Effect of Temperature on Hydrodynamics of Fluidized Beds

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Abstract

The effect of temperature on some hydrodynamic parameters of bubbling gas-solid fluidized beds has been investigated. Despite the fact that most of industrial fluidized bed reactors operate at relatively high temperature, the majority of studies, concerning solids behavior and hydrodynamic correlations of fluidized beds, have been done at ambient temperature. In order to explore the bubbling fluidized bed hydrodynamics at high temperatures, experiments were carried out at different temperatures in the range of 25-700 ^oC and different superficial gas velocities in the range of 0.17-0.78 m/s in a fluidized bed of sand particles. Time-position trajectory of particles was obtained by the Radioactive Particle Tracking (RPT) technique using a radioactive tracer in the bed. With consideration of special algorithm, obtained time-position data from RPT has been used to identify the upward-moving particles (including bubble wake and ascending clusters) and downward-moving ones (descending clusters) and to separate them from the other particles which are present in emulsion phase. Hydrodynamic parameters such as velocity distribution have been investigated by proper processing of the experimental time-position data. Plotting the velocity distribution shows two peaks corresponding to downward-moving particles and upward-moving ones respectively. To study temperature effect on particle velocity, mean velocities have been plotted against temperature at each superficial gas velocity. It was concluded that mean velocities of upward and downward-moving particles increase by increasing the superficial gas velocity. In addition, at each superficial gas velocity, mean velocities of these two groups of particles increase by increasing temperature up to around 300 ^oC, however, these values decrease by continuing increase of temperature to higher than 300 ^oC.

Keywords: fluidized beds, high temperature, hydrodynamics, radioactive particle tracking (RPT)

1. Introduction

The widespread fluidized beds applications in industry and the demand for improvements in fluidization efficiency have increased the need for better understanding of fluidization phenomena. Hence, it has been tried in this study to investigate the behaviour of solids in fluidized beds and obtain more information about the flow structure of fluidized solids. A great deal of research on fluidization has been carried out at ambient temperature over the past years. However, fluidized bed reactors operate at high temperatures industrially. It bears the testimony that there is lack of studies at high temperatures which is due to difficulties associated with measuring techniques under these conditions [1]. To explore the movement of solids in gas-solid fluidized beds, Radioactive Particle Tracking (RPT) technique has been used in present study. This technique provides the three-dimensional coordinates of a radioactive tracer moving inside the bed as a function of time (x, y, z and t).

With consideration of special algorithm [2], obtained time-position data from RPT is used to identify the upward-moving particles (including bubble wake and ascending clusters) and downward-moving ones (including descending clusters). This method is able to separate these two types of particles from ones with Brownian-like motion which are present in emulsion phase.

2. Experimental

Figure 1 shows the schematics of the experimental apparatus used in this work. The fluidized bed was made of stainless steel and capable of withstanding high temperatures. It consists of a bed and freeboard of 0.078 m ID and 0.75 m in height, three heating bands, a windbox, which also serves as a pre-heater and a disengagement zone of 0.15 m ID and 0.9 m in height. The external surface of the windbox and bed were wrapped with heating bands which allow the temperature in the bed to be maintained as high as 800 ^{o}C. The gas flow rate to the reactor was measured by means of a rotameter at low gas velocities and an orifice plate at high gas velocities. The fluidizing gas in all the experiments was air. Air at ambient temperature first passes through the windbox or preheating zone and then enters the bed through a distributor. The distributor was a perforated plate made up of 1-mm holes and total free area of 0.5%. The temperatures in the bed and at various locations in the freeboard are measured using the thermocouples. A controller was used to control and maintain the temperature in the bed at the desired set point value. The bed material consists of sand particles with an average particle size of 250 μm and solid density of 2650 kg/m^3. The static height of the bed was 20 cm for all the experiments. Experiments were carried out at 7 different temperatures and 5 different superficial gas velocities. When changing the temperature from one experiment to another, the flow rate of the air was readjusted to maintain the same superficial gas velocity at the bed temperature. In these experiments, temperature was changed in the range of 25-700 ^{o}C at different superficial gas velocities (0.17-0.78 m/s). The radioactive tracer was made of scandium oxide with a density and size close to those of the bed material. It was activated to 300μ Ci in the SLOWPOKE nuclear reactor at

École Polytechnique de Montréal. Eight detectors were located around the fluidized bed to track the particle in the hot bed of sand. The sampling time in the experiments was 20 mSec.

