Chemical Engineering Journal 91 (2003) 215–218

Chemical Engineering Journal

www.elsevier.com/locate/cej

Studies on the onset velocity of turbulent fluidization for alpha-alumina particles

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Abstract

Transition from bubbling to turbulent fluidization regime for alpha-alumina particles was experimentally studied in the 0.15 m i.d. cold flow model. Experiments were carried out at 1 atm and ambient temperature. Both standard deviation and amplitude spectra analysis were used to determine the transition. Transition velocity of 0.8 m/s was obtained for the particles under investigation.

Keywords: Onset velocity; Turbulent fluidization; Alpha-alumina particles

1. Introduction

In turbulent fluidized beds, better gas–solid contact and higher chemical conversion could be achieved than in bubbling fluidized beds. Another advantage of turbulent fluidized beds is the ability to be scaled up without big loss of reactor efficiency [1]. However, a transition from bubbling to turbulent fluidization regime is not well defined due to differences in measurement techniques, test equipment and experimental data processing methods [2].

Turbulent fluidization is generally characterized by low-amplitude fluctuations of voidage and pressure, which are reported to correspond to the absence of large bubbles or voids [2]. To determine the transition from bubbling to turbulent fluidization, several measurement methods were reported [3,4]. They include visual observations, reading capacitance traces, pressure fluctuations, local and overall bed expansion, and gas tracer RTD measurements. To determine the transition from bubbling to turbulent fluidization, it is generally preferred to measure pressure fluctuations in fluidized beds [2,3,5–7].

The most common method to determine the transition is to study the standard deviation of pressure fluctuations. The transition occurs when a maximum at the plot standard deviation versus gas velocity is reached. Another method to determine the transition is to analyze pressure fluctuations in the frequency domain. Fast Fourier transform (FFT) analysis can be used to obtain pressure fluctuations spectra [8,9]. In bubbling and slugging beds, a dominant frequency in amplitude spectra was found corresponding to bubbles or slugs in the bed. Transitions in regimes were identified when frequency distribution in an amplitude spectra [5] or power spectra [10,11] changes.

It was reported that the transition determined using analysis of the standard deviation can be different from using amplitude spectra analysis. After having studied transition of regimes in fluidized-bed units of different geometries, Johnsson and Leckner [12] concluded that in the units where the transition of fluidization regime took place, there was a pronounced change in the frequency distribution over the transition region from the bubbling bed regime to much wider spectra in the turbulent regime. For the units in which no transition was found, there was little change in the frequency distribution for an increase in velocity. Recently, an amplitude–power spectra analysis of pressure fluctuations was used to identify the state of fluidized [5].

The objective of this work was to investigate the effects of analytical method on the determination of the transition from bubbling to turbulent regime for alpha-alumina catalyst support particles.

2. Experiments

As shown in Fig. 1, experiments were carried out in a cold flow unit with the diameter of 150 mm and the height of 2.25 m. The lower section of the unit with 0.45 in length was made of steel, and the upper part of height 1.8 m was made of glass for the ease of visual observation. One primary and

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PII: S1385-8947(02)00156-0

Nomenclature

Ar	Archimedes number defined as $Ar = [gd_p^3\rho_g(\rho_p - \rho_g)]/\mu^2$
d_p	mean particle size (m)
g	acceleration due to gravity (m/s^2)
M	divide ratio defined by Eq. (3)
f_m	median frequency (Hz)
f_{max}	maximum frequency in the chosen frequency window (Hz)
Re_c	critical Reynold's number defined as $Re_c = (\rho_g U_c d_p)/\mu_g$
U	superficial gas velocity through the pressure probe (m/s)
U_c	superficial gas velocity corresponding to the onset of turbulent fluidization (m/s)
SD	standard deviation of pressure fluctuations (Pa)
SDD	dimensionless standard deviation defined by Eq. (2)

Greek symbols

ΔP_p	pressure drop across the measuring probe (Pa)
ΔP_{av}	average pressure drop measured between two pressure ports (Pa)
ξ	dimensionless resistance coefficient of pressure probe defined by Eq. (1)
μ	gas viscosity (kg/m s)
ρ_g	gas density (kg/m^3)
ρ_p	particle density (kg/m^3)

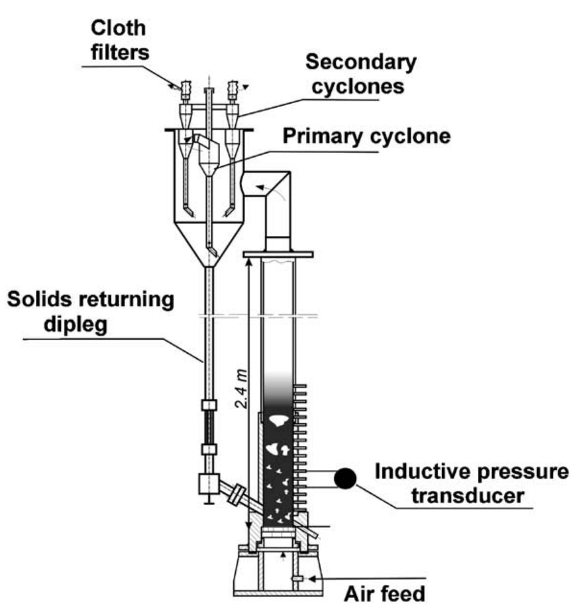

Fig. 1. Scheme of the cold flow unit.

