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Pressure Drop in Conical Packed Beds

Dr J S N Murthy, *Member-*
A Suryanarayana, *Non-member*
Dr G K Roy, *Member*

Department of Chemical Engineering
Regional Engineering College, Rourkela

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In this paper, an equation, based on dimensional analysis is proposed to predict pressure drop in terms of a modified friction factor for conical packed beds. The systems studied include water-glass beads, water-chromite, water-coal and water-ferrosilicon. The effects of the variables. viz, particle size, static bed height, flow rate and cone angle are studied. The equation for the prediction of pressure drop in conical packed beds is given by

$$f = 2.33 \times 10^3 \, (Re)^{-0.86} \left(\frac{h_s}{D_c}\right)^{-0.64} \left(\frac{D_c}{d_p}\right)^{-1.63} \left(\tan\frac{\alpha}{2}\right)^{-2.71}$$

where 'f' is modified friction factor. The equation has been verified and found to hold good within ± 15% with the experimental data.

NOTATIONS

A, B, C_1, C_2 = constants

D = diameter of cone at any height of bed, m

D_c diameter at the entrance of the cone, m

D_0 = diameter of cone at the entrance of the bed, m

d_p = particle size, m

f = modified friction factor for packed bed, dimensionless, $\frac{\Delta P \, g_c \, d_p}{\rho \, V_0^2 \, 2 \, h_s}$

g_c = conversion factor, $\frac{kg_m}{kg_f} \frac{m}{sec^2}$

h_s = static bed height in the cone, m

k = constant

R = radial distance from apex of cone to terminal point of bed, m

R_e = Reynolds number ($= d_p \, V_0 \, \rho / \mu$), dimensionless

R_0 = radial distance from apex of cone to the bottom point of bed, m

V_0 = linear velocity of the fluid based on the cross section at the entrance of the cone, cm/sec

ΔP = pressure drop in packed bed, kg/cm^2

α = apex angle of the cone, degree

ρ_p = density of solid particle. kg/m^3

ρ = density of the fluid, kg/m^3

μ = viscosity of the fluid, kg/m sec

INTRODUCTION

Packed beds find application in many chemical engineering operations like absorption, distillation etc. They are also used as chemical reactors which are usually cylindrical in shape. The efficiency of such beds is seriously affected due to channeling and non-uniform distribution of fluids flowing through the bed. Conical packed beds could ensure uniform distribution of fluids, because of the gradual increase in cross section. Packed reactors of conical configuration would be of specific significance for reactions involving gradual decrease of particle size, because the entrainment can be reduced to a minimum. Study of pressure drop in these beds would be of immense help in the design of equipment.

This paper was presented at the Annual Paper Meeting during the First National Convention of Chemical Engineers held at Calcatta on February 21-23,1986.

LITERATURE REVIEW

Gelperin, *et al*[1] have derived the following equation for the prediction of pressure drop through conical packed beds,

$$\Delta P = KVD \left(\frac{D}{D_0} - 1\right)\left(2 \tan \frac{\alpha}{2}\right) \quad (1)$$

where

$$K = \frac{C_1 \mu}{2 d_p^2}$$

Equation (1) is valid for laminar flow only. Later Baskakov, *et al*[2] have studied the pressure drop through beds of conical shape and presented the equation

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

where the constants (C_1 and C_2) have the same numerical values as those given by Ergun[3]. Murthy, *et al*[4] have presented the following equation to predict pressure drop for conical fixed beds with an apex angle of 10° and water as the fluid passing through the bed,

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

Based on the above lines, a more generalized equation has been proposed by Biswal, *et al*[5] for air-solid systems where cones of varying apex angles have been used which is as under

$$\Delta P = \cos \frac{\alpha}{2} \left[37.17 \tan \alpha^{-0.47} A \frac{R_0}{R} (R - R_0) V_0 + 0.75 B \frac{R_0}{3R^3} (R^3 - R_0^3) V_0^2\right] \quad (4)$$

DERIVATION OF EQUATION

In view of the empirical nature of the earlier equations, it is proposed to derive an expression from dimensional analysis approach.

The pressure drop in the bed is a function of the bed, solid and fluid properties. This dependence can be expressed as

$$\Delta P = f\left(\rho_p, d_p, h_s, \mu, D_c, g_c, \tan \frac{\alpha}{2}, V_0\right) \quad (5)$$

Dimensional analysis of the equation gives

$$f = \frac{\Delta P \, g_c}{2\rho \, V_0^2} \left(\frac{d_p}{2 h_s}\right) = K (Re)^a \left(\frac{h_s}{D_c}\right)^b \left(\frac{D_c}{d_p}\right)^c \left(\tan \frac{\alpha}{2}\right)^d \quad (6)$$

The left hand side of the above equation is designated as friction factor f in accordance with the definition of friction factor for packed beds[6].

