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PRESSURE DROP OVER FLUIDISED BED DISTRIBUTOR CAPS

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SYNOPSIS

The pressure drop across distributor caps in fluidised beds contributes significantly to the running cost. Fluidised beds designed with a low pressure drop over the distributor are prone to slumping, making an accurate model of pressure drop an important design tool for fluidised beds. The pressure drop associated with the unique geometry of distributor caps can be described as $\Delta P = \frac{1}{C_d^2}\left(\frac{\rho u^2}{2}\right)$ with $C_d = 0{,}283 + 0{,}117\left(\frac{L}{d}\right)$, where L/d represents the length/diameter ratio of a single jet. This model has an average error of 2,8% for typical flow rates found in fluidised beds, and a maximum error of 6,9%. The coefficient of discharge was found to be independent of the Reynolds number.

Keywords

Bubble cap distributors, fluidised beds, pressure drop, coefficient of discharge, C_d

Introduction

In the operation of fluidised beds, a significant proportion of the capital and running cost is required for blowing the gas through the distributor caps and the bed. The movement of the bed during fluidisation causes pressure fluctuations at the distributor caps that can affect the gas velocity through the jets. The higher the pressure drop across these jets, the less the likelihood is that the flow in such a jet can be stopped – a situation that can lead to slumping (Geldart, 1985). It is generally accepted that the pressure drop over a distributor cap should be at least 0,3 times the pressure drop over the bed itself (Zenz, 1968).

The distributor cap jets are horizontal so that when the gas supply stops, the bed solids will not flow into the windbox (plenum chamber) of the fluidised bed (Fig. 1). For solids with an angle of repose of 45°, this means that the ratio L/d must be at least 1. Typically, L/d ratios are chosen between 1,5 and 4.

It is important from a design perspective to be able to accurately predict the pressure drop over the distributor caps so that the pressure drop is low enough to minimise the running costs, and high enough to prevent slumping of the bed at the minimum design turn-down ratio.

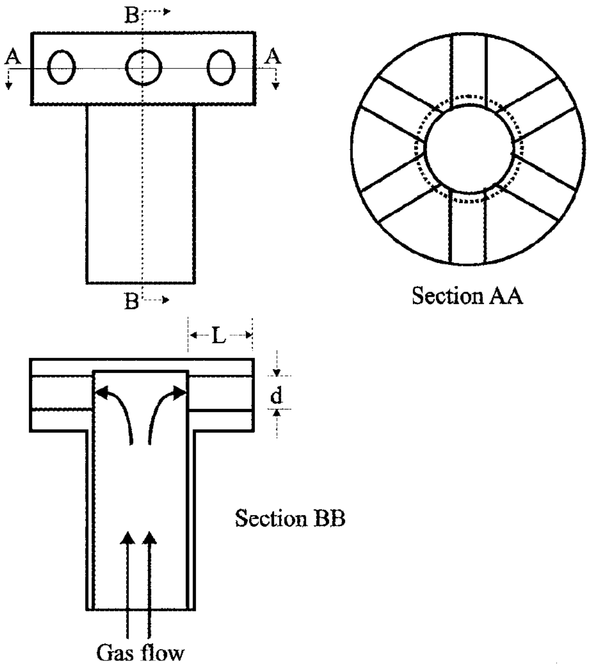

Fig. 1. Cross section of a distributor cap riser

The distinctive shape of fluidised bed distributor caps (Fig. 1) gives pressure drops that are not accurately predicted by conventional pressure drop correlations. The geometry of a single jet can be likened to that of an orifice plate with an exceptionally thick plate. Quereshy & Creasy (1979) suggested the following correlation for coefficient of discharge through a square-edged orifice plate:

$$C_d = 0.82\left(\frac{L}{d_{or}}\right)^{0.13} \tag{1}$$

where L is the plate thickness and d_{or} is the orifice diameter, and $L/d_{or} > 0{,}09$.

However, this correlation was not sufficiently accurate for the geometry given in Fig.1. In this work. pressure drops over distributor caps of this geometry were measured using a range of orifice diameters and lengths, using jet gas velocities commonly used in industrial fluidised beds.

Experimental

A single distributor cap was mounted in a tube of 300 mm inside diameter (See Table 1 for the various distributor caps used). The flow rate was measured using an orifice plate with d and d/2 tapping. The apparatus complied with the ISO 5167 standard. The differential pressure across the orifice plate was measured using a water manometer and the gauge pressure in the piping between the orifice plate and the distributor cap was also measured using a water manometer.

Calculations showed that there was negligible kinetic effect in the pressure measurements, and that pressure drop in the piping up to the jets of the distributor cap could also be neglected.

For each distributor cap, the pressure drop was measured at a range of flow rates. A coefficient of discharge was then calculated for each flow rate using the pressure drop equation:

$$\Delta P = \frac{1}{C_d^2}\left(\frac{\rho u^2}{2}\right) \qquad (2)$$

A typical set of results is shown in Fig. 2.

