EXPERIMENTAL STUDY OF EFFECTS OF PARTICLE SIZE DISTRIBUTION ON BUBBLE BEHAVIOR FOR VALIDATION OF CFD MODELING OF BUBBLING FLUIDIZED BED

Wenjun Wu[1], Sanoja A. Jayarathna[1], Britt M. Halvorsen[1, 2]

[1] Telemark University College, Porsgrunn, Norway
[2]Telemark Technological R&D Centre, Porsgrunn, Norway

wuwenjundfy@hotmail.com (Wenjun Wu)

Abstract

The efficiency of fluidized bed reactors depends on bubble distribution, bubble size and bubble velocity within the reactor. The sizes and size distributions of particles used in the bed may lead to different bubble behaviour. The objective of this work is to study the influence of particle size distribution on bubble behaviour. The results from the experiments will be used for validation of CFD modelling of bubbling fluidized beds.

A lab-scale two dimensional fluidized bed with a uniform air distributor is constructed. A video camera is used to record the bubble behaviour in the bed. Glass particles with a density of 2485 kg/m^3 are used in the experiments. A series of experiments are performed with different particle size distribution. All the particle mixtures have a mean particle diameter of 488 μm. The minimum fluidization velocity for the different mixtures is measured by using a flow meter. The experiments are run with different superficial gas velocities.

Bubble behaviour and bed expansion are studied. The results from experiments show that the bubble behaviour changes significantly due to changes in particle size distribution. The powders with a wide range of particle sizes show a clear tendency of segregation which influence on the bubble formation and bubble orientation in the bed. The results show that the bubble behaviour is not only dependent on the mean particle size, but also strongly influenced by the particle size distribution. Particle size distribution should be included in CFD models to obtain realistic simulations of fluidized beds.

1 Introduction

Gas-solid fluidized bed has been applied in industrial processes in a wide range. It is usually formed when a quantity of solid particles is forced to behave as a fluid, which is called fluidization. The phenomena mainly happen with the introduction of pressurized fluid or gas, which flows upwards from the bottom of the bed and through the solid medium. Under this situation, the bulk density is reduced.

Quantities, which can be recognized as significant factors that determine the fluidization mode and characteristics in a given gas-solid fluidized bed, include the design parameters, superficial fluidizing velocity, minimum fluidization velocity and minimum bubbling velocity, bubble formation, bubble velocity and so on as concluded by Horio and Nonaka [1]. Those factors are strongly affected by the particles characteristics used in fluidized bed.

In a study from Geldart [2], it was found that the performance of gas-solid fluidized system is seriously dependent upon the characterization of the particles used as the solid medium, such as density, particle size, fine content, cohesiveness, etc. One statement was widely recognized at early period that a powder with a wide range size distribution fluidized more satisfactorily than a powder having a narrow size range. However, Geldart [2] showed no effect due to size distribution via an experiment on bubble size performed in 1972 using sand with a mean particle size. This finding led to the idea of the powder groups, which is commonly called Geldart's classification [2]. According to Geldart classification, the uniformly sized particle can be classified into four groups in terms of the density difference between the particle and the fluid and by the mean particle size as presented in Figure 1.

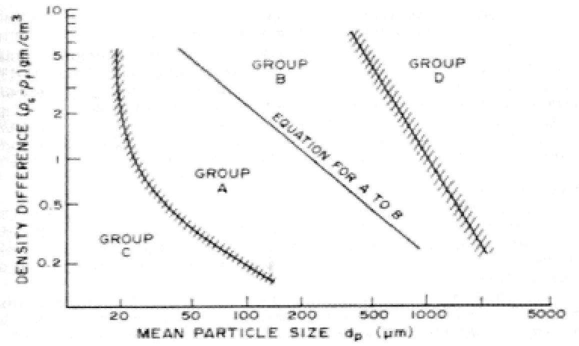

Fig. 1 Geldart diagram for particle classification [2]

Group C powders are cohesive and the fluidization of these powders is extremely difficult and bubble formation will not occur. Group D powders consist of large and/or very dense particles, and large amount of gas is needed to get these particles fluidized. Group C and D give low degree of solid mixing.

