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Multi-Stage Swirling Fluidized Bed: Part 2 - The Velocity Distribution

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ABSTRACT

This task involved numerical analysis study to investigate the air flow distribution affected by blade distributor arrangement of Multi-Stage Swirling Fluidized Bed (SFB). The current systems is in difference with conventional fluidization systems where the current systems will impart swirling motion to the particle. This study focused on the velocity distribution on blade distributor whereby the influence of blades number (30, 45, and 60) via horizontal inclination angle (10°, 12°, and 15) through multi-stage distributor arrangements, therefore a separate velocity component would be obtained. The numerical simulation, was utilised to compute and analyse the performance outcomes of three velocity components: tangential, axial and radial velocity in an Multi-Stage SFB. From the results of the study, the fluidization systems with high blades number of 60 and blades angle of 15° has shown a significant air flow distribution at both stages. Thus, the major velocity component such as velocity magnitude and tangential velocity in the Multi-Stage SFB have shown a retention uniformity along the radius blade distributor and the air flow inside the system rise more than 40 m/s.

1. Introduction

The word "fluidization" refers to the process of a fluid travelling over a densely packed bed of solid particles at a prespecified velocity in order to generate sufficient drag forces to overcome the weight of each particle. As a consequence, the particles will no longer rest on one another, and they will behave and flow as if they were a fluid [1]. Fluidization requires a vessel with a porous base in order to distribute the fluid onto the bed. Haron *et al.,* [2] have compiled an overview of previous studies using the fluidization system application.

Figure 1 displays the annular blade distributor of a Swirling Fluidized Bed (SFB) in its usual form. The gas entering at distributor gap will be split into three components: axial, radial, and tangential.

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In this instance, the gas is injected into the bed horizontally at a particular blade angle. The horizontal and vertical components of v sin ϴ and v cos ϴ, respectively, would be used to calculate the gas's velocity. The horizontal component swirls as a result of liquidation caused by the vertical component [3]. In comparison to conventional fluidized beds, SFB have certain significant advantages. In the spinning field, there are no bubbles and no gas by pass. Radial distance increases the velocity of spinning particles, according to the studies conducted by the previous researcher [4,5] in SFB.

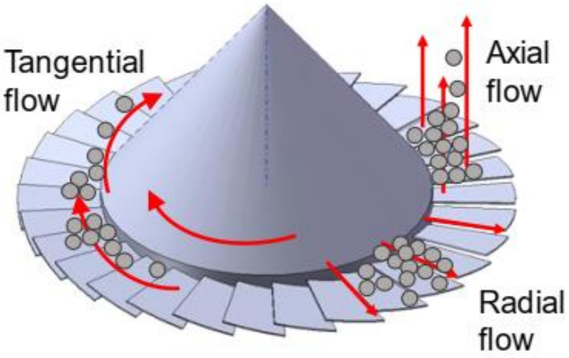


Fig. 1. Annular blade distributor of Swirling Fluidized Bed (SFB)

2. Methodology

2.1 Numerical Simulation Process

The first manuscripts of Part 1 - The Numerical Analysis Procedure might include a flowchart illustrating the study techniques. This study concludes with a postprocessing phase that employs many graphical approaches, including grid, contour, vector, and line plots. The prior research has been completed as follows [6-8].

2.2 Description of the Multi-Stage SFB

ANSYS Fluent commercial CFD software was used to examine the airflow distribution in a Multi-Stage SFB in accordance with what the last researcher observed [9-12]. The computation domain and grid generation were generated using ANSYS. As seen in Figure 2, the phase velocity was specified at the vertical entry of inlet boundary of the plenum chamber as 2.25 m/s (0.22 kg/s mass flow rate), and ambient pressure was adjusted for the pressure outlet (101,325 Pa). The distributor blades' height differences are 350 mm with diameter plenum chamber is 300 mm. Consequently, the flow in the present investigation is constant and incompressible. While a result, the fluid element's density and time do not vary as air flows through the geometrical volume. In addition, no-slip shear condition requires and the fluid has zero velocity with respect to the geometric boundary. Moreover, stationary wall motion was specified.

