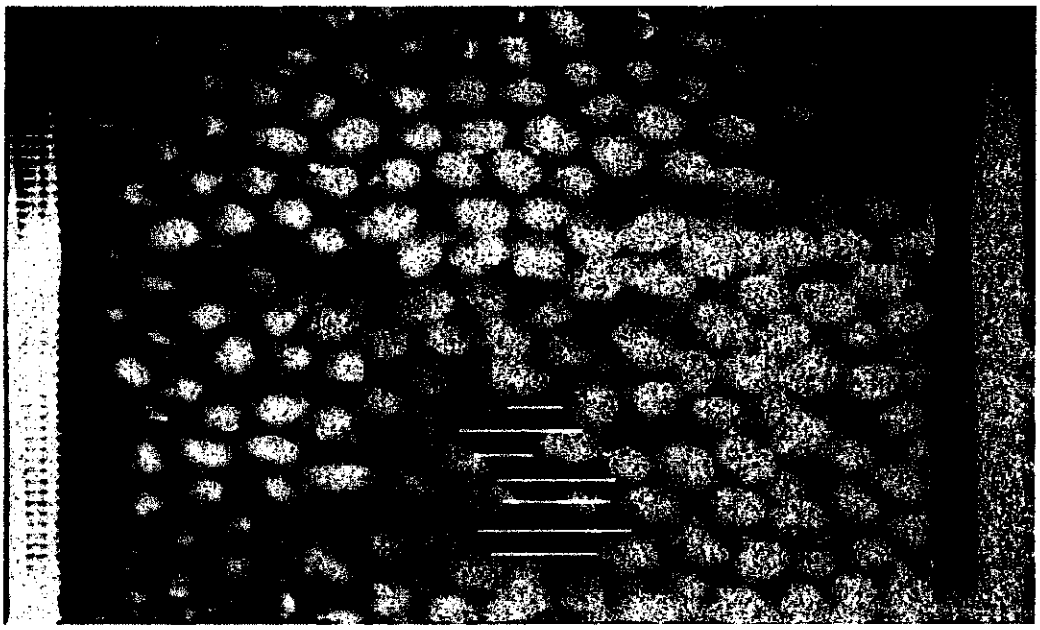

Figure 8 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.7 bar, H_{mf} = 20cm

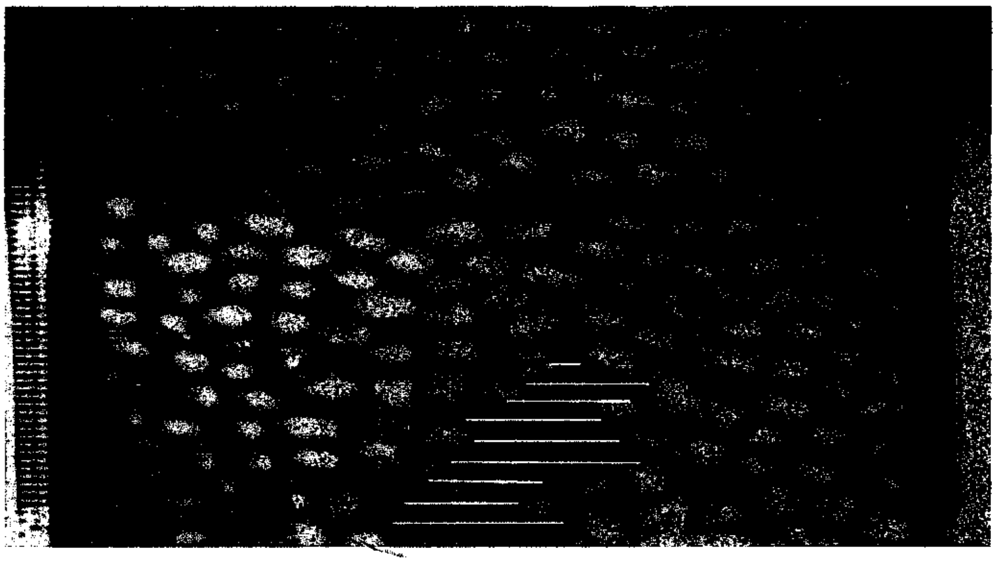

Figure 9 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.7 bar, H_{mf} = 30cm