Powders characterized within Group A are easely fluidized and give a high bed expansion before bubbles appear. This type of powders has the most desirable properties for fluidization, and is mostly used as catalyst in fluidization system. Group B particles the bed expansion is low, and bubbles will appear as soon as the gas velocity reaches the minimum fluidization velocity.

2 Experimental set-up

The fluidized bed is made of Lexan glass plate, with dimensions of 0.8 m (height) × 0.2 m (width) × 0.025 m (depth), which can be considered as a two-dimensional reactor. The whole experimental set-up is shown in Fig. 2.

Glass particles with three different mean particle sizes are used here. The particles have the sizes ranged from 100~200 μm (small particle), 400~600 μm (medium particle) to 750~1000 μm (large particle) respectively. The particle density is 2485 kg/m^3. The structure of the fluidized bed is transparent and the flow behavior inside the bed could therefore be recorded by a video camera (Canon DC50). The digital visual results are obtained at a frequency of 30 Hz. A gas valve is applied here to control the gas flow, and a digital flow-meter is used to show the gas flow rate.

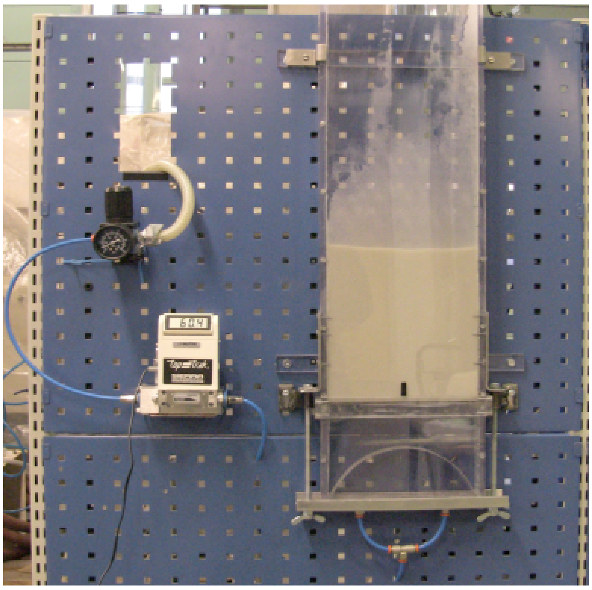

Fig. 2 Experimental set-up

The minimum fluidization velocities for each group of particles are calculated by using the Erguns equation and the simplified Erguns equation [3].

Tab. 1 Design data and operating conditions

Design			
Height	80 cm	Width	20 cm
Depth	2.5 cm	Distributor area	20 × 2.5 cm
Particles (Spherical glass)			
	100~200 μm (small)	**400~600 μm (medium)**	**750~1000 μm (large)**
Mean particle size (μm)	152	484	933
Air velocity (m/s)	0.13~0.21	0.22-0.31	0.38-0.45
u_{mf} (m/s, theoretical)	0.019	0.20	0.71
ε_{mf}	0.416, 0.433	0.378, 0.374	0.388, 0.38
Solid density (kg/m^3)	2485	2485	2485
Bulk density(kg/m^3)	1530	1600	1630
Bed height (cm)	28, 35	28, 35	28, 35

Three different mixtures are made of the three powders. The mixtures have the same mean particle size, but different particle size distribution. The aim is to study how the particle size distribution influences on particle segregation and flow behavior. The mean diameter of the mixtures is 484 μm and is the same as the mean diameter for the medium particles. The details of the mixtures are listed in Table 2:

Tab. 2 Operating conditions for mixtures

Mixture 1: 41% large particle, 59% small particle			
Mean particle size (µm)	484	Bed expansion (cm)	2
Air velocity (m/s)	0.134	Solid density (kg/m^3)	2485
Bed height (cm)	28		
Mixture 2: 29% small particle, 50% medium particle, 21% large particle			
Mean particle size (µm)	484	Bed expansion (cm)	2
Air velocity (m/s)	0.1~0.23	Solid density (kg/m^3)	2485
Bed height (cm)	28		
Mixture 3: 43% small particle, 25% medium particle, 32% large particle			
Mean particle size (µm)	488	Bed expansion (cm)	2
Air velocity (m/s)	0.12~0.25	Solid density (kg/m^3)	2485
Bed height (cm)	28		

For each group of particles, experiments are conducted with increasing air flows and two bed heights. At first, the air flow is adjusted to reach the minimum fluidization, which means the bed is just at the critical point where the bubble would show up by just increasing the air flow very slightly. The air flow rate at this point is recorded as the experimental minimum fluidization velocity of the powder. The air flow rate is raised stepwise to get different bed states, and meanwhile, the videos are taken with a length 20~25 s for each state. For the mixtures, particles are pre-mixed and introduced into rig.