THE EXPERIMENT

SET-UP

The schematic diagram of the experimental set-up is given elsewhere[4]. The cones were made up of 2 mm thick persepex sheet. A screen of 60 mesh served the purpose of support as well as distributor. A cylindrical section packed with 5 mm glass beads had been used as calming section. Pressure drop across the bed was recorded with the help of manometer. The flow rate had been measured by a rotameter. A scale provided on the wall of the cone had been used to measure the height of the bed.

PROCEDURE

A weighed amount of material was charged into the cone and the static bed height was noted. Water was pumped at a low rate initially and the flow rate was increased gradually thereafter. For each flow rate, bed pressure drop was noted. This procedure was repeated for various materials, and cones. The scope of the experimental data is given in Table 1.

TABLE 1 SCOPE OF EXPERIMENTAL DATA

Material	Specific Gravity	Particle Size m × 10³	Bed Height m × 10²	Cone Apex Angle, degree
Glass beads	2.76	0.95	20.6	10
Glass beads	2.76	0.95	15.2	10
Glass beads	2.76	0.95	10.0	10
Glass beads	2.76	0.29	15.0	21
Glass beads	2.76	1.50	17.7	10
Coal	1.27	1.00	21.5	10
Chromite	3.20	1.08	10.7	10
Ferrosilicon	2.69	0.71	18.2	10
Glass beads	2.76	0.29	16.9	15

RESULTS AND DISCUSSION

Friction factor calculated from equation (6) is plotted on log-log graph against the dimensional groups *viz*,

Re, $\frac{h_s}{D_c}$, $\frac{D_c}{d_p}$ and $\tan\frac{\alpha}{2}$. The final correlation is given by

$$f = 2.33 \times 10^3 (Re)^{-0.86} \left(\frac{h_s}{D_c}\right)^{-0.64} \times \left(\tan\frac{\alpha}{2}\right)^{-2.71} \left(\frac{D_c}{d_p}\right)^{-1.63} \quad (7)$$

Values of f calculated from equation (7) have been compared with the experimental values in Table 2. The deviations between the calculated and the observed values of friction factor have been found to lie within ± 15% for most of the cases.

The present correlation has the specific advantage over the earlier ones[1-4] as it is free of packed bed porosity term, correct prediction of which is difficult especially for a conical bed.

TABLE 2 COMPARISON OF CALCULATED AND EXPERIMENTAL VALUES OF FRICTION FACTOR

h_s m×10[2]	d_p m×10[3]	D_c m×10[2]	Re	α	MATERIAL	f_{obs}	f_{cal}	error
20.6	0.95	4.0	1.31	10	Glass beads	1 098.7	1 107.7	– 0.82
20.6	0.95	4.0	2.23	10	Glass beads	744.2	701.7	5.71
20.6	0.95	4.0	4.61	10	Glass beads	421.4	375.8	10.82
15.2	0.95	4.0	1.71	10	Glass beads	1 055.9	1 067.1	– 1.06
15.2	0.95	4.0	4.40	10	Glass beads	440.0	473.6	– 7.64
10.0	0.95	4.0	2.26	10	Glass beads	1 112.3	1 095.5	1.51
10.0	0.95	4.0	3.56	10	Glass beads	743.5	741.4	0.29
17.7	1.50	4.0	5.40	10	Glass beads	859.6	756.1	12.04
17.7	1.50	4.0	7.65	10	Glass beads	657.8	561.6	14.62
21.5	1.00	4.0	0.75	10	Coal	1 743.6	1 892.2	– 8 52
21.5	1.00	4.0	1.28	10	Coal	1 076.1	1 211.2	– 12.56
10.7	1.08	4.0	2.38	10	Chromite	1 010.4	1 239.5	– 22.67
10.7	1.08	4.0	0.65	10	Chromite	4 386.0	3 789.0	13.61
18.2	0.71	4.0	1.17	10	Ferrosilicon	985.8	821.8	16.64
18.2	0.71	4.0	2.83	10	Ferrosilicon	450.5	384.4	14.67
18.2	0.71	4.0	3.62	10	Ferrosilicon	391.6	310.0	20.84
15.0	0.29	4.5	3.80	21	Glass beads	12.3	9.2	25.20
16.9	0.29	4.0	1.23	15	Glass beads	76.8	64.1	16.54
16.9	0.29	4.0	1.90	15	Glass beads	34.1	43.9	– 28.86

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