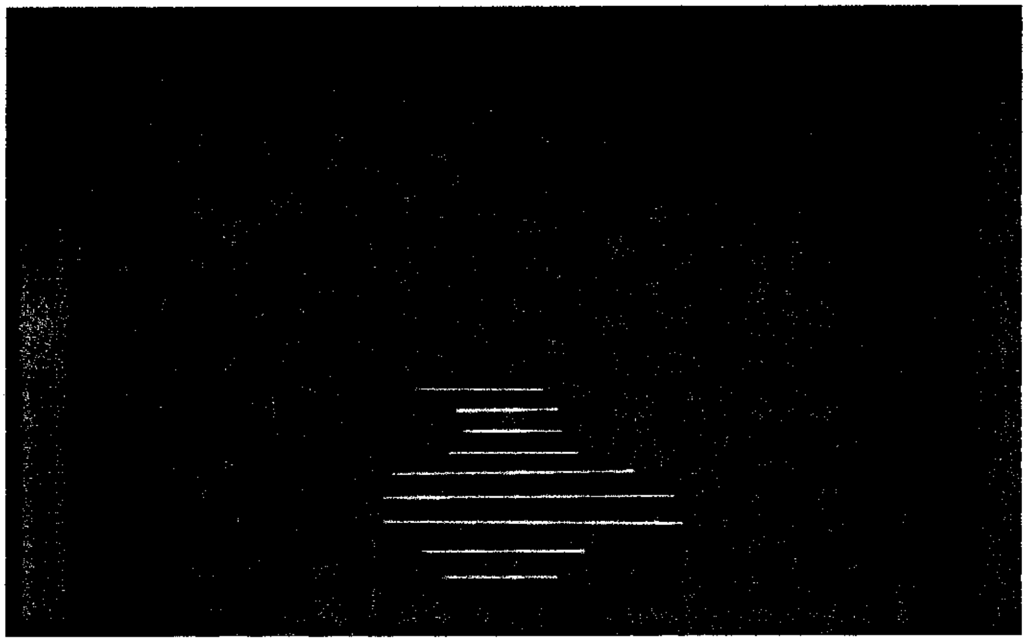

Figure 10 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.9 bar, H_{mf} = 10cm

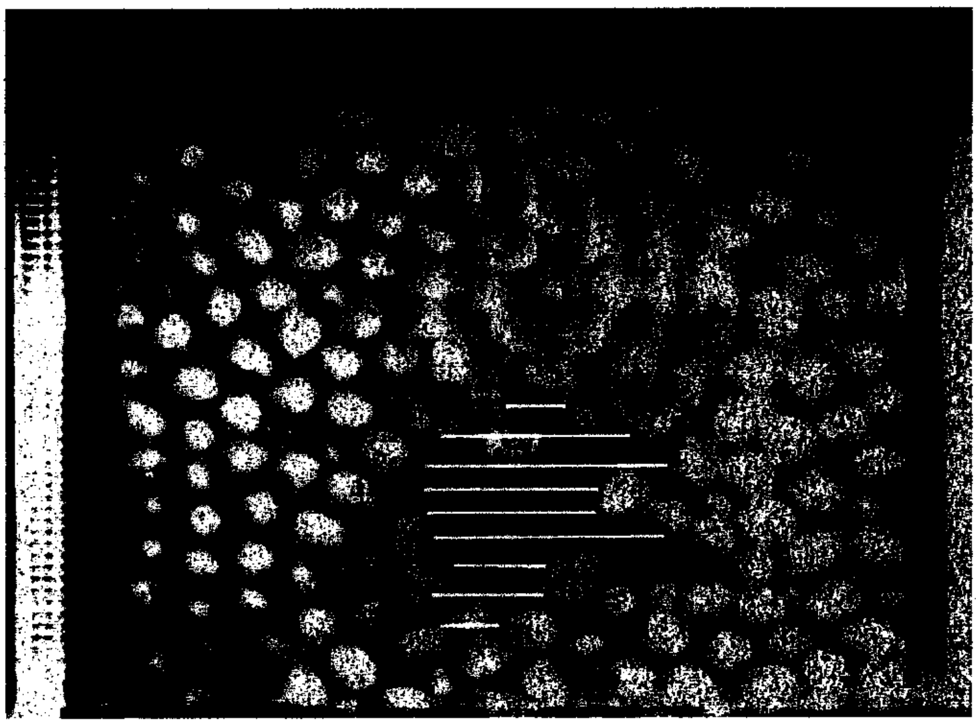

Figure 11 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.9 bar, H_{mf} = 20cm

