Reprinted from the Journal of the Institution of Engineers (India) vol 61, ft CH2 February 1981

UDC 662.9

Gas—Solids Fluidization in Baffled Beds

S Krishnamurty, *Non-member*
J S N Murty, *Non-member*
G. K. Roy, *Associate Member*
V S Pakala, *Non-member*

It has been suggested by many that the provision of baffles improves the quality of fluidization by limiting the size of bubbles. Various types of baffles such as slotted baffles, tubes, horizontal baffles and vertical baffles have been used. Of these, vertical baffles of circular cross-section have been found suitable for improving the quality of fluidization. This paper presents a study into the effect of vertical baffles on minimum fluidization velocity and quality of fluidization. Correlations are proposed for the prediction of minimum fluidization velocity and fluctuation ratio in terms of bed, gas, solid and baffle properties.

NOTATIONS

D_p = particle size, cm
D_e = equivalent diameter, cm
D_t = inner diameter of the column, cm
D_B = diameter of the baffle, cm
G = fluidization velocity, gm/cm²-sec
G_{mf} = minimum fluidization velocity, gm/cm²-sec
g = acceleration due to gravity
H = bed height, cm
N_B = number of baffles
ΔP = pressure drop across the bed, gm/cm²
r = fluctuation ratio
ρ_s = density of the solid, gm/cm³
ρ_f = density of the fluid, gm/cm³
μ_f = viscosity of the fluid, gm/cm sec

INTRODUCTION

The phenomenon of gas-solid fluidization changes drastically when scaling up is done from laboratory set-up to industrial units. This is mainly due to formation of bubbles and their behaviour in fluidization column. As the size of the reactor increases, there is more and more non-uniform fluidization phenomenon. Hence, if it is required to simulate the phenomenon observed in laboratory, it is necessary to prevent the formation of bubbles to the extent possible and ensure uniformity of fluidization. A few attempts have been made to ensure uniform fluidization by the provision of internals in the reactor and their effect is reported to be quite encouraging.

LITERATURE REVIEW

Different types of reactor internals used are diplegs, nozzles, immersed objects, slotted baffles, tubes, horizontal baffles and vertical baffles[1]. Since a baffled bed reactor has the advantages of good contact between gas and solid, which is characteristic of a fixed bed reactor, and of high heat transfer rates and low pressure drop, characteristic of a fluidized bed reactor, baffles are the most suitable as reactor internals. Overcashier, *et al*[2] reported that the use of horizontal baffles narrows the retention time spectrum of gas and solids and permits concurrent or counter-current flow while not seriously reducing gas solids throughput or solids hold up. But Glass and Harrison[3], Rowe and Everett[4] reported that the tubes obstruct, the flow of fluidizing gas so that solids immediately above the tube cannot be fluidized. Beneath a tube gas pockets will tend to collect and tubes can become increasingly enveloped by bubbles at higher gas flow rates.

Volk, *et al*[5] suggested that vertical tubular surfaces should be inserted in large diameter beds to prevent the development of very large bubbles and thereby improve the uniformity and general quality of fluidization. Yogesh Chandra, *et al*[6] showed that in the fluidized beds with vertical baffles, the fluid velocity varies from zero at the walls to the maximum at the centres of all the compartments formed by the insertion of the baffles. This variation in the fluid velocity in the bed leads to improve gas-solids contacting.

Lewis, *et al*[7] studied the solid-catalyzed hydrogenation of ethylene in a fluidized bed with multiple coarse screen baffles and without baffles. They observed that these baffles break up the emulsion phase and help the transfer of gas from one phase to the other. Due to this, there was greater gas exchange and also increased catalyst fraction was utilized for the reaction at any given velocity in the case of the reactor with baffles. Massimmilla and Johnstone[8] studied the kinetics of oxidation of ammonia in fluidized beds without baffles and also with baffles. They reported that baffled beds improved the conversion from 10 to 40% over that obtained in non-baffled fluidized reactors.

