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Prediction of Minimum Fluidization Velocity for Gas–Solid Fluidization of Regular Particles in Conical Vessels

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ABSTRACT

The application of a conical fluidized bed as a remedial measure for certain inherent drawbacks of gas–solid systems is suggested Investigations were carried out in Perspex cones with apex angles of 10°, 30°, 45° and 60°, with spherical glass beads of different sizes as the bed material, and air as the fluidizing medium With the help of available correlations and packed bed pressure drop data, minimum fluidization velocities for the above cases were computed and compared with experimental data obtained from bed pressure drop versus fluid mass velocity plots, and the mean and standard deviations were calculated

INTRODUCTION

Entrainment of particles, slugging, channelling and bubbling are some of the disadvantages of a deep large-diameter gas–solid fluidized bed which affect the fluidization quality to a considerable extent in a conventional cylindrical unit Better fluid–solid mixing and improved quality of fluidization can be achieved in a conical fluidizer [1], this is attributed primarily to the gradual decrease in superficial velocity due to the varying cross-sectional area. This is of specific importance in the case of solid fuel combustion and gas–solid reactions, where particles continuously decrease in size. So that conical beds may be used widely in the chemical process industry, adequate knowledge of the static and dynamic behaviour of such beds is needed. Although considerable information is available concerning the characteristics of packed and fluidized cylindrical beds [2 - 5], there is comparatively little identical information for conical beds [6 - 13].

In this paper an attempt has been made to develop an expression for the minimum fluidization velocity in the case of conical gas–solid fluidized beds

EXPERIMENTAL

Apparatus

A schematic diagram of the set-up has been given elsewhere [10] Cones with different apex angles, namely 10°, 30°, 45° and 60°, were used in the investigations; they were made from thick Perspex sheets. The inlet diameter of the cones was 4 cm. A screen of 60 mesh, used at the lower end, served as a support as well as a distributor. The calming section for the cones was filled with glass beads to obtain a uniform fluid distribution. Two pressure tappings, one at the entrance and the other at the exit section of the cone, were provided to record the bed pressure drop. Air was used as the fluid and was passed through a constant pressure reservoir followed by a silica-gel tower. The air flow rate was recorded with the help of two rotameters for two different ranges of flow.

Procedure

The porosity of the static bed was determined in separate experiments by allowing water to pass through the bed, without imparting movement to the particles, and then collecting the entrained water carefully. The procedure was repeated for a particular case until a nearly constant amount of water was recorded. For a given run, a cone was charged to a definite fixed bed height with a particular size of glass bead. The variation of pressure drop with fluid mass velocity was noted until particle movement was initiated in the bed Bed pressure drops were also recorded under fluidized bed conditions. In

TABLE 1

Experimental variables

Bed material glass beads, density of material 2 3 × 10^3 kg m^{-3}

Run No	*Cone angle* (deg)	*Bed height* (cm)	*Particle diameter* (mm)
1	10	9 2	1 0
2	30	10 7	1 5
3	45	13 0	2 0
4	60	15 4	2 5
5	—	—	3 0

subsequent runs the particle size as well as the fixed bed height were altered The above procedure was repeated for other cones The experimental variables are listed in Table 1

DEVELOPMENT OF THE CORRELATION

On the basis of Ergun's equation [14] and Baskakov and Gelperin's modification [6] for cone geometry, Suryanarayana *et al* [8] obtained an equation to predict the minimum fluidization velocity from the bed pressure drop for a cone of apex angle 10° and water as the fluid passing through the bed. Using a similar approach, a packed bed pressure drop equation for conical beds was developed by the present authors for gas–solid systems [12]

$$\Delta P_c = \cos\frac{\alpha}{2}\left\{37\ 17(\tan\alpha)^{-0\ 47}\frac{\mu(1-\epsilon_{pa})^2}{g_c d_p^2\epsilon_{pa}}\times\right.$$
$$\times\frac{R_0}{R}(R-R_0)V_0+0.75\frac{\rho_f(1-\epsilon_{pa})}{g_c d_p\epsilon_{pa}^3}\times$$
$$\left.\times\frac{R_0}{3R^3}(R^3-R_0^3)V_0^2\right\} \qquad (1)$$