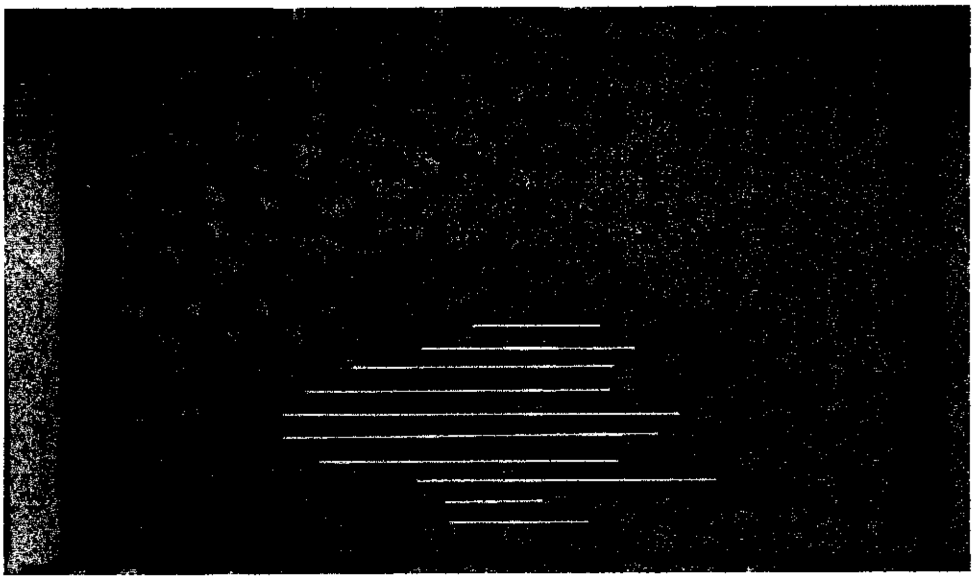

Figure 12 : Bubble diameter distribution for height above air distributor Dp = 2.71mm
Pressure = 0.9 bar, H_{mf} = 30cm

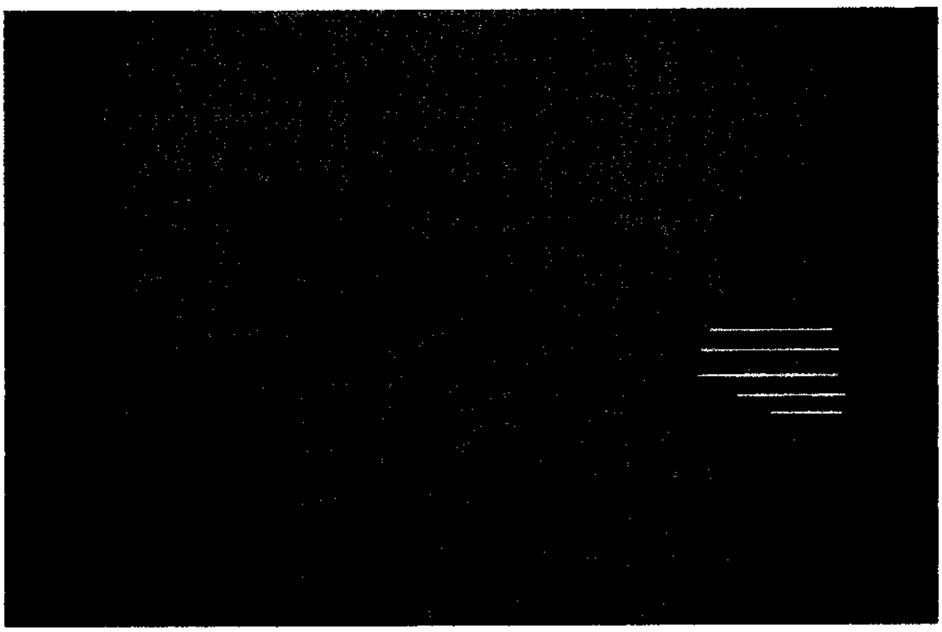

Figure 13 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.3 bar, H_{mf} = 10cm

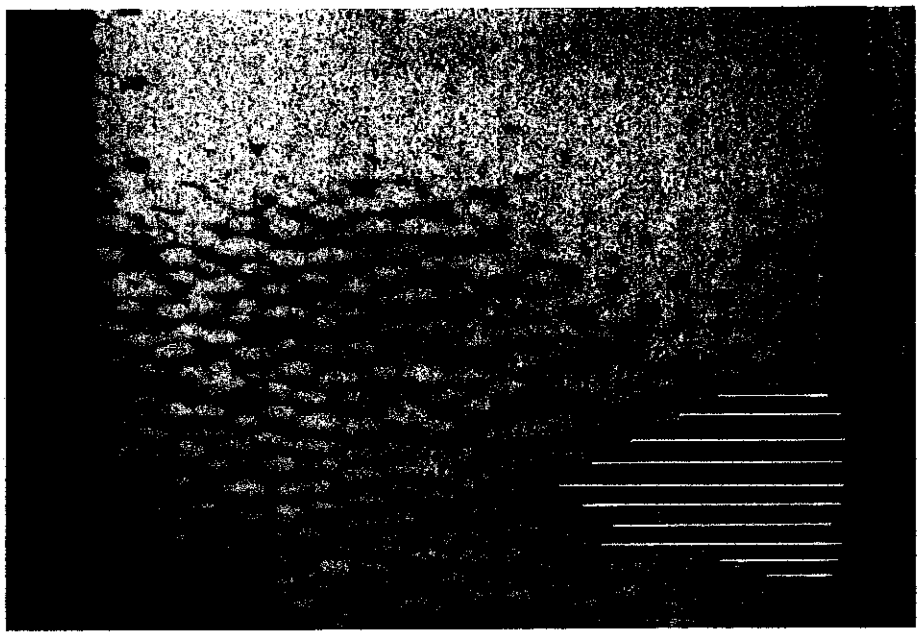

Figure 14 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.3 bar, H_{mf} = 20cm