Figure 2 depicts the data retrieval location of 30, 45, and 60 blade distributors at both stages in the centre of the fluidization plenum chamber at horizontal inclination angles of 10°, 12°, and 15° were used, as shown in Table 1. Therefore, the flow may be considered unrestricted. The dimensions of the blade distributor are derived from [4-6, 8], and for data confirmation, [8] was consulted. According to previous research, a 15° angle produces a high tangential velocity and a high degree of velocity magnitude uniformity.

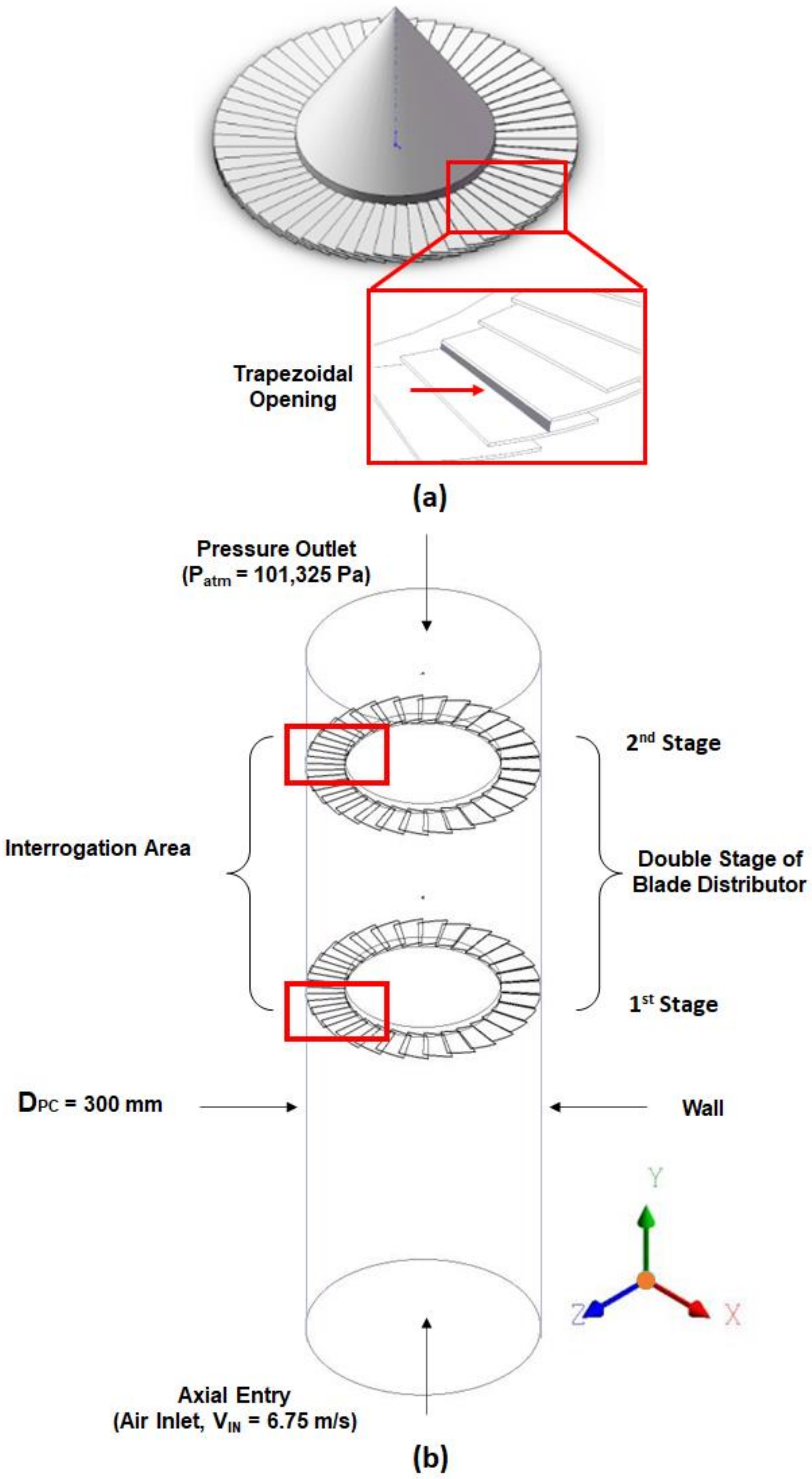


Fig. 2. Multi-StageSFB systems; (a) Fraction of Open Area (FOA) (Trapezoidal Opening) and (b) Boundary conditions

