Reprinted from the Journal of the Institution of Engineers (India) vol 68 part CH 1 October 1987

UDC 66.096.5

A Quantitative Study of Fluidization Quality in Baffled and Conical Gas-Solid Fluidized Beds

S K Agarwal, *Non-member*
Dr G K Roy, *Member*

Literature relating to improvement of fluidization performance in case of gas-solid systems by the incorporation of baffles in columnar beds and use of conical conduits has been briefly reviewed. Investigations relating to gas-solid fluidization have been carried out in four different types of conduits, viz, cylindrical, baffled cylindrical with VT baffles, baffled cylindrical with ST baffles and conical. From a dimensional analysis approach, correlations have been proposed for the prediction of fluctuation ratio in terms of static and dynamic characteristics of the system for the conventional and the modified conduits. The quality of fluidization, measured in the scale of fluctuation ratio, has been compared for the above cases and the quantitative improvement achieved in case of the modified conduits over the conventional one has been presented.

NOTATIONS

d_p = particle diameter, m

D_o = inlet diameter of the fluidizer, m

G_f = superficial fluid mass velocity in fluidized state, kg/hr m^2

G_{mf} = G_f at minimum fluidization, kg/hr m^2

h_s = static bed height, m

r = fluctuation ratio, dimensionless

W_s = weight of bed material, kg

α = angle of cone, degrees

ρ_f = density of fluid, kg/m^3

ρ_s = particle density of solid bed material, kg/m^3

INTRODUCTION

As an established fluid-solid contacting technique, fluidization has found extensive applications in unit operations like drying, adsorption and in chemical processes *viz,* solid-catalyzed reactions, carbonization, gasification and combustion. In spite of the many advantages claimed of fluidization, the efficiency and the quality in large scale and deep gas-solid cylindrical fluidized beds are seriously affected by bubbling, slugging and channeling behaviour of such beds, resulting in poor gas-solid contact, lower diffusion and heat transfer rates.

The quality of fluidization can be quantified by a term called 'fluctuation ratio' which is defined as the ratio of the highest and the lowest levels which the top of the fluidized bed occupies for any particular gas flow rate. Thus a lower value of fluctuation ratio indicates less fluctuation of the top of the bed in fluidized condition and thereby better quality of fluidization with reduced bubbling and slugging.

Incorporation of baffles in the bed and fluidization in conical conduit instead of a columnar one, have been reported to result in significant improvement in the fluidization performance. A few aspects of fluidization dynamics for various types of baffled bed have been investigated by Krishnamurthy *et al*[1] and Chandra *et al*[2] in the recent past and correlations have been proposed. For gas-solid fluidization in tapered conduits Kumar *et al*[3] developed correlations for minimum fluidization velocity and pressure peak. Further investigations in conical beds relating to minimum linear fluidization velocity and fluctuation ratio for regular and irregular particles have been reported by Biswal *et al*[4-6] in form of empirical correlations. As evidenced from literature no effort has yet been made to quantitatively compare and determine the quality of fluidization, as represented by the fluctuation ratio, in case of unbaffled, baffled and conical beds. In this communication an attempt has, therefore, been made to propose correlations to predict the fluctuation ratio in terms of system parameters and to compare the quality of fluidization, in the scale of fluctuation ratio, for four different conduits, *viz,* cylindrical, baffled cylindrical (vertical and stirrer type baffles) and conical beds;

S K Agarwal and Dr G K Roy are with Regional Engineering College, Rourkela.

This paper was received on May 12, 1986, and was presented and discussed at the Annual Paper Meeting of Chemical Engineering Division held concurrently with the Second National Convention of Chemical Engineers at Rourkela on February 21-22, 1987.

EXPERIMENTAL PROCEDURE

The experimental set-up used for the investigation was a conventional one in which four different types of conduits had been used for fluidization. Fig 1 shows the details of the cylindrical and conical conduits and the baffles used in the experiment. Table 1 lists out the different experimental variables studied.

