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Hydrodynamics of Spouted Bed with Porous Draft Tube

Khadse Jagdish B[1]., Gajbhiye Nikhil K.[2], and Dawande S. D[3].

Department of Chemical Engineering
Laxminarayan Institute of Technology
Nagpur University, Nagpur-440033 INDIA.

Abstract :

A spouted bed with a Porous draft tube was employed to obtain hydrodynamic data of different spouting material like Mustard, Glass beads, Sago, Sand for varying operating condition. These data were compared with the conventional spouted bed and non porous draft tube. The stability and hydrodynamics properties of a spouted bed are determined primarily with respect to, minimum spouting velocity, pressure drop, holdup of solid particles within a 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. The pressure drop for porous draft tube is more as compared to conventional and non porous draft tube. At about 1.7 U_{ms} some bed instability was observed which is characterized by fluctuation in pressure drop. With increase in gas flow rate this phenomenon disappeared.

Key words: Spouted Bed, Minimum Spouting Velocity, Bed Gas -solid voidage fraction.

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1. Introduction

Spouted beds possess certain structural and flow characteristics that are very desirable for fast, highly exothermic and endothermic catalytic reactions. However, the use of spouted 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. Therefore, it may be more favorable to operate spouted beds with relatively finer particles when applying as catalytic reactors .For spouting of fine particles, stable spouting and regular circulation of solids can be obtained only for a low gas velocity. Moreover, in order to fulfill the criteria for stable spouting, 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 porous or perforated distributor surrounding the central orifice, the spout-fluid bed technique increases the fluid-solid contact in the annulus.

Spouted bed is a column open at top and filled with relatively coarser 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 spouted bed, the central core is called the spout and the principle annular reason is called annulus(8). The spouting and its stability, operating condition, spouting bed height along with the changing phenomenon from spouting to bubbling, slugging etc. depends on many factors like effect of particle size, orifice size of spouting fluid, flow rate of 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 spoutable bed depth (H_m), beyond which the spouting action does not exist but is replaced by a poor quality fluidization . The minimum spouting velocity at this bed depth can be 1.25 to 1.5 times greater than the corresponding minimum fluidization velocity (U_{mf}).

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

Mathur and Gishler(1) investigated the effects of column diameter, bed depth and physical properties of solids and fluids on spouting behavior. They also correlated a minimum fluid velocity for spouting

empirically as follows:

$$Ums = (dp/dc)(di/dc)^{0.99}*((2gH(\rho p- \rho g)/ \rho g)^{0.5} \qquad (1)$$

Mathur and Epstein(2) carried out hydrodynamics and heat transfer studies in spouted beds. Kmiec(3) introduced an equation for a maximum pressure drop in a spouted bed as follows :

$$\Delta P/H\rho g = 1+0.206\ [Exp(0.62*(H/rc))] \qquad (2)$$

The experimental Pressure drop calculated as(6) :

$$\Delta P= (1-\varepsilon)(\rho_p-\rho_g)g*\Delta h \qquad (3)$$

Experimental setup :

The experimental set-up as shown in Fig 1.consists of an air compressor , an air accumulator for storing the compressed air from compressor, a rotameter , a fluidized bed column of diameter 4cm, air distributor and U-tube water manometer. The experiment are carried out to study the hydrodynamic characteristics of spouting material with respect to static bed height(H) during spouting process. The experiments were carried out in acrylic column having length 80cm. The experimental set up comprises of the spouted 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 spouted bed column. The spouted bed column. is arranged such that the draft tube is acting as the multi-circulating medium for spouting 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.The perforated draft tubes are having length of 39.5 cm. The perforation is provided by the drilling of the acrylic material at the gap of 5cm having the perforation diameter 7.5 –8cm The perforation is provided at the three side of the acrylic draft tube with the angle of the of 120 °.

Procedure :

The Experimental study consist of measuring pressure drop across the column with different gas flow rate ,particle density, minimum spouting velocity and comparing the hydrodynamics data with non porous draft tube and conventional spouted bed readings.

1) In the experimental study four different types of spouting materials are used such as, Mustard, Sand, Glass Beads and Sago etc..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 porous draft tube , non porous draft tube and conventional spouted bed column.