3 Experimental results

3.1 Minimum fluidization velocity

Minimum fluidization velocities are measured and calculated. The comparison is shown in Fig. 3. The minimum fluidization velocities are calculated for bed height 28 and 35 cm. The particle height is not expected to influence on the fluidization velocity.

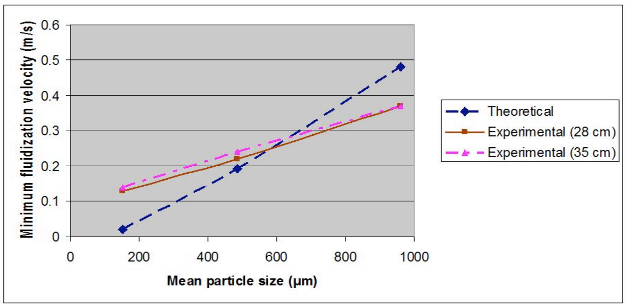

Fig. 3 Comparison of the calculated and the measured minimum fluidization velocity

According to Fig. 3, the minimum fluidization velocity increases with increasing particle size. The minimum fluidization velocities for the small and the large particles differ significantly from the theoretical velocity, whereas the minimum fluidization velocity for the medium particles agrees well with the theoretical velocity. The theoretical minimum fluidization velocity is calculated based on the mean particle size, whereas the powders in the experiment have a particle size distribution. The comparison of the curves indicates that the fluidization velocity is very much influenced of the particle size distribution. This is due to particle segregation and differences in void fraction in the bed. All the three powders are classified as Geldart group B powders. However, the small particles are close to group A particles and the large particles are close to group D particles. The medium particles are more typical group B particles. The equation used for calculating the minimum fluidization velocity is based on group B particles, and that may be another reason that the deviation between experimental and theoretical minimum fluidization velocity is less for the medium particles than for the large and small particles.

3.2 Bubble behavior

Fig. 4, 5 and 6 show movie sequences of the bubble rise for small, medium and large particles respectively. It can be seen that the bubble size, shape and velocity are influenced of the particle size in the bed.

In the small particle bed the bubbles are small and do not change significantly in size during the movement in the bed. It takes about 0.6 s for the bubble to move from the position where it is first clearly observed to top of the bed. The bubbles in the medium particle bed changes significantly in size and shape during the rise. It grows from a very small bubble into a big one, which is turbulent and tends to break up as it reaches the top. The time taken from the appearance to the top is about 0.34 s. In the large particle bed the bubble appears more clearly and it shows a tendency to split during its movement. The bubble size also increases significantly when it approaches the top of the bed. A new bubble is formed and rising before the first bubble has reached the top of the bed. The time taken from the bubble appears to it reaches the top is around 0.44 s.

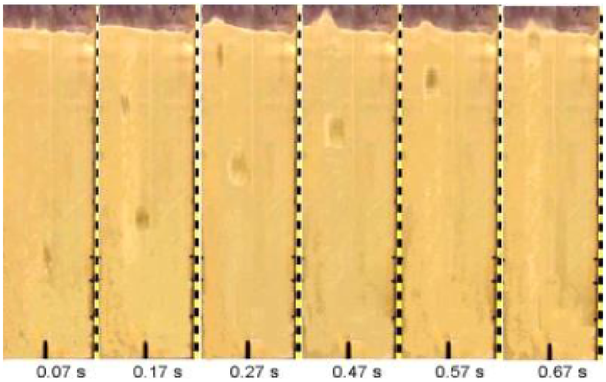

Fig. 4 Movie sequence of the bed of small particles, superficial gas velocity is 0.15 m/s

