Reprinted from the Journal of the Institution of Engineers (India), vol 57 pt CH 3 June, 1977

UDC 66 :096.5

Prediction of Pressure Drop Across A Gas-Solid Semi-fluidized Bed

Dr G K Roy, *Associate Member*
Dr K J R Sarma, *Non-member*

The necessity of a generalized correlation for prediction of pressure drop in a gas-solid semifluidized bed is emphasized. A correlation has been developed in terms of dimensionless numbers for calculating the pressure drop. The pressure drop at the onset of semi-fluidization has been chosen as the reference.

NOTATIONS

C = correction factor for pressure drop correlation in semi-fluidization.

D_c = diameter of the column, L

d_p = particle diameter, L

f = function

g_c = gravitational constant, $L\theta^{-2}$

G = mass velocity of fluid, $ML^{-2}\ \theta^{-1}$

G_{sf} = semi-fluidization mass velocity, $ML^{-2}\ \theta^{-1}$

h = overall height of column (or semi-fluidized bed), L

h_f = height of fully fluidized bed, L

h_{pa} = height of packed section in semi-fluidization, L

h_s = height of initial static bed, L

$\triangle P_a$ = additional pressure drop in the restraining plate, FL^{-2}

$\left(\frac{\triangle P}{L}\right)_f \left(\frac{\triangle P}{L}\right)_{pa}$ = pressure gradient across fluidized bed and packed bed, FL^{-3}

$\triangle P_{osf}$ = pressure drop across bed corresponding to the onset of semi-fluidization condition, FL^{-2}

$\triangle P_T$ = overall pressure drop across the semi-fluidized bed, FL^{-2}

R = bed expansion ratio in semi-fluidization, dimensionless, h/h_s

t = average fluid temperature, T (^oC)

u = linear velocity of fluid, $L\theta^{-1}$

ρ_s = density of solid, ML^{-3}

ρ_f = density of fluid, ML^{-3}

ϵ_f = porosity of fluidized bed or fluidized section of semi-fluidized bed, dimensionless

ϵ_{pa} = porosity of packed bed or packed section of semi-fluidized bed, dimensionless

μ = viscosity of fluid, $ML^{-1}\ \theta^{-1}$

INTRODUCTION

Semi-fluidization is a new type of fluid-solid contact technique. Studies relating to the dynamics of gas-solid semi-fluidization can broadly be classified into (i) prediction of the onset and the maximum semi-fluidization velocities[1], (ii) prediction of packed bed formation[2,3] and *(Hi)* prediction of pressure drop across a semi-fluidized bed.[3] The first two aspects have been exhaustively studied but the latter aspect has not been explored in detail. The available correlations indicate wide deviations between the calculated and the experimental values of pressure drop and involve laborious calculations as well. An attempt has therefore been made to develop a simplified working correlation for the prediction of the pressure drop across a gas-solid semi-fluidized bed in terms of the system parameters.

PREVIOUS WORK

Measurements of total pressure drop occurring in semi-fluidization have been first reported by Fan, *et al*[3] for gas-solid systems and the measured values have been compared with those calculated from the theoretical equation. In case of semi-fluidization, the total pressure

Dr G K Roy and Dr K J R Sarma are with Regional Engineering College, Rourkela.
This paper was received on November 20,1975. Written discussion on this paper will be received until August 31,1977.

is ideally the algebraic sum of the pressure drop across the fluidized and the packed sections. Hence

$$\triangle P_T = \left(\frac{\triangle P}{L}\right)_f (h - h_{pa}) + \left(\frac{\triangle P}{L}\right)_{pa} h_{pa} \qquad (1)$$

With the help of Leva's equation for fluidized section and Ergun's equation for the packed section,[4] equation (1) becomes

$$\triangle P_T = \frac{1}{gc}\left[150\,\frac{(1-\epsilon_{pa})^2}{\epsilon^3{}_{pa}}\,\frac{\mu u}{d_p{}^2} + 1.75\,\frac{(1-\epsilon_{pa})}{\epsilon^3{}_{pa}}\,\frac{G\epsilon u}{d_p}\right]$$

$$\left[(h_f - h)\frac{(1-\epsilon_f)}{\epsilon_f - \epsilon_{pa}}\right] + \left[h_f - \frac{(1-\epsilon_{pa})(h_f - h)}{(\epsilon_f - \epsilon_{pa})}\right]$$

$$(1-\epsilon_f)(\rho_s - \rho_f) \qquad (2)$$

Fan, *et al* measured the pressure drop in fixed and fluidized beds separately and the total pressure drop was obtained using equation (1). This has been compared with the observed bed pressure drop and also with that calculated using equation (1). It has been observed that the experimental values are nearer to those calculated by using equation (1) whereas equation (2) gave lower values.

