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Hydrodynamic studies and comparison of flat plate, conical, and partitioned distributors for pressurized fluidized bed gasifier

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ABSTRACT

The gas solid hydrodynamic studies of a Flat plate, Conical and partitioned concave distributor is reported. The study included hydrodynamic characteristics and moving pattern of particles in the bed. One of the objective of the present work is to investigate the influence of distributor types on the performance of fluidized bed reactors using group B particles as per Geldart D,.1972. Classification Gas - solid hydrodynamic characteristics viz ; Bubble diameter Froude no , Bubble rise velocity of partitioned concave distributor are compared with the conical and flat plate distributors commonly used. The bed void age is used as the parameter for indicating the fluidization quality in selecting the final configuration of the distributor. The bed void age arrived for partitioned concave distributor are compared with the conical and flat plate distributors and results presented.

1. Introduction

Integrated Gasification Combined Cycle (IGCC) is an emerging advanced clean coal technology wherein coal is converted to coal gas in a Pressurized Fluidized Bed Gasifier (PFBG) and combusted in gas turbine of a combined cycle power plant.. To properly design a PFBG operating at elevated pressure and temperature, there is a need to develop lab scale hydro dynamically similar cold model fluidized bed operating at ambient conditions which will simulate the desired hydrodynamic performance of commercial unit using selected type of distributor.

In Pressurized Fluidized Bed Gasifier (PFBG) during gasification of low grade coal, the elutriation of un burnt carbon with fly ash is observed to be about 10-16% bringing down the carbon conversion efficiency. The reason for the same is attributed to bubble coalescence and breaking of large bubbles at the surface (splash zone) throwing out fines along with un burnt carbon at higher than the terminal velocity of particles as reported by Davidson. J.F,etal 1971while using conventional flat plate or conical type of distributors The elutriation is further expected to increase with increase in gasifier operating pressure . One of the objective of this work is to investigate the influence of distributor types on the performance of fluidized bed reactors using group B particles as per Geldart D,.1972. classification, with most particles of size 40 µm < d_p < 500 µm and density 1.4 < ρ_s < 4 gm / cm^3 covering bubbling regime . Many measures, such as circulation in bed and re- injecting fly ash into bed, etc, can be taken to improve above deficiency in performance. One of the effective methods of overcoming the problem is to use partitioned concave distributor instead of conventional flat plate or conical type of distributors This type of distributor with chosen configuration facilitates circulating movement of particles within the fluidized bed thus increasing fines residence time and improved carbon conversion efficiency.

The paper is treated in two fold, the first part is to investigate the influence of varying apex angle of the conical distributor on the hydrodynamic behavior of fluidized bed covering bubbling regime The first part of the experimental study is carried out on 940 mm ID semi circular cold model decreases with the increase in distributor apex angle hydrodynamically scaled down model of 168 TPD-PFBG. The bed void age measured for conical distributor is compared with flat plate distributor and results presented.

The second part is to study the gas-solid hydrodynamic characteristics of partition distributor with three segments (flat plate followed by two numbers of conical distributors with apex angles of 60°,90°, 120°) and present effects of various factors on particle trajectory and compared with commonly used conical and flat plate distributors.

Gas - solid hydrodynamic characteristics viz; Bubble diameter, Froude no, bubble rise velocity of partitioned concave distributor are compared with the conical and flat plate distributors commonly used and presented graphically.

2.0 Cold Model Studies:

On the basis of full scaling parameters, the cold model reactor has dimensions that are too smaller than those of the hot gasifier. Hence, it is desirable to identify a reduced set of scaling relationships that permits a scale factor to be supplied as a free parameter rather than determined by the scaling parameters themselves. Glicksman et al (1984 ,1986) also proposed a simplification to the full set of scaling parameters, which allow the scale factor for the bed dimension to be chosen independently. The simplification is based on the reduction on the number of dimensionless groups when either viscous or

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inertial effects dominate the fluid particle drag. In both viscous and inertial limits the scaling parameters reduce to groups listed below are referred as the simplified set of scaling parameters.

