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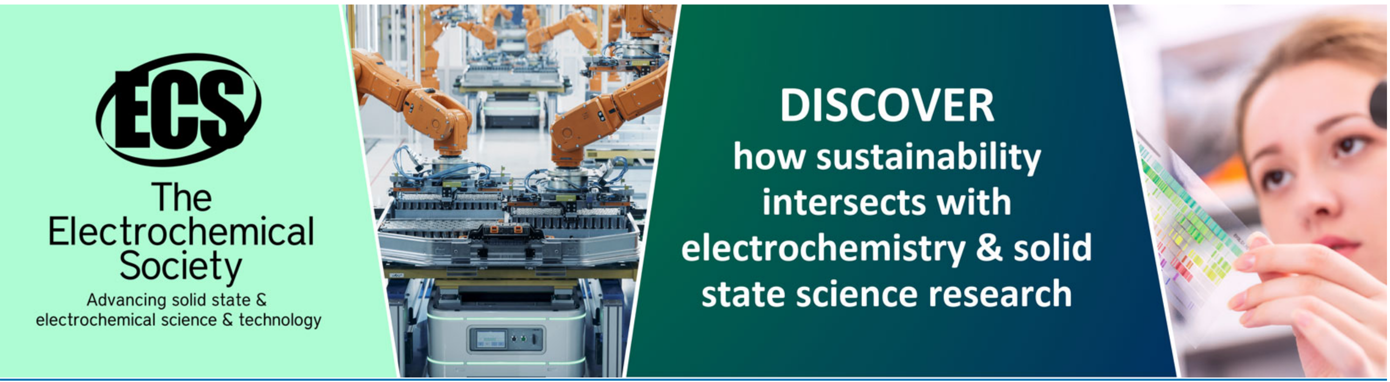

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The Effect of Multi-staged Swirling Fluidized Bed on Air Flow Distribution

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Abstract. Fluidization is characterized as an activity that transforms fine solids into a liquid-state via contact with either a gas or a liquid. Currently, Swirling Fluidized Bed (SFB) is one of the new system that contribute on flow mixing to the beds due to the gas source which impart on the solid particles. Further the fluidized beds system are used mostly in the chemical process industry, mineral processing, processes energy and etc. Based on the current fluidized bed system there are still lacking in reducing high pressure drop and keep the energy consumption at high efficient condition. Due to this tips, the conceptual design of a multi-stages SFB was proposed to improve fluidization quality and minimize elutriation at the same time without requiring any extra facilities. By using the simulation method (Ansys Fluent) the behavior of velocity component via selected configuration of fix blades number (30) and through to variant of blade horizontal inclination angle (10°, 12° & 15°) the multi-stage SFB will be investigate. Aims of this study is to identify the air flow behavior at first and second stage blade distributor. Therefore, effect with less blades number in producing on high uniformity velocity would be acquired. The present study has found that by using blade inclination angle of 10° the high velocity magnitude (more than 60 m/s) at two different level of stage distributor can be reached. Moreover, it clearly be seen at blade inclination angle, 15° the velocity uniformity was sustain at certain width and less superficial velocity value occurred compared to other configurations.

1. Introduction

1.1. Swirling Fluidized Bed

Fluidization is a technique where the fluid is flowing a gas to static particles [1]. The gas meet contact to the solid particle with a drag force. According to the appropriate values, the force was large enough to cause the static bed to move or fluidized [2]. Normally, the fluidized beds system are used mostly in gasification, particle drying [3-4], oxidation, endothermic and etc [2]. Afterwards, the Swirling Fluidized Bed (SFB) system has been proposed with better improvement process on resident time, discharge coefficient and energy consumption. The SFB systems possess an annular blade distributor that mimic to the blade in turbine system. Due to this multi-stage SFB the system it will improved especially on the energy consumption where an optimum of air flow distribution was distribute nicely in plenum chamber. The idea of this study is an extension from previous study [5-7]. The researcher [5-7] has emphasis more on the principle of residence time during the fluidization process. Further, the resident time is a key to surpass the lack of the conventional fluidization. With resident time distribution (RTD) [7] it will proposed a better efficiency of a fluidized bed. Moreover, the researcher have stated that by applying this newest system in SFB, by increasing the time and reducing the work load, the fluidization quality can be improved towards on high efficiency fluidization system. Therefore, this study was conducted to identify the characteristic of air velocity component in new multi-stage SFB.

