Short Communication

Prediction of pressure drop for a conical fixed bed of spherical particles in gas-solid systems

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ABSTRACT

The object of this work was to develop an equation to predict the pressure drop in conical beds of spherical particles. Work reported earlier is limited to a single cone angle in liquid-solid systems, whereas in the present study cone angles of 10°, 30°, 45° and 60° were used to predict the pressure drop for fixed beds. Air was used as the fluid medium and the bed consisted of spherical glass particles of various sizes. The constants C_1 *and* C_2 *were determined and were used to calculate pressure drop values. Experimental and theoretical values of pressure drop were compared and the mean and the standard deviation were calculated.*

1. INTRODUCTION

Packed beds are used in many chemical engineering operations such as solid-catalysed reactions, absorption, adsorption and distillation. Conical packed beds have potential application in processes such as fuel combustion and gasification, the roasting of ores and waste heat recovery. The prediction of pressure drop in such beds will be of immense help in the design of equipment for the above-mentioned applications. Furthermore, the minimum fluidization velocity in conical beds can also be calculated from a knowledge of the fixed bed pressure drop values.

2. EXPERIMENTAL DETAILS

2.1. Apparatus

Thin Perspex sheets were made into cones with varying apex angles and with an inlet diameter of 4 cm. A 60 mesh screen at the bottom served as a support as well as the distributor. The calming section for the cone was filled with glass beads for uniform distribution of fluid. Two pressure taps, one at the entrance and the other at the exit section of the cone, were provided to record the bed pressure drops. Air, used as the fluid, was passed through a constant reservoir and a silica gel tower. Two rotameters, one for the lower range and the other for the higher range, measured the flow rate of air. Figure 1 shows the details of the experimental set-up.

2.2. Procedure

For an experimental run a cone was charged with a particular size of glass beads to a definite fixed bed height. The variation in pressure drop with fluid mass velocity was monitored until there was initiation of particle movement in the bed. The particle size as well as the fixed bed height were altered in subsequent runs. This procedure was repeated for the other cones. The ranges of the experimental variables were as follows: apex angle of cone (deg), 10, 30, 45, 60; initial fixed bed height (cm), 9.2,10.7,13.0, 15.4; particle size (cm), 0.1, 0.15, 0.20, 0.25, 0.30.

3. DEVELOPMENT OF CORRELATION

On the basis of Ergun's [1] equation and the modification of Baskakov and Gelperin [2] for cone geometry, Murthy *et al.* [3] have presented the following equation for predicting the pressure drop for a conical fixed bed with an apex angle of 10° and water as the fluid passing through the bed:

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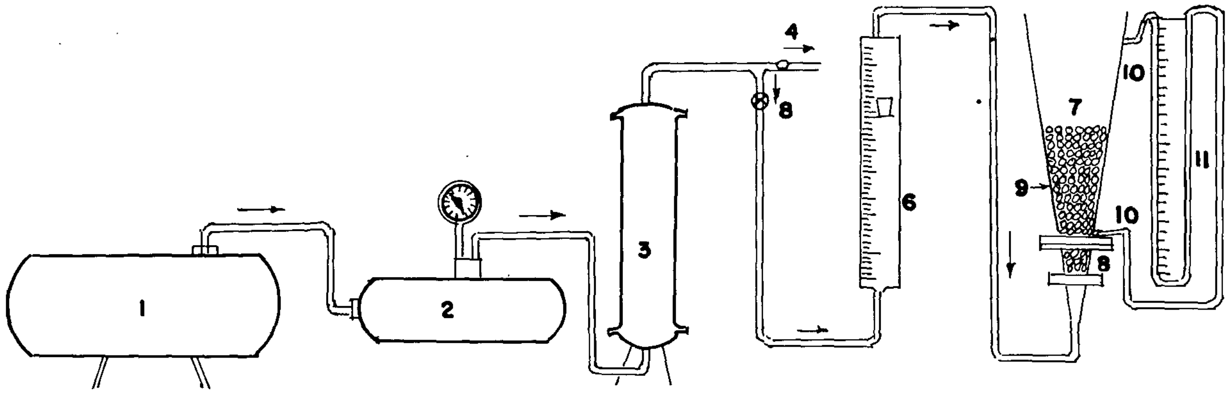

Fig. 1. Experimental set-up: 1, compressor; 2, receiver; 3, silica gel tower; 4, bypass valve; 5, line valve; 6, rotameter; 7, conical fluidizer; 8, glass bead packing; 9, glass beads in fluidization state; 10, pressure tappings to manometer.