$d_p^3\rho_g\,(\rho_p-\rho_g)g/\ \mu_g^2$, $\rho_g/\ \rho_s$, U_o^2/gD , U_o/U_{mf}, L/D , $Ø_s$, PSD …. (1)

where $Ø_s$ and PSD are included to match ε_{mf} between two fluidized beds beds

A perspex three dimensional semi circular test rig reactor of ID 940mm hydrodynamically scale down model of a demonstration size 168 tpd PFBG plant is constructed as shown schematically in Fig.1. The cold model of fluidized bed reactors is discussed at M.T. Nicastro and L.R.Glicksman (1984), Jochim Werther (1992), R .DiFelice, S.Rapagna, P.U.Foscolo and L.G.Gibilaro (1992) and Peter E.G.Gogolek and John R.Grace (1995), The simplified scaling relations are used to arrive at the particle density in cold model conditions. The simplified scaling parameters of 168 tpd PFBG hot and cold models is given at table- 1.

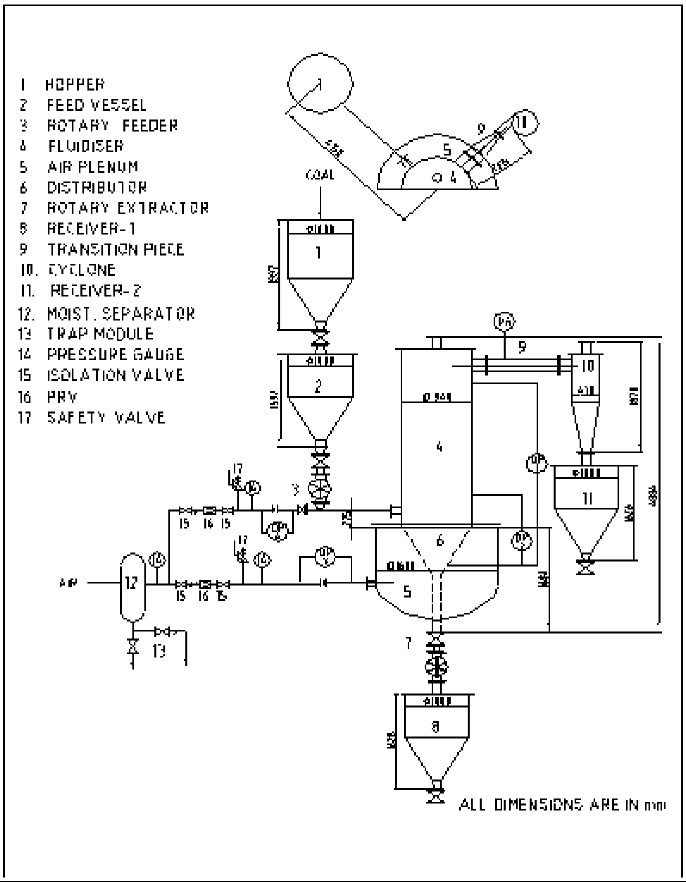

Fig.1 . Schematic drawing of 940 mm dia Semi Circular Test Rig

It is found that Iso-propylene material with a density of 925 kg/m^3 for cold model tests is hydro dynamically similar to bed ash material used in hot model test rig. The scale factor of two thirds is chosen and accordingly the bed diameter, expanded bed height and other hydrodynamic parameters have been fixed for the cold model test rig. A comparison of hydrodynamic parameters of 168 tpd PFBG hot and cold model is given at table 2 .

The experimental study is carried out on 940 mm ID semi circular cold model (hydro dynamically scaled down model of 168 TPD-PFBG) .The paper presents in the first part the influence of varying apex angle of the conical distributor on the hydrodynamic behavior of fluidized bed covering bubbling regime and compared with that of flat plate distributor. The expanded bed height and bubble size were measured for each of the test conditions. The bed void age is used as the parameter for indicating the fluidization quality in selecting the final configuration of the distributor .In the second part of the paper, the bed void age measured for partitioned concave distributor are compared with the conical and flat plate distributors commonly used and results presented.

3.0 Description Of Experimental Set up :

A perspex three dimensional 940 mm dia semi circular test rig reactor hydro dynamically scale down model of 168 tpd – PFBG plant is shown schematically at Fig.1. The photographs of Semi circular test rig and contol valves are given at figures 5 a & 5 b. The scaling relations are used to arrive at the particle density. The scale factor (m) of two thirds is chosen and accordingly the bed diameter was fixed for the test rig.