1.2. Research Motivation

Swirling Fluidized Bed also known as vortexing beds which proposed a swirling motion on beds to promote lateral mixing in fluidized bed. The fluidization have a variant design especially on the distributor such as perforated plate, multi-horizontal nozzle, Dutch weave mesh, punched plate and etc. [8]. Different with SFB system which is used such number of blade to spread the fluidizing gas equally through the bed inlet. The particle were contacting to each other in swirling motion of air or gas inside the plenum chamber [9]. Lately, the researcher who are involved in fluidization get more interested to study on blade distributor configuration [10-11]. Compared to the conventional fluidization system, the gas that following through the distributor has not shown an effective gas-solids contacting. Some of the distributor design the air movement across the bed inconsistent and led poor bed utilization. Currently, the distributor design of Ouyang and Levenspiel [12] has proposed a concept of swirling fluidization by using a distributor plate. One of the key benefits on SFB is has low pressure drop at the bed distributor. In terms of pressure drop value and flow behavior after passing the blade distributor, the appropriate blade distributor configuration would produce an optimum performance in SFB. Moreover, past researcher [13] has found that blade distributor with radial inclination angle give the shortest time for the creation of vortexing. This will make the fluidization system were less using energy. However, the pressure drop by using this type of distributor design is still high. There-fore, by using a numerical approach that has been used in a lot of studies [14–20], CFD software packages (Ansys Fluent) has been selected to be used in current study. Therefore the simulation method on multi-stage blade distributor in plenum chamber will elucidate more details on the air flow distribution.

2. Methodology

2.1. Multi-stage Swirling Fluidized Bed

A commercial solid modeling computer-aided design as SolidWork has been used to design the computation domain of the multi-stage SFB system as shown in Figure 1. Followed by previous study [20] the multi-stage SFB modelling has been runs in Computational Fluid Dynamics (CFD) via ANSYS Fluent software for air flow distribution analysis. A selected angle of blade horizontal inclination of 10°, 12° & 15° in multi-stage SFB will be investigate as followed past researcher [20-25] parameter which blades number has been selected with fixed height of the two stage of blade distributor. All configuration of this present study can be referred in Table 1. The boundary layer of multi-stage SFB like air inlet (axial entry) has been modelled as velocity (6.75 m/s) boundary condition. The multi-stage of blade distributor has been design and placed at selected plenum chamber height. The plenum chamber is 600 mm height while the inner diameter was 300 mm [20-25]. The annular blades are set in clockwise direction [20]. Each blade has 1 mm thick. The angle degree of blade distributor has been selected based on the previous study [20-24].

