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Prediction of the fluctuation ratio for gas–solid fluidization of regular particles in a conical vessel

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Fluidization as an established fluid–solid contacting technique has found extensive applications in carbonization, gasification, combustion and many other process industries in the last four decades. In spite of the many advantages claimed for the fluidization phenomenon, the efficiency and quality of large-scale and deep gas–solid continuous fluidized beds are seriously affected by bubbling and slugging behaviour, when gas velocities are higher than the minimum fluidization velocity. Introduction of baffles to a conventional fluidizer or operation in a multistage unit can overcome some of the above mentioned difficulties. Another alternative solution to the above problems of gas–solid fluidization is the use of a conical vessel instead of a conventional cylindrical one. It has been claimed by some of the earlier investigators [6 - 8] that better solid–fluid mixing and improved quality of fluidization can be achieved in such a conical fluidizer. The gradual decrease in superficial fluid mass velocity due to varying cross-sectional area along the vertical direction in a conical bed entails the use of the continuously decreasing-sized particles for smooth and stable operation of such a fluidizer. Hence this will be of unique importance in situations where a gradual decrease of particle size is encountered along the course of a chemical reaction, like that of solid fuel combustion or gasification. Before proceeding for any reaction studies of the above type it is essential to be well acquainted with the dynamics of fluidization in conical vessels. Although some information for liquid–solid system in conical vessel is available [1 - 4] practically no work relating to the dynamics of gas–solid system has been reported. The present experimental investigations have been undertaken for the prediction of 'fluctuation ratio' in conical vessels which is an important aspect of the dynamics of gas–solid fluidization.

Apparatus

The schematic diagram of the apparatus used in the investigations is shown in Fig. 1. The cone is made using a thick Perspex sheet. The angle of the cone is 10° and the inlet diameter 4 cm. The grid consists of a screen of 60 mesh. Below this is a conical section packed with glass beads which serves as the calming section. Air, used as the fluidizing medium, is supplied from a compressor through a constant pressure reservoir. Drying of air is achieved by passing it through a silica gel tower. Two rotameters, one for lower and the other for the higher range, measure the flow rate of air. Bed pressure drop is noted with the help of two manometers, one for lower and the other for the higher rate of flow.

Procedure

A weighed amount of material is charged to the fluidizer and the slant static bed height is recorded. Air flow rate is gradually increased and the corresponding bed pressure drops are noted. After the point of incipient fluidization the expanded bed heights (slant) are also noted. As the bed fluctuates between two limits typical of gas–solid fluidization, the upper and lower surfaces of the fluctuating bed are recorded for each fluid velocity higher than the minimum fluidizing ones. Fluctuation ratio is calculated. In each of these cases vertical heights were used which in turn were estimated from the cone angle and the slant heights. The above procedure has been repeated for different amounts of samples of varying particle sizes. The properties of the

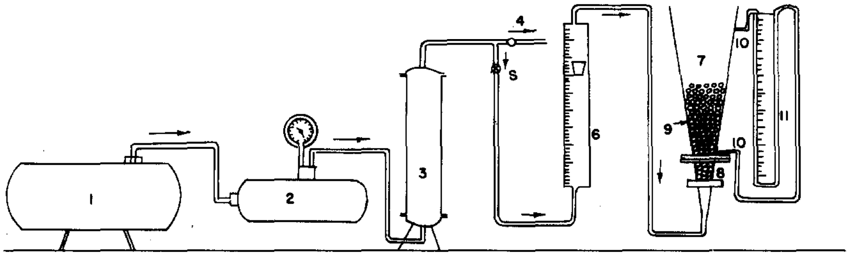

Fig. 1. Experimental apparatus: 1, compressor; 2, receiver; 3, silica gel tower; 4, bypass valve; 5, line valve, 6, rotameter; 7, conical fluidizer; 8, glass bead packing; 9, glass beads in fluidization state; 10, pressure tappings to manometer.

TABLE 1

Physical properties of fluidized bed materials

Run no.	*Material*	*Density* (kg/m^3)	*Particle size* (m)	*Amount* (kg)	*Bed height* (m)
1	glass beads	2300	3.0×10^{-3}	0.200	9.28×10^{-2}
2	glass beads	2300	1.5×10^{-3}	0.200	9.28×10^{-2}
3	glass beads	2300	0.85×10^{-3}	0.200	8.28×10^{-2}
4	glass beads	2300	1.5×10^{-3}	0.250	10.98×10^{-2}
5	glass beads	2300	1.5×10^{-3}	0.325	12.97×10^{-2}
6	glass beads	2300	1.5×10^{-3}	0.425	15.56×10^{-2}

