HYDRODYNAMIC CHARACTERISTICS OF A CIRCULATING FLUIDIZED BED

Gui Young Han, Geun Seong Lee and Sang Done Kim*

Department of Chemical Engineering, Korea Advanced Institute of Science and Technology, Seoul 131, Korea
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Abstract—In a circulating fluidized bed (7.8 cm-ID x 260 cm-high), flow regime of coal-air system at room temperature has been determined.

Bituminous coal particles used were either 0.73 mm or 1.03 mm in the mean diameter having density of 1400 Kg/m$^3$.

The transition velocities from bubbling to turbulent beds and the transport velocities between turbulent and fast beds have been determined. The resulting transition velocities between bubbling and turbulent beds were 103 cm/s for 0.73 mm and 130 cm/s for 1.03 mm coal particles, respectively. The transport velocities between turbulent and fast beds were 180 and 209 cm/s for 0.73 and 1.03 mm particles, respectively.

In addition, choking velocities were determined at different solid feeding rates. The resulting values were in the range of 2.55-2.65 m/s for 0.73 mm particle and of 2.77-2.84 m/s for 1.03 mm particle, respectively.

The published literature data of the transition velocity between bubbling and turbulent bed have been correlated with particle properties.

INTRODUCTION

In order to circumvent the disadvantage of the conventional combustion processes, several fluidized bed combustors have become the subject of intense research and development efforts in recent years.

One of the promising fluidized bed combustor is the circulating fluidized bed which is claimed to have excellent contacting between the solids and fluid and high processing capacity with low emission of sulfur dioxide and nitric oxides.

Consider a fluidized bed maintained at minimum fluidizing condition. As the fluidizing gas velocity increases slowly, bubble appear, and the bubbling activity intensifies due to the increase of bubble size and its frequency of formation. With further increase of gas velocity, the heterogeneous two phase flow begins to change toward a condition of increasing homogeneity until a point is reached at which large bubbles are on the absent. This condition can be termed as the onset of the turbulent regime. The absence of large bubbles in the turbulent bed may afford better contacting between gas and solid. As the fluidizing gas velocity approaches the transport velocity, there is a sharp increase in the carryover rate, and without the recycle of carry-over solids, the bed would empty in a short period of time. The fast fluidized bed is an entrained dense suspension in which considerable backmixing of solid in the form of refluxing of clusters and streamers of particles. The fast fluidized bed may have the following advantages over the bubbling fluidized bed; 1) the temperature is uniform throughout the fast bed [4], this is a consequence of the high degree of solids mixing in the fast bed [5, 13], 2) the fast bed is capable of bringing a cold solid or gas feed almost instantaneously to the bed temperature [13, 15-18], 3) heat transfer rates to wall and immersed surfaces in the fast bed are comparable to those for a bubbling fluidized bed [2, 15], 4) high processing capacity [13, 15-18], 5) the fast bed affords excellent contact between gas and solids [3, 6, 7] which provides excellent carbon burnout and high desulfurization efficiency at low CaS mole ratio [9], 6) the high gas velocities preclude appreciable backmixing of gas so that the operation might approach a plug flow condition [2, 15], 7) the fast bed ought to handle cohesive solids that might be difficult to fluidize in the bubbling bed [2, 15-18], 8) the fast bed might prove easier to scale up than bubbling bed [15-18], 9) in the fast bed, the combustion results in smaller excess air for complete combustion and reduced nitrogen oxides emission [9].

Therefore, the objective of this study is to determine the hydrodynamic characteristics of a circulating fluidized bed such as minimum fluidizing velocity, the transition velocities between bubbling and turbulent beds and...
between turbulent and fast fluidized beds. In addition, choking velocity in the given bed of solids have been determined.

**EXPERIMENTAL**

The coal used were either 0.73 mm (0.601-0.894 mm) and 1.03 mm (0.894-1.17 mm) bituminous coal with density of 1.4 g/cm³.

Experiments were carried out in a stainless steel column of 7.8 cm-ID x 260 cm-high. The details of the equipment and the particle size distributions were described previously [4]. Initially, the bed was loaded with 3.100 cm³ of coal through the feeding port at the top of the bed. Oil-free compressor air was fed to the column at the desired superficial velocities through a pressure regulator and a calibrated rotameter.

In the bubbling and turbulent fluidized beds conditions, the recycle line should be closed. Whereas, in a circulating fluidized bed condition, same amount of coal in the main bed was loaded into the auxiliary bed for recycle. When steady state was reached, the pressure profile up to the entire height of the column was measured using the water manometers.

Experimental variables in the present study are shown in Table 1.

### Table 1. Experimental Ranges of the Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Particle Size ($d_0$)</td>
<td>0.73, 1.03 mm</td>
</tr>
<tr>
<td>Superficial Air Velocity</td>
<td>1.4 – 350 cm/s</td>
</tr>
<tr>
<td>Recycle rate</td>
<td>20 – 40 Kg/hr.</td>
</tr>
<tr>
<td>Feeding rate for Choking</td>
<td>30 – 50 Kg/hr.</td>
</tr>
<tr>
<td>Condition</td>
<td></td>
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</tbody>
</table>

**RESULTS AND DISCUSSION**

1. **Minimum Fluidizing Velocity**

The minimum fluidizing velocity of the coal particles have been determined from the plot of pressure drop versus air velocity as shown in Fig 1. As can be seen from the figure that the minimum fluidizing velocities are 12.6 cm/s and 20.6 cm/s for the mean particle sizes of 0.73 and 1.03 mm, respectively.

The obtained data were compared with the values from the correlation of minimum fluidizing velocity of Wen and Yu [14]. The values from the correlation [14] were 10.8 cm/s and 21.4 cm/s for the 0.73 and 1.03 mm coal particles, respectively. Thus the present experimental values of minimum fluidizing velocities are well accord with the values from the correlation.

2. **Transition velocity between Bubbling and Turbulent Bed (Uk):**

As the gas velocity is further raised from minimum fluidizing velocity, the size of bubbles increases, which results in the extensive vertical acceleration and deceleration of the bed, and the heterogeneous two phase character of bed begins to change toward a condition of increasing homogeneity until a point is reached at which large bubbles are on the whole absent, which marks the onset of the turbulent flow regime.

The transition from bubbling to turbulent is reflected in the fluctuations of both the dynamic pressure at any point in the bed and of the pressure drop across it. In that sense, it can be characterized by two velocities, namely the velocity at which pressure fluctuations begin to diminish from their peak value ($U_c$) and the velocity at which the pressure drop fluctuations having decayed from their peak value and begin to level off ($U_k$).

With this regard, the transition velocities, $U_k$, are found to be 103 and 130 cm/s for 0.73 and 1.03 mm particles, respectively (Fig. 2, 3) since the terminal velocity of larger particle has a higher value than that of smaller one.

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**Fig. 1.** Pressure drop vs. gas velocity for minimum fluidizing velocity determination.

**Fig. 2.** Pressure fluctuation vs. gas velocity for determination of $U_c$ and $U_k$.

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