A correction factor in terms of system parameters for the gas-solid semi-fluidized bed pressure drop was suggested by Roy and Sen Gupta[5]:

For Non-spherical Particles

$$C = \frac{(\triangle P_T)_{actual}}{(\triangle P_T)_{calculated}}$$

$$= 1.95\times10^{-1}\left[\left(\frac{D_c}{d_p}\right)^{-0.24}\left(\frac{\rho_s}{\rho_f}\right)^{0.55}\left(\frac{h_s}{D_c}\right)^{-0.94}\right.$$

$$\left.(R)^{0.72}\left(\frac{h_{pa}}{h_s}\right)^{0.29}\right] \qquad (3)$$

For Spherical Particles

$$C = \frac{(\triangle P_T)_{actual}}{(\triangle P_T)_{calculated}}$$

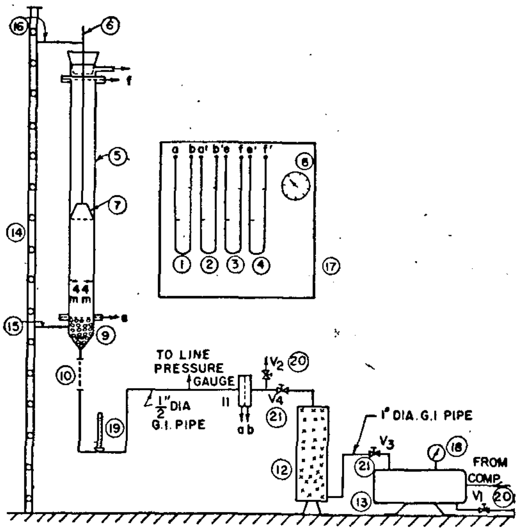
$$= 7.3\times10^{-3}\left[D_c\times\left(\frac{D_c}{d_p}\right)^{-0.53}\left(\frac{\rho_s}{\rho_f}\right)^{1.18}\left(\frac{h_s}{D_c}\right)^{-2.05}\right.$$

$$\left.(R)^{1.56}\left(\frac{h_{pa}}{h_s}\right)^{0.64}\right] \qquad (4)$$

The calculated values were obtained with the help of equation (2).

As it appears from above, the equations involve very laborious calculations for the prediction of semi-fluidized bed pressure drop.

EXPERIMENTAL WORK



1 & 2. MANOMETERS FOR ORIFICEMETER	11. ORIFICE METER
3, 4. MANOMETERS FOR BED PRESSURE DROP	12. DRYING TOWER
5. SEMIFLIDIZER	13. RESERVOIR
6. MOVABLE RESTRAINT ASSEMBLY	14. TUPPORTING STRUCTURE
7. TOP RESTRAINT	15. BASE PLATE SUPPORT
8. LINE PRESSURE GAUSE	16. CLAMP
9. DISTRIBUTOR	17. PANEL BOARD
10. FLEXIBLE CONNECTION	18. RESERVOIR PRESSURE GAUGE
a. b. ORIFICE PRESSURE TAPPINGS	19. THERMOMETER
	20. V_1, V_2 BY-PASS VALVES
	21. V_3, V_4 CONTROL VALVES
	e, f. COLUMN PRESSURE TAPPINGS

Fig 1 Schematic diagramme of the gas-solid semi-fluidization set-up

The experimental set-up used in the present study is shown in Fig 1. The semi-fluidizer was a perspex column 4.4 cm in internal diameter and 100 cm long. The bottom grid was a 60 mesh stainless steel screen. A movable restraint made up of 60 mesh brass screen and fitted to a truncated plastic cone was fixed rigidly to a mild steel rod 6.4 mm in diameter extending from the top of the semi-fluidizer. The rod could be fixed with respect to a particular position of the movable restraint by means of a clamp at the top. Two sets of manometers were provided, one for the measurement of pressure drop across orificemeter to measure the flow rate and the other for the bed pressure drop.

While taking a run, the sample was introduced into the column and the fixed bed height was noted. The movable restraint was adjusted for a particular bed expansion ratio. Pressure drops across the bed and the orifice were noted as the air flow rate was increased. The top formations were recorded after the onset of semi-fluidization. The static and expanded bed porosities were determined in separate experiments with samples of known weight.

RESULTS AND DISCUSSION

Table 1 gives physical properties of materials and ranges of variables studied. Typical data showing nature of the variation of pressure drop and packed bed formation with fluid mass velocity are presented in Table 2. These effects are illustrsted in Figs 2 and 3.

