Numerical Investigate on the Centre-Bodies of Plenum Chamber in a Swirling Fluidized Bed

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ABSTRACT

The primary objective in this study is to numerically investigate the tangential velocity influence by center-bodies of plenum chamber in swirling fluidized bed (SFB). A numerical simulation using CFD package software was conducted with 3 hub geometrical designs (empty hub, full cylindrical hub and half cylindrical-half frustum) via plenum chamber depths (175 mm, 350 mm & 525 mm). In this study, 60 blades with 15° horizontal inclination were used. Distributor pressure drop and uniformity of flow at the distributor is set as performance criterion, which analyzed using a statistical analysis, i.e. mean and standard deviation. High tangential velocity at the interrogation area will tends a tremendous swirl flows and produce low pressure drops to ensure minimal energy consumption in the system. From this investigation, it shows that the empty hub geometries via 525 mm of plenum chamber depth offers a good balance in the required of airflow performance characteristics in a SFB.

Keywords: Plenum chamber; Swirling fluidized bed; Pressure drop, Statitical analysis

1. INTRODUCTION

A swirling fluidized bed is one of the recent developments in providing a variant in fluidized bed operation. It consists of an annular distributor made of a number of blades arranged at an angle to the horizontal plane [1]. The fluidizing medium enters the bed at an inclination to the horizontal distributor will produce the tangential velocity component of air and provides the mixing capacity in the bed column at the suitable design of distributor which as an array of blades with centre body, which forms annular opening as shown in Fig. 1 [2].

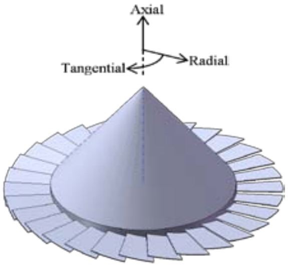


Fig. 1. Distributor Blade with a Conical Centre Body

The swirling fluidized bed is an outcome of studies carried out in order to overcome disadvantages of the conventional fluidized bed. Though a number of bed operating with similar technique are commercially available such as the rotating and vortexing beds, they have not received their due share in terms publication [1,2]. The objective of this study is to numerically investigate the effect of various type of center-bodies in a plenum chamber via height plenum chamber depth on air flow distribution in a swirling fluidized bed (SFB). The findings are important to improve the plenum chamber design in the attempt to increase overall performance of the system.

2. METHODOLOGY

2.1. Simulation Investigation

Investigation of the air flow distribution in a SFB was conducted using commercial CFD software – FLUENT 6.3. The computation domain and grid generation was developed via GAMBIT 2.4.6. The 60 blades with 15° horizontal inclination has been selected based on previous studies [3]. Two parameters were changed to obtain the correlation between the plenum chamber depth and design of hub geometries plenum chamber as shown in Table 1.

Table 1. Configuration of Plenum Chamber Depth via Hub Geometries in a Swirling Fluidized Bed

Case	Plenum Chamber Depth (mm)	Hub Geometries
1	175	Empty Hub
2		Full Cylindrical Hub
3		Half Cylindrical Half Frustum
4	350	Empty Hub
5		Full Cylindrical Hub
6		Half Cylindrical Half Frustum
7	525	Empty Hub
8		Full Cylindrical Hub
9		Half Cylindrical Half Frustum

2.2. Computational Domains

The actual system is shown in Fig. 1 while the computation domains with triple tangential entry via height plenum chamber depth as depicted in Fig. 2 and Fig. 3.