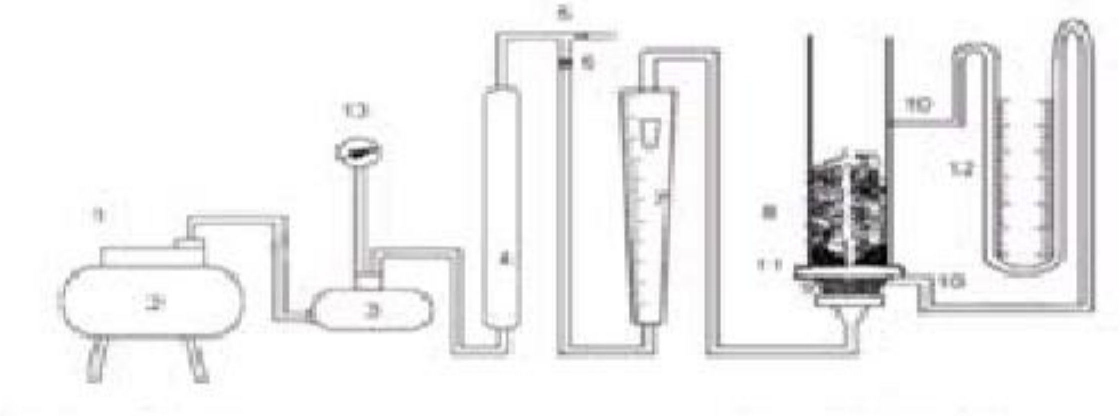

Fig .1 Schematic of experimental set up

Table 1.Properties of Different Spouting Material

Sr. NO	Material	Density (kg/m3)	Diameter of Particles (mm)	Shape
1	Mustard	1191	2.2	Spherical
2	Glass Bead	2886	1.1	Spherical
3	Sago	979	1.1	Spherical
4	Sand	2670	710	Irregular

RESULTS AND DISCUSSION :

1) Pressure Drop :

The operating bed pressure drop has been experimentally determined in spouted beds with a porous draft tube with change in static bed height and draft tubes at different operating conditions of beds consisting of four spouting materials of different particle diameters, densities and shapes. A total bed pressure drop ΔP_S is important from a viewpoint of the stable spouting.

Fig. 2 shows the relationship between the typical total bed pressure drop ΔP_S and superficial gas velocity (U) for spouting without a draft tube and with a nonporous and a porous draft tube for mustard. As shown in Fig. 2, ΔP_S for spouting without a draft tube is lower than those of others. Therefore, conventional spouted bed has a considerable advantage from the viewpoint of power consumption. ΔP_S for spouting with a porous draft tube is higher than for a non-porous draft tube, due to gas percolation from the draft tube to the annulus. Similarly,for spouting with a porous draft tube, Fig. 3,4,5 shows a relationship between the total bed pressure drop(ΔP_{S}) and superficial gas velocity (U) with the static bed height(H) for sand ,glass bead ,sago respectively. ΔP_S for spouting with a porous draft tube are higher than for spouting with a non-porous tube, particularly at a lower static bed height(H). This is due to the decrease of the energy of vertical gas stream entering from bottom of the porous draft tube by the radial gas percolation through a porous draft tube.

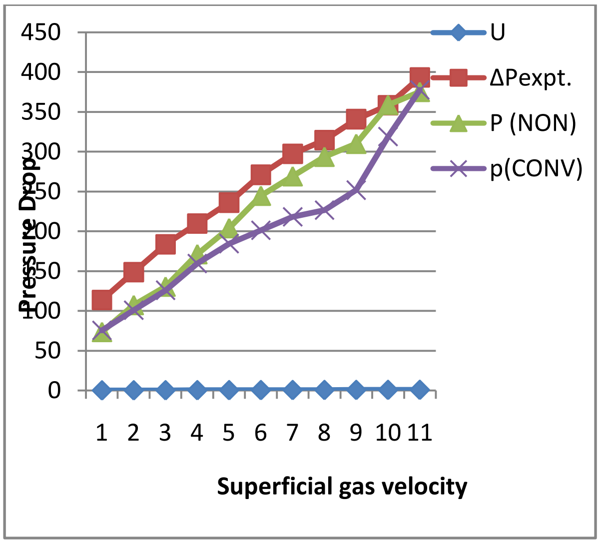

Fig.2 Relationship between ΔP_S and U as a parameter of H for a porous draft tube for Mustard .

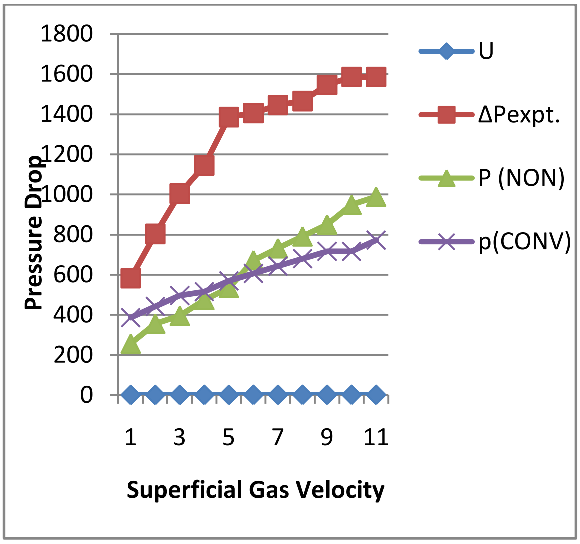

Fig.4 Relationship between ΔP_S and U as a parameter of H for a porous draft tube for Glass Beads.