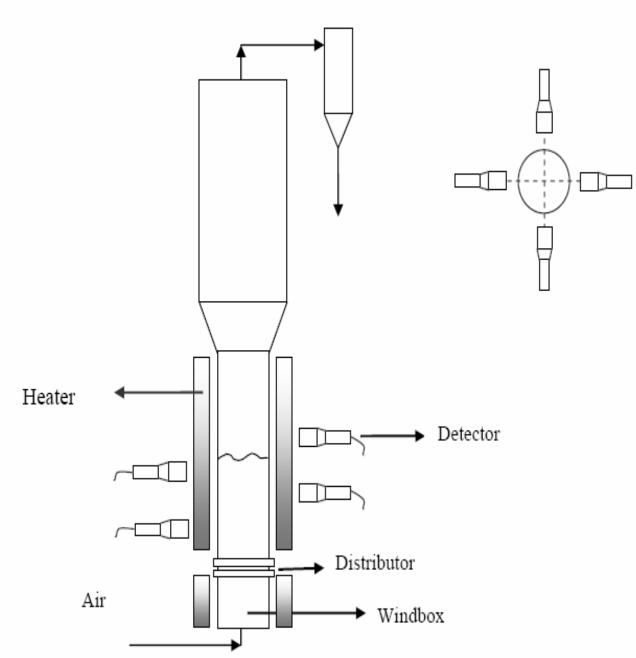

Figure 1.Schematic Illustration of Fluidized Bed Reactor

3. Data Processing

It has been shown that the particles in a gas–solid fluidized bed usually do not move as single and isolated particles [3, 4]. The particles in the bed may move as a part of emulsion, ascending cluster, descending cluster, bubble wake and the drift induced by the bubble [2, 5].

Particles in the emulsion phase can exhibit a Brownian-like motion, i.e., they move randomly in different directions. In addition, the particles in the emulsion phase can form clusters, moving either upward or downward. In a bubbling fluidized bed, it has been established that bubbles of constant size, rise at constant velocity above the bottom coalescing zone [2]. Therefore, the tracer particle rising inside the bubble wake or cloud would exhibit a constant velocity at the same velocity as the bubble and represents the bubble rise velocity. Moreover, the bulk upward movement of bubbles induces a net upward movement of emulsion in the region surrounding the bubble. Consequently, particles located in the vicinity of rising bubbles can also show persistent upward movement. Therefore, particles in the bed can be categorized into two main groups including upward-moving particles (bubble wake and ascending clusters) and downward-moving ones (descending clusters). In the present work, the axial coordinates of the particle trajectory is expected to exhibit a straight line when plotted against time, heading either up or down, respectively. It means that if the particle is associated with either upward or downward-moving bubble or cluster, its trajectory would be a straight line with positive or negative slope, respectively. Of course, the straight line in the trajectory corresponds to the constant velocity of the particle which means only bubbles and clusters which have reached their stable velocity were considered in this study. In other words, bubbles and clusters detected by such an algorithm have reached either their equilibrium size or the change in their size was negligible in the period of observation. Therefore, in the following it was assumed that the straight lines on the axial trajectory of the tracer correspond to stable bubbles and clusters, whereas, nonlinear parts of the trajectory correspond to either the random movement of the single particle in the emulsion or bubbles or clusters which have not reached their stable size. The above idea forms the basis of the algorithm for recognizing the portions associated with bubbles and clusters among the trajectories in the RPT experiments, as explained in the following section.

Calculating velocity of upward and downward-moving particles

A computer program was developed based on the above described algorithm. This program finds the linear segments of the trajectory and calculates the velocity from their slope. The program finds the linear portions of the trajectory by evaluating the correlation coefficient of each set of 10 successive data points (*z* vs *t*). The minimum number of points in each set has been set to 10 to ensure that the tracer has been associated with a bubble/cluster during a significant period. If the correlation coefficient of the set is less than 0.985, it would not be considered to be a line and thus, the tracer had not been associated with a bubble or cluster in such segment. The program would then continue the search by performing the same calculation for the next subsequent set of 10 data points. However, if the correlation coefficient of the set is equal or greater than 0.985, it would be recognized as a bubble or cluster, from slope of which their velocity could be determined. In such a case, subsequent data points were added one by one to the set in order to check if these subsequent points also belong to the same linear segment of the trajectory. This addition of subsequent point to the linear segment continues until addition of another point would lower the correlation coefficient of the set to less than 0.985.

4. Results and Discussion

The velocities of all upward and downward-moving particles were found by the above described computer program for each experiment and the velocity distribution of these movements were obtained. The velocity distribution function, $p(V)$, is defined so that $p(V)\Delta V$ is the fraction of velocity that lie in the range (V, $V+\Delta V$), i.e.,

$$p(V)\Delta V = \frac{\sum_{V}^{V+\Delta V} V_i}{\sum_{-\infty}^{+\infty} V_i}$$

As an example, Figure 2 shows such a velocity distribution at 25 ^oC and superficial gas velocity of 0.52 m/s. Obviously, there is no distribution for the velocities close to zero in this figure since this range of velocity could be associated with the random movement of particles, while such movement has been filtered out from the trajectories by the algorithm described above. However, two distinguishable segments can be observed in this distribution, corresponding to velocities of downward-moving particles and upward-moving ones. Evidently, the left peak with negative velocity indicates the velocity distribution of downward-moving particles and the right peak with positive velocity belongs to the upward-moving ones. Therefore, ascending and descending particles in the fluidized beds could be recognized by plotting the velocity distribution of these species over a significant period of the experiment.