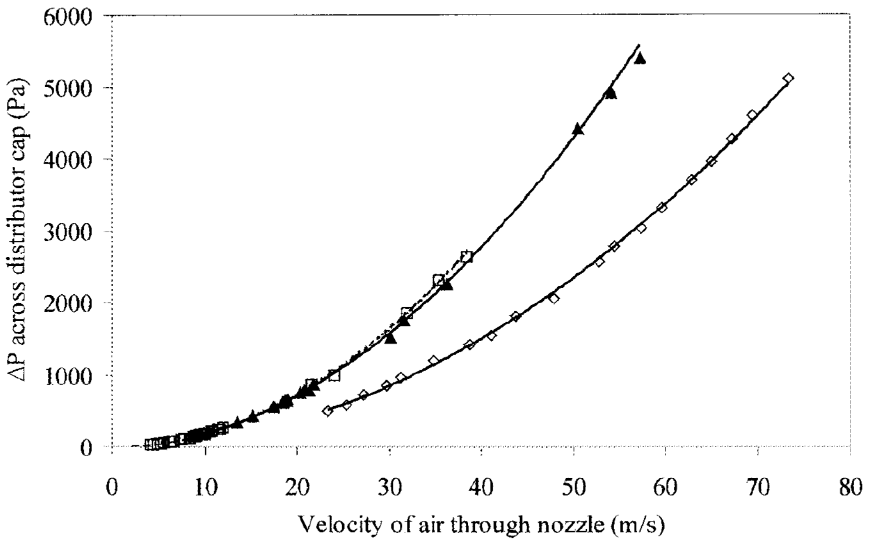

Fig. 2. A typical set of data used to estimate C_d shows a good fit to the standard pressure drop equation. □ L/d = 2,14; ▲ L/d = 2,40; ◇ L/d = 3,90

Table 1. Distributor cap geometries used, and number of readings taken. Risers are all 25 mm internal diameter

L(mm)	d (mm)	Number of jets	L/d	Number of pressure readings
12	7	12	1,71	25
15	7	12	2,14	25
19	8	12	2,38	25
12	5	12	2,40	25
19	7	12	2,71	25
12	4	12	3,00	25
19	6	12	3,17	24
19,5	5	12	3,90	19

Results and discussion

The following generalised form of equation was used to correlate L, d and Re:

$$C_d = \left[C3 + C1\left(\frac{L}{d}\right)^{C2} \right] Re^{C4} \tag{3}$$

Using a least squares fit for the coefficients C1 to C4, the following correlation was obtained:

$$C_d = \left[0{,}369 + 0{,}033\left(\frac{L}{d}\right)^{1{,}627}\right] Re^{0{,}011} \tag{4}$$

Clearly, C_d has very little dependence on Re. This is illustrated graphically in Fig. 3.

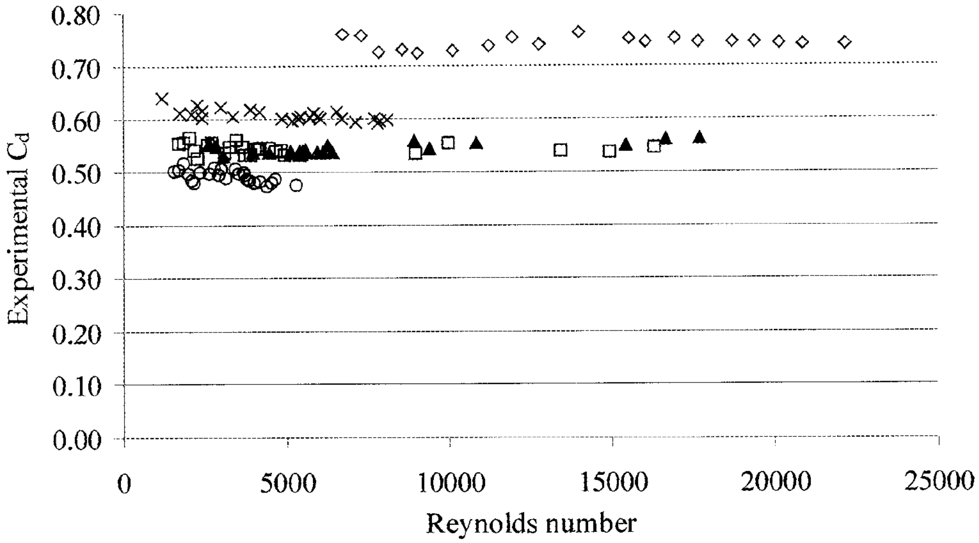

Fig. 3. Measured C_d is independent of Re

Eliminating Re from the correlation, the following 3-parameter model was fitted:

$$C_d = 0{,}389 + 0{,}045\left(\frac{L}{d}\right)^{1{,}53} \tag{5}$$

The following 2-parameter model was then fitted to test whether the constant term makes a meaningful contribution:

$$C_d = 0{,}358\left(\frac{L}{d}\right)^{0{,}532} \tag{6}$$

The errors (model vs. experimental) using each of the preceding models are summarised in Table 2:

Table 2. The error using a 2-parameter model is not significantly higher than the 3 and 4-parameter models.