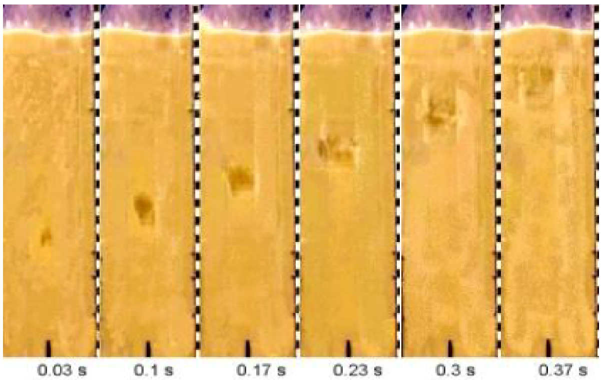

Fig. 5 Movie sequence of the bed of medium particles, superficial gas velocity is 0.26 m/s

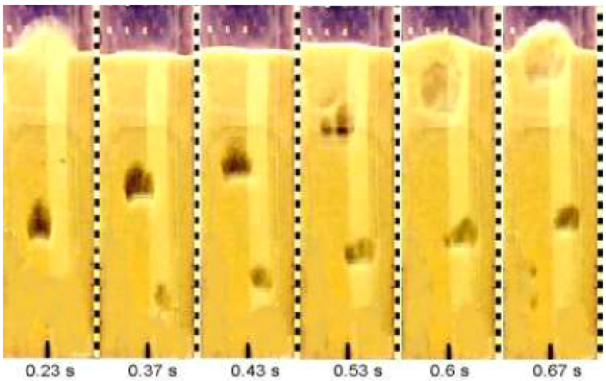

Fig. 6 Movie sequence of the bed of large particles, superficial gas velocity is 0.42 m/s

The average bubble velocity is one output from the analysis of the experimental measurements. The average velocity is calculated by using the height from where the bubble is firstly observed to the top of the bed, divided by the time consumed during the movement. Fig. 7 presents the variation of average bubble velocity with increasing superficial gas velocity.

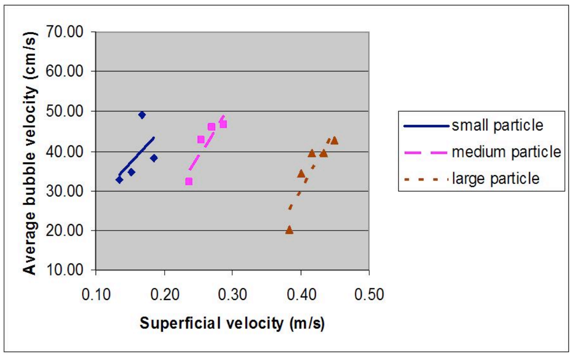

Fig. 7 Average bubble velocity as a function of superficial velocity

The average bubble velocities increase with increasing superficial gas velocity. The bubble velocities increase significantly with small increases in superficial velocities. The highest bubble velocities are observed in the small and the medium particle beds. The large particle bed has the highest bubble frequency and the largest bubbles. This is due to the high superficial gas velocity in the bed.

3.3 Study of the influence of the particle size distribution on bubble behavior

As a contribution to computational study of bubbling fluidized bed, experiments with mixtures of different powders are performed. The mixtures have the same mean particle size, 484 μm, but different particle size distribution. It is important to study the influence of particle size distribution to make a good model for CFD simulations of fluidized bed. An incorrect description of particle size may give rise to a completely deviated output, and further lead to a total uselessness of the whole simulation.

The details about the mixtures are presented in chapter 2. The three different mixtures used, have the same mean particle size, 484 μm, as the medium powder. Mixture 1 consists of 41% large particle, 59% small particle, mixture 2 is made up by 29% small particle, 50% medium particle, 21% large particle, mixture 3 is constituted by 43% small particle, 25% medium particle, 32% large particle. It can be therefore expected that the segregation may occur in beds of mixtures.

Fig. 8, 9 and 10 show the flow behavior in bed with mixture 1, 2 and 3 respectively. In all the experiments the superficial gas velocity is 0.134 m/s. The small particle bed gives a sharp segregation, where the small particles can be observed at the top and the large particles at the bottom. There is not clear bubbles observed, instead, turbulence occurs in the upper part of the bed.

In the bed with mixture 2, no bubbles are observed in the lower part of the bed. Due to the segregation of particles, the gas penetrates through a layer of larger particles and bubble appears as the gas reaches layer of the smaller particles.

