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# **Chemical Engineering**



# Hydrodynamics of fluidized bed reactor with perforated draft tube Nikhil K. Gajbhiye<sup>1</sup> and S. D. Dawande<sup>2</sup>

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ABSTRACT

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A fluidized bed reactor with a perforated draft tube was employed to obtain hydrodynamic data for different Geldart's particle group A, B, C & D by using various operating condition. The stability and hydrodynamics properties of a fluidized bed are determined primarily with respect to minimum fluidization velocity, pressure drop, minimum bubbling velocity, fluidization quality with a perforated draft tube by changing the total gas flow rate through the column. The result of calculation showed that, the pressure drop through the column increases with the increase in gas flow rate. At about 1.7  $U_{ns}$  some bed instability was observed which is characterized by fluctuation in pressure drop, with increase in gas flow rate this phenomenon disappeared. The effects of perforated draft tube on fluidization can be evaluated by comparing the experimental results by using the Geldart's correlation with the correlation derived. Moreover the various correlations are derived by using the multiple regression analysis method (Polynomial method) for fluidized bed with perforated draft tube.

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# Introduction

Fluidized beds possess certain structural and flow characteristics that are very desirable for fast, highly exothermic and endothermic catalytic reactions. However, the use of fluidized beds as chemical reactors may suffer from less catalyst interfacial area due to relatively larger particles, especially for fast catalytic reactions which are limited by mass transfer and only the external catalyst surface is effective. It is known that the fluidization behavior in gas-solid fluidized beds depends on the particles diameter and density. Geldart's<sup>(1)</sup> classified powders into four groups, i.e. C, A, B & D, based on their fluidization behavior.

Therefore, it may be more favorable to operate fluidized beds with relatively finer particles when applying as catalytic reactors. For fluidization of fine particles, stable fluidization and regular circulation of solids can be obtained only for a low gas velocity. Moreover, in order to fulfill the criteria for stable fluidization, relatively smaller nozzle is required, which gives rise to the formation of dead zone at the bed bottom and high particle attrition. By introducing auxiliary fluid through a perforated or perforated distributor surrounding the central orifice, this fluid bed technique increases the fluid-solid contact in the annulus portions.

Fluidized bed is a column open at top and filled with relatively different diameter particle of solid. The fluid is injected through a centrally located small opening at the base of the vessel. If the fluid injection rate is high enough, the resulting high velocity jet causes a stream of particles to rise rapidly in to a hollowed central core within the bed of solids. This system is termed as fluidized bed and the principle annular reason is called annulus<sup>(8).</sup> The fluidization and its stability, operating condition, fluidization bed height along with the changing phenomenon from fluidization to bubbling, slugging, turbulent fluidization & fast fluidization etc<sup>(8)</sup>. depends on many factors like effect of particle size, orifice size of fluidization fluid, flow rate of

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fluidizing fluid, bed height and the density of particle used. For a given solid material contacted by a specific fluid in a vessel of fixed geometry, there exists a maximum bed height (H\_), beyond which the fluidization action does not exist but is replaced by a poor quality fluidization. The minimum fluidization velocity at this bed depth can be 1.25 to 1.5 times greater than the corresponding minimum fluidization velocity  $(U_{mf})$ .

Fluidized bed technique is widely used for operations such as blending of solids, gas cleaning ,thermal cracking of crude oil, drying of heat sensitive solids<sup>(4),</sup> combustion and gasification of coal or waste material<sup>(7)</sup> ,granulation and coating. Drying of suspension <sup>(5),</sup> solution and paste can be achieved in bed of inert particle of fluidized bed reactor.