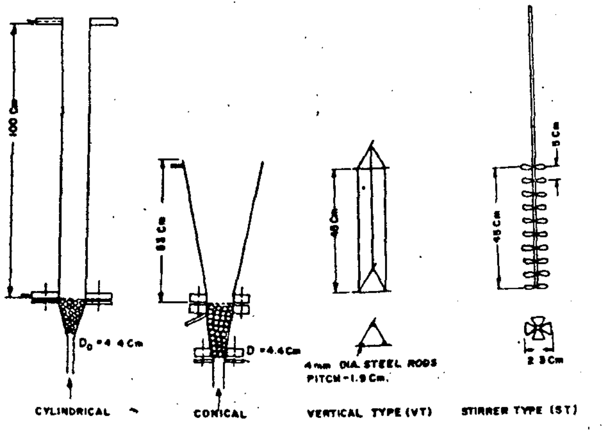

Fig 1 Conduit and baffle details

TABLE 1 EXPERIMENTAL VARIABLES

Bed Materials	ρ_s (kg/m³)	Clnduits*	Weights of Bed Material (gm)	d_p (mm)
Glass-Beads (GB)	2300	Cyl, VT, ST and Cone (45°)	250, 350, 450 and 550	2
-do-	,,	-do-	350	1, 1.5, 2.5 & 3
-do-	,,	Cone (10°, 30° and 60°)	350	2
Mustard Seed (MS)	1150	Cyl, VT and ST	175	1.5
-do-	,,	Cone (45°)	350	1.5
Urea	1335	Cyl, VT and ST	175	1.5
-do-	,,	Cone (45°)	350	1.5

* Cyl refers to cylindrical bed, VT refers to cylindrical bed with vertical baffle, ST refers to cylindrical bed with stirrer type baffle, cone refers to conical bed with apex angle within the bracket

A known weight of the bed material was charged to the column from top. The surface of the bed was made smooth by fluidizing and then allowing it to settle slowly for a number of times. The compressed and dried air was admitted to the column from a constant pressure tank maintained at 2 kg/cm². The bed pressure drop was recorded, against the fluid mass velocity in the fixed bed region and both the pressure drop and the fluctuation ratio were noted in the fluidized bed region. Minimum fluidization velocity for the different cases was then obtained by plotting separately the pressure drop against fluid mass velocity.

DEVELOPMENT OF CORRELATIONS

The fluctuation ratio is found to be a function of the static properties, *ie*, d_p, D_o, h_s, ρ_s and ρ_f and the dynamic properties, *ie*, G_f and G_{mf} in case of cylindrical columns with and without baffles. In the case of conical fluidized beds, in addition to these, another static property of importance is the apex angle of the cone.

From a dimensional analysis approach, the following correlations have been developed for the prediction of fluctuation ratio for four different conduits in terms of the static and dynamic properties of the system (Figs 2-5).