The flow behavior in the bed with mixture 3 shows the same tendency as described for the medium particle bed. Bubbles appear when the gas reaches the smaller particle layer. In the lower part of the bed, the gas moves through channels with high porosity. Larger bubbles appear in the bed of the mixture 3.

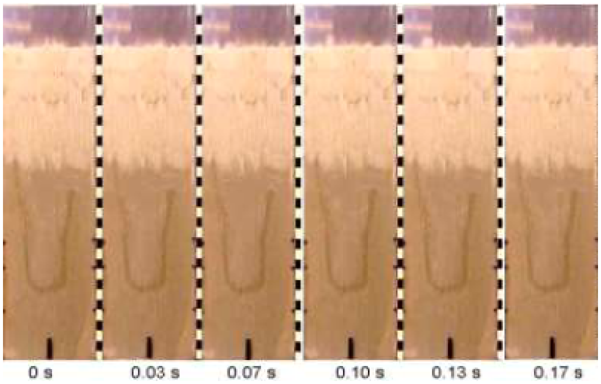

Fig. 8 Movie sequence of the bed with mixture 1, superficial gas velocity is 0.134 m/s

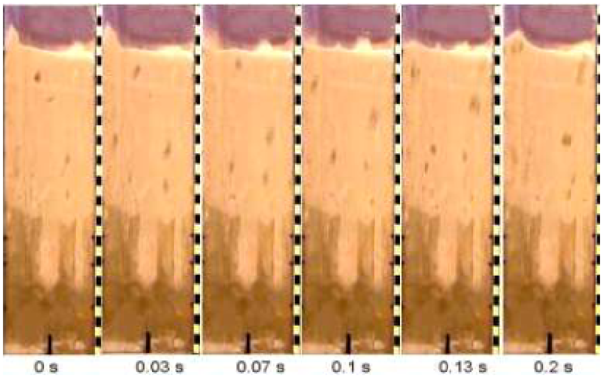

Fig. 9 Movie sequence of the bed with mixture 2, superficial gas velocity is 0.134 m/s

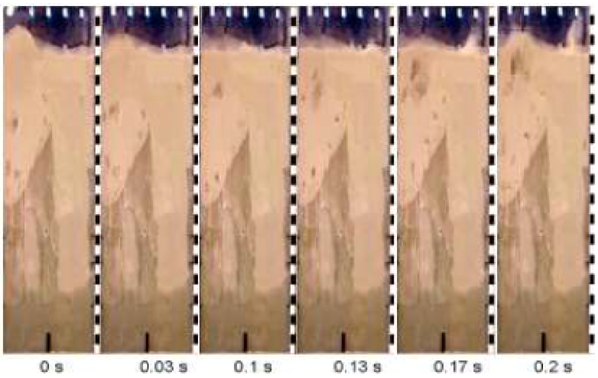

Fig. 10 Movie sequence of the bed with mixture 3, superficial gas velocity is 0.134 m/s

Also from the figures above, very sharp segregations of particles can be observed in all the three beds. Besides, channels appear apparently at the middle regions between larger and smaller particles. Bubbles show up in upper region mostly through channels from the bottom of beds. There are no bubbles at the lower layers and rarely at the layer between. It is supposed to be that the small, medium and large particles are taking the dominance of particle mixtures at upper, middle and lower layer, and decide the bubble behaviors mainly.

The experimental results show that the flow behavior in fluidized beds have strong correlation to the composition of particles, not only the mean particle size. Several simulations with the same particles and operating parameters as for the experiments are performed by S. A. Jayarathna at Telemark University College, Norway. Comparisons of computational and experimental flow behaviour are performed to verify the model that is used in the simulations. The simulations are performed with mixture 1 and mixture 2.

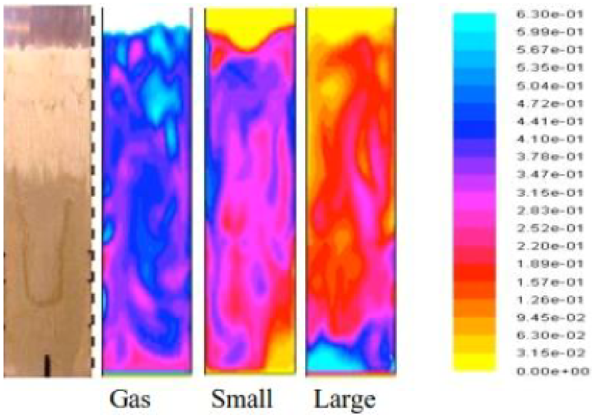

Fig. 11 Comparison of the experimental and computational results for mixture 1

Fig 11 shows the comparison of computational and experimental data for mixture 1. Small bubbles are observed in the top of the computational bed. The simulations also show a high concentration of large particles in the bottom and small particles near the top.