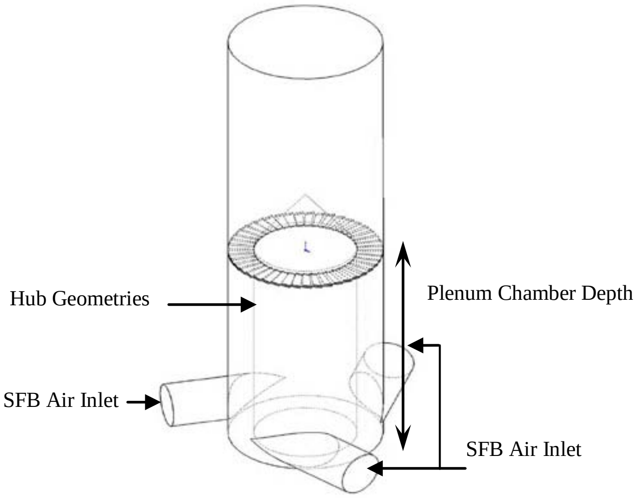
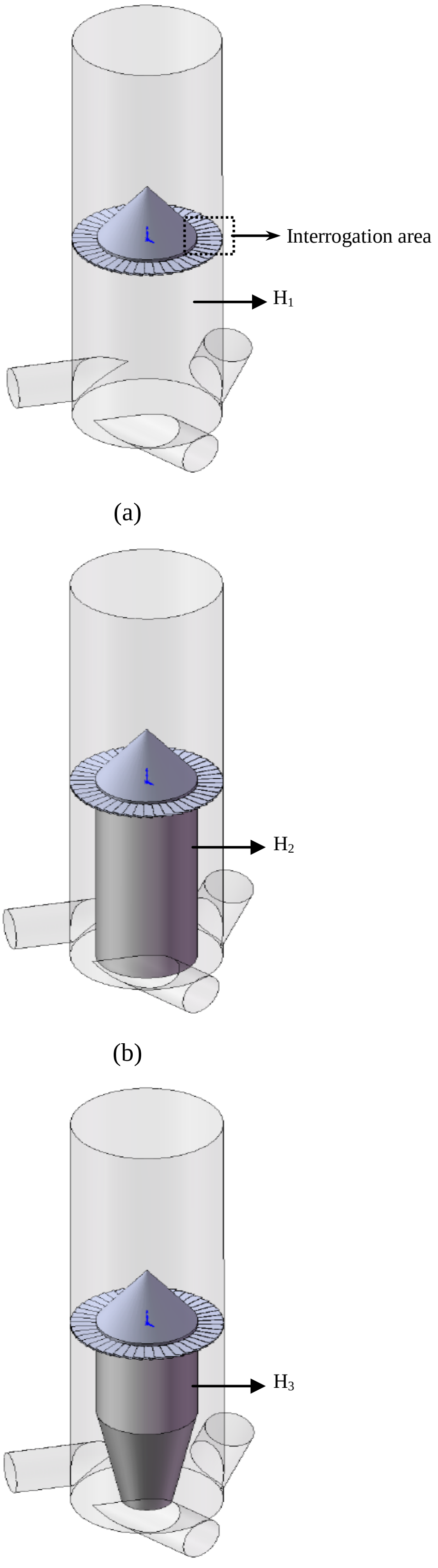


Fig. 2. Swirling Fluidized Bed Actual System via Plenum Chamber Depth



(a)

(b)

(c)

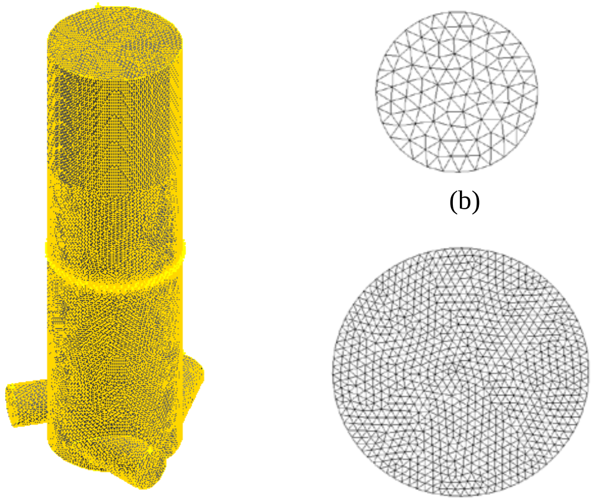
Fig. 3. Computational Domain in CFD for Plenum Chamber with Various Hub Geometries; (a) H_1=Empty Hub, (b) H_2=Full Cylinder Hub and (c) H_3=Half Cylinder, Half Frustum