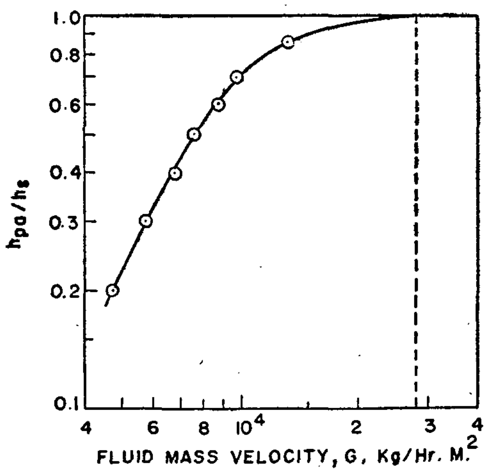
TABLE 1 PHYSICAL PROPERTIES OF MATERIALS AND RANGE OF VARIABLES STUDIED

MATERIALS USED	PARTICLE SIZE, d_p, cm	DENSITY gm/cc	FIXED BED POROSITY, ϵ_{pa}	R	h_s cm
Dolomite	0.2435	2.83	0.470		6.0
Dolomite	0.1104	,,	0.351		6.0, 8.0 10.0, 12.0
Dolomite	0.0550	,,	0.310	2.0	6.0
Dolomite	0.0388	,,	0.256	2.5	6.0
Chromite	0.1104	3.72	0.500	3.0	6.0
Baryte	0.1104	4.45	0.415	3.5	6.0
Iron Ore	0.1104	5.25	0.436		6.0

TABLE 2 VARIATION OF PRESSURE DROP AND PACKED BED FORMATION (BELOW THE TOP RESTRAINT) WITH FLUID MASS VELOCITY

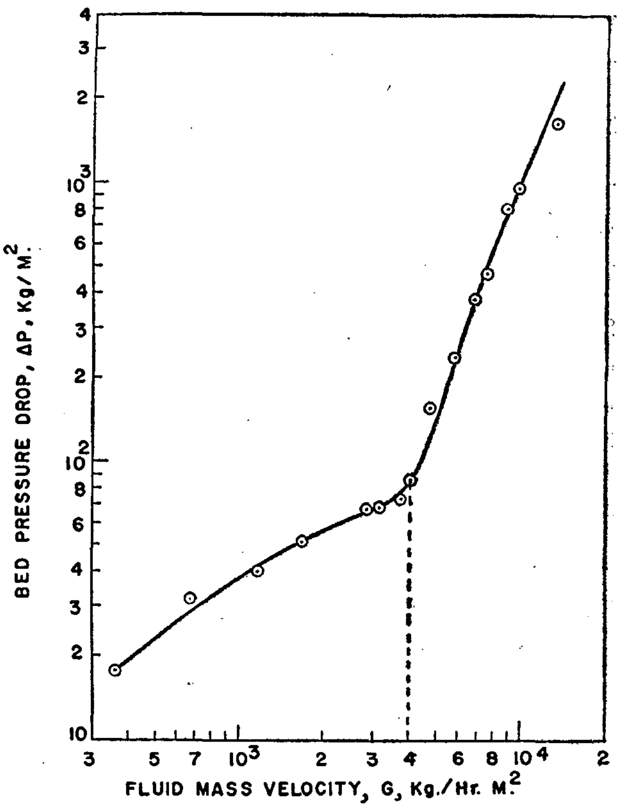
SYSTEM: DOLOMITE-AIR h_s = 6.0 cm
PARTICLE SIZE: 14/16 BSS R = 2.0
AVERAGE TEMPERATURE OF FLUID = 33°C

G, kg/hr m²	ΔP_T, kg/m²	h_{pa}, cm	$\frac{h_{pa}}{h_s}$
361.9	17.4	—	—
671.2	31.6	—	—
1 184.4	40.4	—	—
1 645.0	52.0	—	—
2 822.8	67.5	—	—
3 112.3	68.8	—	—
3 645.3	74.2	—	—
4 007.2	86.0	—	—
4 737.6	155.0	1.2	0.200
5 724.6	236.5	1.8	0.300
6 843.2	387.0	2.4	0.400
7 567.0	475.0	3.0	0.500
8 718.5	813.0	3.6	0.600
9 738.4	971.0	4.2	0.700
13 225.8	1 610.0	5.2	0.866



System: Dolomite — Air
Particle Size: 14/16 BSS Bed Expansion Ratio: 2.0
Static Bed Height: 6 CMS

Fig 2 Variation of packed bed formation with fluid mass velocity



SYSTEM : DOLOMITE-AIR
PARTICLE SIZE : 14/16 BSS
BED EXPANSION RATIO : 2.0
STATIC BED HEIGHT : 6 CMS

Fig 3 Variation of pressure drop with fluid mass velocity

DEVELOPMENT OF THE CORRELATION

As has been reported earlier and observed in the present case the porosities of the packed and fluidized-sections of the bed present difficulties in the calculation of overall pressure drop in the semi-fluidized bed. Available equations for packed bed pressure drop are quite sensitive to bed porosity variation. Hence an attempt has been made to report the semi-fluidized bed-pressure drop as a dimensionless ratio and relate it to various system variables.