Applying the above packed bed equation to the situation at the onset of fluidization, the equation becomes

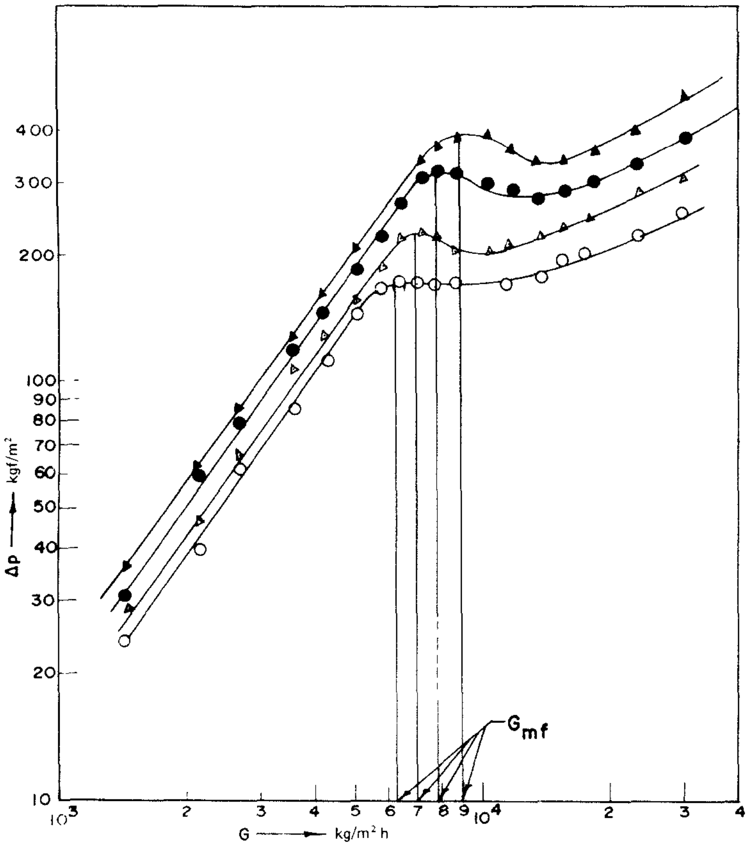

Fig 1 Prediction of G_{mf} from a Δp–G plot (bed height effect) Bed height ○, 9 2 cm, △, 10 7 cm, ●, 13 0 cm, ▲, 15 4 cm

$$\Delta P_{\mathrm{mf}} = \cos\frac{\alpha}{2}\left\{37.17(\tan\alpha)^{-0.47}\frac{\mu(1-\epsilon_{\mathrm{pa}})^2}{g_c d_p^2 \epsilon_{\mathrm{pa}}} \times \frac{R_0}{R}(R-R_0)V_{0\mathrm{mf}} + 0.75\frac{\rho_f(1-\epsilon_{\mathrm{pa}})}{g_c d_p \epsilon_{\mathrm{pa}}^3} \times \frac{R_0}{3R^3}(R^3-R_0^3)V_{0\mathrm{mf}}^2\right\} \tag{2}$$

ΔP_{mf} may also be written as

$$\Delta P_{\mathrm{mf}} = R_{\mathrm{mf}}(1-\epsilon_{\mathrm{mf}})(\rho_p-\rho_f) \tag{3}$$

Experimental values for the minimum fluidization mass velocity, G_{mf}, were obtained from the pressure drop *versus* fluid mass velocity plots. Representative plots of G_{mf} as a function of static bed height, particle size, particle density and cone angle are given in Figs. 1 - 4, respectively. The linear fluid velocity corresponding to the minimum fluidization condition, $V_{0\mathrm{mf}}$, was calculated from G_{mf} and the fluid density.

