Reprinted from the Journal of the Institution of Engineers (India) vol 65, pt CH 2 February 1985

UDC 66.096.5

Prediction of Fluctuation Ratio for Gas-Solid Fluidization of Irregular Particles in Conical Vessels

K C Biswal, *Non-member*
Dr G K Roy, *Member*

In this paper the relative merits of conical vessels over the conventional cylindrical ones have been highlighted. The necessity of a generalized correlation for the prediction of fluctuation ratio for gas-solid fluidization in conical vessels has been emphasized. Details of the experimental set-up and the procedure have been outlined. A correlation in terms of system parameters have been developed for the prediction of fluctuation ratio. Values of fluctuation ratio calculated with the help of the developed correlation have been compared with the experimental ones.

NOTATIONS

D_c = mean diameter of cone, m
D_o = Inlet diameter of cone, m
d_p = 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
h_s = static bed height, m
r = fluctuation ratio, dimensionless
ρ_f = density of fluid, kg/m^3
ρ_s = density of solid, kg/m^3

INTRODUCTION

Extensive applications of fluidization as a fluid-solid contacting technique have been achieved in the chemical process industries during the last several years. In-spite of the various claimed advantages, the efficiency and quality of large-scale and deep gas-fluidized beds are affected seriously by slugging, bubbling and channelling behaviour. Various solutions *viz*, incorporation of baffles, operation in a multistage unit and imparting periodic vibrations to the bed have been advocated from time to time to tackle the above mentioned problems. Introduction of conical fluidizer instead of a conventional cylindrical one has also been thought of as an alternative solution to the above problems of gas-solid fluidization in the recent past[1,2]. Better solid-fluid mixing and improved quality of fluidization can be achieved in conical fluidizer. The gradual decrease in superficial velocity due to varying cross-sectional area in a bed of conical configuration entails the use of continuously decreasing sized particles for smooth and stable operation of such a unit. This consideration is of specific importance where a gradual decrease of particle is encountered, like that of solid fuel combustion or gasification and gas-solid reactions. Prior to reaction and combustion or gasification studies a clear understanding of the dynamics of fluidization in conical vessels is of paramount importance. Although some information is available for solid-liquid system in conical vessels[2-4], information relating to gas-solid fluidization in conical vessels are very meagre[5,6]. In this communication an attempt has been made to quantify the bed fluctuation of gas-solid conical fluidized bed of irregular particles in terms of a dimensionless group called the 'fluctuation ratio'[7].

EXPERIMENTAL SET-UP

Fig 1 is the schematic diagram of the set-up. Cones with different apex angles *viz* 10°, 30°, 45° and 60° used in the investigations were made from thick perspex sheets. The inlet diameter of the cones was 4 cm. A screen of 60 mesh used at the bottom served the purpose of support as well as distributor. The calming section for the cones was filled with glass beads for uniform distribution of the fluid. Two pressure tappings, one at the entrance and the other at the exit section of the cone, were provided to record the bed pressure drop. Air used as the fluid was passed through a constant reservoir followed by a silica-gel tower. Flow rate of air was recorded with the help of rotameters, one for the lower and the other for the higher range.

Dr K C Biswal and Dr G K Roy are with Regional Engineering College, Rourkela.

This paper was received on October 3, 1983. Written discussion on this paper will be received until May 31, 1985.