A relation between the group, $\frac{\Delta P_T}{\Delta P_{osf}}$ and the other parameters can be written as

$$\frac{\Delta P_T}{\Delta P_{osf}} = f\left[\frac{D_c}{d_p}, \frac{\rho_s}{\rho_f}, R, \frac{h_s}{D_c}, \frac{h_{pa}}{h_s}\right] \quad (5)$$

During investigations it has been observed that the height of the initial static bed has no appreciable effect on the semi-fluidized bed pressure drop. In a semi-fluidized bed, the major contribution to pressure drop is due *to* the formation of packed bed below the top-restraint and is independent of the total material being; distributed in the two sections. Since the column diameter has not been altered, the effect of $\frac{h_s}{D_c}$ is not accounted for. Consequently, equation (5) reduces to,

$$\frac{\Delta P_T}{\Delta P_{osf}} = A\left(\frac{D_c}{d_p}\right)^{a_1}\left(\frac{\rho_s}{\rho_f}\right)^{a_2}(R)^{a_3}\left(\frac{h_{pa}}{h_s}\right)^{a_4} \tag{6}$$

where A is a constant and a_1, a_2, a_3 and a_4 are exponents of the system variables.

TABLE 3 EFFECT OF SYSTEM PARAMETERS ON PRESSURE DROP RATIO

(*a*) Influence of Wall Effect

Operating Parameter D_c/d_p	ΔP_{osf} kg/m²	ΔP_T kg/m²	$\Delta P_T/\Delta P_{osf}$	Constant Parameter
18.1	152.7	565.0	3.70	$\rho_s/\rho_f = 1210.0$
39.8	173.1	475.0	2.74	$R = 2.0$
80.0	176.5	402.0	2.28	$h_s/D_c = 1.363$
113.3	168.0	385.0	2.29	$h_{pa}/h_s = 0.500$

(*b*) Influence of Density Ratio

Operating Parameter ρ_s/ρ_f	ΔP_{osf} kg/m²	ΔP_T, kg/m²	$\Delta P_T/\Delta P_{osf}$	Constant Parameters
1 210.0	173.1	475.0	2.74	$D_c/d_p = 39.8$
1 590.0	171.8	613.0	3.57	$R = 2.0$
1 900.0	221.5	782.0	3.53	$h_s/D_c = 1.363$
2 244.0	286.5	980.4	3.42	$h_{pa}/h_s = 0.500$

(*c*) Influence of Bed Expansion Ratio

Operating Parameter R	ΔP_{osf} kg/m²	ΔP_T kg/m²	$\Delta P_T/\Delta P_{osf}$	Constant Parameters
2.0	173.1	475.0	2.74	$D_c/d_p = 39.8$
2.5	205.3	764.0	3.72	$\rho_s/\rho_f = 1210.0$
3.0	220.4	1 220.0	5.54	$h_s/D_c = 1.363$
3.5	231.6	2 245.0	9.69	$h_{pa}/h_s = 0.500$

(*d*) Effect of Packed Bed Formation

Operating Parameter h_{pa}/h_s	ΔP_{osf} kg/m²	ΔP_T kg/m²	$\Delta P_T/\Delta P_{osf}$	Constant Parameters
0.200	173.1	155.0	0.90	
0.300		236.5	1.37	
0.400		387.0	2.24	$D_c/d_p = 39.8$
0.500		475.0	2.74	$\rho_s/\rho_f = 1210.0$
0.600		813.0	4.70	$h_s/D_c = 1.363$
0.700		971.0	5.61	$R = 2.0$
0.866		1 610.0	9.30	

The exponents of equation (6) have been evaluated by plotting the pressure drop ratio against each of the system variables on log-log coordinates (Table 3).

