Effect of plenum chamber depth of a four duct plenum chamber in a swirling fluidized bed

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Abstract- This paper presents the numerical investigation via Computational Fluid Dynamic (CFD) to study the effect of plenum chamber depth on air flow distribution in a swirling fluidized bed (SFB). A total of 7 simulations were conducted for 3 plenum chamber depths of 500 mm, 600 mm and 700 mm (below the distributor) for four duct plenum chamber. Air flow distribution was analyzed based on the tangential velocity distribution, pressure drop at the distributor outlet and bed pressure drop. An optimum plenum chamber depth has low statistical values, implying a uniform velocity distribution inside the bed while low pressure drops are necessary to reduce energy loss in the system. The findings yield that plenum chamber with 500 mm depth suffices both criteria of high uniformity and low pressure drops. Both computational and numerical result results are used for getting the result.

Index Terms— CFD, Plenum chamber, Pressure drop, Swirling fluidized bed

1. INTRODUCTION

Fluidization is a process by which solid particles are made to behave like a fluid, by being suspended in a gas or liquid. One of the recent developments in providing a variant in fluidized bed operation is the swirling fluidized bed (SFB), which provides swirling motion inside the bed apart from fluidization. In contrast with conventional fluidization, in a SFB the fluidizing gas enters the bed at an inclination to the horizontal directed thus by a suitable design of distributor which as an array of blades with centre body, which forms annular opening.

For the present, it has been proposed to bed. With an increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted regions. This is the expanded bed. At a still higher velocity, the pressure drop through the bed increases. At a certain velocity the pressure drop through the bed reaches the maximum and a point is reached when the particles are all just suspended in the upward flowing gas or liquid. At this moment, the particles at the bottom of the bed begin to fluidize, thereafter the condition of fluidization will extend from the bottom to the top and the pressure drop will decline fairly sharply. Study the hydrodynamic characteristics of swirling fluidized bed. The present works have investigated the aerodynamics of a SFB by taking into the effect of distributor design on velocity distribution and pressure drop inside the bed. As for this study, particular attention is given on the plenum chamber design by varying its depth and their effect on aerodynamic characteristics of the bed. The findings are important to improve the plenum chamber design in the attempt to increase overall performance of the system.

2. EXPERIMENTAL INVESTIGATION

Experimental set up and describes the procedure adopted to determine parameters like pressure drop in empty bed at different points of distributor plate and the effective height during fluidization. The schematic diagram shown in Figure describes important parts of the experimental set-up and the photograph of the complete view of the experimental setup is presented in figure. A blower supplies air to the plenum chamber through a 24 cm * 19 cm cross Sectional pipe. The air flow rate can be controlled by the four butterfly valves each valves controlling the air flow rates to each ducts. The flow rate can be calculated from the water column manometer connected to the pitot tube. The pitot is fixed on to the pipe which is 50 cm from blower the static and dynamic ends of pitot tube are connecting to the two ends of u tube manometer for measuring velocity of inlet air. U tube manometer is converting the velocity to corresponding pressure heads.

Fig 2.1: Swirl inlets
A pointer attached to a rack and pinion arrangement helps to measure the readings on the manometer without parallax error. The entry of air in to the plenum chamber is made tangential to it so as to have a clockwise air circulation within this chamber. This
is to reduce the pressure loss at entry in the distributor, as the inclined vane hole type distributors were also designed to have a clockwise air entry into the bed. The bed pressure drop can be obtained by connecting the pressure tapings from the bed to the positive terminal of the digital micro manometer (FCO 520 air pro) and leaving the negative terminal open to the atmosphere.