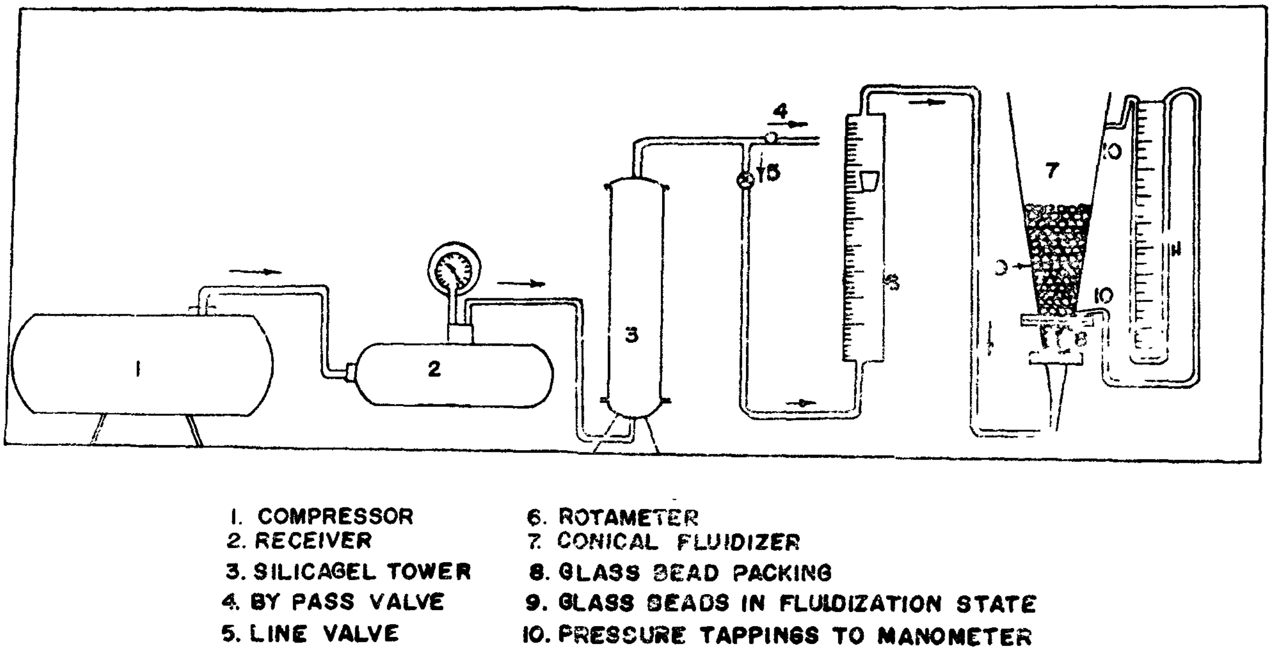

Fig 1 Experimental set-up

PROCEDURE

The fluidizer was charged with a weighed amount of material and the slant static bed height was noted. Bed pressure-drop was recorded with the gradual increase of air flow rate. After the point of incipient fluidization the expanded slant bed heights were also noted. For air flow rates higher than the minimum fluidization velocity, the fluctuation was recorded and the fluctuation ratio was calculated. The above procedure was repeated for different amount of samples of varying particle size in all the four cones. Table 1 gives an account of the experimental variables.

TABLE 1 EXPERIMENTAL VARIABLES

Cone Angle (degree)	Static Bed Height (m)	Particle Size (m)
Bed Material = Iron ore*		
Density = 5020 Kg/m^3		
10	9.2×10^{-2}	1.2×10^{-3}
10	10.7×10^{-2}	0.8×10^{-3}
10	13.0×10^{-2}	0.6×10^{-3}
10	15.4×10^{-2}	0.5×10^{-3}
30	9.2×10^{-2}	1.2×10^{-3}
30	10.7×10^{-2}	0.8×10^{-3}
30	13.0×10^{-2}	0.6×10^{-3}
30	15.4×10^{-2}	0.5×10^{-3}
45	9.2×10^{-2}	1.2×10^{-3}
45	10.7×10^{-2}	0.8×10^{-3}
45	13.0×10^{-2}	0.6×10^{-3}
45	15.4×10^{-2}	0.5×10^{-3}
60	9.2×10^{-2}	1.2×10^{-3}
60	10.7×10^{-2}	0.8×10^{-3}
60	13.0×10^{-2}	0.6×10^{-3}
60	15.4×10^{-2}	0.5×10^{-3}

* The above set of readings have been repeated for limestone ρ = 2500 kg/m^3, coal ρ = 1500 kg/m^3 and ferrosilicon, ρ = 3000 kg/m^3.