Table 1
Parametric study on Multi-Stage Swirling Fluidized Bed configurations

Case	Number of Blades at 1st stage of SFB	Number of Blades at 2nd stage of SFB	Horizontal Inclination
1	30	30	10°
2			12°
3			15°
4	45	45	10°
5			12°
6			15°
7	60	60	10°
8			12°
9			15°

2.3 Numerical Model

As a consequence, the condition setting for this investigation was comparable to that of earlier studies [12,8]. The RNG k- model, commonly known as the Reynolds Averaged Navier Stokes (RANS) turbulence equation, has been selected for use in the FLUENT environment. This model is based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). Similar to another semi-empirical model, this turbulence model has been used. Prior articles have focused especially on addressing processing details that identify solution strategies and particular discretization schemes (Part 1 – Numerical Analysis Procedure).

2.4 Governing Equation

The current study's governing equations [13] are three-dimensional momentum and continuity equations in cylindrical coordinates that were solved for Newtonian, incompressible fluid in steady flow.

2.4.1 Continuity Equation

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

where u, v, and w are velocities in the x, y, and z axes, respectively.

2.4.2 Momentum Equation

(x direction)

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial u}{\partial t}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial u}{\partial z}\right)\right]+\rho g_x \qquad (2)$$

(y direction)

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial v}{\partial z}\right)\right]+\rho g_y \tag{3}$$

(z direction)

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial w}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial w}{\partial z}\right)\right]+\rho g_z \tag{4}$$

where ρ is density, t is time, P is pressure, η is viscosity, and $g_x, g_y, g_z,$ are gravities in the x, y, and z axes, respectively.

3. Results

This section will discuss the numerical analysis investigation's findings. This study examined the velocity distribution, which consists of tangential velocity, radial velocity, and axial velocity. Since this was the optimal point for analysing the air flow characteristics, data was taken 10 mm above the distributor on a horizontal plane.

3.1 Velocity Distribution Analysis

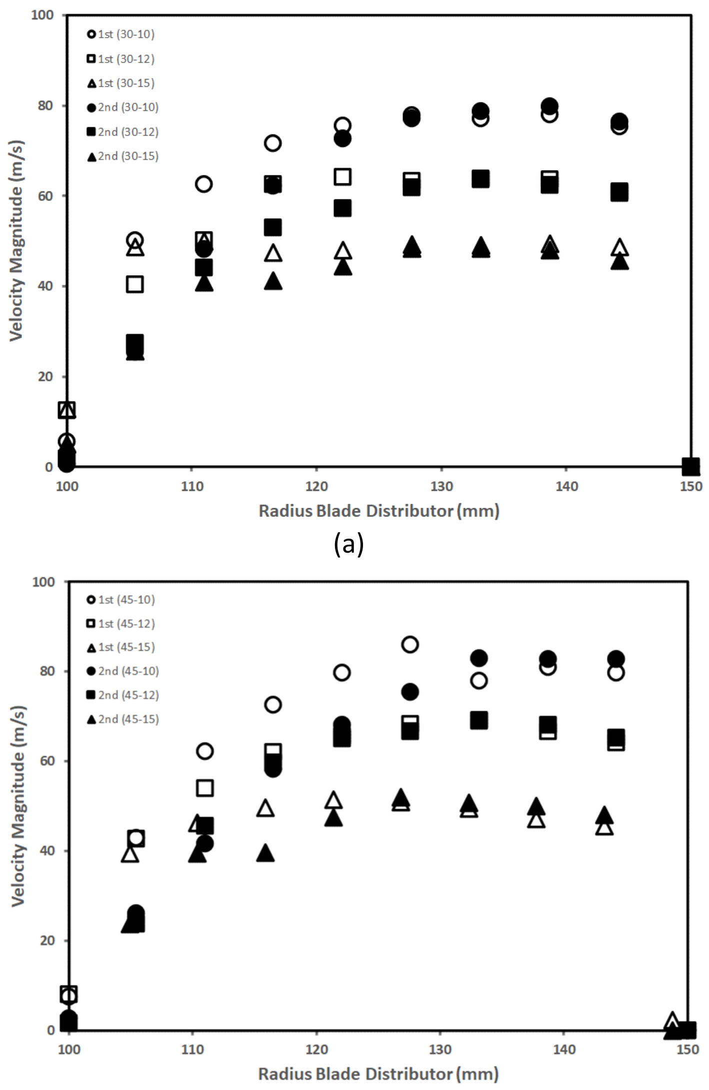
The present study utilises a variety of plenum chamber arrangements with specified blade numbers of 30, 45, and 60 through blade horizontal inclination angles of 10°, 12°, and 15° (as seen in Table 1). Previous manuscript had detailed the numerical modelled geometry of Multi-Stage SFB. A swirling flow is caused when air enters the distributor gape and next deflected as soon as it contacts the blade. This will affect the mass at the body wall section of the column due to centrifugal force. The velocity distribution may be divided into tangential, radial, and axial components as illustrated in Figure 1.