The criterion for slug formation (Yang, 1976), maximum stable bubble size (Geldart 1986), under similar operating conditions minimum bubbling velocity and the fluidization index (the ratio of minimum bubbling velocity to minimum fluidization velocity.

$$Umb = 2.07 \ dp \times \varepsilon^{2} \times \frac{\exp(0.176W45)}{u^{0.347}}$$
(1)

And

$$Umf = \frac{9 \times 10^{-4} \times d_p^{1.8} \times \{(\rho_p - \rho_g) \times g\}^{0.0934}}{\varepsilon_g^{0.066} \times \mu_g^{027}}$$
(2)

The Abrahamsen & Gelart (1980) proposed (14) the following correlation for the ratio of minimum bubbling velocity to minimum fluidization velocity  $(U_{mb}/U_{mb})$ .

$$\frac{Umb}{Umf} = \frac{\{2300 \times 1.293^{0.13} \times 0.018 \times 10^{-3} \times \exp(0.72 W_{45})\}}{d_p^{1.8} (\rho_p - \rho_g)^{0.93}}$$

Above Ergun's equation is used for the theoretical pressure which is given as below <sup>(11)</sup>

$$\left(\frac{\Delta P}{L}\right) = \frac{150(1-\varepsilon)^2}{\varepsilon^3 dp^2} \times U_g \mu_g + 1.75 \frac{(1-\varepsilon)(\rho_g U_g^2)}{\varepsilon^3 \times dp}$$
(3)



When the particle of the fluidized bed starts fluidized the ergun's equation is not used. Therefore for the theoretical pressure drop calculation in the perforated fluidized bed for the

Geldart's particle Ergun's equation is not used. The experimental Pressure drop calculated as  $^{(6,12)}$ :

$$\Delta P = (1 - \varepsilon) (\rho_p - \rho_g) g \times \Delta h$$
(4)
Fluidization Quality (FQ)

The flow of gas in a gas-solid fluidized bed is characterized by the predominance of bubbles which lead to considerable bed fluctuation at fluid velocity higher than that at the minimum fluidization. Consequently, an instability in the operation results which affects the fluidization quality adversely. Fluidization quality is defined as the dimensionless pressure drop through the bed. Bed fluctuation and fluidization quality being inter-related, previous investigations on the quality were aimed at the development of correlations for fluctuation ratio in terms of static and dynamic parameters. Fluidization quality is define by the equation is given by the<sup>(13)</sup>.

$$F.Q = \frac{\Delta \tilde{P} \times S}{M \times q} \tag{6}$$

Where

S = cross sectional area of the bed  $(m^2)$ . and

S = d ? h

M = Mass of the particles (materials) in the packed bed heights. d = diameter of the fluidized bed column.

h = Total height of the fluidized bed column.

An FQ equal to unity characterizes a homogenous fluidization of either individual particles or ephemeral agglomerates. In contrast, channeling and slugging phenomena lead to poorer fluidization qualities.

#### **Experimental** setup:

The experimental set-up as shown in Fig 2.Which consists of an air compressor, an air accumulator for storing the compressed air from compressor, rotameter, a fluidized bed column of diameter 4cm, air distributor and U-tube water manometer.



Fig.1 Schematics of experimental setup

The experiment is carried out to study the hydrodynamic characteristics of fluidization material with respect to static bed height (H) during fluidization process. The experiments were carried out in fluidized bed made up of acrylic column having length of 80cm. The experimental set up comprises of the fluidized bed column having the perforated draft tube and the annular portion. The draft tube with 39.5cm length and having the perforation at a gap of 5cm on the three sides of the draft tube having the angle of 120 degree on the draft tube. The draft tube was set up by providing the circular perforating plate to the annulus portion of the fluidized bed column. The fluidized bed

column is arranged such that the draft tube is acting as the multicirculating medium for fluidization material. The screen of very fine size was placed just below the distributor to prevent the backflow of bed materials. The rotameter was used for measuring the air flow rate passing to the column. A U-tube manometer was used for measuring the pressure drop across the bed with the water as the manometric fluid.

# Procedure:

The Experimental study consist of measuring pressure drop and minimum fluidization height across the column with different gas flow rate, different particle density, minimum fluidization velocity and minimum bubbling velocity.

1) In the experimental study four different types of fluidization materials of Geldart's particles (Group A, B, C & D). Their properties are shown in table.1.

2) The experiments were carried out by passing air through the distributor plate by varying the different system parameters. The expanded bed height and bed manometer reading were noted down at different flow rates of air.