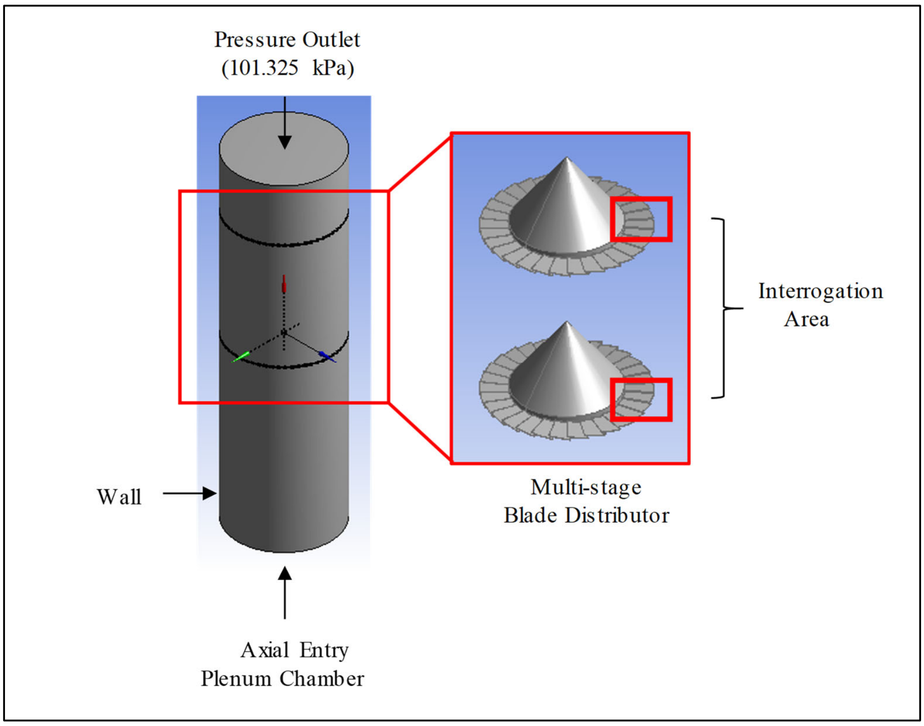

Figure 1. Multi-stage Swirling Fluidized Bed with Axial Entry Plenum Chamber

Table 1. Cases of parametric study on swirling fluidized bed distributor

Case	Number of Blades	Horizontal Inclination Angle
1		10°
2	30	12°
3		15°

2.2. Simulation and Modeling

Hence, same condition setting as previous researchers [20] and [22] has been applied in this study. The Tri:Pave Meshing Scheme was applied to the surface and it allowed the software to create a face mesh consisting of irregular triangular mesh elements. Steady-state segregated implicit solver and Reynolds-Averaged Navier-Stokes (RANS) equation model, RNG k-ε model standard wall treatment were applied to simulate the turbulence flow in the SFB [24]. To reduce numerical diffusion, a second order upwind scheme was selected for the discretization of the momentum equa-tions [25]. The meshing assessment is still the same as the previous study and as the details are as follows [20]. In FLUENT environment, the Reynolds Averaged Navier Stokes (RANS) turbulence equation of RNG k-ε model has been selected and applied in this study [20, 24, 25].

2.3. Governing Equation

The 3-D momentum and continuity equation in the governing equations [25] has been applied in the present study. The both equations mention above which is cylindrical coordinates system was solved in Newtonian, incompressible fluid for in steady flow. The equation was represented below.

(r-direction)

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

(ø-direction)

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

(z-direction)

$$\rho\left(v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta \partial v_z}{r\partial\theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{\partial^2 v_z}{r^2\partial\theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right] \quad (3)$$

Continuity Equation

(z-direction)

$$\frac{\partial\rho}{\partial t}+\frac{1}{r}\frac{\partial(\rho r u_r)}{\partial r}+\frac{1}{r}\frac{\partial(\rho u_\theta)}{\partial\theta}+\frac{\partial(\rho u_z)}{\partial_z}=0 \quad (4)$$