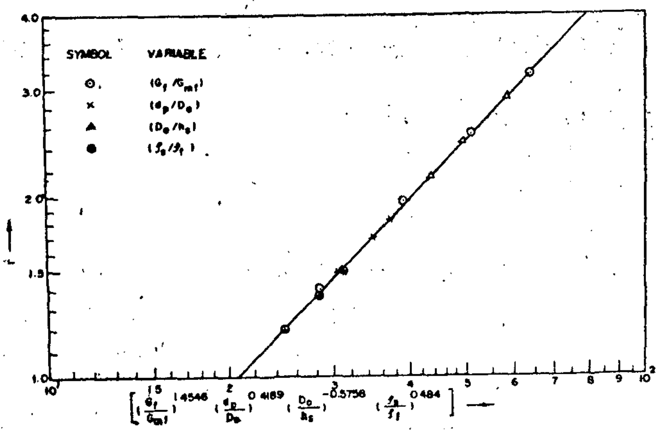

Fig 2 Relation of r with system variables for cylindrical bed

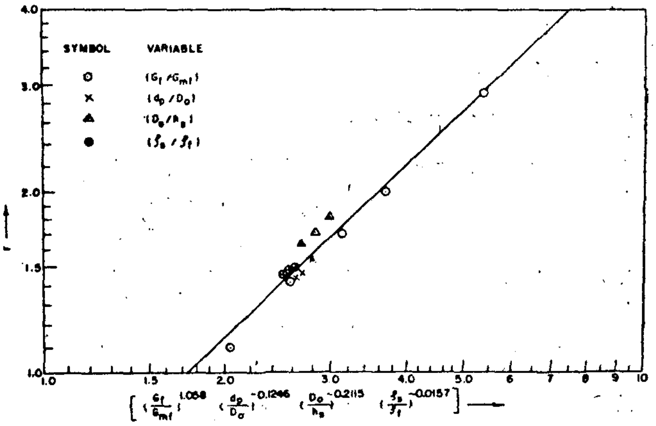

Fig 3 Relation of r with system variables for baffled cylindrical (VT) bed

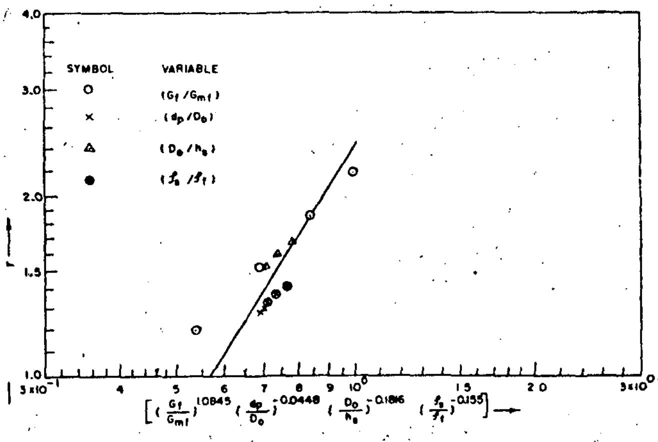

Fig 4 Relation of r with system variables for baffled cylindrical (ST) bed

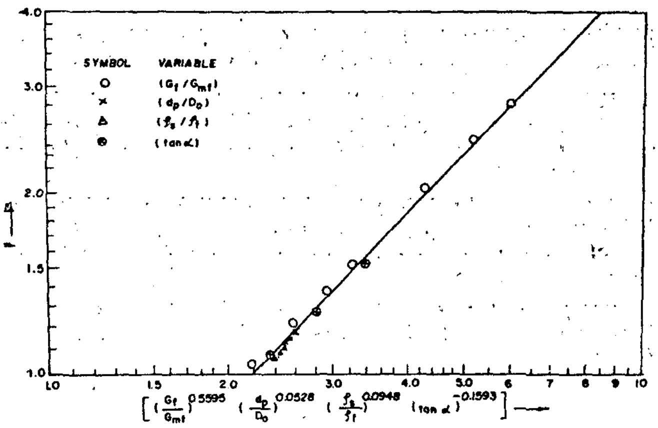

Fig 5 Relation of r with system variables for conical beds

FOR CYLINDRICAL BEDS

$$r = 0.045 \left(\frac{G_f}{G_{mf}}\right)^{1.49} \left(\frac{d_p}{D_o}\right)^{0.43} \left(\frac{D_o}{h_s}\right)^{-0.59} \cdot \left(\frac{\rho_s}{\rho_f}\right)^{0.50} \quad (1)$$

FOR BAFFLED CYLINDRICAL BEDS

(a) With vertical baffle (VT)

$$r = 0.59 \left(\frac{G_f}{G_{mf}}\right)^{1.01} \left(\frac{d_p}{D_o}\right)^{-0.12} \left(\frac{D_o}{h_s}\right)^{-0.20} \cdot \left(\frac{\rho_s}{\rho_f}\right)^{-0.02} \quad (2)$$

(b) With stirrer type baffle (ST)

$$r = 2.49 \left(\frac{G_f}{G_{mf}}\right)^{1.75} \left(\frac{d_p}{D_o}\right)^{-0.07} \left(\frac{D_o}{h_s}\right)^{-0.29} \cdot \left(\frac{\rho_s}{\rho_f}\right)^{-0.25} \quad (3)$$

and for conical beds

$$r = 0.44 \left(\frac{G_f}{G_{mf}}\right)^{0.58} \left(\frac{d_p}{D_o}\right)^{0.06} \left(\frac{\rho_s}{\rho_f}\right)^{0.10} \cdot (\tan \alpha)^{-0.17} \quad (4)$$

The values of the fluctuation ratio have been calculated by using the above equations and compared with the experimental values. In most of the cases, the values agree fairly well. Table 2 depicts the mean and standard deviations for the values of fluctuation ratio in case of the four different types of conduits used.