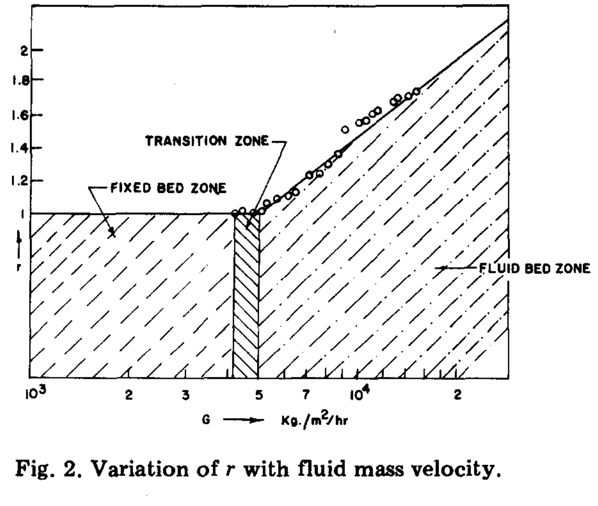

Fig. 2. Variation of r with fluid mass velocity.

fluidized materials are presented in Table 1. Variation of fluctuation ratio with fluid mass velocity has been depicted in Fig. 2 which is based on a typical experimental run.

Results and discussion

Fluctuation ratio (r) is defined as the quotient of the highest and the lowest levels, which the top of the bed occupies for any particular fluid flow rate. This varies with the fluid mass velocity as is evident from Fig. 2. However, from dimensional analysis the fluctuation ratio can be related to the characteristic groups of the system as follows.

$$r = f\left(\frac{hs}{D_c}, \frac{D_c}{dp}, \frac{G_f - G_{mf}}{G_{mf}}\right) \tag{1}$$

Equation (1) can be written as

$$r = k\left[\left(\frac{hs}{D_c}\right)^{a}\left(\frac{D_c}{dp}\right)^{b}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{c}\right] \tag{2}$$

where k is the coefficient and a, b, c are the exponents. The effects of the individual groups on r have been separately evaluated and the values of the exponents determined. Incorporating these values, eqn. (2) becomes

$$r = k\left[\left(\frac{hs}{D_c}\right)^{-2.709}\left(\frac{D_c}{dp}\right)^{0.586}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{1.0}\right]^{n} \tag{3}$$

where k = correlation coefficient, n = correlation exponent.

The values of k and n have been obtained by plotting the correlation factor against the fluctuation ratio in Fig. 3. The final correlation reads as follows

$$r = 1.43\left[\left(\frac{hs}{D_c}\right)^{-0.415}\left(\frac{D_c}{dp}\right)^{0.09}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.153}\right] \tag{4}$$

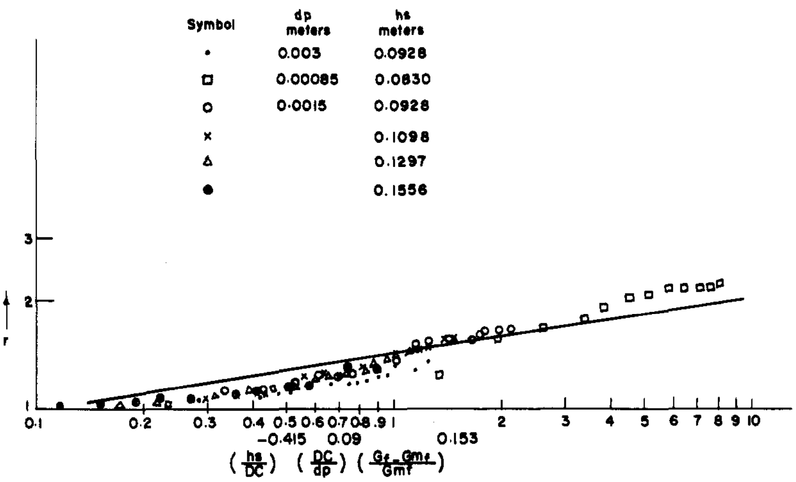

Fig. 3. Variation of r with system parameters

Symbol	*dp* (m)	*hs* (m)
•	0.003	0.0928
□	0.00085	0.0830
○	0.0015	0.0928
X		0.1098
△		0.1297
⊕		0.1556

Using the above relation fluctuation ratio has been calculated and compared with the experimental ones. It has been found that most of the calculated values agree fairly well with the experimental values. The mean and standard deviations for 75 readings have been calculated to be 7.22 and 8.63 respectively.

Conclusion

Knowledge of fluctuation ratio in gas–solid fluidization is of importance in the design of fluidized bed reactors specifically for calculation of the height. The above equation can be successfully utilized for the prediction of fluctuation ratio. However, a correlation of more generalized nature incorporating more variables like the cone angle and particle shape factor is warranted which is the proposed extension of the present investigation.

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Nomenclature

D_c	mean diameter of cone, m
dp	particle diameter, m
G	mass velocity of fluid, kg/m^2 h
G_f	mass velocity of fluid at fluidization condition, kg/m^2 h
G_{mf}	mass velocity of fluid at minimum fluidization, kg/m^2 h
hs	static bed height, m
ρ_s	density of the solid, kg/m^3
ρ_f	density of the fluid, kg/m^3
r	fluctuation ratio, dimensionless

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