![Experimental setup](image)

**Fig 2.2: Experimental setup**

**Experimental setup specification**

<table>
<thead>
<tr>
<th>Diameter of plenum chamber</th>
<th>800 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of central cylindrical hub</td>
<td>400 mm</td>
</tr>
<tr>
<td>Middle zone diameter</td>
<td>600 mm</td>
</tr>
<tr>
<td>Air Inlet area</td>
<td>190 * 240 mm</td>
</tr>
<tr>
<td>No. of inlet ducts</td>
<td>4</td>
</tr>
<tr>
<td>Area of each duct</td>
<td>95 * 120 mm</td>
</tr>
<tr>
<td>Height of plenum chamber</td>
<td>500mm,600mm,700mm</td>
</tr>
</tbody>
</table>

**Table 2.1: Experimental setup specification**

Distributor is the vital part in any fluidized bed. As the name indicates it distributes the air uniformly to the bed. In a conventional fluidized bed air is admitted vertically upwards to the bed, whereas in a swirling fluidized bed air enters the bed at an angle.

This is achieved by providing slits inclined at an angle with the radius of the distributor. In conventional fluidized beds a distributor pressure drop as high as 350 mm of water is required for good fluidization. However in a swirling fluidized bed, effective fluidization can be achieved with a comparatively lower distributor pressure drop. The distributor has an outer diameter of 800 mm. A 400 mm diameter wooden cone was provided at the centre of the distributor. The slits were arranged in four rows along four concentric circles. A ridge having a width of 11 mm was provided in between each row, which facilitated the pressure tapings to be conveniently located there. The length of the slit can be determined from the following relation.

Length of slit \( L = \frac{[r_d - r_c - (3xbr)]}{n_r} \)

Where \( r_d \) - radius of the distributor = 400 mm

\( r_c \) - radius of the hub at the centre = 200 mm

\( b_r \) - width of the ridge = 4 mm

\( n_r \) - number of rows = 7

Thus length of the slit \( L = \frac{[400-200-(3x4)]}{7} = 25 \text{ mm} \)

The inner radius of each row of slits can be determined from the relation

\[ R_i = r_c + (ns - 1) \times [L + br] \]

\[ = 200 + (ns - 1) \times [25 + 4] \]

Where \( ns \) - position of the row starting from the centre

**Table 2.2: The inner radius of each row**

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Position of the row ( 'ns' )</th>
<th>Inner radius of the row ( (R_i)=)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>228</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<td>4</td>
<td>4</td>
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<td>312</td>
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<td>6</td>
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<td>340</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>368</td>
</tr>
</tbody>
</table>

**Fig 2.3: Geometry of slits in distributor**

3. METHODOLOGY

Investigation of the air flow distribution in a SFB was conducted by experimental and also using commercial CFD software –FLUENT 15. The computation domain and grid generation was developed. The blades in each raw with 15° horizontal inclination has been selected based on previous studies by [1]. Three parameters were varied to observe the relation between the plenum chamber depths for a four duct plenum camber in a swirling fluidized bed.

Distributor pressure drop can be determined by observing the pressure difference across the distributor in an empty bed. In here using 7 raw 15° vane angle distributor so that the percentage of area opening increases but it is sufficient for getting optimum pressure drop, 300 mm of water pressure drop obtained from the experiment. The distributor
pressure drop is lower for a distributor with higher percentage area of opening. For a given superficial velocity, as the percentage area of opening reduces, the air jet passing through a single opening will have higher velocity. This higher velocity causes higher pressure loss through the openings. Further, for the same percentage area of opening, if the area of a single opening is reduced, the pressure loss through the opening increases. The individual or combined effect of the above two, as the case may be, ultimately causes a higher distributor pressure drop with a lower percentage area of opening of the distributor.

FLUENT was used to generate and model the CFD model. There are two sections of this program: ‘model’ and ‘solve’. The model section is used to define fluid properties, turbulence models and boundary conditions. The solver section is used to control the iteration, relaxation and output to start the solver.

For finding the minimum fluidization velocity the pressure drop taken from different points on distributor in radial direction. From the figure the distributor plate divided into 3 different sections first section has no air flow because below that hub region second and third sections has same air flow rate because of same area. So D1, D2, D3 are 400mm, 600mm, 800 mm respectively. Here we are taking the bed pressure drop along radial distance on the distributor by from different tapings are at various distance from the center.