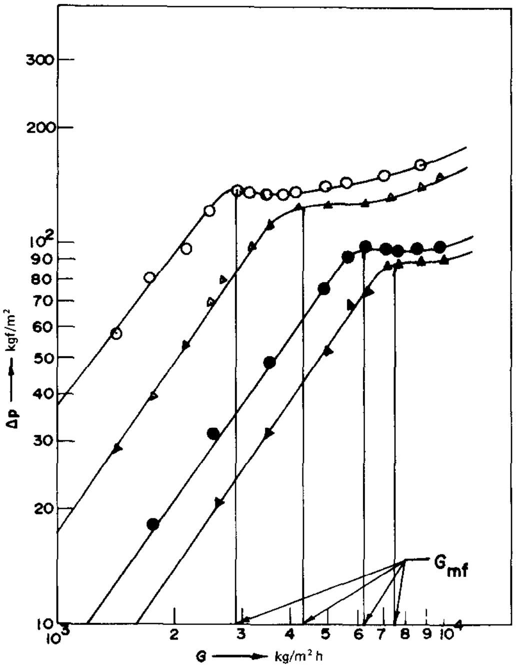

Fig 2 Prediction of G_{mf} from a Δp–G plot (particle size effect) Particle size ○, 1 mm, △, 1.5 mm, ●, 2 mm, ▲, 2.5 mm

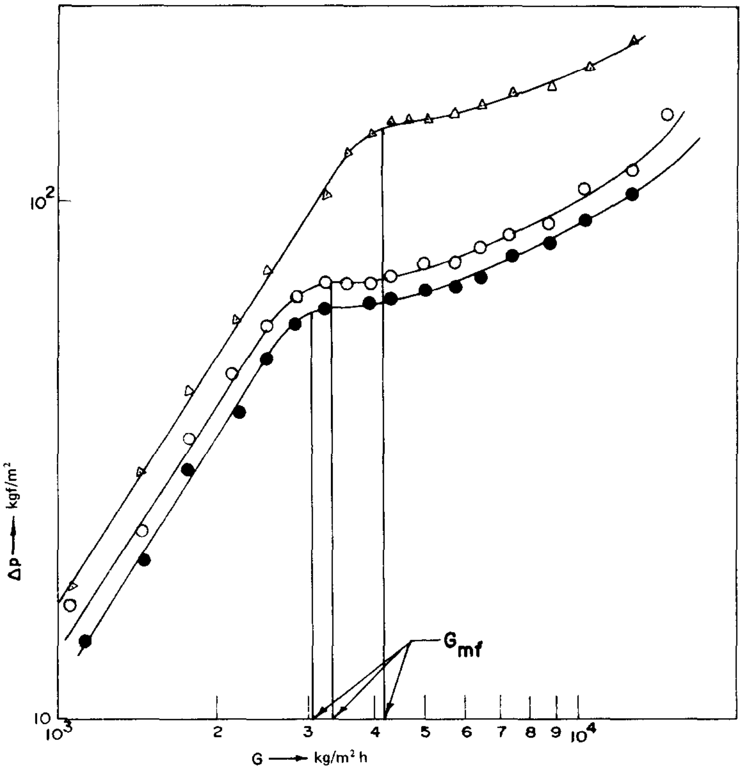

Fig 3 Prediction of G_{mf} from a Δp–G plot (particle density effect) Bed material ○, mustard seed, △, glass beads, ●, sago Cone angle = 10° for each case