Table 1
Particle size distribution for alpha-alumina

Particle size (μm)	wt.%
0–25	1.0
25–45	25.5
45–65	51.5
65–85	15.0
85–105	7.0
>105	0

four parallel secondary cyclones are installed at the column top to separate gas from entrained solids. Particles, captured by the cyclones are returned to the unit through a main dipleg. Cloth filters are used to further clean the gas before it is vented. A ceramic plate is used as gas distributor.

There are pressure ports on the reactor wall for every 50 mm along the height. Differential pressures fluctuations with the distance between ports of 0.05, 0.10 and 0.15 m were measured. Absolute pressure fluctuations were measured at the heights of 0.21, 0.31 and 0.36 m from the distributor. DMI inductive low-pressure transducers were used for both absolute and differential pressure measurements. Pressure fluctuations were recorded at a frequency of 100 Hz for a intervals of 40 s. The tips of all pressure probes were covered with a fine glass fiber filters to prevent blockage by particles. To avoid the pressure signals being damped by the filters, the resistance coefficient ξ was kept below 300 to minimize the effects of the filters [2], where ξ is defined as

$$\xi = \frac{\Delta P_p}{0.5\rho_g U^2} \qquad (1)$$

Experiments were carried out at atmospheric pressure and ambient temperature. Air was used for fluidization. To reduce static charge during the tests, the air was humidified. Relative humidity of air at the moistening column exit was kept at 70–80%.

Fine alpha-alumina particles of mean particle size 50 μm and particle density of 2100 kg/m^3 were used as bed material. Particle size distribution is given in Table 1. Settled bed height was 0.5 m.

The following two methods were used to study the transition from bubbling to turbulent regime.

2.1. Analysis of the standard deviation of pressure fluctuations

Similar to the methods reported by Bi and coworkers [2,3], the transition from bubbling to turbulent regime was identified when a maximum value in the standard deviation of pressure fluctuations was reached. Both dimensional and dimensionless standard deviations were used for regime transition determination. Dimensionless standard deviation was calculated as follows:

$$\mathrm{SDD} = \frac{\mathrm{SD}}{\Delta P_{av}} \qquad (2)$$

where SD is the dimensional standard deviation (Pa), ΔP_{av} the average pressure drop measured by differential pressure transducer (Pa) and SDD the dimensionless standard deviation.

2.2. Analysis of amplitude spectra of pressure fluctuations

Trnka et al. [5] applied FFT to obtain amplitude spectra of pressure fluctuations. The lines of the amplitude spectra were assorted in the degressive order for the frequency window of 1–30 Hz. The divide ratio of the amplitude spectra, M, was calculated as follows:

$$M = 1 - \frac{f_m}{f_{max}} \qquad (3)$$

where f_m is the median frequency, f_{max} the maximum frequency ($f_{max} = 30$ Hz). Value of M is was reported to be about 0.6 for the signal with random, uniformly distributed amplitudes and M approaches to zero when there is a single dominant frequency in a signal. Transition from bubbling to the turbulent regime occurs when M starts to decrease when increasing gas velocity, i.e. when dominant frequencies of pressure fluctuations start to disappear.

3. Results

As shown in Fig. 2, a clear peak of the standard deviation of differential pressure fluctuations was found at gas velocities of 0.8 m/s. The velocity is close to the transition velocity U_c calculated from the correlation proposed by Bi and Grace [2] as follows.:

$$Re_c = 1.24Ar^{0.46} \qquad (4)$$

As shown in Fig. 3, no clear peak was reached in the dimensionless standard deviation of the differential pressure fluctuations with the space between two ports of 0.26 and 0.31 m above the distributor. However, for measurements at ports of 0.36 and 0.41 m above the distributor, a peak at superficial gas velocity of 0.8–0.85 m/s.

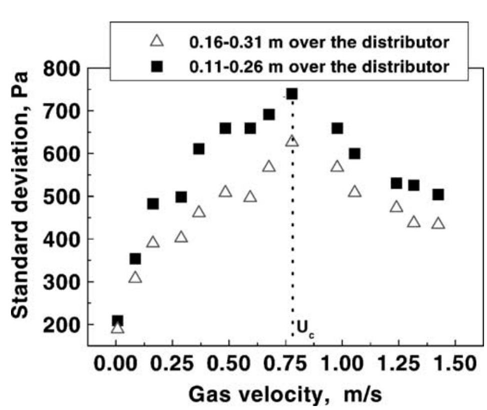

Fig. 2. Determination of the transition velocity by analysis of the standard deviation of differential pressure fluctuations.