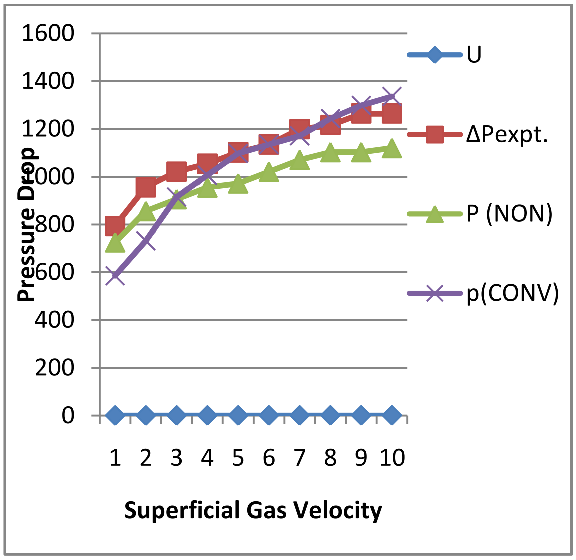

Fig.3Relationship between ΔP_S and U as a parameter of H for a porous draft tube for Sand .

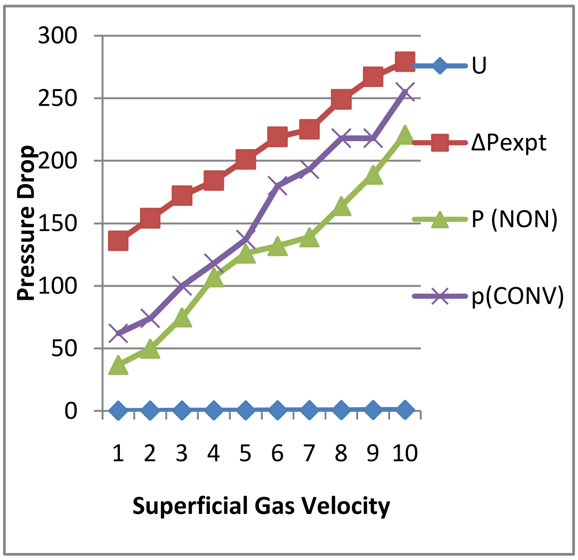

Fig.5Relationship between ΔP_S and U as a parameter of H for a porous draft tube for Sago.

2) Minimum Spouting Velocity (U_{ms}):

At flow rate close to minimum spouting velocity , the packing of particle is loosened in the central zone and then spouting takes place. At about 1.7 Ums 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 minimum spouting velocity (Ums) and static bed height (H) for mustard. It is observed that the minimum spouting velocity increases as stagnant bed height increases. Similarly, fig.7, 8, 9 shows the linear relationship between minimum spouting velocity (Ums) and static bed height (H) for sand, glass bead, sago 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.

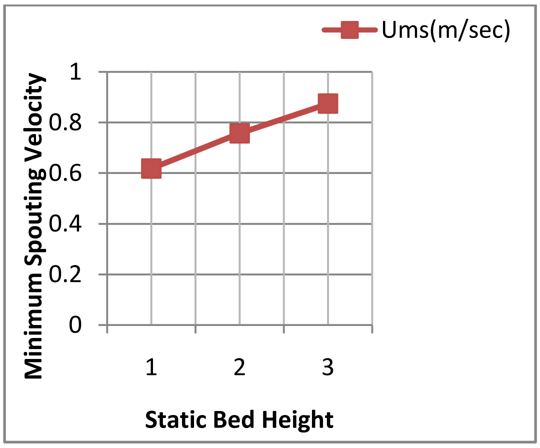

Fig.6 Relationship between Ums and static bed Height for porous draft tube for Mustard .

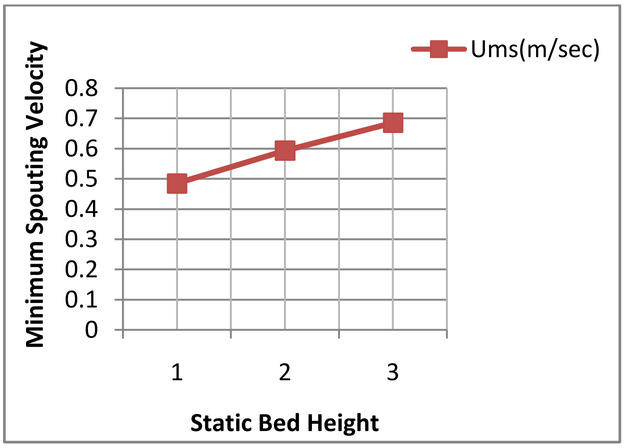

Fig.8 Relationship between Ums and static bed Height H for porous draft tube for Glass bead .