TABLE 2

Comparison of minimum fluidization velocity in conical vessels

Run No	h_s (cm)	$V_{0,\mathrm{cal}}$ (cm s^{-1})	$V_{0,\mathrm{exp}}$ (cm s^{-1})	Deviation (%)
Cone angle = 10°				
d_p = 1 0 mm				
1	9 2	52 92	54 25	2 45
2	10 7	55 12	69 00	−20 12
3	13 0	58 55	71 61	−18 24
4	15 4	62 47	75 95	−17 75
d_p = 1 5 mm				
5	9 2	97 44	91 14	6 91
6	10 7	101 38	97 65	3 82
7	13 0	107 56	99 82	7 20
8	15 4	114 06	108 5	5 12
d_p = 2 0 mm				
9	9 2	145 81	123 69	17 88
10	10 7	151 64	128 03	18 44
11	13 0	160 97	138 88	15 91
12	15 4	169 48	160 58	5 54
d_p = 2 5 mm				
13	9 2	177 83	149 53	18 93
14	10 7	185 60	154 07	20 46
15	13 0	196 21	180 11	8 94
16	15 4	207 55	199 64	3 96
d_p = 3 0 mm				
17	9 2	219 60	156 24	40 55
18	10 7	228 60	167 09	36 81
19	13 0	241 60	195 30	23 71
20	15 4	255 69	199 64	28 08
Cone angle = 30°				
d_p = 1 0 mm				
21	9 2	52 09	56 7	−8 13
22	10 7	57 35	60 48	−5 18
23	13 0	63 25	63 31	−0 09
24	15 4	69 46	68 04	2 09
d_p = 1 5 mm				
25	9 2	92 59	85 05	8 87
26	10 7	100 23	94 50	6 06
27	13 0	109 64	103 95	5 47
28	15 4	120 11	113 40	5 92
d_p = 2 0 mm				
29	9 2	13 81	120 96	11 45
30	10 7	144 46	130 41	10 77
31	13 0	157 59	149 31	5 55
32	15 4	171 13	160 65	6 52
d_p = 2 5 mm				
33	9 2	154 33	141 75	8 87
34	10 7	164 47	166 32	−1 11
35	13 0	179 41	181 44	−1 12
36	15 4	194 36	193 73	0 33
d_p = 3 0 mm				
37	9 2	176 90	171 99	2 85
38	10 7	188 91	173 88	8 64
39	13 0	206 40	193 73	6 54
40	15 4	222 77	226 80	−1 78
Cone angle = 45°				
d_p = 1 0 mm				
41	9 2	52 77	56 70	−6 93
42	10 7	58 05	66 15	−12 24
43	13 0	66 34	70 87	−6 39
44	15 4	71 68	102 0	−29 73
d_p = 1 5 mm				
45	9 2	71 53	104 88	−32 07
46	10 7	81 57	114 0	−28 45
47	13 0	88 79	129 96	−31 91
48	15 4	96 88	159 6	−39 30
d_p = 2 0 mm				
49	9 2	127 6	129 96	−1 82
50	10 7	133 33	145 92	−8 63
51	13 0	151 96	171 00	−11 13
52	15 4	165 91	189 96	−11 26
d_p = 2 5 mm				
53	9 2	171 90	171 00	0 53
54	10 7	184 75	200 64	−7 92
55	13 0	211 43	239 40	−11 68
56	15 4	218 58	262 22	−16 64
d_p = 3 0 mm				
57	9 2	196 02	207 48	−5 53
58	10 7	210 63	228 00	−7 62
59	13 0	231 73	250 08	−7 34
60	15 4	250 78	296 40	−15 39
Cone angle = 60°				
d_p = 1 0 mm				
61	9 2	43 07	67 29	−35 99
62	10 7	47 18	71 24	−33 77
63	13 0	53 11	79 16	−32 91
64	15 4	59 13	94 99	−37 78
d_p = 1 5 mm				
65	9 2	76 51	93 0	−22 72
66	10 7	82 71	112 0	−26 15
67	13 0	92 47	130 0	−28 87
68	15 4	101 83	134 0	−24 43
d_p = 2 0 mm				
69	9 2	103 05	112 0	−7 99
70	10 7	110 90	138 5	−19 93
71	13 0	123 08	148 4	−17 06
72	15 4	135 10	186 0	−27 37
d_p = 2 5 mm				
73	9 2	125 14	152 38	−17 88
74	10 7	134 95	162 28	−17 34
75	13 0	149 2	180 09	−17 15
76	15 4	162 97	197 92	−17 65
d_p = 3 0 mm				
77	9 2	175 52	217 00	−19 12
78	10 7	188 88	227 59	−17 01
79	13 0	208 47	257 27	−18 97
80	15 4	226 71	296 85	−23 63