2.3. Varying Boundary Conditions

The air inlet was modeled as a velocity inlet boundary condition of 2.25 m/s. This velocity are been using in actual design in Faculty of Mechanical & Manufacturing Engineering (FKMP), UTHM laboratory. The air outlet was modeled as a pressure outlet of 1.01325 bar (atmospheric pressure). Meshing on the model of the swirling fluidized bed must be suitable through blade distributor to the appropriate sizing of the mesh due to the model scale. The same method of these studies by conducting a grid sensitivity study prior to actual investigation has been done by [4]. The best and suitable appropriate size of mesh has be determine by conducting a grid sensitivity due to the model of the swirling fluidized bed and it will be applied on all the simulation cases.

2.4. Meshing Schemes

The Tri:Pave Meshing Scheme has be applied to surface in geometry studies and it allowed GAMBIT 2.4.6 to creates a face mesh consisting of irregular triangular mesh elements. The type of Tet/Hybrid parameter that specifies of tetrahedral, hexahedral, pyramidal and wedge element were be defines the meshing algorithm to the overall pattern of mesh element in the volume as shown in Fig. 4.



(a) (b) (c)

Fig. 4. Meshes; (a) Domain, (b) Inlet plane & (c) Outlet plane

The mesh quality was be evaluated using the EquiAngle Skew (Q_{EAS}) criterion same as method that be applied by [5], which are lower or equal to 0.2 for more than 95 % of the control volumes. From this evaluation the mesh quality could be considered satisfactory.

2.5. The Finite Volume Method

In FLUENT application, the Reynolds Averaged Navier Stokes (RANS) turbulence equation model of the (Re-Normalization Group) RNG methods based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε) which is RNG k-ε model has been selected [6] in this study. This turbulence models is similar in form to the standard k-ε model, but has additional term in its ε equation that significantly improves the accuracy for rapidly strained flows and provides an analytical formula for turbulence Prandtl numbers and also the effect of swirl on turbulence is included in the RNG model [7]. A second-order upwind scheme was selected for the discreatisation of the momentum equations which is suitable to moderate swirl and SIMPLE algorithm have be applied to solve the pressure-velocity coupling algorithms in this case studies.

2.6. Governing Equation

These equations are first prensented for a compressible, viscous, Newtonian fluid, and then particularized for simpler cases. The equation that were used are as shown below:

Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

Conservations of Momentums Equation

(r-direction)

$$\begin{aligned}&\rho\left(v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta\partial v_r}{r\partial\theta}-\frac{v_\theta{}^2}{r}+v_z\frac{\partial v_r}{\partial z}\right)=-\frac{\partial P}{\partial r}+\rho g_r+\\&\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_r}{\partial r}\right)-\frac{v_r}{r^2}+\frac{\partial^2 v_r}{r^2\partial\theta^2}-\frac{2\partial v_\theta}{r^2\partial\theta}+\frac{\partial^2 v_r}{\partial z^2}\right]\end{aligned} \tag{2}$$

(ø-direction)

$$\begin{aligned}&\rho\left(v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta\partial v_\theta}{r\partial\theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right)=-\frac{1}{r}\frac{\partial P}{\partial\theta}+\rho g_\theta+\\&\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_\theta}{\partial r}\right)-\frac{v_\theta}{r^2}+\frac{\partial^2 v_\theta}{r^2\partial\theta^2}+\frac{2\partial v_r}{r^2\partial\theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]\end{aligned} \tag{3}$$

(z-direction)

$$\begin{aligned}&\rho\left(v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta\partial v_z}{r\partial\theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\\&\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{\partial^2 v_z}{r^2\partial\theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right]\end{aligned} \tag{4}$$

3. RESULT AND DISCUSSION

Nine simulations of various plenum chamber depth and different hub geometries was obtained from this simulation throughout the whole swirling fluidized bed system, yet only tangential velocity and pressure drop of the system was studied. Data has been extracted on a horizontal plane at 10 mm above the distributor which is the area of interrogation in this study. In actual process the gas-solid has been started to fluidize to contact each other. Having a various plenum chamber depth due to different center bodies in a plenum chamber will achieve a different results agreement and might reduce or avoid airflow from losses.