Three types of distributors viz., flat plate, conical and partitioned distributor have been used and hydrodynamically investigated. The first segment of partitioned distributor is a flat plate followed by conical distributor of lower apex angle of 90° with final segment of concave distributor having included angle of 120°.

3.1 Flat Plate Distributor :

Many types of distributors have been developed to improve the gas distribution in a fluidized bed. The choice of distributor is governed by the process and the operating conditions. The multi-orifice plate is the simpliest gas distributor used in industries. Its ease of construction and maintenance makes it a common choice. Further the bubble-cap type of orifice have been specially designed to prevent the back-flow of solids through the distributor. In a fluidized bed the distributor plate must be designed to offer uniform fluidization through the bed cross section. Uniform fluidization is achieved only if the distributor plate imposes a resistance to the total flow sufficient to over-come the fluids inherent resistance to rearranging and redistributing itself. Hence for proceeding with design and sizing of a distributor, the pressure drop across the distributor has to be assumed. The usual practice is to assume the distributor loss as a fraction of the bed pressure loss. Many investigations show that a ratio of distributor loss to bed pressure loss of about 0.3 to 0.4 has been recommended. The flat plate distributor is shown in Fig.2. with ID of about 940mm and is provided with 10 rows, each row consisting of 16 equispaced holes of diameter 5.7mm.

3.2 Concave Distributor :

In a fluidized bed with a concave distributor a different flow pattern is observed. In view of different bed heights on inclined plates lead to different pressure drops across the bed more gas tends flowing through the region where bed material layer is thinner. Less gas passes through the central zone where bed material layer is thicker. As a result, acted by gravity, buoyance and drag force, the particles in the central zone move down wards and the particles at both sides between the central zone and wall zone flow upwards rapidly. Once reaching the bed surface, most of them turn to central zone and then move downwards, the others turn to the wall zone and move downwards along the wall. Two different particle circulations formed in the bed, the big one in the center and the small one in the wall zone. The distributor for the cold model is designed to have equivalent kinetic energy factor (α) to the orifices and the number of holes is arrived to be 160 The conical distributor is shown in Fig 3 and is provided with 10 rows, each row consisting of 16 equispaced holes of diameter 5.7mm arranged in a zigzag manner at a pitch of 40mm between each row.

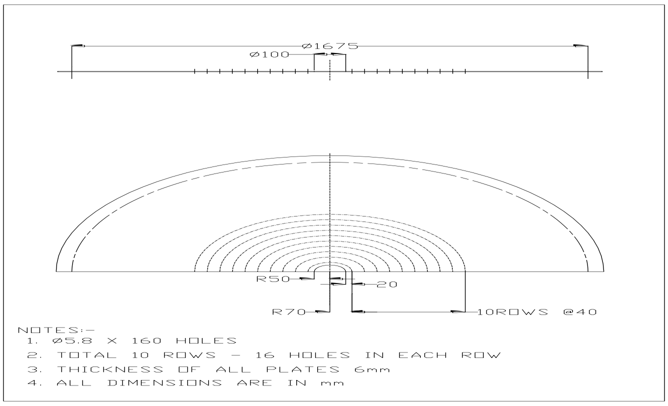

Fig. 2 . Flat Plate Distributor of Semi circular Test Rig

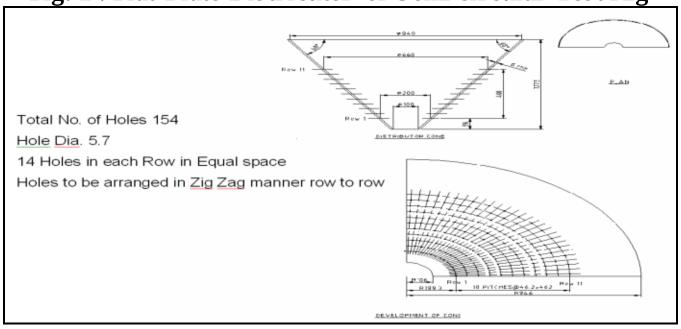

Fig. 3 Conical Distributor of Semi circular Test Rig

3.3 Partitioned Concave Distributor:

The first segment of partitioned distributor is a flat plate followed by conical distributor of lower apex angle of 90° with final segment of concave distributor having included angle of 120°. Thus the wind box is divided into three compartments for providing each compartment with air individually. The materials used are iso- propylene .Air at ambient temperature was used as fluidizing medium. By operating the valve system at inlet, the flow through each passage leading to each of the compartment in the distributor can be varied and the bed dynamics can be changed to achieve better circulation pattern within the bed.