In actual industrial applications, tangential velocity produces a swirling effect whereas axial velocity causes fluidization. Radial velocity would be explained by the centrifugal force produced by the circulating gas. Since it measures the velocity of the swirling air in the annular region of the Multi-Stage SFB, the tangential velocity plays an essential element throughout the analysis. These airflow distributions focusing on velocity components will be covered in more detail in the next section. Overall, nine samples were examined, and the data of the obtained velocity components differed according to how the current fluidization systems were constructed.

3.2 Velocity Magnitude Analysis

A description was given of the tangential, axial, and radial components of velocity, which together made up the overall magnitude of the velocity. The air that moves through the distributor blades when it is inserted axially is one concept of this velocity component. This causes the flow to now be fully addressed by the three different velocity components. As a direct result of this, the annular blade distributor is causing a swirl in the air flow. In addition, the swirling effect adds mass to the air at the farthest margins of the column due to centrifugal force. The most recent fluidization research was used to get to the conclusion that the prescribed horizontal inclination angle should be 10°, 12°, and 15° in each case. The air is deflected by the distributor blades when it achieves its maximum velocity.

Furthermore, distributors with high quantity of blades help maintain the uniform velocity of the system, as illustrated in Figure 3 through Figure 4. In addition, as shown in Figure 3, the number of 60 blade distributors has significantly dispersed the velocity magnitude compared to other values. The graph in Figure 3 to Figure 4 shows the velocity distribution of the velocity magnitude for each instance and the result reveals when the blade angle is lowers (10°) the resultant velocity of high air flows is form and will yield high centrifugal forces on the bed’s wall. The resultant velocity tends to diverge more. In a Swirling Fluidized Bed (SFB), it is very important to have uniformity in velocity magnitude. This is important because the flow characteristics may be influenced on particles or solids inside the bed for drying.



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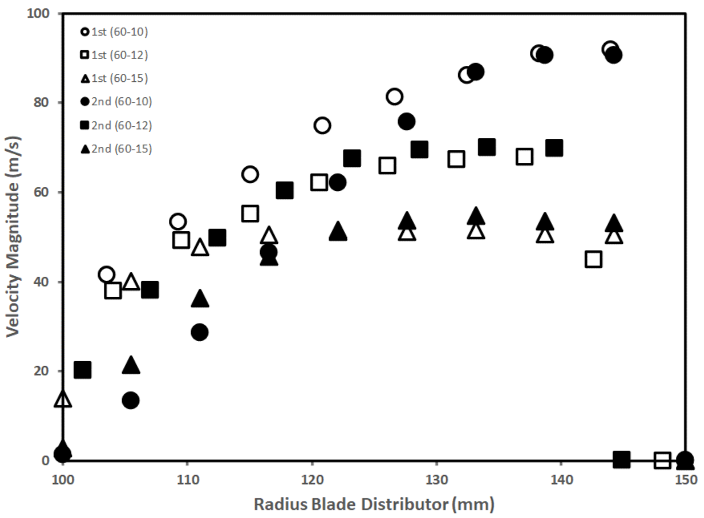


(c)