From previous researcher [7] reported that a full-length cylindrical hub in the center on the three-inlet plenum yields good uniformity in the velocity profile and the hub will cover the entire inner diameter where there is no air gap will loose before the velocity reached at the annular blades. Based on previous study [4,5], the airflow velocity at the tangential entry source, there was an occurrence inflection due to diameter inlet through to size of full cylindrical hub in plenum chamber. Somewhat it will reduce the kinetic energy of airflow before the velocity could be reached to the top bottom of distributor.

Furthermore, the researcher [7] agreed that half cylindrical-half frustum will also provide low pressure drop and low standard deviation of velocity which implies high uniformity. Hence from this study the author has come out with an easy way application in a swirling fluidized bed without applied hub geometries at the center in a plenum chamber.

3.1. Tangential Velocity Distribution

Tangential velocity is one of the major velocity components that exist in the swirling fluidized bed. It represents the velocity of the swirling air in the annular region of the bed. The tangential velocity profile of various configurations can be seen on Fig. 5 where in general, it tends to increase along its radius, which also means that the tangential velocity increases as it approaching bed's wall. However, at the wall itself, the velocity of air is equal to zero due to non-slip condition, caused by the shear motion against the stationary wall.

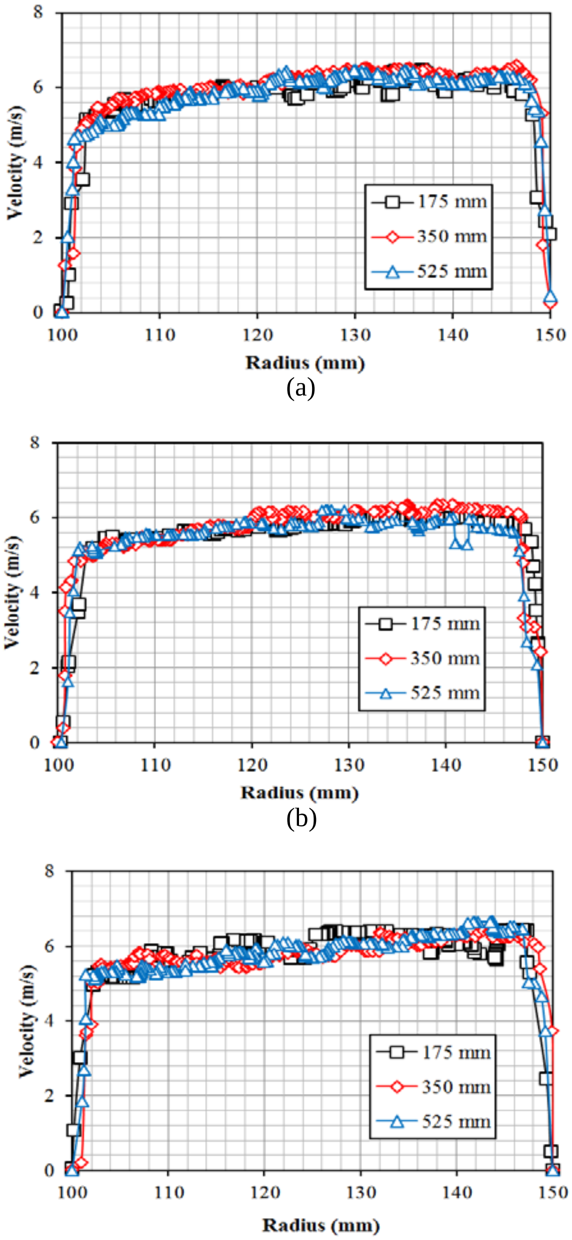


Fig. 5 Tangential velocity distribution for various plenum chamber depth and different hub geometries: (a) Empty Hub; (b) Cylindrical Hub; and (c) Half Cylindrical Half Frustum

It also shown by applying the triple tangential entry will produce more higher velocity due to the increase in overall mass flowrate. Table 2 shows the summarized of the tangential velocity magnitude for various hub geometries configuration.