RESULTS AND DISCUSSION

Fluctuation ratio (r) is defined as the quotient of the highest and the lowest levels, which the top of the expanding bed occupies for any particular flow rate of the fluid. The variation of fluctuation ratio with fluid mass velocity has been depicted by authors elsewhere[6]. From a dimensional analysis approach, the fluctuation ratio for gas-solid fluidized beds in conical vessels can be related to the system parameters as follows :

$$r = f\left(\frac{D_c}{h_s}, \frac{d_p}{D_o}, \frac{G_f - G_{mf}}{G_{mf}}, \frac{\rho_s}{\rho_f}\right) \tag{1}$$

Equation (1) can be written as,

$$r = K\left(\frac{D_c}{h_s}\right)^a \left(\frac{d_p}{D_o}\right)^b \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^c \left(\frac{\rho_s}{\rho_f}\right)^d \tag{2}$$

Where K is the co-efficient and a, b, c and d are the exponents. The effect of individual parameters on 'r' are presented in table 2. The values of the exponents in equation (2) are evaluated by plotting the fluctuation ratio against each of the system variables. After substitution of these exponents equation 2 becomes,

$$r = K\left[\left(\frac{D_c}{h_s}\right)^{-0.74} \left(\frac{d_p}{D_o}\right)^{0.24} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.28} \left(\frac{\rho_s}{\rho_f}\right)^{-0.13}\right]^n \tag{3}$$

Where K and n are the correlation co-efficient and the correlation exponent respectively. The values of K and n have been obtained by plotting the correlation factor

$$\left(\frac{D_c}{h_s}\right)^{-0.74} \left(\frac{d_p}{D_o}\right)^{0.24} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.28} \left(\frac{\rho_s}{\rho_f}\right)^{-0.13}$$

TABLE 2 EFFECT OF VARIOUS PAPAMETERS ON FLUCTUATION RATIO

(A) EFFECT OF BED HEIGHT (STATIC) NON SPHERICAL.

Operating Parameter, $\frac{D_c}{h_s}$	Fluction · Ratio 'r'	Constant Parameter
0.390	1.525	$\frac{d_p}{D_o} = 0.0175$
0.570	1.500	
0.690	1.125	$\frac{\rho_s}{\rho_f} = 2192.9$
0.807	1.075	$\frac{G_f - G_{mf}}{G_{mf}} = 1.0$

(B) EFFECT OF DENSITY RATIO

Operating Parameter, $\frac{\rho_s}{\rho_f}$	Fluctuation Ratio 'r'	Constant Paramater
4385.9	1.30	$\frac{D_c}{h_s} = 0.57$
2631.0	1.30	$\frac{d_p}{D_o} = 0.0175$
2192.9	1.50	
1315.8	1.55	$\frac{G_f - G_{mf}}{G_{mf}} = 1.0$

(C) EFFECT OF PARTICLE SIZE

Operating Parameter $\frac{d_p}{D_o}$	Fluctuation Ratio 'r'	Constant Parameter
0.0075	1.30	$\frac{D_c}{h_s} = 0.57$
0.0097	1.30	
0.0128	1.20	$\frac{\rho_s}{\rho_f} = 2192.7$
0.0175	1.50	$\frac{G_f - G_{mf}}{G_{mf}} = 1.0$

(D) EFFECT OF FLUIDIZATION VELOCITY

Operating Parameter $\frac{G_f - G_{mf}}{G_{mf}}$	Fluctuation Ratio 'r'	Constant Parameter
0.0!89	1.000	
0.119	1.000	$\frac{D_c}{h_s} = 0.57$
0.222	1.015	
0.429	1.086	
0.431	1.144	$\frac{d_p}{D_o} = 0.0175$
0.631	1.357	$\frac{\rho_s}{\rho_f} = 2192.7$
0.883	1.448	
1.038	1.533	
1.155	1.666	
1.618	1.812	
1.910	1.888	
2.178	2.301	

against the fluctuation ratio 'r' in fig 2. The final correlation is

$$r=9.48\left[\left(\frac{D_c}{h_s}\right)^{-0.83}\left(\frac{d_p}{D_o}\right)^{0.27}\left(\frac{G_f-G_{mf}}{G_{mf}}\right)^{0.32}\left(\frac{\rho_s}{\rho_f}\right)^{-0.15}\right] \tag{4}$$