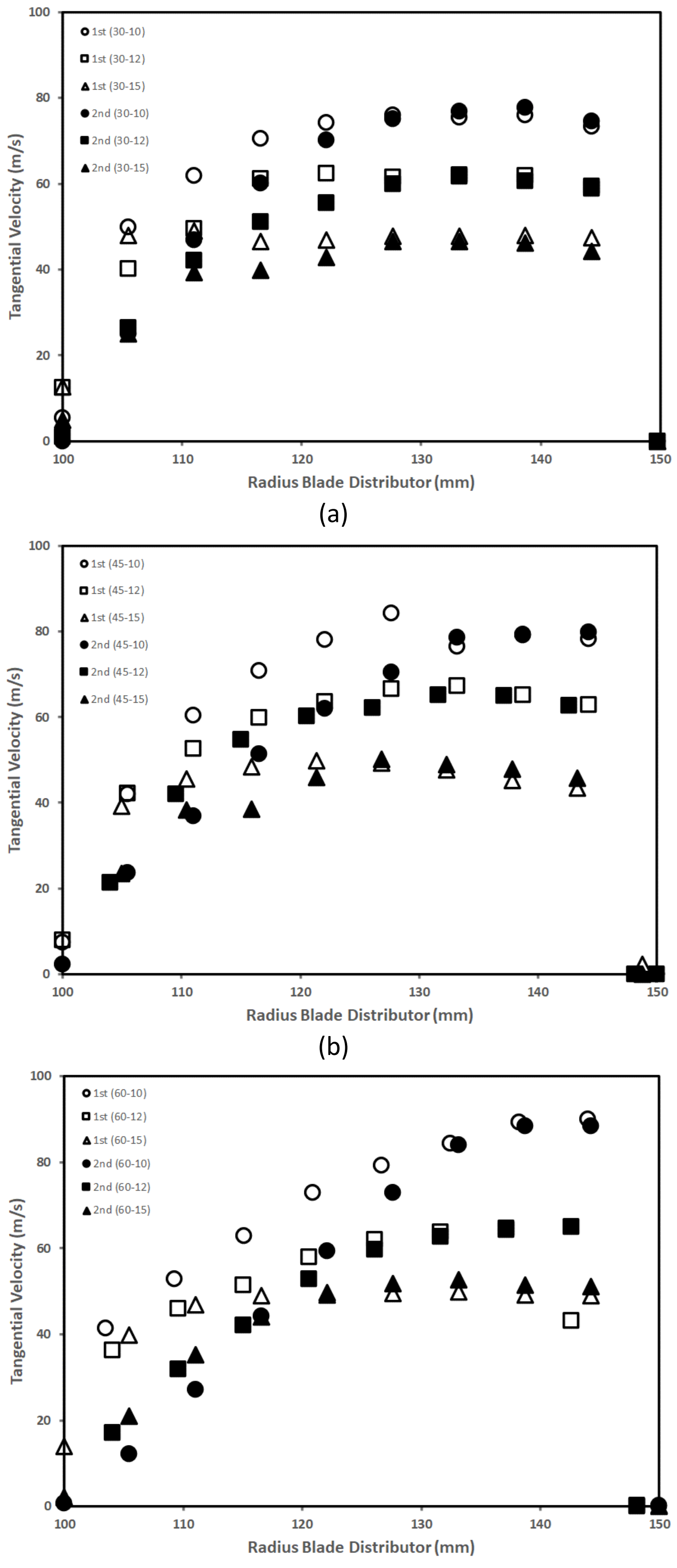
Fig. 3. Comparing the velocity magnitude of blades number of 30, 45, and 60 with different blade angle 10°, 12°, and 15° at first and second stage blade distributor

3.3 Tangential Velocity Distribution

The SFB's primary velocity component is tangential velocity. It represents the velocity of the air in the annular zone of the bed. The tangential velocity profile will be determined by comparing the data according to the modification of annular blade distributor on the number and the impact of blade angle on swirl formation. All of the tangential velocity data gathered from the parametric case studies are illustrated in Figure 4. On the annular blade distributor, the current study conditions have exhibited a similar pattern to the earlier study [8] on the matter. It seems that the flow occurred as expected.

Generally, the airflow affected by annular distributor s expands as it approaches the bed wall along the radius. Although there isn't any slippage at the stationary wall, which would cause shear motion, the air velocity at the wall itself is equal to zero. Higher blade angles result in more consistent airflow for the same reasons stated in earlier sections. Lower blade angles account for greater quantities of tangential velocity, which results in a greater horizontal component of velocity.