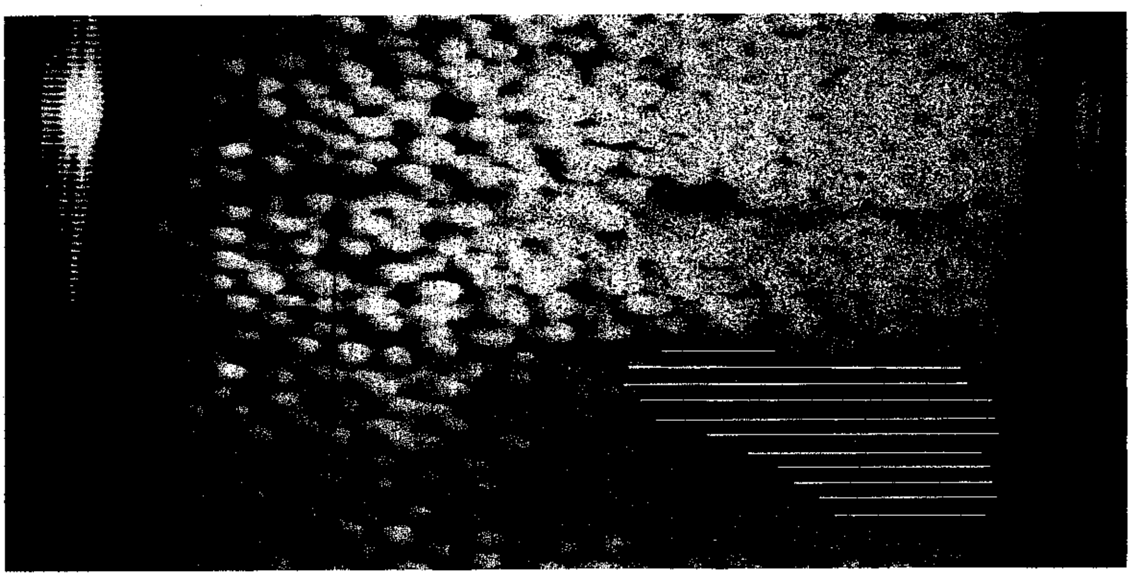

Figure 15 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.3 bar, H_{mf} = 30cm

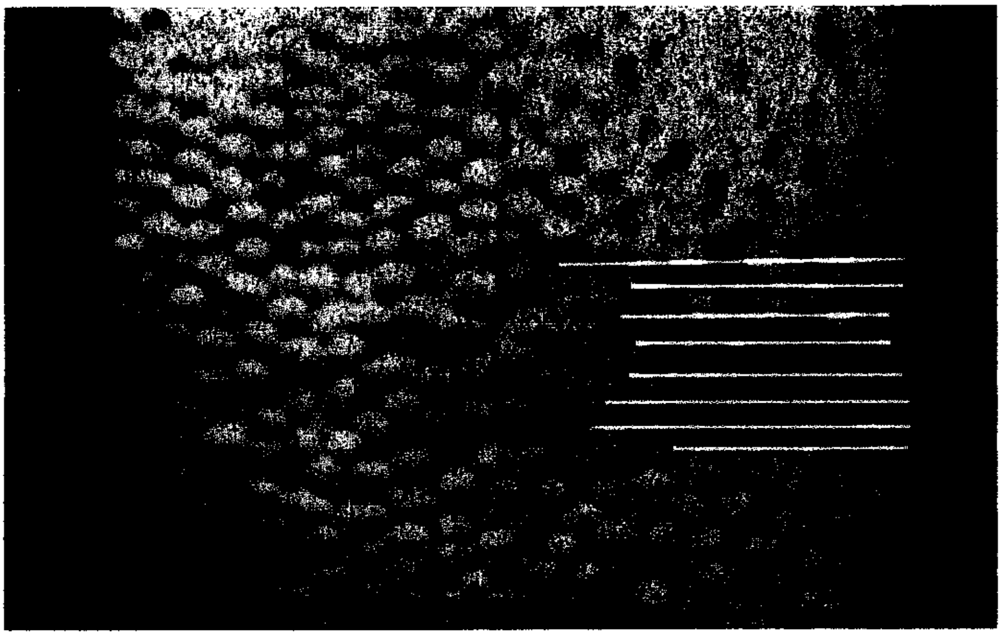

Figure 16 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.5 bar, H_{mf} = 10cm