L_{10} = 210 mm, L_{11} = 240 mm, L_{12} = 300 mm
L_{13} = 330 mm, L_{14} = 360 mm

Investigation of the air flow distribution in a SFB was conducted using commercial CFD software – ANSYS FLUENT 15. At first the analysis started with 2 million of cells then got total pressure of 101388 pa at 5 mm above distributor then repeating the analysis with increasing number of elements by 3.2 to 4.4 million total pressure also increases. The number of cells beyond 4.4 million the total pressure changes become negligible as shown in figure. Almost constant pressure obtained when increasing cell number 5 to 7.7 million so easy to fix the number of cells. After completing this study number of elements taken as 4.4 million because beyond that no effect on total pressure which also reducing the iteration time. Meshing of the SFB system was generated in such a way that it may capture airflow taking place through narrow opening of the distributor blades. Grid sensitivity was done prior to actual investigation to ensure the independence of grid size on the flow and to reduce possible numerical errors. The suitable grid size is chosen in such a way that the total numbers of elements are less without compromising simulation results.

Meshing Scheme was applied to the surface and it allowed creating a face mesh consisting of irregular triangular mesh elements. The Hybrid parameter type that specifies tetrahedral, hexahedral, pyramidal and wedge element were defined to the meshing algorithm. The mesh elements in the computation domain as well as the plenum chamber depth are presented in figure.

In commonly used conventional fluidized bed which is not suitable for drying purposes so increasing the drying effect by using swirling fluidized beds. Here we using heavy plenum chamber for drying agricultural products because of simple fluidized bed which does not create sufficient amount of swirling and vortices above the distributor. So four duct plenum chamber creates proper vortices above the distributor which hold the particles and creates better swirls shown in figure. We created large number of vanes on the distributor which suddenly drops the velocity above that and provides better pressure for carrying Gerald d type heavy particles. More vortices creating on the inner and middle portions of the distributor that shown in figure reduces gradually moving to outer region. The vortices creating on the centre around the hub region which reduce the tendency of particle sedimentation on the centre.

4. RESULT AND DISCUSSION

Analyse the flow distribution inside the SFB due to the effect of varying plenum chamber depth.
portion of the distributor as shown below.

![Image](image_url)

Fig 4.1: Swirling effect above the distributor plate.

a) Pressure drop
Pressure is become constant above and throughout the distributor and high pressure accumulated below the distributor more pressure is at the centre and low in outer region. Figure shows the total pressure variation in fluidized bed. From the figure we can see that the pressure on above of distributor is constant so we have concluded that the distributor pressure drop is constant a slight difference on the outer sides.

![Image](image_url)

Fig 4.2: Variation of total pressure above the distributor with the inlet velocities.

Then take the values 10 mm above from the distributor here the pressure also constant at the middle portion and lower values obtained at outer region nearer to wall. Figure shows the contour plot of velocity 6 m/s and pressure variation 10 mm above from distributor.

The figure shows variation of total pressure above the distributor with the inlet velocities. The values taken from different points along the radial direction 10 mm above the distributor, Pressure first increases with increase in velocity then it became constant and decreases with increases in velocity.
From the all figures the cut in velocity is constant that is 4m/s then the pressure constant in between 4 to 5 m/s velocities. Then Total pressure above the distributor decreasing towards the wall of fluidized beds and high pressure obtained the middle 3 points because the fluidized plenum chamber divided into two parts and giving separate inlets to each chamber. Experimental graphs are varies from the analytical graph because of some errors obtaining during the experiment so the values taking when the time of experiment results some variations.

a) Bed pressure drop

The formation of vortex in swirling fluidized bed causes a variation of bed height in the radial direction and this variation increases with an increase in the swirl velocity. Hence a variation in the bed pressure drop along the radial direction is always to be expected in a swirling fluidized bed when the gas velocities are considerably more than at minimum fluidization.

Typical results showing the variation of bed pressure drop in the case of coffee beans are presented in figures In general, it can be said that, the bed pressure drop increases with an increase in the superficial velocity up to the minimum fluidizing velocity. Beyond the minimum fluidizing velocity and up to the beginning of the swirl motion, there is no significant variation in the bed pressure drop with an increase in the superficial velocity. However, if the superficial velocity is increased in the swirl region, the bed behaves differently.