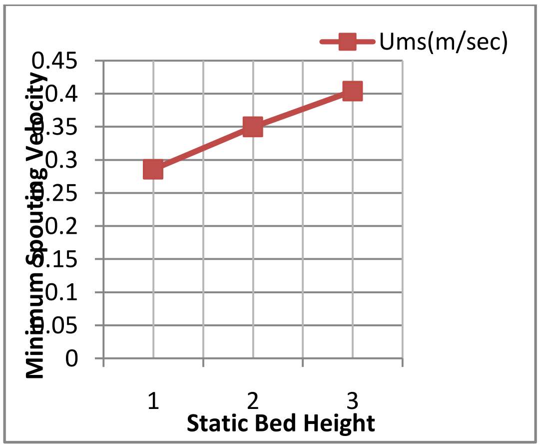

Fig.7 Relationship between Ums and static bed Height for porous draft tube for sand .

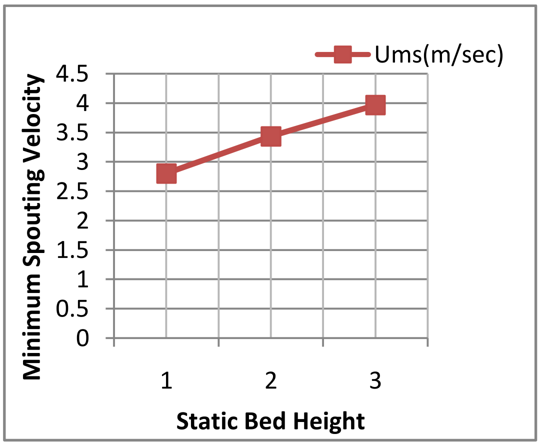

Fig.9 Relationship between Ums and static bed Height H for porous draft tube for sago .

Correlation between Pressure drop and gas superficial velocity for porous draft tube at static bed height (H)=4cm for four spouting materials are tabulated as follows:

Correlation				
Sr. No.	**Material**	**Porous draft tube**	**Non porous draft tube**	**Conventional**
1)	Mustard	$\Delta P = 4.1 \times 10^2$ Ug + 72	$\Delta P = 4.6 \times 10^2$ Ug + 18	$\Delta P = 4 \times 10^2$Ug + 18
2)	Glass Beads	$\Delta P = 1.4 \times 10^3$ Ug 6.1×10^2	$\Delta P = 1.1 \times 10^3$ Ug + 1.2×10^2	$\Delta P = 5.7 \times 10^2$Ug + 3.4×10^2
3)	Sand	$\Delta P = 6.5 \times 10^2$Ug + 8.2×10^2	$\Delta P = 1.2 \times 10^3$ Ug + 5.5×10^2	$\Delta P = 5.7 \times 10^2$Ug + 7.4×10^2
4)	Sago	$\Delta P = 2.4 \times 10^2$Ug + 1.1×10^2	$\Delta P = 3.1 \times 10^2$Ug -6.3	$\Delta P = 3.3 \times 10^2$Ug + 14

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

Sr.No.	Material	Correlation
1)	Mustard	$U_{ms} = 0.111 H^2 – 0.0014 H +0.00052$
2)	Glass Beads	$U_{ms} = 0.27 H – 0.092$
3)	Sand	$U_{ms} = 0.53 H^2 – 0.027 H +0.0048$
4)	Sago	$U_{ms} = 0.034 H – 0.057$

Conclusion :

In all the experimental systems studied, it is observed that by means of an appropriate design of the central draft tube, the range of stable operating conditions in cylindrical spouted beds with a porous draft tube is wider than without draft tube without any instability or operation drawbacks. Draft tube inserted into spouted bed provide 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 with both porous and nonporous draft tube the percentage annular air flow is increased as the separation distance increases. The porous draft tube have a characteristics maxima in annular flow which can be attributed to variation in overall pressure gradient.

Nomenclature

di	Air inlet nozzle diameter,m
H	Static Bed height, m
dc	Bed diameter, m
dp	Particle diameter, m
$(1-\varepsilon)$	hold-up of solid particles within draft tube
ΔP	Overall bed Pressure drop (N/m^2)
U	superficial gas velocity based on cross-sectional area of column (m/s)
U_{ms}	minimum superficial gas velocity for spouting (m/s)
Us	Spouting gas velocity (m/sec)
ρ_p	Density of particle (kg/m3).
ρ_g	Density of gas (kg/m3).

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