The contours of gas fraction in Fig. 12 show a significantly concentrated distribution of bubbles mainly at upper part of the bed. The simulation with mixture 2 also shows the segregations of small and large particles. High concentrations of the medium particles are located both in the bottom and the top of the bed.

By studying Fig. 11 and 12, it can be found that the bed behaviors revealed in simulations agree well with the experimental data. It is observed that sharp segregations occur in beds of mixtures with wide range of particle sizes. The particle segregation influences significantly on the flow behavior in the bed. Particle size distribution has to be accounted for in the simulations.

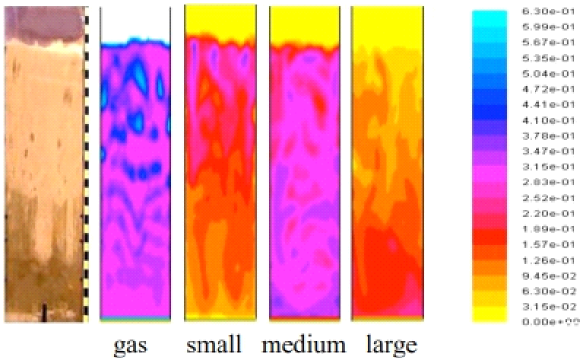

Fig. 12 Comparison of the experimental and computational results for mixture 2

4 Conclusions

The performance of bubbling fluidized bed depends strongly on the bubble behavior. A 2-D fluidized bed with dimension 0.8 m × 0.2 m × 0.025 m is constructed. The experiments are run with different powders and flow conditions. Three powders, with mean diameter of 153 µm, 484 µm and 933 µm, are used as working powders. Three mixtures consisting of different composition of the three powders are also tested. The mixtures have a mean diameter of 484 µm. The applied flow rates range from 0.13 to 0.45 m/s. The visible experimental data are analyzed and compared with computational results performed by S. A. Jayarathna at Telemark University College, 2008. The analysis of the experiments focus on minimum fluidization velocity, bubble velocity, bubble size and particle segregation. The experimental visible data is used to verify the computational results in order to investigate the effects of particle size distribution on bubble behaviors in bubbling fluidized bed. Based on the analysis, some important conclusions could be made.

The minimum fluidization velocity increases with increasing the particle size. The minimum fluidization velocities of small and large particles differ significantly from theoretical values, whereas the minimum fluidization velocity of medium particle agrees well with the theory. The reason can probably be that medium particles are more close to typical group B particles, for which the theories are more applicable. Three experiments of different powders are selected for detailed analysis. In movie sequences extracted from visual experimental data, it can be seen that bubbles have different behaviors according to size and shape in different beds of particles due to their intrinsic properties, even thought the operating conditions are similar.

The tendency is that the bubble velocity changes with distance above the distributor and the superficial velocities. The bubble velocities also increase with increasing superficial velocity. The ratio bubble velocity to superficial velocity increases with decreasing particle sizes. The bubble shape also changes with the distance above the distributor.

The experiments with the three mixtures showed that the mixtures behave in a significant different way than the medium particle does, even thought they have same mean particle size, 484 µm. The simulations show the same tendency as the experiments. Very sharp segregations of particles can be seen in all the three beds of mixtures. Besides, channels appear apparently at the middle regions between larger and smaller particles. The bed behaviors revealed in simulations fit the experimental data well. Distributions of particles are divided into three layers generally. Large particles normally stay at the bottom of the bed, while high concentration of small particles can be found at the higher level of the bed. Medium particles are distributed both in the top and in the lower region of the bed. As concluded above, behaviors of beds have a strong correlation with the size distribution of particles, not only the mean particle size. This has to be accounted for in CFD simulations of fluidized beds.

5 References

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