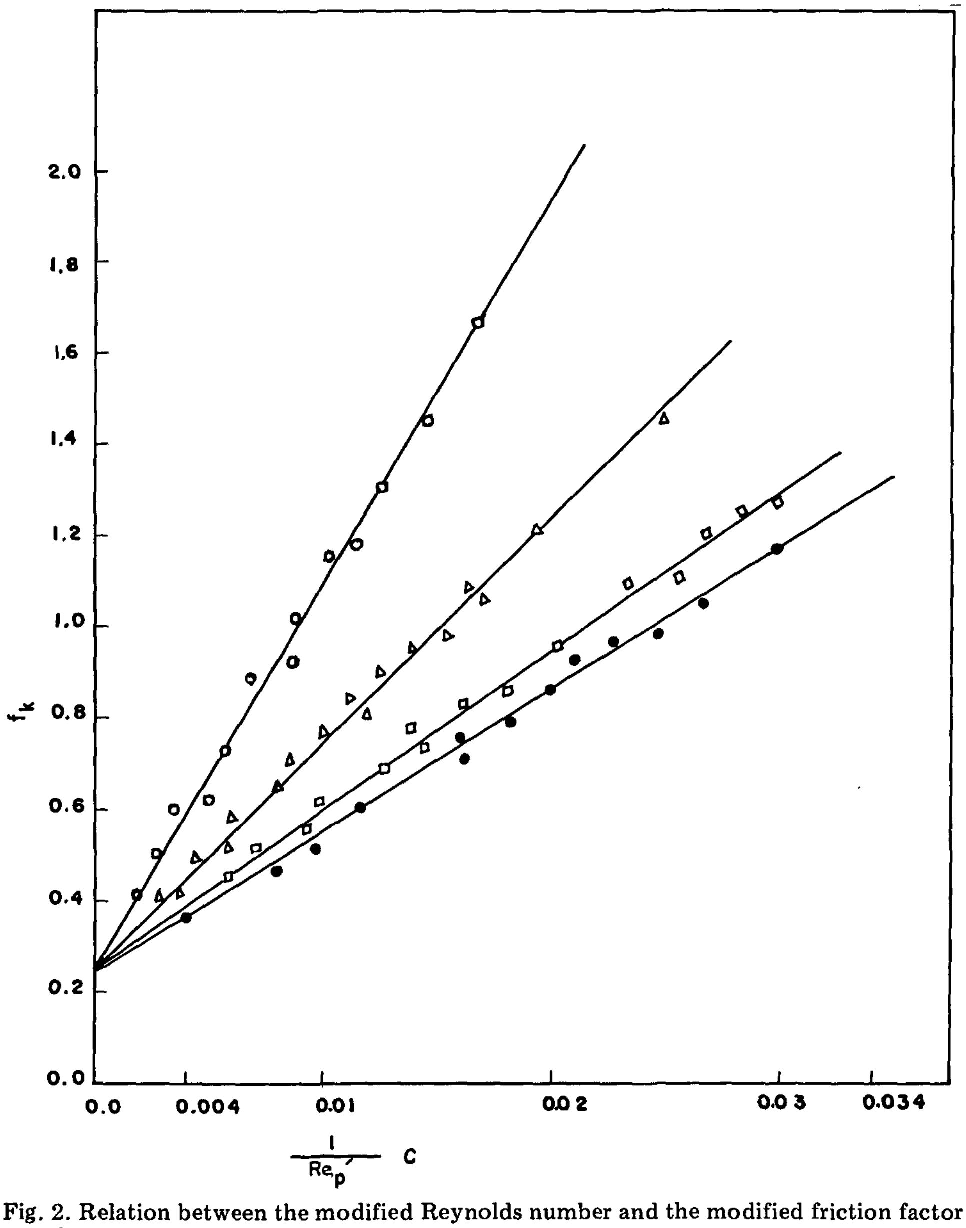

Fig. 2. Relation between the modified Reynolds number and the modified friction factor for various cone angles: ○, 10°; △, 30°; □, 45°; ●, 60°. In the labelling on the horizontal axis, $C = (1 - R_0/R)/(1 - R_0^3/R^3)$.

$$\Delta P = \cos\left(\frac{\alpha}{2}\right)\left\{C_1 A \frac{R_0}{R}(R - R_0)V_0 + C_2\frac{BR_0}{3R^3}(R^3 - R_0^3)V_0^2\right\} \quad (1)$$

where

$$A = \frac{\mu(1-\epsilon_{pa})^2}{g_c d_p^2 \epsilon_{pa}^3}$$

$$B = \frac{\rho_f(1-\epsilon_{pa})}{g_c d_p \epsilon_{pa}^3}$$

The values of C_1 and C_2 are obtained from the plot of modified friction factor *versus* Reynolds number as

$$f_k = \frac{C_2}{3} + C_1 \frac{1-\epsilon_{pa}}{\mathrm{Re_p}'}\,\frac{1-R_0/R}{1-R_0^3/R^3} \quad (2)$$

The values of the constants C_1 and C_2, obtained from the slope and the intercept respectively, depend on the solid and fluid properties and on the cone geometry.

In Fig. 2, f_k is plotted against $1/\mathrm{Re_p}'$ where $\mathrm{Re_p}'$ has been calculated for different values of the particle diameter and fluid mass velocity. Four different straight lines, one for each different apex angle of the cones, were obtained. Although all the straight lines converge to the same point on the y axis (*i.e.* a constant intercept), their slopes are different, thereby indicating the influence of the apex angle of the cones. So the slopes (*i.e.* C_1 values) can be related to the apex angle as

$$C_1 = K_1(\tan\alpha)^{K_2} \quad (3)$$

The values of K_1 and K_2 obtained from the plot of C_1 and $\tan\alpha$ are 37.17 and −0.47 respectively.