Volk, *et al*[5] recommended vertical baffles for obtaining uniform fluidization. They also indicate that this

S. Krishnamurthy, J S N Murthy, G K Roy and V S Pakala are with Regional Engineering College, Rourkela
This paper was received on May 2, 1980. Written discussion on this paper will be received until May 31,1981.

type of baffled reactors are useful for roasting reactions and other chemical reactions.

EXPERIMENTAL SET-UP

The experimental unit is shown in Fig 1. The experiments were carried out in a 7.62 cm inner diameter and 70 cm long cylindrical perspex column. Glass beads and ilmenite were used as fluidized particles. Air was used as fluidizing medium. Two rotameters, one for low range and the other for high range, were used to measure the flow rate of air. The baffles are vertical rods of mild steel of length 45.72 cm. The properties of materials and the medium used and the details of baffles are given in Table 1. The layout of baffles are shown in Figs 2 and 3. The number of baffles used are 5 and **10** of 5 mm and 3 and 5 of 12.5 mm.

EXPERIMENTAL PROCEDURE

The bed was first fluidized and then allowed to settle. Later for various flow rates of air, pressure drop was measured across the bed with the help of a manometer. The manometric liquid was carbontetrachloride. The flow rate of air was measured by a rotameter. For various flow rates of air, pressure drop across the bed was noted till the bed was completely fluidized. The change in temperature was observed to be 5°C from room temperature and the average temperature was taken as 27°C.

DEVELOPMENT OF CORRELATIONS

Correlations are developed for predicting the minimum fluidization velocity (G_{mf}) and the fluctuation ratio (r) in fluidized beds, provided with rods as internal baffles.

MINIMUM FLUIDIZATION VELOCITY

To get the value of minimum fluidization velocity, log ΔP is plotted against log G and G_{mf} values are given in Table 1.

Minimum fluidization velocity is a function of D_p, difference in the densities of solid and fluid ($\rho_s - \rho_f$), μ_f, ρ_f, H, D_e and g.

TABLE 1

MATERIAL	D_p, cm	ρ_s gm/Cm³	N_B	D_B, cm	D_e, cm	H, cm	G_{mf}, gm/cm²-sec
Glass beads	0.0851	2.6	5	0.50	22.73	11.3	0.060
Glass beads	0.0851	2.6	10	0.50	11.11	11.3	0.072
Glass beads	0.0851	2.6	3	1.25	14.23	11.3	0.068
Glass beads	0.0851	2.6	5	1.25	8.04	11.3	0.080
Ilmenite	0.0851	4.2	5	0.50	22.73	7.4	0.110
Ilmenite	0.0851	4.2	10	0.50	11.11	7.4	0.130
Ilmenite	0.0851	4.2	3	1.25	14.23	7.4	0.120
Ilmenite	0.0851	4.2	5	1.25	8.04	7.4	0.140
Glass beads	0.0486	2.6	10	0.50	11.11	5.0	0.064
Glass beads	0.0486	2.6	10	0.50	11.11	7.4	0.069
Glass beads	0.0486	2.6	10	0.50	11.11	11.3	0.075
Ilmenite	0.0486	4.2	10	0.50	11.11	7.4	0.180

From dimensional analysis,

$$\frac{D_p G_{mf}}{\mu} = f \left[\left(\frac{D_e}{D_p} \right)^f \left(\frac{H}{D_p} \right)^e \left(\frac{D_p^3 \rho_f (\rho_s - \rho_f) g}{\mu_f^2} \right)^h \left(\frac{\rho_s - \rho_f}{\rho_f} \right)^b \right] \quad (1)$$