Coefficient	C1	C2	C3	C4	Average error	Maximum error
Eqn. 4	0,033	1,627	0,369	0,011	2,59%	7,05%
Eqn. 5	0,045	1,530	0,389	set to 0	2,63%	6,33%
Eqn. 6	0,358	0,523	set to 0	set to 0	3,09%	8,41%

Noting that the error does not significantly change even when C2 changes from 1,53 to 0,52, a sensitivity analysis was done by choosing the best values of C1 and C3 with C2 as an independent variable (Fig. 4).

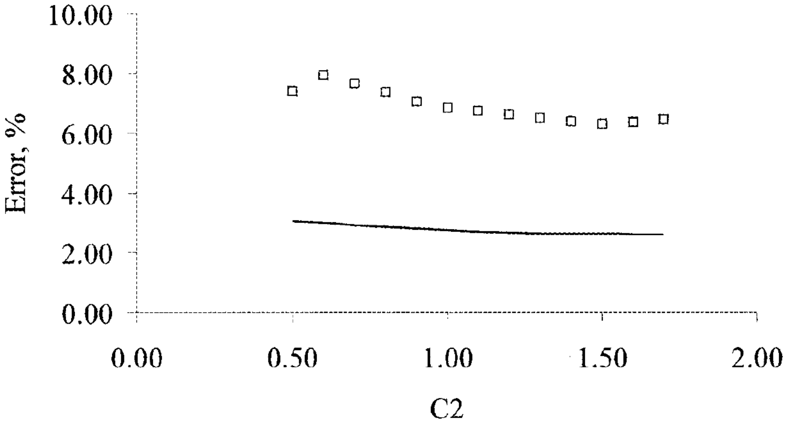

Fig. 4. The value of coefficient 2 does not significantly influence the error.

☐ Maximum error, ________ Average absolute error

These results indicate that the most preferable model to choose, simply from an ease-of-use viewpoint, would be to choose C2 = 1:

$$C_d = 0{,}283 + 0{,}117\left(\frac{L}{d}\right) \tag{7}$$

This correlation has been plotted in Fig. 5. Also shown in Figure 5 are the absolute errors between model and experimental C_d for each distributor cap. There is no clear trend that errors are increasing near the limits of the measured L/d ratios, indicating that the model probably has applicability to L/d ratios from 1 to 5.

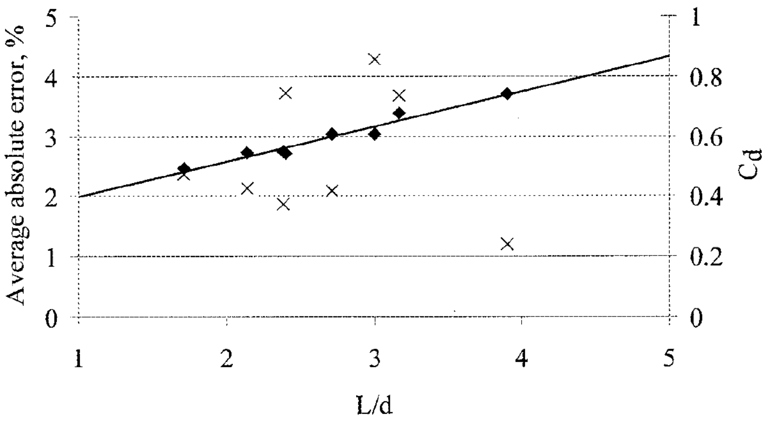

Fig. 5. Average absolute errors for each distributor cap (X) and the linear fit of L/d that gives rise to the recommended model (◆, right hand axis)

A comparison of the model presented here with the correlation of Quereshy & Creasy (1979) gives the following predictions of C_d at the L/d ratios measured in this study:

Table 3. The model of Quereshy & Creasy (1979) overpredicts C_d

L/d	Recommended model $C_d = 0{,}283 + 0{,}117\left(\frac{L}{d}\right)$	Quereshy & Creasy $C_d = 0.82\left(\frac{L}{d_{or}}\right)^{0.13}$
1,7	0,48	0,88
2,1	0,53	0,90
2,4	0,56	0,92
3,0	0,63	0,95
3,9	0,74	0,98

Conclusion

The model $C_d = 0{,}283 + 0{,}117\left(\frac{L}{d}\right)$ accurately predicts pressure drop in distributor caps for Reynolds numbers from 2 000 to 22 000 and for L/d ratios from 1,5 to 4.

Acknowledgements

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Notation

C1, C2, C3, C4	Dimensionless parameters
C_d	Coefficient of discharge
d	Diameter of a distributor cap nozzle, m
d_{or}	Orifice diameter
L	Length of a distributor cap nozzle, m
ΔP	Pressure drop, kg m^{-1} s^{-2}
u	Gas velocity in nozzle, m s^{-1}
ρ	Gas density, kg m^{-3}
Re	Nozzle Reynolds number

References

Geldart, D. & Baeyens, J.; 1985. “The design of distributors for gas-fluidised beds”, Powder Technology, 42, 67-78

Quereshy, A.E. & Creasy, D.E.; 1979. Powder Technology, 22, 113

Zenz, F.A. ;1965. Proc. of Tripartite Chem. Engineering Conf. Montreal, 1968, Inst. of Chemical Engineers, London, p136.