Incorporating the expression for C_1 obtained above and the value of C_2 already obtained from eqn. (1), the final expression

TABLE 1

Comparison of the experimental and calculated pressure drop values in conical fixed beds

Sample	G (g cm^{-2} s^{-1})	$R - R_0$ (cm)	ΔP_c (gf cm^{-2})	ΔP_{obs} (gf cm^{-2})	*Deviation* (%)
Cone angle, 10°; d_p = 0.1 cm; ϵ_{pa} = 0.26					
1	1428	9.2	8.23	7.17	−14.78
2	2491	10.7	17.59	14.51	−21.23
3	3350	13.0	28.67	24.72	−15.98
4	2491	15.4	21.9	17.43	−25.65
Cone angle 10°; d_p = 0.15 cm; ϵ_{pa} = 0.304					
5	2849	9.2	7.89	8.80	+10.34
6	1780	10.7	4.72	4.89	+3.48
7	1428	13.0	3.97	3.91	−1.53
8	2138	15.4	7.29	7.17	−1.67
Cone angle, 30°; d_p = 0.2 cm; ϵ_{pa} = 0.242					
9	3566	9.2	5.19	4.80	−8.13
10	1428	10.7	1.63	1.42	−13.19
11	3566	13.0	5.92	5.44	−8.82
12	5007	15.4	10.36	8.96	−15.63
Cone angle, 45°; d_p = 0.25 cm; ϵ_{pa} = 0.216					
13	6416	9.2	12.78	14.26	+10.38
14	4277	10.7	6.55	6.34	−2.99
15	7133	13.0	16.14	18.22	+11.42
16	4277	15.4	6.92	5.42	−27.21
Cone angle, 60°; d_p = 0.30 cm; ϵ_{pa} = 0.1848					
17	9167	9.2	18.40	18.02	−2.11
18	10186	10.7	22.68	24.40	+7.05
19	12733	13.0	34.82	37.64	+7.49
20	14773	15.4	46.57	47.69	+2.35

for the pressure drop in conical fixed beds becomes

$$\Delta P_c = \cos\left(\frac{\alpha}{2}\right)\left\{37.17(\tan\alpha)^{-0.47} \times \times \frac{(1-\epsilon_{pa})^2}{g_c d_p^2 \epsilon_{pa}} \frac{R_0}{R}(R-R_0)V_0 + + 0.75\frac{\rho_f(1-\epsilon_{pa})}{g_c d_p \epsilon_{pa}^3} \frac{R_0}{3R^3}(R^3-R_0^3)V_0^2\right\} \quad (4)$$

4. RESULTS AND DISCUSSION

The values of the fixed bed pressure drops calculated with the help of eqn. (4) were compared with the experimental values for a number of cases. The deviations lie within ±20% in most cases. The mean and the standard deviation calculated for 226 experimental points were found to be 14.90 and 17.40 respectively. A comparison of the experimental and calculated pressure drop values for a few representative points are given in Table 1.

5. CONCLUSION

The equation developed here can be used to predict the pressure drop of spherical particles of different sizes in cones of varying apex angles, with air as the fluid medium. The equation was also tested for some other spherical particles such as sago (ρ_p = 1.2; d_p = 1.5 mm) and mustard seeds (ρ_p = 1.15; d_p = 1.5 mm) and it was found that the calculated values agree fairly well with the corresponding experimental pressure drop values.

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REFERENCES

1 S. Ergun, *Chem. Eng. Prog., 48* (1952) 89.
2 A. P. Baskakovand L. G. Gelperin, *Inzh.-Fiz. Zh., 9* (2) (1965) 217.
3 J. S. N. Murthy, A. S. Narayana, P. Rath and K. J. R. Sarma, *Ind. Chem. Eng., 23* (1981) 44.

APPENDIX A: NOMENCLATURE

C_1, C_2	constants
d_p	particle diameter (cm)
f_k	friction factor
g_c	Newton's constant (gf cm g^{-1} s^{-2})
G	mass velocity of fluid (g cm^{-2} s^{-1})
K_1	constant in eqn. (3)
K_2	exponent in eqn. (3)
ΔP_c	calculated pressure drop values (gf cm^{-2})
ΔP_{obs}	observed pressure drop values (gf cm^{-2})
Re_p'	$d_pG/\mu(1-\epsilon_{pa})$, modified Reynolds number
R	radial distance from the apex of the cone to the top of the bed (cm)
R_0	radial distance from the apex of the cone to the bottom of the bed (cm)
V_0	linear velocity of fluid at the entrance to the bed (cm s^{-1})

Greek symbols

α	angle of the cone (deg)
ϵ_{pa}	porosity of the bed
μ	viscosity of the fluid (g cm^{-1} s^{-1})
ρ_f	density of the fluid (g cm^{-3})
ρ_p	density of the particle (g cm^{-3})