Table 2. Tangential Velocity Magnitude for Various Hub Geometries Configuration

Case	Hub Geometries	Plenum Chamber Depth (mm)	Average Tangential Velocity (m/s)
1	**Empty Hub**	175	5.672
2		**350**	**5.882**
3		525	5.773
4	Full Cylindrical Hub	175	5.428
5		350	5.559
6		525	5.456
7	Half Cylindrical Half Frustum	175	5.681
8		350	5.651
9		525	5.690

Even though velocity magnitude was resolve into three major components [8], only tangential was being considered and having significant effect on bed particles compared to other velocity components (radial and axial) especially during drying processes. From this analysis, empty hub geometries has the highest average tangential velocity of 5.882 m/s due to the plenum chamber depth and hub geometries design and it also provides a high swirling motion which lead to high tornado effect. However, empty hub at 525 mm of plenum chamber depth the deviation is quite low the standard deviation is only about 0.48% as shown in Table 3. Drying process can be maximized if this configuration is applied on a swirling fluidized bed.

3.2. Uniformity of Tangential Velocity Distribution

Table 3. Analysis on Uniformity of Tangential Velocity Distribution

Case	Hub Geometries	Plenum Chamber Depth (mm)	Std Deviation (m/s)	Std Deviation Percentage (%)
1	**Empty Hub**	175	0.996	0.66
2		350	0.944	0.52
3		**525**	**0.866**	**0.48**
4	Full Cylindrical Hub	175	1.085	0.85
5		350	1.023	0.60
6		525	0.968	0.78
7	Half Cylindrical Half Frustum	175	1.051	0.74
8		350	0.866	0.50
9		525	0.880	0.52

Uniformity of tangential velocity is required as the bed particles being process need to uniformly being dried for instance. Non-uniformity flows might result into a non-uniform drying process where the drying process is not optimized. Early dispatch of bed particles might result in a mixture of fully and partly processed particles. A bit longer the production rate will be slowed down and some particles might be over processed [4,8,9].

3.3. Pressure Drop

High pressure drop is needed to sustain the pressure needed to run the swirling fluidized bed processes. It should be as low as possible to reduce the power being wasted during the processes. By selecting the suitable plenum chamber depth via hub geometries configuration it will obtain the lowest pressure drop an optimized the fluidization in a swirling fluidized bed. Displaced air also yields in pressure reduction due to formation of empty spaces at the center of the swirling air flow. Since full cylindrical hub with 350 mm of plenum chamber depth is the lowest pressure drop of 44.392 Pa, it has the highest score for low pressure drop criterion.

Table 4. Pressure Drop for various Plenum Chamber Configuration

Case	Hub Geometries	Plenum Chamber Depth (mm)	Pressure Drop (Pa)
1	Empty Hub	175	48.442
2		350	50.855
3		525	50.223
4	**Full Cylindrical Hub**	175	46.089
5		**350**	**44.392**
6		525	45.315
7	Half Cylindrical Half Frustum	175	46.756
8		350	46.874
9		525	49.114

CONCLUSION

The airflow characteristics in plenum chamber which influence various center hub geometries via the plenum chamber depth have been investigated. In this study, CFD simulation showed an effective method to understand the complex air flow distribution in a swirling fluidized bed. From the numerical results it shows the empty hub geometries via 525 mm of plenum chamber depth is the best configuration in the present study by considering the tangential flow uniformity as well as high tangential velocity.

ACKNOWLEDGMENT

The authors would like to extend their deepest appreciation to Universiti Tun Hussein Onn Malaysia (UTHM) for sponsoring the research under Postgraduate Incentive Fund Vot No. 1024 and the related facilities and equipment in the Centre for Energy and Industrial Environment Studies (CEIES).

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