TABLE 2 MEAN AND STANDARD DEVIATIONS

CONDUIT	% DEVIATION	
	MEAN	STANDARD
Cylindrical	3.33	5.57
Vertical baffle (VT)	4.31	6.01
Stirrer type baffle (ST)	8.81	10.80
Conical	5.19	10.00

DISCUSSION ON RESULTS

The developed correlations (equation Nos 1-4) can be used to predict the value of the fluctuation ratio for the corresponding conduits.

The fluctuation ratio is used as' a parameter to compare the fluidization quality in different conduits. A lower value of the fluctuation ratio indicates less fluctuation of the top of the bed, resulting in smoother and better fluidization with reduced bubbling and slugging. It has been, observed from the experiments that for cases of equal particle size, weight and density of the bed material, fluidized at identical mass velocity in the four types of conduits, the fluctuation ratio decreases in the following order, *viz*, cylindrical, baffled cylindrical with vertical (VT) type baffle, baffled cylindrical with stirrer type (ST) baffle and conical beds, indicating thereby an improvement of fluidization quality in the same order.

In table 3, the percentage improvement of fluidization quality, represented by a dicrease in fluctuation ratio, has been presented for the three modified conduits compared to the conventional cylindrical one.

TABLE 3 IMPROVEMENT OF FLUIDIZATION QUALITY IN MODIFIED CONDIUTS

(With Reference to Cylindrical Bed)

EXPT VARIABLES			IMPROVEMENT OF FLUIDIZATION QUALITY, %		
ρ_s	($d_p \times 10^3$) m	Ws, kg	VT	ST	45° cone
2300	2.0	0.250	35.67	40.94	66.52
2300	2.0	0.350	31.23	32.98	63.86
2300	2.0	0.450	31.17	52.91	76.91
2300	2.0	0.550	20.81	44.98	75.48
2300	1.0	0.350	23.96	24.65	62.22
2300	1.5	0.350	17.98	27.27	58.38
2300	2.5	0 350	22.54	29.78	59.36
2300	3.0	0 350	36.84	49.71	69.82
1150	1.5	0.175	21.74	43.78	69.24
1335	1.5	0.175	35.69	50.42	70.59

CONCLUSIONS

1. The developed correlations can be used to predict the value of fluctuation ratio for the four conduits.
2. The fluidization quality has been found to improve considerably in case of baffled cylindrical and conical beds.
3. Conical fluidized beds can be subjected to much higher range of fluid mass velocity, at which the entire bed material will be entrained and carried away in case of other conduits.
4. Based on this study, the fluidization quality in existing units can be improved by the incorporation of suitable baffles and in case of new proposal, conical beds should be preferred.

REFERENCES

1. S Krishnamurthy, J S N Murthy, G K Roy and V S Pakala. 'Gas Solid Fluidization in Baffled Beds'. *Journal of the Institution of Engineers (India)*, vol 61, Pt CH 2, 1981, p 38.

2. Y Chandra, N Jagannatha Rao, P S Panesar and N Gopal Krishna. 'Continuous Gas-solid Fluidization with Internal Vertical Baffles'. *Journal of the Institution of Engineers (India)*, vol 62, Pt CH 2, 1982, p 25.

3. A Kumar, Y Chandra and N Gopal Krishna. 'Studies on Fluidization in Tapered Vessels'. *Indian Chemical Engineer*, vol 23, no 3, 1981, p 8.

4. K C Biswal, B B Samal and G K Roy. 'Dynamics of Gas-solid Fluidization of Regular Particles in Conical Vessels'. *Journal of the Institution of Engineers (India)*, vol 65, Pt CH 1, 1984, p 15.

5. K C Biswal and G K Roy. 'Prediction of Fluctuation Ratio for Gas-solid Fluidization of Irregular Particles in Conical Vessels'. *Journal of the Institution of Engineers (India)*, vol 65, Pt CH 2, 1985, p 32.

6. K C Biswal and G K Roy. 'Prediction of Minimum Fluidization Velocity for Gas-solid Fluidization of Regular Particles in Conical Vessels'. *The Chemical Engineering Journal*, UK, vol 30, 1985, p 57.

7. S K Agarwal. 'A Quantitative Study of Fluidization Quality in Various Conduits', M Sc Engineering Dissertation, *Sambalpur University*, 1983.