3. Results and Discussions

3.1. Influence of Multi-stage SFB towards Velocity Magnitude

Selected data which focused on air flow behavior, has been discusses in this sub-topic. The results of velocity component has been extracted from the Ansys Fluent simulation software. A variant velocity data such as tangential velocity, radial velocity & axial velocity distribution has be main velocity component when analyzed using simulation method. However, this present study only cover on velocity magnitude. The rest velocity component will be discussed in future manuscripts. The selected data on velocity magnitude was extracted at the horizontal plane of 10 mm above of the SFB blade distributor. The role of blade distributor is to distribute the gas when the gas pass through the gap between two annular blade distributors. The gap between these distributors is in trapezoidal openings which the large area of blades inclination was located at the wall SFB column while less area was placed at the center cone of SFB. This type circumstances also known as Fraction of Open Area (FOA). Further, with different variant configuration of blade distributor it will create the flow mixing in the SFB column. Either the flow mixing was high or low it would affect the kinetic energy on the velocity component. The relationship of mixing is always associated with the tangential force. So, in the present study the behavior of velocity magnitude is more looked like the tangential velocity component. Figure 2 shown the velocities components in multi-stage SFB at different blade inclination angle and different level of distributor. Further, as shown in Figure 2 same graph pattern was clearly be seen either the velocity was extracted at different stage blade distributor. Moreover, as result was shows, near to the wall SFB column which have large trapezoidal opening area the velocity component was form uniformity at 115 mm to 145 mm radius from the cone centre to extend radius of distributor. The air flow at variant blade distributor configuration the air velocity magnitude is increasing sharply from cone centre to the opening area of SFB column. This condition raise up and sustain around of radius quarter of SFB plenum chamber. Moreover, due to this finding the air velocity has not exceed more than the inlet velocity setting at entry inlet of plenum chamber. Surprise that the velocity at second stage blade distributor is still high same with the first stage of SFB. This can also be formulated that the kinetic energy on vortexing / mixing flow was high even further away from the air sources. This condition may lead on superficial velocity if more installation of blade distributor is done. Another criteria that contribute on superficial velocity is a blades distributor number, getting more blades number it will produced high velocity condition. Surprise in this study, less blades number can still produce high velocity especially in tangential velocity component. As we can see in Figure 2, less number of blade distributor at blade inclination angle, 10° the velocity still shows high compared to other blade distributor configuration. As in previous study (first stage of blade distributor) high velocity magnitude in the fluidized bed system may leads to high swirling motion which causes on high vortexing mixing. This present study, the velocity magnitude can be used as a reference in determining whether the SFB system was in high efficient or not. Retention of velocity uniformity in fluidization was compared to the particles or solids in the bed greatly influenced in drying which seems to be significant factor of swirling fluidized bed (SFB). Results on air flow distribution would contribute a great swirling motion on bed particles and it will make the all particles are partly processed in the same time.

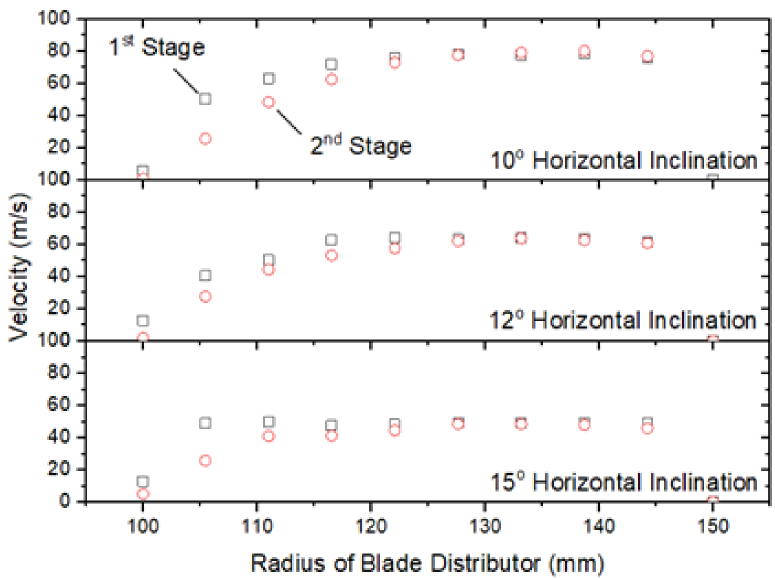

Figure 2. Velocity magnitude via 30 blade distributor at different horizontal inclination

4. Conclusions

As conclusion, (answer on first objective); the type of twist blade distributor via the blades number has shown significantly affected on air velocity distribution especially on velocity magnitude. At low blades number, 30 with low horizontal inclination blade angle, 10° has produce on high tangential and uniformity velocity. Therefore, this present study of different distributor configuration can be considered to promote a better air fluidization which helped in increasing the processing rate of drying. Moreover, when the Fraction of Open Area (FOA) was small it tend to generate in high velocity and high swirl motion on the solid particles due to the effect of tangential force.

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