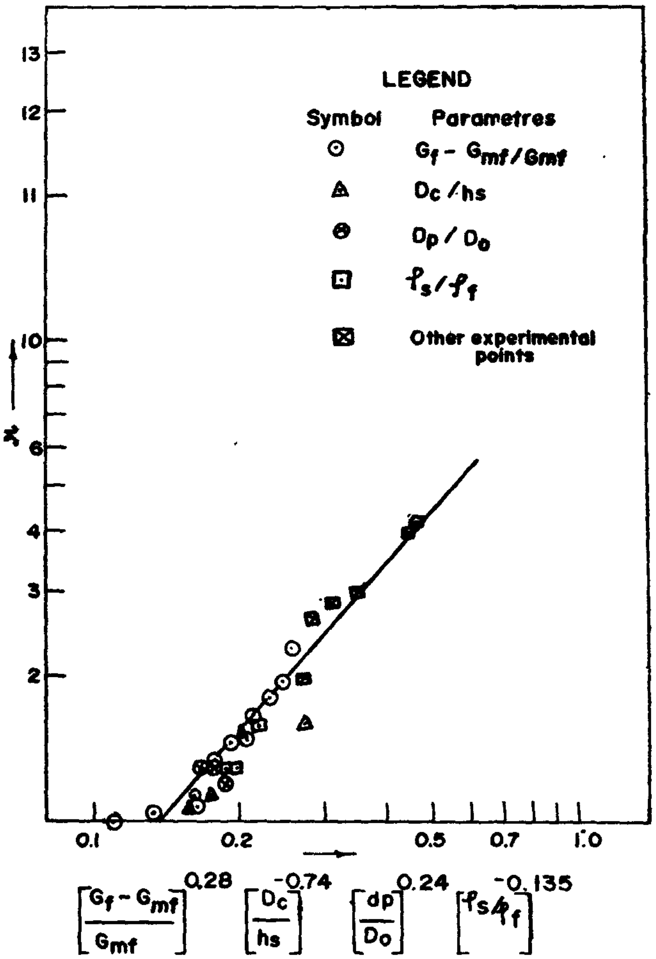

Fig 2 Relationship between fluctuation ratio and system variable

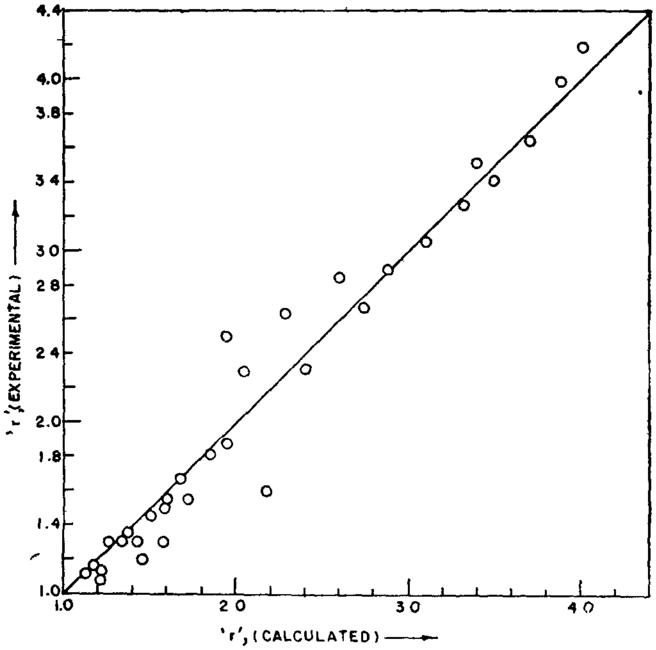

Fig 3 Comparison of experimental and calculated values of 'r'

With the help of equation 4 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 (Fig 3).

The mean and standard deviation have been calculated to be 9.6 and 12.72 respectively.

CONCLUSION

Prediction of fluctuation ratio in gas-solid fluidization is of particular importance in the design of fluidized bed reactors, gasifiers and combustors, specifically in the fixation of bed heights for such units. The developed correlation can be usd successfully for the calculation of fluctuation ratio for non-spherical particles in conical fluidized beds of varying cone angles and hence in the fixation of heights for commercial conical fluidized bed units of chemical process industries.

ACKNOWLEDGMENT

The authors are thankful to Government of India, Ministry of Education and Social Welfare for providing necessary finance to carry out the above investigation.

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