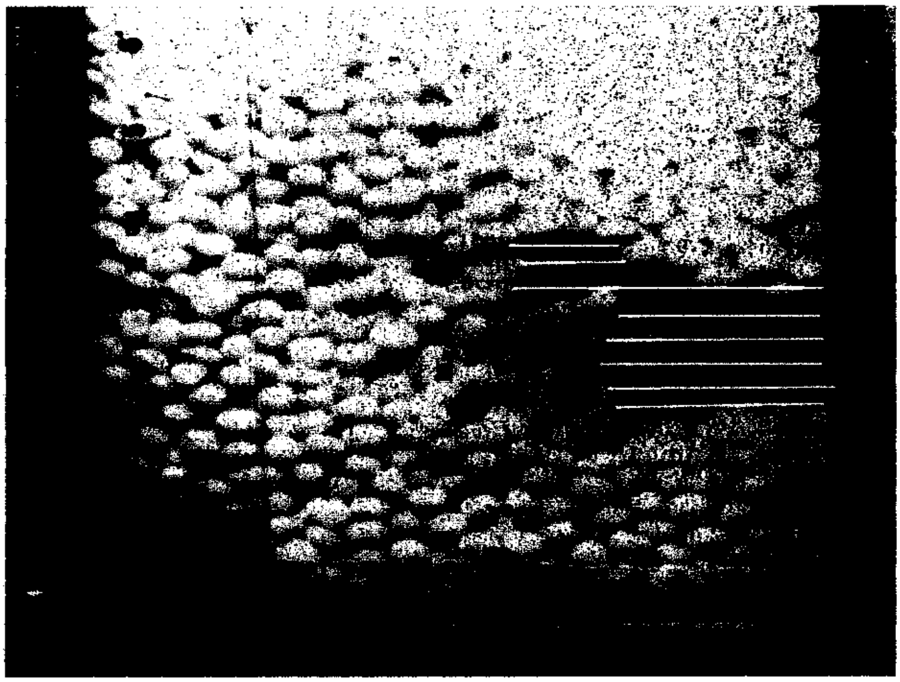

Figure 17 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.5 bar, H_{mf} = 20cm

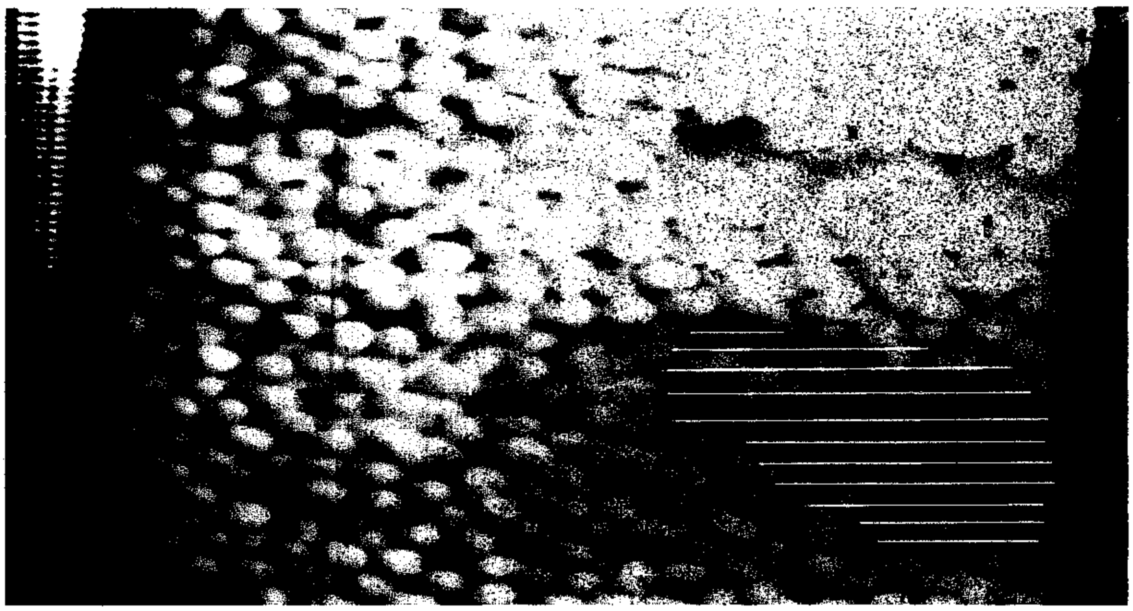

Figure 18 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.5 bar, H_{mf} = 30cm