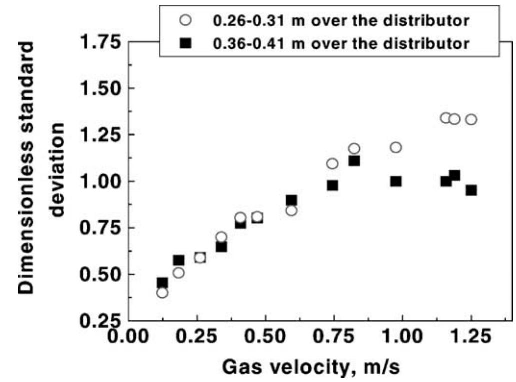

Fig. 3. Determination of the transition velocity by analysis of the dimensionless standard deviation of differential pressure fluctuations.

As shown in Fig. 4, standard deviations of the absolute pressure fluctuations reaches maximum at gas velocities 0.55–0.8 m/s. The transition velocities determined from absolute pressure measurements are lower than those from differential pressure measurements.

Amplitude spectra analysis of both absolute and differential pressure fluctuations was used to determine the transition velocity. As shown in Fig. 5, results from amplitude spectra analysis is only slightly higher than from those obtained from analysis of standard deviation of pressure fluctuations.

An example of amplitude spectra of pressure fluctuations is presented in Fig. 6. At low gas velocities of 0.06 m/s dominant frequencies in amplitude spectra of pressure fluctuations correspond to bubbles passing the pressure probe. At higher gas velocity of 0.8 m/s dominant frequencies band shifted to the lower frequency range. Meanwhile, dominant frequency amplitude rose significantly. At gas velocities above the transition velocity, U_c wider dominant frequency band and lower amplitude of the dominant frequencies were found.

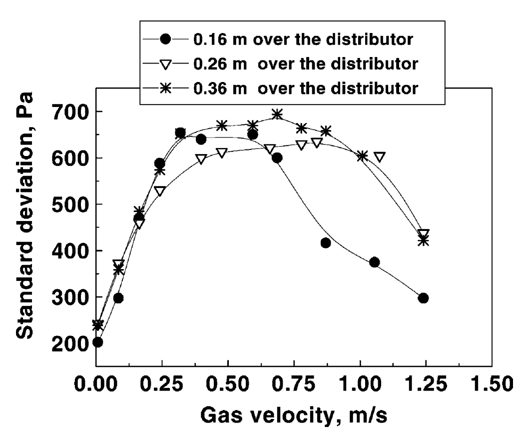

Fig. 4. Determination of the transition velocity by the analysis of the standard deviation of absolute pressure fluctuations.

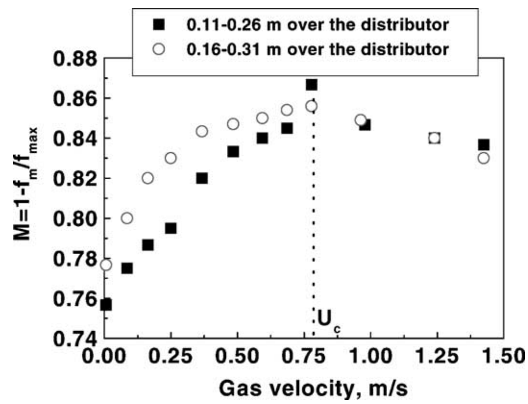

Fig. 5. Determination of the transition velocity by analysis of amplitude spectra of differential pressure fluctuations.

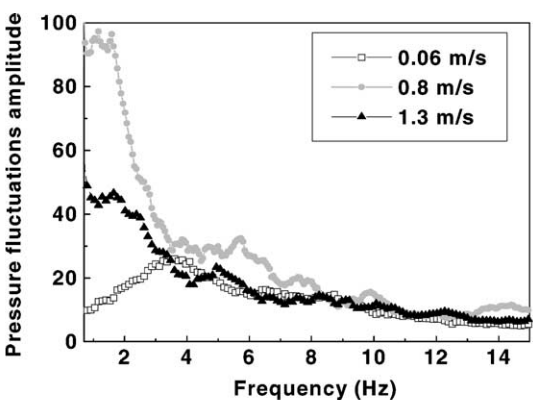

Fig. 6. Amplitude spectra of the differential pressure fluctuations at different gas velocities.

4. Conclusions

Effects of analytical method on the determination of the transition from bubbling to turbulent fluidization regime were studied. The transition velocity from bubbling to turbulent regime determined from the standard deviation of differential pressure fluctuation agreed well with from amplitude spectra analysis. For alpha-alumina particles used in this work, the transition velocity was found to be 0.8 m/s.

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