3) The data for different material were collected with perforated draft tube and compared with Geldart's correlation.

| Tab   | le 1.Properties of different | fluidization | material                |
|-------|------------------------------|--------------|-------------------------|
| Group | Name of Particles            | dp           | Density of Particles    |
| С     | Cement particles             | 5µm          | $2120 \text{ kg/m}^3$   |
| С     | Fly ash particles            | 17 µm        | 2890 kg/m <sup>3</sup>  |
| А     | Marble powder                | 75 µm        | $3800 \text{ kg/m}^3$   |
| А     | M arble powder               | 90 µm        | 4980 kg/m <sup>3</sup>  |
| В     | Sand particles (Mesh No.60)  | 250 µm       | 5200 kg/m <sup>3</sup>  |
| В     | Sand particles (Mesh No.52)  | 300 µm       | 5260 kg/m <sup>3</sup>  |
| D     | Sand Particles (Mesh No.22)  | 710 µm       | $5.22 \text{ kg/m}^3$   |
| D     | Sand Particles (Mesh No.14)  | 1204 µm      | $5.42 \text{ kg/m}^3$   |
|       | Air                          |              | 1.293 kg/m <sup>3</sup> |

#### **Results And Discussion**

#### Pressure Drop

In ideal fluidization, when the superficial gas velocity  $(U_o)$  is increased from zero, the bed pressure drop ( $\Delta P$ ) increases, and bed expansion occurs at  $U_{mf}$  and the pressure drop levels off beyond  $U_{mf}$  because it reaches the total weight of the particles in the bed.

The operating bed pressure drop has been experimentally determined in fluidized beds with a perforated draft tube with change in static bed height at different operating conditions of beds consisting of four Geldart's particles with different particle diameters, densities and shapes. Ergun equation is not applicable for fluidized bed with perforated draft tube for calculating the pressure drop, new corrections are derived which is used in the calculation of the pressure drop is tabulated in table No.2. A total bed pressure drop  $\Delta P$  is important from a viewpoint of the stable fluidization.



Fig. 2 Pressure Drop for Geldart's Group B particles.

Fig. 2 shows the relationship for the Geldart's group B particles (Mesh No. 52, Initial bed height = 8cm) between the typical total bed pressure drop  $\Delta P$  (Experimental & Correlation) and superficial gas velocity (U<sub>g</sub>).

| Multiple  | Regression | Analysis Me | ethod (p | olynomial Method)   |                    |
|-----------|------------|-------------|----------|---------------------|--------------------|
| Geldart   | Mesh       | Bed         | dn       | Lineer Deletion     |                    |
| Particles | No         | Height      | up       | Linear Kelation     |                    |
|           |            | 8           | 5        | P = 4031  U + 348.2 |                    |
| С         | 5          | 12          | J        | P = 3835 U + 283.6  |                    |
|           |            | 16          | μΠ       | P = 1602 + 1245     |                    |
|           |            | 8           | 18       | P = 3995 U + 435.1  |                    |
| С         | 18         | 12          | 10       | P = 2884 U + 1273   |                    |
|           |            | 16          | μΠ       | P = 1364 U + 1232   |                    |
|           |            | 8           |          | P = 3306 U + 933.6  |                    |
| А         | 75         | 12          | 75       | P = 3909 U + 518.5  |                    |
|           |            | 16          | μm       | P = 5470  U + 561.5 |                    |
|           | 90         | 8           | 90       | P = 2284 U + 747.2  |                    |
| А         |            | 12          | )0<br>um | P = 2729 U + 792.9  |                    |
|           |            | 16          | μΠ       | P = 5989 U + 339.8  |                    |
|           | 60         | 8           |          | P = 4396.8 X +      |                    |
| B         |            |             | 250      | 707.54              |                    |
| D         |            | 12          | μm       | P = 4408 U + 795.9  |                    |
|           |            | 16          |          | P = 4455 U + 1223   |                    |
|           | 52         |             | 8        | 300                 | P = 4397 U + 707.5 |
| В         |            | 12          | 500      | P = 4435 U + 427.5  |                    |
|           |            | 16          | μΠ       | P = 5400  U + 733.5 |                    |
| D         | 22         | 8           |          | P = 6048 U - 181.2  |                    |
|           |            | 10          | 710      | P = 6388.3 U -      |                    |
|           |            | 12          | μm       | 77519               |                    |
|           |            | 16          |          | P = 7267 U - 622.2  |                    |
|           | 14         | 8           |          | P = 5468.5 U +      |                    |
|           |            |             | 120      | 2171.9              |                    |
| D         |            | 12          | 4        | P = 6288.3 U +      |                    |
|           |            | 12          | μm       | 1437.9              |                    |