It is to be noted that, while the bed pressure drop increases with velocity in the outer region of the bed, it decreases in the inner region. The rate of reduction in the bed pressure drop in the inner region of the bed is greater with a higher velocity in the swirl region. Due to the lower bed pressure drop in the inner region of the bed, the air might get by-passed through the inner boundary of the bed (around the cone) which may reduce the efficiency of gas-particle contact in the bed. Depending on the process for which the bed is used, by-passing of air may affect the bed performance, particularly for drying processes. This means that the maximum superficial velocity is to be limited in the swirl region to have an optimum bed performance for drying process.
Generally, the velocity profile increases along the radius towards the bed wall as a result of swirling motion which generates centrifugal force. This centrifugal force pushes the air to mass at outer periphery towards the bed wall, hence higher momentum is present at this location. The velocity of air is zero at the wall itself due to no-slip condition as a result of shear force at wall. Apart from velocity distribution, pressure drop of the system were also extracted from the simulation to gain a better understanding of the system behavior. The pressure drops were distributor pressure drop, which was extracted at equal distances of 10 mm below and above the distributor blades.

Fig 4.4: pressure drop vs velocity above the distributor plate.

Fig 4.5: Analysis with distributor plate 500, 600 and 700 mm height
Fig 4.6: Pressure contour for actual, distributor plate 500, 600 and 700 mm height

Fig 4.7: Pressure contour for each set up

Fig 4.8: Points taken for plotting graph
Once the swirling starts, the bed height variation with superficial velocity is different in the swirling fluidized bed compared to a conventional bed. Unlike inclined hole type distributors, vane type distributors have a wave region and assessment of bed height in the wave region is difficult. At low velocity, the bed behaves as a packed bed and the horizontal movement of the air will be obstructed by the particles. So the entire flow percolates upwards. When the airflow rate is increased, the bed reaches the minimum fluidizing condition. At this point, the particles are, on an average, no longer in contact with each other. The particle-particle friction essentially disappears and the particles are free to move relative to each other at this stage.

Fig 4.9: Pressure vs velocity at point p1

Fig 4.10: pressure at point 2

Fig 4.11: pressure at point 3

Fig 4.12: pressure at point 4

Fig 4.13: pressure at point 5
From the statistical analysis summary in the computational result shown in the above, it was found that case 1 has better velocity distribution in relative to others. Once the swirling starts, the bed height variation with superficial velocity is different in the swirling fluidized bed compared to a conventional bed. Unlike inclined hole type distributors, vane type distributors have a wave region and assessment of bed height in the wave region is difficult. Hence inclined hole type distributors are considered for the study of the variation of bed height with superficial velocity. The bed height considered in the present study was the average readings from three scales placed symmetrically to the outer periphery of the bed column. However, the air flow in the studied location was skewed to the left towards the centre body. This skew was anticipated due to the centrifugal force from the swirling motion and hence evident for all other configurations.

5. CONCLUSION

CFD simulation is an effective method to understand the complex phenomena of velocity distribution such as in the swirling fluidized bed. These hydrodynamic characteristics are imperative in optimizing the plenum chamber design towards increasing the overall efficiency of the system. It can be concluded that plenum chamber depth has an influence on velocity distribution and distributor pressure drop plenum chamber. From the statistical point of view, case 1: 500 mm depth can be considered the best configuration in the preset study. In a shallow conventional fluidized bed the air velocity is primarily in the vertical direction and hence the radial and axial mixing of particles is generated by the gas bubbles within the bed. On the other hand, in inclined hole/vane type distributor air will swirl in the bed. Because of this swirling, at any point in a plane parallel to the distributor, the air will have radial and tangential components of velocity. Once the swirling starts, the bed height variation with superficial velocity is different in the swirling fluidized bed compared to a conventional bed. Unlike inclined hole type distributors, vane type distributors have a wave region and assessment of bed height in the wave region is difficult. Hence inclined hole type distributors are considered for the study of the variation of bed height with superficial velocity.

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REFERENCES


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