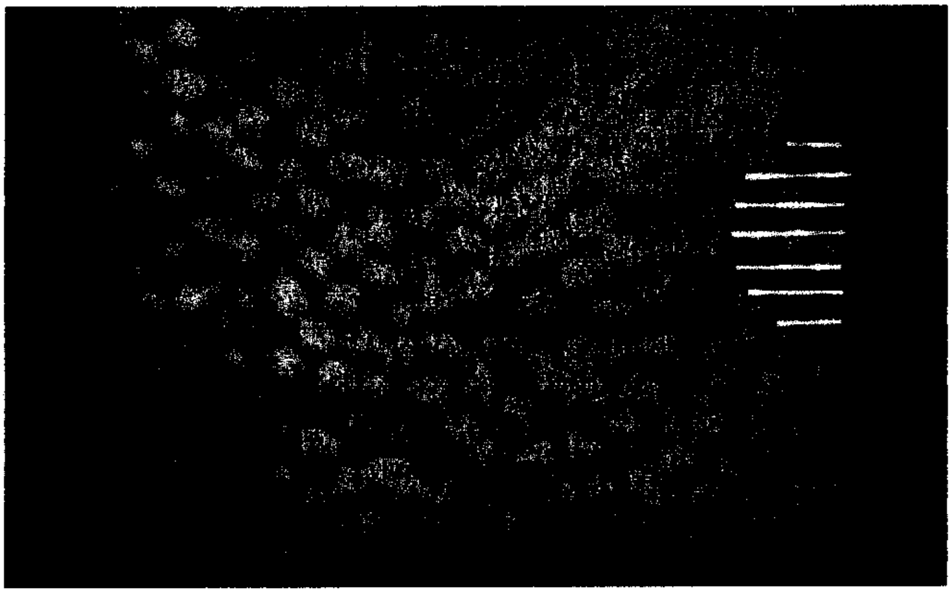

Figure 19 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.7 bar, H_{mf} = 10cm

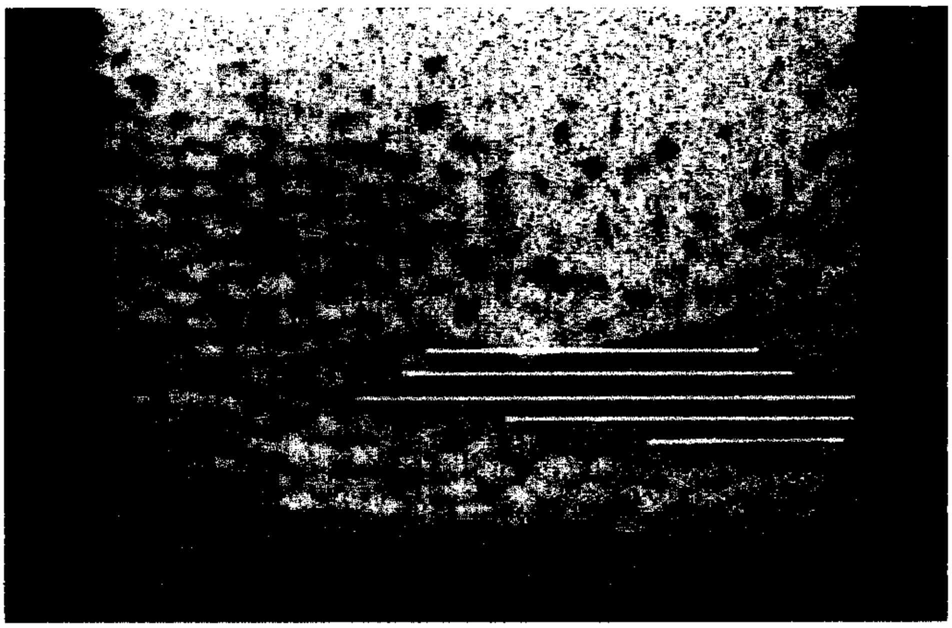

Figure 20 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.7 bar, H_{mf} = 20cm