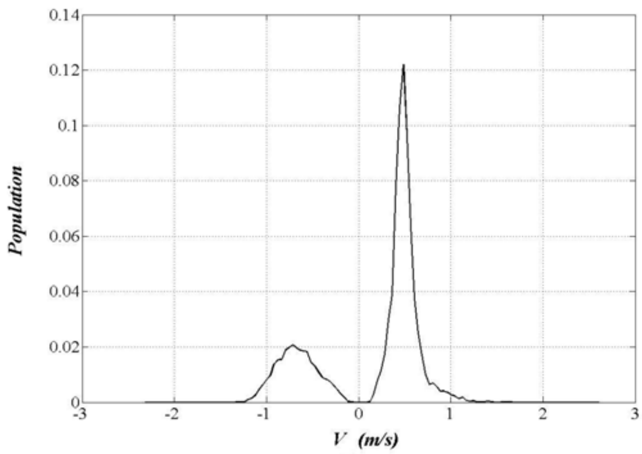

Figure 2.Velocity Distribution at Superficial Gas Velocity of 0.52 m/s and T=25 ^oC

Calculated mean velocities of upward and downward-moving particles have been plotted as a function of temperature at different superficial gas velocities in Figure 3. As expected, by increasing the superficial gas velocity, mean velocities have been increased. This means that more particles are being picked up by bubbles and ascending clusters when superficial gas velocity is increased. It can be concluded from the phenomena observed in this figure that at each superficial gas velocity, the mean velocities of these two groups of particles (upward and downward-moving particles) increase when increasing the temperature from ambient up to around 300 ^oC. However, these velocities decrease by continuing the increase of temperature to values higher than 300 ^oC. The reason for this phenomenon is that increase of temperature makes the gas density decrease and the gas viscosity increase which makes the drag force to increase after initially decrease [6].

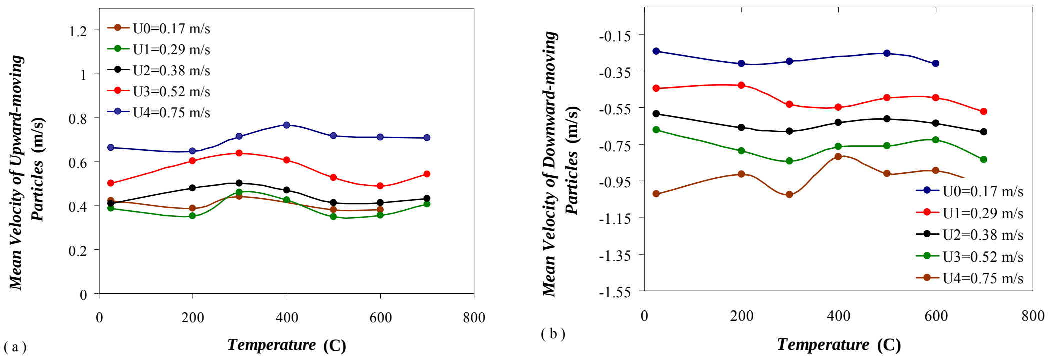

Figure 3. Mean velocity of particles as a function of temperature a) upward-moving b) downward-moving

5. Conclusion

In the present work, the radioactive particle tracking (RPT) technique was used to study the movement of particles through a fluidized bed reactor. The measured time-position data were used to calculate the particles velocities in the bed. By plotting velocity distribution of the particles, two main groups, including upward-moving particles (ascending clusters and bubbles) and downward-moving ones (descending clusters), were identified. In order to investigate the effect of temperature on the particle velocity, mean velocities were plotted against temperature at each superficial gas velocity. It was concluded that the mean velocities of upward and downward moving particles increase by increasing the superficial gas velocity. In addition, it was observed that at each superficial gas velocity the mean velocities of these two groups of particles increase by increasing the temperature from the ambient condition up to around 300 ^{o}C. However, these values decrease by continuing the increase of temperature to higher than 300 ^{o}C. The reason is that increase of temperature makes the gas density decrease and the gas viscosity increase. Therefore at a gas velocity it makes the drag force increase after initially decrease.

Nomenclature

U	superficial gas velocity, m/s
V	velocity, m/s
z	axial coordinate, m
t	time, s
$p(V)$	velocity distribution function, s/m

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