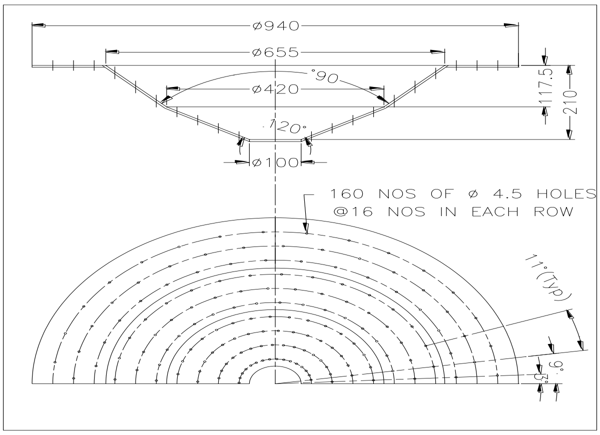

Fig. 4 Partitioned Concave Distributor of Semi circular Test Rig

In the partitioned distributor the total flow through distributor is divided into three streams as shown in Fig. 4 . By operating the valve system at inlet, the flow through each passage leading to each of the compartment in the distributor can be varied and the bed dynamics can be changed to achieve better circulation pattern within the bed. As shown in the figure, the first segment of distributor is a flat plate followed by conical distributor of lower apex angle of 90° with final segment of concave distributor having included angle of 120°. Thus the wind box is divided into three compartments for providing each compartment with air individually. Air at ambient temperature was used as fluidizing medium.

4.0 Results and Discussion:

By maintaining same Particle size distribution (PSD) of bed material, experiments were conducted with varying flow rate fractions into each compartment and thus varying superficial velocity. The fluidization characteristics and particle moving trajectory in the bed were observed and drawn graphically.. The expanded bed height and bubble size were measured for each of the test conditions and the results presented graphically.

Fig. 5a. Photograph Of Semi Circular Cold Model Test Rig

Fig. 5 b. Photograph Of control valves of Semi Circular Cold Model Test Rig

4.1 Discussions on Experiments of Flat plate and Conical Distributor - Part 1:

The data has been recorded by carrying experiments with 'Iso-propylene' of mean particle sizes - 0.8 mm at different bed heights using conical distributors with varying apex angles (α) from 60^0 to 120^0 and repeated with Flat plate Distributor (apex angles. of 180^0). The data is then used to find the bed void age derived using Ergun's equation (2).

$$\Delta P_{mf} = H_{mf}\,(1-\epsilon_{mf})\,(\rho_p-\rho_f) \qquad \text{------------} \quad (2)$$

As the bed void age is indicative parameter for quality of fluidization, the results of cold model studies for flat plate distributor and conical distributor are given at table 3. The bed void age obtained from above equation is observed to decrease with the increase in distributor apex angle The results shows that flat plate distributor is superior to conical distributor. However it may be noted that flat plate distributor has the disadvantage of forming single large bubble due to bubble coalescence which will lead to plug flow through the reactor This has negative effect on gasifier performance due to increase of elutriation of carbon particles resulting in lower overall carbon conversion efficiency. Therefore the conical distributor with 60^0 apex angle is advisable from ease of extracting the solids from fluidized bed gasifiers as well as for better back mixing compared to flat plate distributor. Besides flat plate Distributor has the disadvantage of forming single large bubble due to bubble coalescence which will lead to formation of slugs through the reactor and hence lower carbon conversion efficiency

Fig. 6 . Variation of particle circulation in the bed at Flow fraction 40% -35% -25% .