After substitution of these exponents equation (6) becomes,

$$\frac{\Delta P_T}{\Delta P_{osf}} = A\left[\left(\frac{D_c}{d_p}\right)^{-0.268}\left(\frac{\rho_s}{\rho_f}\right)^{0.546}(R)^{2.160}\left(\frac{h_{pa}}{h_s}\right)^{1.570}\right]^{B} \tag{7}$$

where A is the coefficient and B the exponent of the overall product. The pressure drop ratio has been plotted against the overall product in Fig 4. The data-fits well into a straight line relation and the equation for this can be given by[6]

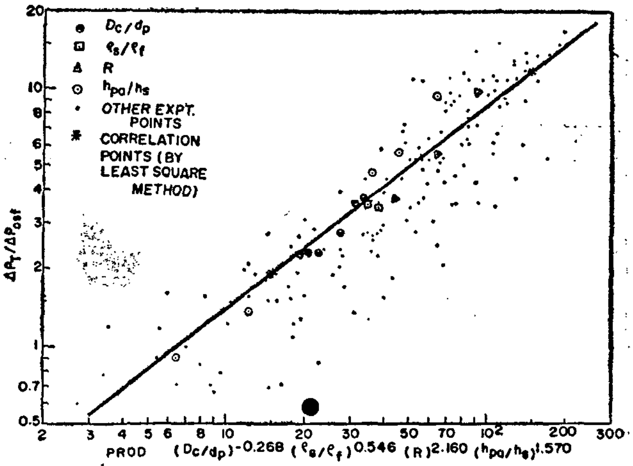


Fig 4 Relation of $\frac{\Delta PT}{\Delta Posf}$ with system variables

$$\frac{\Delta P_T}{\Delta P_{osf}} = 0.22\left(\frac{D_c}{d_p}\right)^{-0.21}\left(\frac{\rho_s}{\rho_f}\right)^{0.43}(R)^{1.71}\left(\frac{h_{pa}}{h_s}\right)^{1.24} \tag{8}$$

The values of the pressure drop calculated by using the above equation have been compared with the experimental values in Fig 5. From the figure it can be observed that there are certain points deviating much beyond the

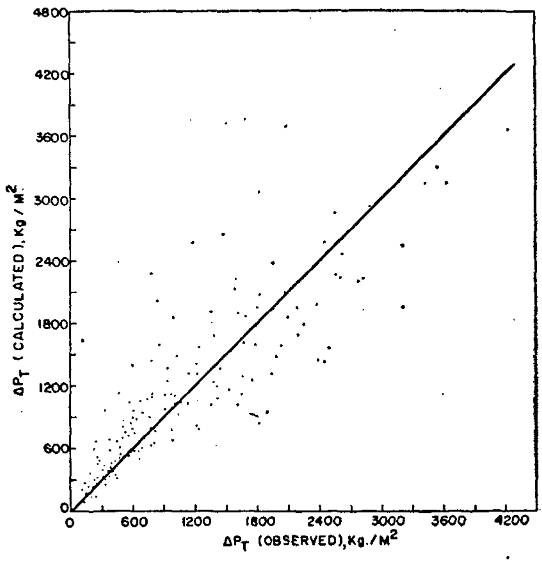


Fig 5 Comparison of pressure drop values

equilibrium line and these refer particularly to particles of large size, particles of higher density and in the regions of packed bed heights approximately that of the initial static bed height. Similar discrepancies have been observed by earlier investigaters[3]. They are of the opinion that (i) configuration of screen, (ii) the change in orientation of particles forming packed bed below the restraint, (iii) the blinding of screen or (iv) influence of particle shape may cause these deviations. Further work is warranted in these lines to give a better explanation for these variations.

ACKNOWLEDGMENTS

The authors are thankful to the BS & IR, Orissa for providing necessary finance to carry out this work.

REFERENCES

1. G K Roy and P Sen Gupta. 'Semi-fluidization: Design Study'. Processing, UK, January 1975,-p 10.

2. G K Roy and P Sen Gupta. 'Prediction of Packed Bed Height in Gas-Solid Semi-fluidization'. *Ind Eng Chem Process Des Development,* vol 13, no 3, 1974, p 219.

3. L T Fan, S C Wang and C Y Wen. 'Semi-fluidization Characteristics of Gas-Solid systems'. *A I Ch E Journal,* vol 9, 1963, p 316.

4. M Leva. 'Fluidization'. *McGraw-Hill Book Co Inc,* New York, 1959.

5. G K Roy and P Sen Gupta. 'Prediction of the Pressure Drop Across a Gas-Solid Semi-fluidized Bed'. *The Chemical Engineering Journal,* vol 5, 1973, p 191.

6. G K Roy. 'Studies on Certain Aspects of Semi-fluidization'. Ph D Thesis Submitted to Sambalpur University, 1974.