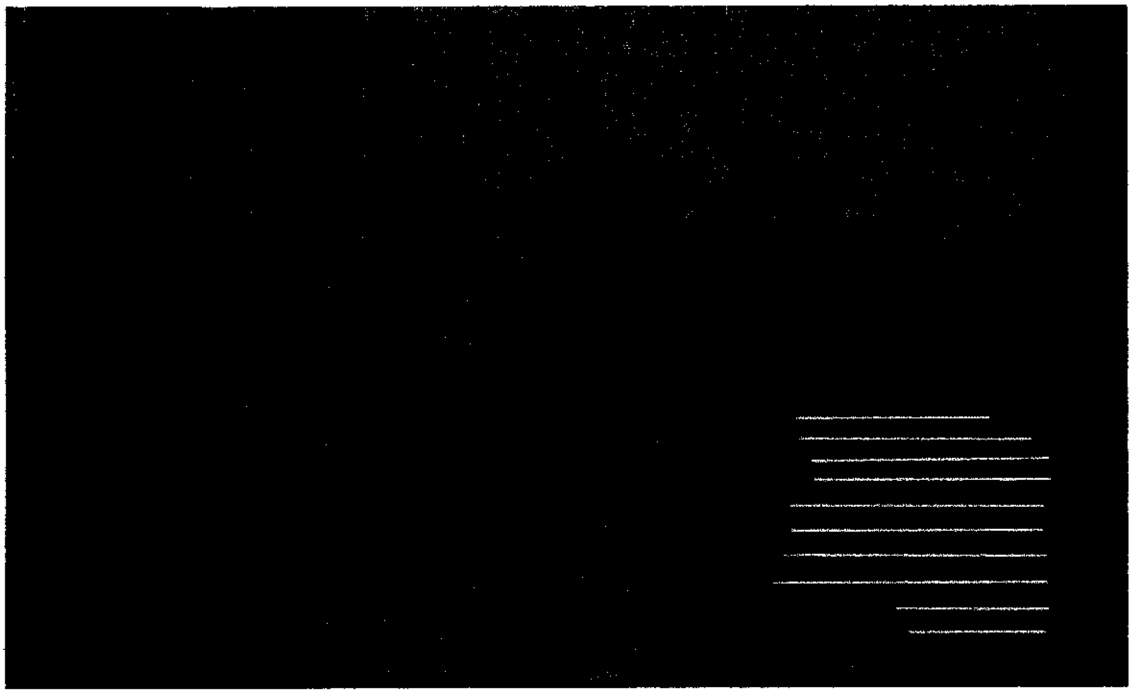

Figure 21 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.7 bar, H_{mf} = 30cm

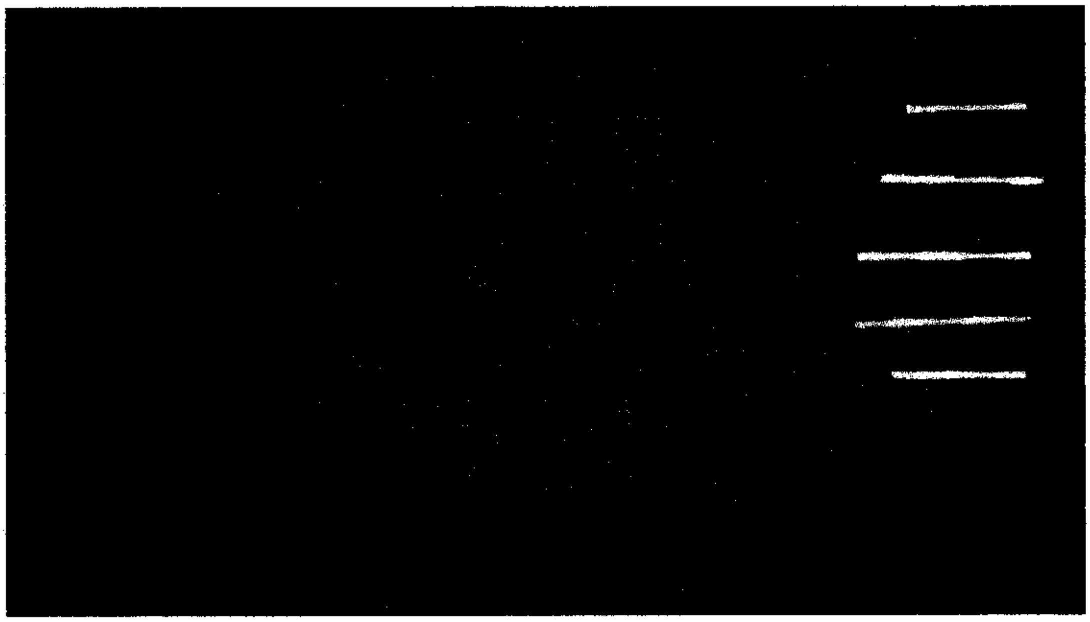

Figure 22: Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.9 bar, H_{mf} = 10cm