4.2 Discussions on Experiments of Partition Distributor-Part 2 :

By maintaining same particle size distribution of bed material, experiments were conducted with varying flow rate fractions into each compartment and thus varying superficial velocity. The fluidization characteristics and particle moving trajectory in the bed were observed and drawn graphically. The expanded bed height and bubble size were measured for each of the test conditions. Fig 6 depicts gas-solids flow circulation pattern for air distributions in the ratio of 40:35:25 within the bed with the partitioned distributor.

For a partitioned concave distributor provided with three different compartments, when air flowing through individual compartments varies in the ratio of q1: q2: q3, the following flow pattern of particle circulation is observed:

The more the air fraction (q1) passing through the central zone, the smaller the defluidizing zone in the center of the bed and the peaks of expanded bed surface approach the center.. This condition of operation results in smaller circulating zone of particles. On the other hand, if q1 passing through the central zone is too large, and air fraction q2 through mid channel is too small, it will be possible for a channeling flow to take place in the region. In case of higher gas velocity on the inclined plates and more air fraction through middle channel (q2) the central dead zone will be enlarged, as shown in table 4. (refer case no 2 and 5). when the bed height is shallower, this operating conditions also shortens the path of circulating movement of particles besides reducing the utilization factor of overall bed volume.

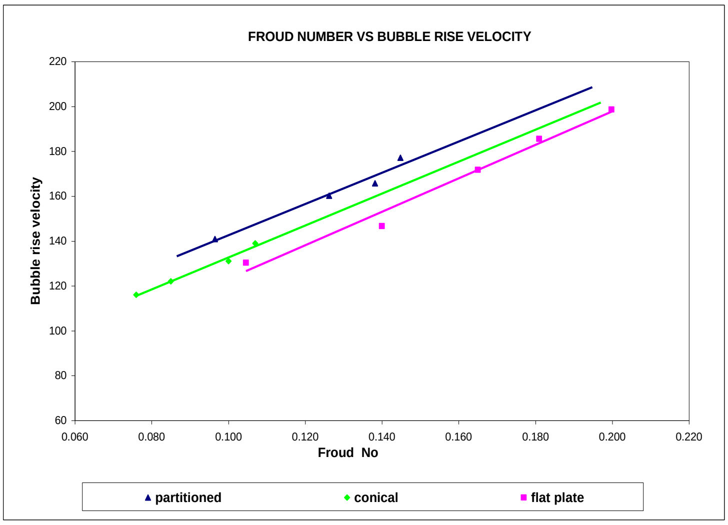

Fig. 7. Froude Number Vs Bubble Rise Velocity

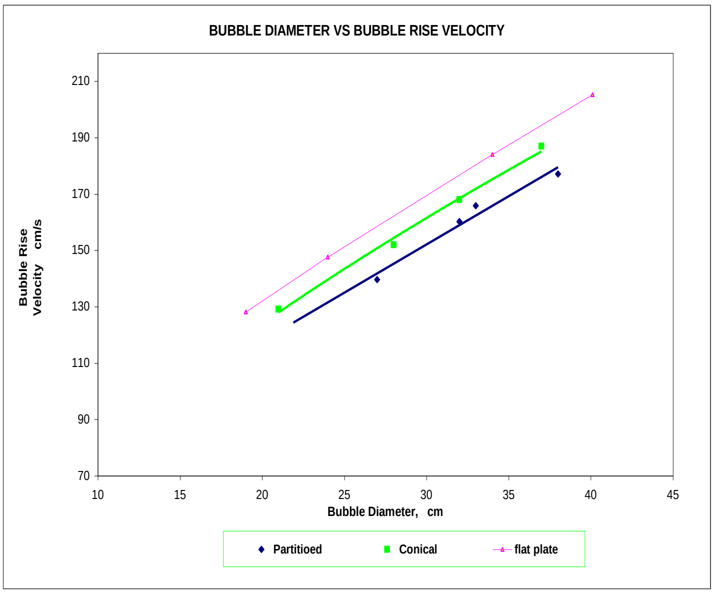

Fig. 8. Variation of Bubble Diameter with Bubble Rise Velocity

The results of partition distributor in the form of computed bed void ages using Ergun's equation are given at table 4. From the parameters it is observed that fluidization quality is improved by partition distributor and optimal air flow distribution for the chosen partitioned distribution configuration is found to be in the ratio of 40:35:25. At this flow condition this is further confirmed from the circulation pattern which ensures no defluidizing zones in the bed .