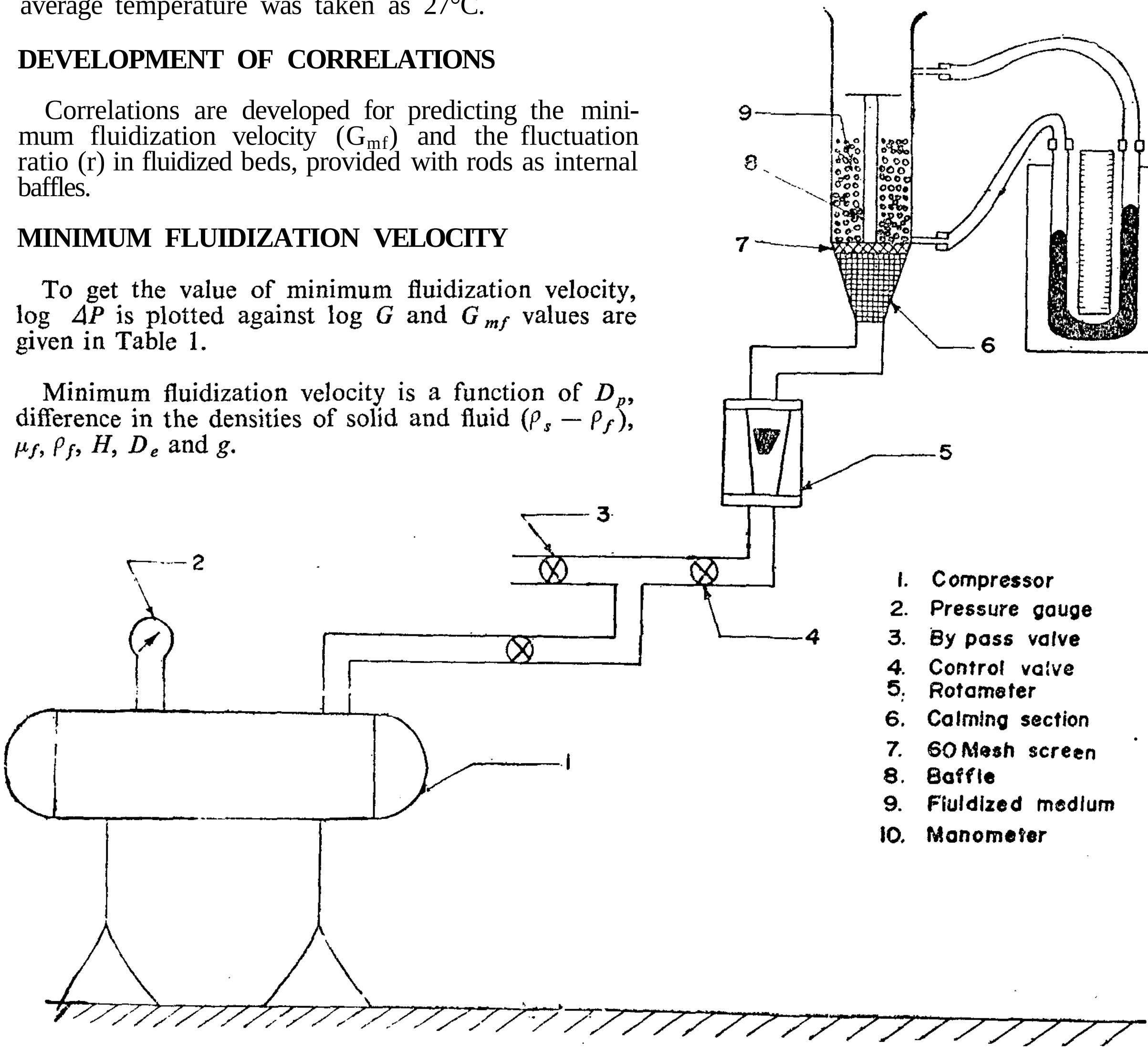

Fig 1 Experimental set-up

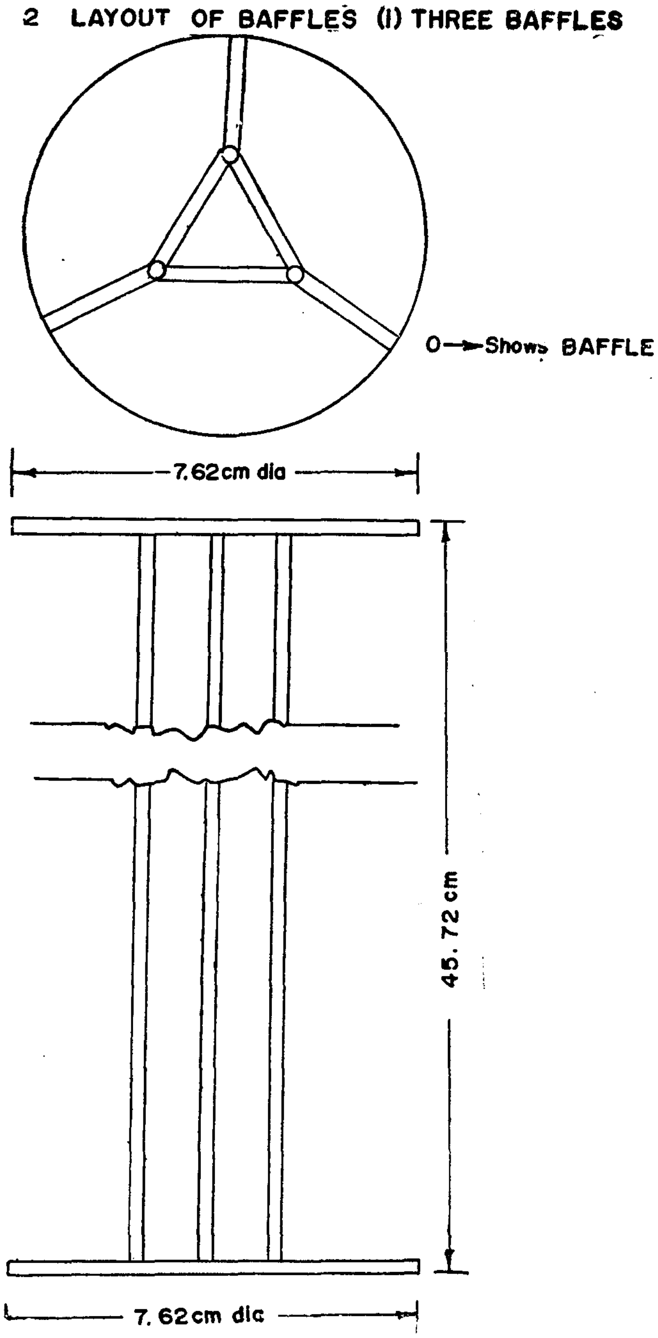

Fig 2 Layout of three baffles

Exponents of various dimensionless variables are found from experimental results.

EXPONENT OF GROUP $\left(\frac{D_e}{D_p}\right)$

To get the exponent f of $\left(\frac{D_e}{D_p}\right)$, D_e is varied keeping all the others constant so that the rest of the variables are not changed. $\log\left(\frac{D_p\,G_{mf}}{\mu}\right)$ has been plotted as a function of $\log\left(\frac{D_e}{D_p}\right)$ as shown in Fig 4. For both materials glass beads and ilmenite, the lines are parallel with a slope of 0.3. Hence, the exponent f of $\left(\frac{D_e}{D_p}\right)$ in equation (1) is 0.3.

EXPONENT OF GROUP $\left(\frac{H}{D_p}\right)$

To get the exponent e of $\left(\frac{H}{D_p}\right)$, H is varied keeping all the others constant. $\log\left(\frac{D_p\,G_{mf}}{\mu_f}\right)$ has been plotted as a function of $\log\left(\frac{H}{D_p}\right)$ as shown in Fig 5. The line has a slope of 0.18. Hence, the exponent e of $\left(\frac{H}{D_p}\right)$ in equation (1) is found to be 0.18.