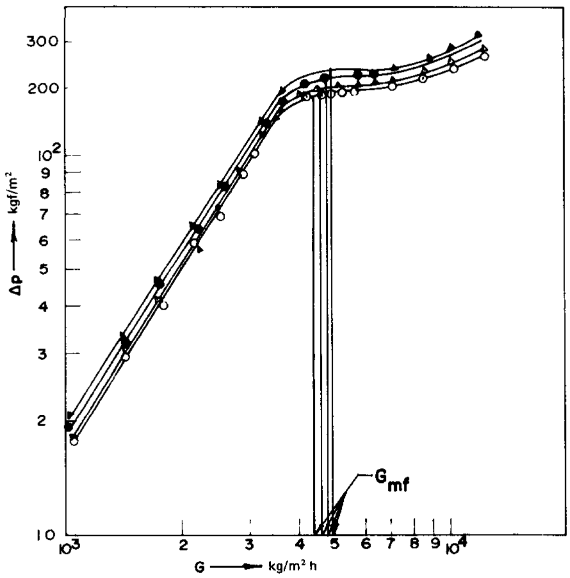

Fig 4 Prediction of G_{mf} from a Δp–G plot (cone angle effect) Cone angle ○, 10°, △, 30°, ●, 45°, ▲, 60°

RESULTS AND DISCUSSION

Values of the minimum fluidization velocity calculated with the help of eqns. (2) and (3) were compared with the experimental values for a number of cases. The deviations lie within ±25% for most of the cases (Table 2). The mean and standard deviation calculated for about 80 experimental points were found to be 14.20% and 21.52%, respectively.

CONCLUSION

The equation developed here can be used for the prediction of the minimum fluidization velocity of spherical particles of different sizes in cones of varying angles, with air as the fluid medium. The equation has also been tested for a few other spherical particles, such as sago (ρ_p = 1 30 kg m^{-3}, d_p = 1 5 mm) and mustard seeds (ρ_p = 1.10 kg m^{-3}, d_p = 1.5 mm); it was found that the calculated values agree fairly well with the experimental minimum fluidization velocity values.

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APPENDIX A NOMENCLATURE

D	diameter of cone at any bed height (cm)
D_0	diameter of cone at entrance of bed (cm)
d_p	particle diameter (mm)
g_c	Newton's constant (kg m kgf^{-1} h^{-2})
h_s	static bed height (cm)
G	mass velocity of fluid (kg m^{-2} h^{-1})
G_{mf}	mass velocity of fluid for minimum fluidization conditions (kg m^{-2} h^{-1})
ΔP_c	calculated value of bed pressure drop (kgf m^{-2})
ΔP_{mf}	bed pressure drop for minimum fluidization conditions (kgf m^{-2})
R	radial distance from apex of cone to terminal point (m)
R_0	radial distance from apex of cone to bottom of bed (m)
R_{mf}	radial distance from apex of cone to terminal point corresponding to minimum fluidization conditions (m)

V_0	linear velocity of fluid (cm s^{-1})
$V_{0\mathrm{mf}}$	linear velocity of fluid for minimum fluidization conditions (cm s^{-1})

Greek symbols

α	apex angle of cone
ϵ_{mf}	porosity at minimum fluidization condition
ϵ_{pa}	porosity of packed bed
μ	viscosity of fluid (kg m^{-1} h^{-1})
ρ_{f}	density of fluid (kg m^{-3})
ρ_{p}	density of particle (kg m^{-3})