Besides the hydrodynamic parameters of partition distributor are measured and presented as (a) Froude no versus bubble rise velocity and (b) Bubble diameter versus bubble rise and given at figs. 7 & 8 respectively.

Table 1: Simplified Scaling Parameter Comparison Of 168 TPD-PFBG and Cold Model

PARAMETERS	168 TPD HOT BED	COLD MODEL(2/3 SCALE)
ρ_s / ρ_g	750	750
U_o^2/gD	0.051	0.051
U_o / U_{mf}	2.96	2.96
ϕ_s	0.63	0.65
D_{rig} / d_p	1420	1420

Table 2: Comparison Of 168TPD HOT PFBG plant and Cold Model Parameters

PARAMETERS	168 TPD HOT BED	COLD BED ($2/3^{rd}$ SCALE) SEMI-CIRCULAR
Temperature(K)	1273	303
Pressure(atm)	13	1
Gas Density(kg/m^3) ρ_g	3.26	1.2
Solid Density(kg/m^3) ρ_s	2248	900
Air Flow in Distributor(kg/hr)	12733	1025
Minimum Fluidization Velocity(m/s)U_{mf}	0.2256	0.231
Operating Velocity(m/s)U_o	0.843	0.683
Diameter of Bed(m)	1.4	0.94
Particle Diameter(mm)	0.986	0.662
Orifice Diameter (mm)	5.7	5.7
Number of orifices in distributor N	370	154
Orifice velocity (m/s) U_{or}	38.6	54
Pressure Drop in bed (kg/m^2)ΔP_b	2898	795
Pressure Drop in distributor (kg/m^2)ΔP_d	1159	318
Static bed height(m) H_{static}	1.745	1.203
Expanded bed height (m) H_f	2.473	1.660

Table-3: Comparison of void age (€mf) for Conical and Flat plate Distributor.

Material	Apex angle of conical /Flat plate Distributor	Bed Voidage of Cylindrical Reactor
Sand	60^0	0.5089
	120^0	0.4862
	150^0	0.466
	Flat plate 180^0	0.4451
Bottom ash	60^0	0.6504
	120^0	0.6178
	150^0	0.6071
	Flat plate 180^0	0.5983

Table 4. Experimental results of semi circular cold model with partitioned distributor.

Case No	1	2	3	4	5
Flow Ratio.	40:35:25	35:40:25	33:33:33	50:40:10	20:50:30
Distributor DP,mmWc	450	370	450	325	456
Total DP, mmWc	882	761	959	810	919
Bed DP,mmWc	432	391	510	486	464
Bubble size,cm	35	38	27	24	19
Bubble frequency,(1/S)	1.25	0.7	2	1.5	1.5
Density of gas, Kg/m^3	1.2	1.2	1.2	1.2	1.2
Density of particle,Kg/m^3	900	900	900	900	900
Bed Voidage	0.6296	0.6499	0.579	0.6092	0.5824
Expanded bed height,cm	166	159	172	177	158

The parameters are also compared with conical and flat plate distributor and it is found that the fluidization quality is improved by adopting partition distributor .

5.0 Conclusions:

It can be inferred from the experimentation on Semi circular test rig which is scaled down model of 168 TPD PFBG that the flat plate distributor has marginal advantage over conical distributor based on the bed void age obtained from Ergun's equation. Also the bed void age decreases with the increase in distributor apex angle of conical distributor. However from ease of extraction of bottom ash in PFBG, the conical distributors are being preferred over flat plate as this will also overcome stagnation zones which are likely to be formed at the side wall of the flat plate distributor.

The measured hydrodynamic parameters of partition distributor are plotted graphically viz Froude no veruss bubble rise velocity and bubble diameter versus bubble rise velocity and are compared with conical and flat plate distributor. It is observed that the fluidization quality is further improved by adopting partition distributor .

6.0 Acknowledgement:

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