EXPONENT OF GROUP $\frac{D_p^3\,\rho_f(\rho_s-\rho_f)\,g}{\mu_f^2}$-GALILEO NUMBER

To get the exponent h of Galileo number,

$$\log \frac{D_p\,G_{mf}}{\mu_f\left(\frac{D_e}{D_p}\right)^{-0.3}\left(\frac{H}{D_p}\right)^{0.18}}$$

has been plotted as a function of $\log \frac{D_p^3\,\rho_f(\rho_s-\rho_f)\,g}{\mu_f^2}$ as shown in Fig 6. For both materials glass beads and ilmenite, the lines are parallel with a slope of 0.23. Hence, the exponent h of Galileo number in equation (1) is found to be 0.23.

EXPONENT OF GROUP $\frac{\rho_s-\rho_f}{\rho_f}$

$$\text{As}\quad \frac{D_p\,G_{mf}}{\mu_f\left(\frac{D_e}{D_p}\right)^{-0.3}\left(\frac{H}{D_p}\right)^{0.18}(G_a)^{0.23}} =$$

$$f\left(\frac{\rho_s-\rho_f}{\rho_f}\right);\quad \log \frac{D_p\,G_{mf}}{\mu_f\left(\frac{D_e}{D_p}\right)^{-0.3}\left(\frac{H}{D_p}\right)^{0.18}(G_a)^{0.23}}$$

has been plotted as a function of $\log\left(\frac{\rho_s-\rho_f}{\rho_f}\right)$ as shown in Fig 7. The line has a slope of 1.34. Thus, the exponent b of $\frac{\rho_s-\rho_f}{\rho_f}$ in equation (1) is found to be 1.34.

The intercept of the line is 1.55×10^{-4}. Thus, the final correlation for minimum fluidization velocity (G_{mf}) is

$$\frac{D_p\,G_{mf}}{\mu} = 1.55\times10^{-4}\left(\frac{D_e}{D_p}\right)^{-0.3}\left(\frac{H}{D_p}\right)^{0.18}\left(\frac{D_p^3\,\rho_f(\rho_s-\rho_f)g}{\mu_f^2}\right)^{0.23}\left(\frac{\rho_s-\rho_f}{\rho_f}\right)^{1.34}$$

EXPONENT OF $\left(\frac{\rho_s - \rho_f}{\rho_f}\right)$

As

$$\frac{m}{\left(\frac{D_e}{D_t}\right)^{-1.13}\left(\frac{H}{D_t}\right)^{-0.58}\left(\frac{D_p}{D_t}\right)^{1.64}} = f\left(\frac{\rho_s - \rho_f}{\rho_f}\right)$$

$$\log \frac{m}{\left(\frac{D_e}{D_t}\right)^{-1.13}\left(\frac{H}{D_t}\right)^{-0.58}\left(\frac{D_p}{D_t}\right)^{1.64}}$$

has been plotted as a function of log $\frac{\rho_s - \rho_f}{\rho_f}$ as shown in Fig 11. The line has a slope of 1.01. Hence, the exponent a of $\frac{\rho_s - \rho_f}{\rho_f}$ in equation (2) is found to be 1.01. The line has an intercept of 24.4×10^{-2}.

Thus, final correlation for fluctuation ratio (r) is given by

$$r = e^m \left(\frac{G - G_{mf}}{G_{mf}}\right)$$

$$\text{Where } m = 24.4 \times 10^{-2}\left(\frac{D_e}{D_t}\right)^{-1.13}\left(\frac{H}{D_t}\right)^{-0.58}\left(\frac{D_p}{D_t}\right)^{1.64}\left(\frac{\rho_s - \rho_f}{\rho_f}\right)^{1.01}$$

The values calculated from this equation have been compared with the experimental ones and the deviations are found to be within + 12.5 and − 10.5%.