| Table.2.The  | various  | correlations | had  | derived  | by u  | ising th | e  |
|--------------|----------|--------------|------|----------|-------|----------|----|
| Multiple Reg | pression | Analysis Met | thod | (polyno) | mi al | Metho    | d) |



Fig. 4 Pressure Drop for Geldart's Group C particles



Similarly fig 2, 3, 4 & 5 shows the linear correlation between in pressure drop and superficial gas velocity.

As shown in Fig. 2,  $\Delta P$  for fluidization with a perforated draft tube the experimental pressure & the correlation pressure drop is found to equal, from that it is clear that the derived correlation is correct. From fig. 3,4 & 5 it is prove that the Geldart's A, C & D show the same correlation, for the pressure drop and superficial gas velocity. The graph of experimental and correlation pressure drop graph plotted against superficial gas velocity, from that it is clear that the experimental and correlation is found to be same. Various correlations for the pressure drop derived by using Multiple Regression Analysis Method (polynomial Method).

#### Minimum Fluidization Velocity $(U_m)$

At flow rate close to minimum fluidization velocity, the packing of particle is loosened in the central zone and then fluidization takes place. At about 1.7  $U_g$  some bed instability was observed which is characterized by fluctuation in pressure drop. With increase in gas flow rate this phenomenon disappeared. Fig.6 shows the linear relationship between superficial gas velocity (Experimental & Predicted superficial gas velocity) and minimum fluidization Height (H) for Group B particles. Various correlations for minimum fluidization velocity derived by using Multiple Regression Analysis Method (polynomial Method) (tabulated in table No.3). It is observed that the minimum fluidization velocity increases as stagnant bed height increases. Similarly, fig.7 shows the linear relationship between superficial gas velocity (Ums) and minimum fluidization height (H) for Group D particles respectively.

Nevertheless, this increase is less pronounced for beds in contactors with draft tube, so the stability range increases by inserting a draft tube in the contactor.



Fig.6. Minimum fluidization height for Group B particle



Fluidization Quality:

The fluidization quality has been experimentally determined in fluidized beds with a perforated draft tube with change in static bed height at different operating conditions of beds with different diameter of particles, densities and shapes.

Fig. 8 shows the linear relationship for the geldart's group B particles (Mesh No. 52, Initial bed height = 8cm) between the fluidization quality and superficial gas velocity  $(U_g)$ . The result reveals the fluidization quality with perforated draft tube gives the significant results. Similarly fig. 9, 10 &11 shows the linear correlation between in fluidization quality and superficial gas velocity for Geldart's group A, C & D particles.







Fig.11. Fluidization Qualityfor Group D particles *Minimum Bubbling Velocity:* 

Geldart's proposed correlation for the minimum bubbling velocity<sup>(1)</sup>( $U_{mb}$ ) for the different diameter of the particles, which gives the linear relationship for minimum bubbling velocity with respect to diameter of the particles. The result reveals that Geldart's correlation for the minimum bubbling velocity is applicable to the fluidized bed with perforated draft tube.





From Geldart's proposed equation for minimum fluidization velocity<sup>(2)</sup> for different diameter of particles, gives the parabolic relationship between minimum fluidization velocities with respect to diameter of the particles. The results reveal that Geldart's correlation for the minimum fluidization velocity is applicable to the fluidized bed with perforated draft tube.