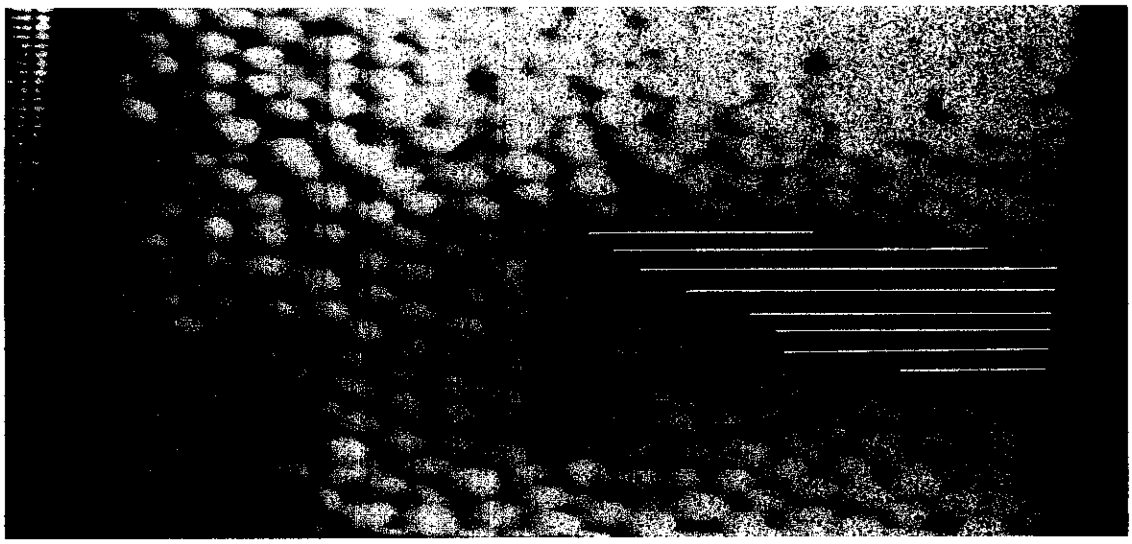

Figure 23 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.9 bar, H_{mf} = 20cm

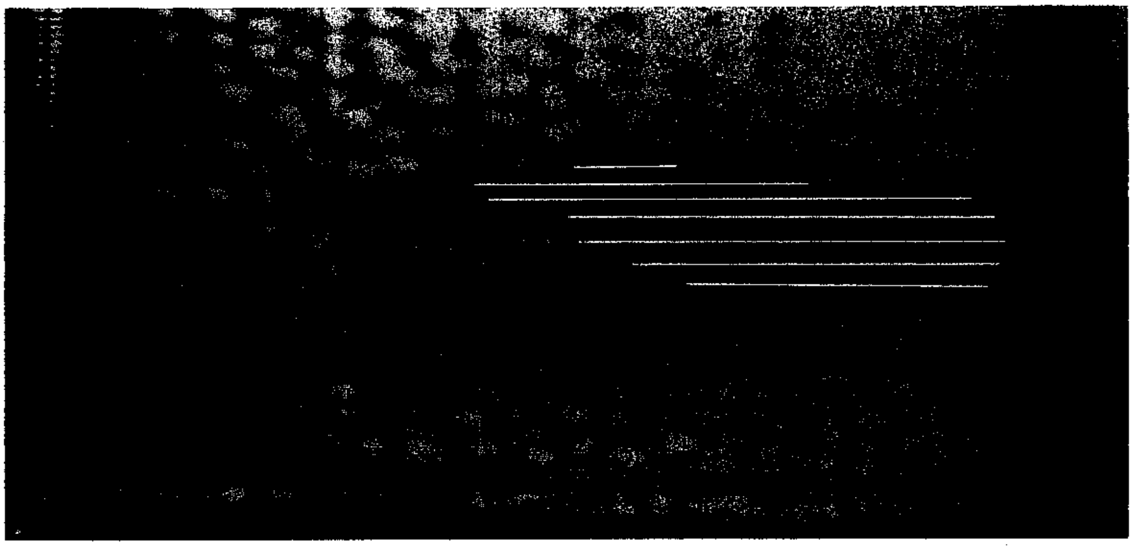

Figure 24 : Bubble diameter distribution for height above air distributor Dp = 3.35mm
Pressure = 0.9 bar, H_{mf} = 30cm

1	Selection of FYP title															
2	Submission of Extended Proposal to Supervisor															
3	Submission of draft report to Supervisor															
4	Submission of final report to FYP Coordinator															
	Briefing & Seminar															
1	FYP Briefing															
2	Seminar on "Research Methodology"															
3	Briefing on " Risk Assessment /Lab Safety/ Rules & Regulations"															
4	Briefing on " Library Facilities & How to access Journals"															

	Project Work	1	2	3	4	5	6	7		9	10	11	12	13	14	15
1	Develop objective & scope of study															
2	Research & study the journals															
3	Literature review															
4	Identify experimental parameters															
5	Develop methodology of experiment															
6	Experiment set-up															
7	Experimental work															

Figure 25: Project Gant Chart