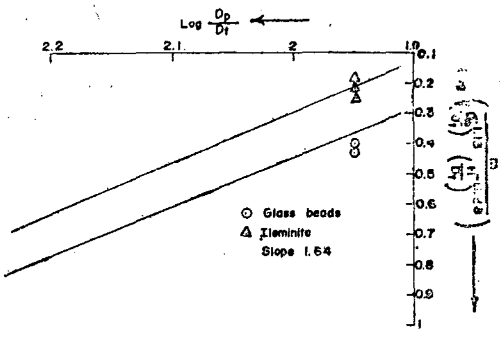

Fig 10 Effect of D_p on fluctuation ratio

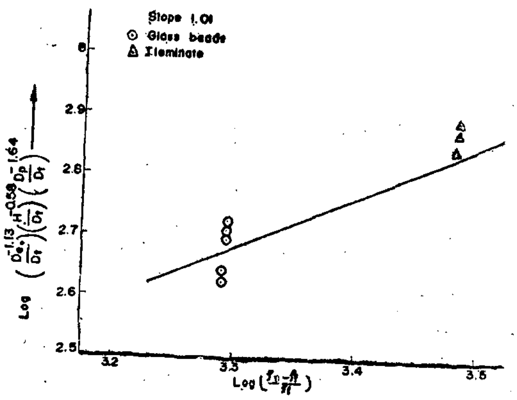

Fig 11 Effect of ρ_s on fluctuation ratio

DISCUSSION

The experiments were conducted on two materials, namely, glass beads and ilmenite of specific gravity 2.6 and 4.2. Experiments could not be conducted on materials of specific gravity more than 4.2 because of the experimental restraints such as low compressor pressure. For the same reason, bed height is also limited to 7.4 cm for ilmenite and 11.3 cm for glass beads.

Fluctuation ratio is the ratio of maximum height to minimum height. These two heights are observed visually, which is a difficult task because bubbles bursting at the bed surface throw a considerable amount of solids into the free board. Yet, it was possible to observe height fluctuations of the bed as a whole, especially near the walls, where the distinction between the projected particles and the bed surface can be observed.

EFFECT OF VARIABLES ON MINIMUM FLUIDIZATION VELOCITY

It is observed that the value of minimum fluidization velocity (G_{mf}) increases with the number of baffles (N_B) and diameter of baffles. Height of the bed (H), specific gravity of the material (ρ_s) and decreases with the increase in particle size (D_p). As equivalent diameter (D_e) increases, G_{mf} value decreases.

EFFECT OF VARIABLES ON FLUCTUATION RATIO

For the same flow rate, fluctuation ratio (r) increases with an increase in D_e and with materials of higher specific gravity. The slope of the line increases. As the bed height increases, for the same flow rate, fluctuation ratio decreases and the slope of the line decreases.

CONCLUSION

To obtain correlations of more generalized nature, it is suggested that investigations should be carried out with varied specific gravity and size of fluidized particles and different column diameters. The effect of orientation of the baffles is also to. be observed. For the same equivalent diameter, by changing *DE* and *NB*, the effect is to be observed.

REFERENCES

1. Fluidization, *Academic Press,* London.

2. R H Overcashier, D B Todd and R B Olney. *A I Ch E Journal,* no 1, vol 5, 1959, p 54.

3. D H Glass and D Harrison. *Chemical Engineering Science,* vol 19, 1964, p 1001.

4. P N Rowe and D J Evjrett. *Transactions of the Institute of Chem Engg,* vol 50, 1972, p 42.

5. W Volk.C A Johnson and H H Stotkr. *Chemical Engineering Progress,* vol 58, 1962, p 44.

6. N J Yogssh Chandra Rao, P S Paneswar and N Gopal Krishna. 29TH *Annual Session of 11 Ch E,* p 82.

7. W K Lewis, E R Gilliland and G Werner. *A I Ch E Journal,* 195 9,p 419

8. L Massimilla and H F Johnstone. *Chemical Engineering Science,* vol 16,1961, p 105.

9. M Leeva. 'Fluidization'. *Mc Graw-Hill Series in Chemical Engineering,* London.