The characteristic fluidization behavior of Group A particles is the existence of the non-bubbling regime in the region between the minimum fluidization velocity  $U_{mf}$  and the





Geldart's proposed correlation for the ratio of minimum bubbling velocity to Minimum fluidization velocity  $(U_{mb}/U_{mf})$ for the different diameter of the particles, it gives the parabolic relationship with ratio of minimum bubbling velocity to minimum fluidization velocity  $(U_{mb}/U_{mf})$  with respect to diameter of the particles as shown in the below figure. 14. The results reveal that Geldart's correlation for the ratio of minimum bubbling velocity to minimum fluidization velocity  $(U_{mb}/U_{mf})$  is applicable to the fluidized bed with perforated draft tube.



Fig.14. Ration of Minimum Bubbling velocity to Minimum fluidisation velocity (Umb/Umf), bed height = 8cm.

A correlation between minimum fluidization velocity (Ums) and Static bed height (H) for perforated draft tube for different material is proposed as:

| Table.3.The | various  | correlations | had | derived  | by ı  | using the |
|-------------|----------|--------------|-----|----------|-------|-----------|
| Multiple Re | gression | Analysis Met | hod | (polynor | ni al | Method):  |

| Geldart<br>Particles | Mesh<br>No | Bed<br>Height | Dp             | Linear Relation   |
|----------------------|------------|---------------|----------------|---|
| В                    | 60         | 8<br>12       | 250            | $\begin{array}{l} U = 0.6006H + 0.07771 \\ U = 0.6006H + 0.07771 \end{array}$ |
|                      |            | 16            | μιι            | U = 0.5527 H + 0.0136   |
| _                    |            | 8             | 300            | U = 0.45506 H + 0.042681  |
| В                    | 52         | 12            | μm             | U = 0.4683 H + 0.07   |
|                      |            | 16            | •              | U = 0.6108 H + 0.06421  |
| D                    | 22         | 8<br>12<br>16 | 710<br>μm      | U = 0.4276 H + 0.01149 U = 0.4344 H + 0.03595 U = 0.7327 H + 0.06001          |
| D                    | 14         | 8<br>12<br>16 | 120<br>4<br>µm | U = 0.2724 H+ 0.03196 U = 0.2313 H+ 0.07683 U = 0.2171 H+ 0.1151              |
|                      |            |               |                |   |

## **Discussion and Conclusion:**

In this research the experimental studied, it is observed that by means of an appropriate design of the concentric perforated draft tube, the range of stable operating conditions in cylindrical fluidized beds with a perforation gives better results. The cohesive force in Geldart's C particles is very strong and it is very difficult to fluidized, but due to perforated fluidized bed it is very easy. The perforated draft tube helps in minimizing the cohesive &adhesive forces between the particles. Draft tube inserted into fluidized bed provides a means for controlling the magnitude and spread of Particle residence time. At the same time, the draft tubes reduce the air flow through annuals. However perforated draft tube the percentage annular air flow is increased as the separation distance increases. The perforated draft tubes have acharacteristics maximum in annular flow which can be attributed to variation in overall pressure gradient. The predicted pressure drop and the operating gas velocity are found to from the above table no 2 & 3 is corrected. Geldart's correlation for the minimum bubbling velocity & the minimum fluidization is also applicable for the fluidized bed with perforated draft tube. Fluidization quality for the various Geldart's particles is also applicable for the fluidized bed with perforated draft tube.

# Nomenclature

- di Air inlet nozzle diameter (m).
- H StaticBed height(m).
- dc Bed diameter (m)
- dp Particle diameter(m)
- $(1 \varepsilon)$  hold-up of solid particles within draft tube.
- H<sub>w</sub> Liquid head in the manometer (m)
- $\Delta \hat{P}$  Overall bed Pressure drop (N/m<sup>2</sup>).
- $\Delta P/L$  Pressure drop unit length of static bed height (N/m).
- U superficial gas velocity based on cross-sectional area of column (m/s)
- U<sub>mb</sub> Minimum bubbling velocity (m/s)
- $U_{ns}$  Minimum superficial gas velocity for fluidization (m/s)
- Us Fluidization gas velocity (m/sec)
- $W_{45}$  Weight fraction of solid at having the diameter less than 45µm
- $\mu_g$  Gas viscosity (N-S/m<sup>2</sup>)
- $\rho_p^{\circ}$  Density of particle (kg/m3).
- $\rho_g$  Density of gas (kg/m3).

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