In addition, it was evident that increasing the number of blades increases tangential velocity at the expense of flow uniformity. This was due to the reduced amount of open area, which increased the magnitude and tangential velocity component of the air flow velocity [8]. The features of the air velocity component and the velocity magnitude distribution graphs exhibited the same pattern (Figure 3). In the vast majority of graphs, velocity uniformity has been achieved. It has been established that minimal-velocity (6.75 m/s) air flow intake will result in swirling conditions. The air flows inside the plenum chamber configuration are capable of causing centrifugal force and migrating toward the bed's wall.



(a)

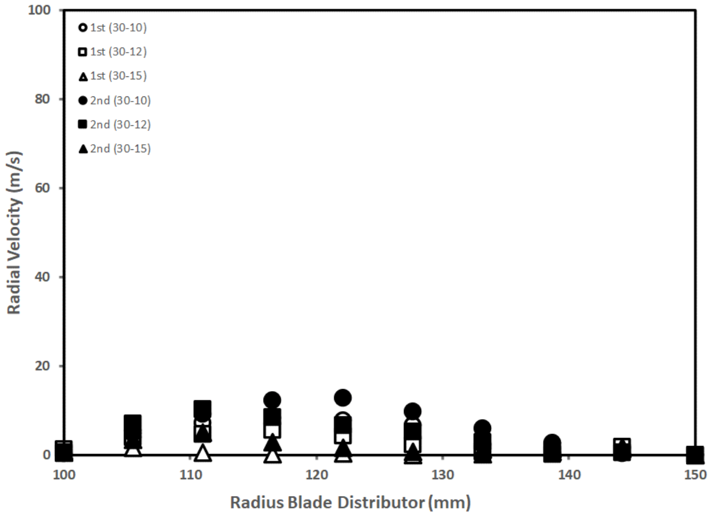
(b)

(c)

Fig. 4. Comparing the tangential velocity of blades number of 30, 45, and 60 with different blade angle 10°, 12°, and 15° at first and second stage blade distributor

3.4 Radial Velocity Distribution

Radial velocity is one of the important elements of the swirling motion in a Swirling Fluidized Bed (SFB). It depicts the velocity at which air is being forced to the bed wall as it flows from the centre body's cylinder base to the plenum chamber's wall via the radial blade distributor. Factors that have contributed to this situation, at high-angle blades, it achieves low radial velocity as shown in Figure 5, and the flow distribution of the radial velocity profiles is unique and unusual. The result of the higher tangential velocity in the tangential velocity component is an increase in radial velocity. This condition has been confirmed in Figure 4(c) and 5(c) where both velocity component are in higher velocity via high blades number and low blades angle. As the blade angle decreases, more air is forced against the wall of the bed because of the high tangential velocity. The radial velocity curve for all parameter is shown in Figure 5. The velocity magnitude study indicates the overall pattern of the radial velocity distribution. The velocity increases as it moves from the cylinder base to the outer blade distributor.



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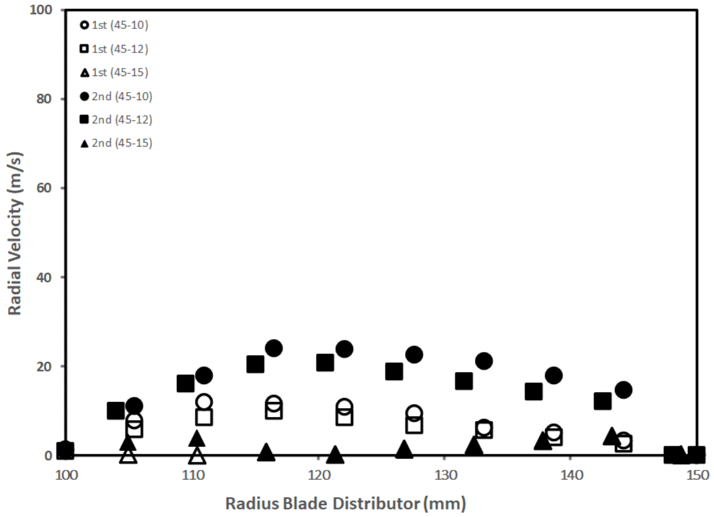

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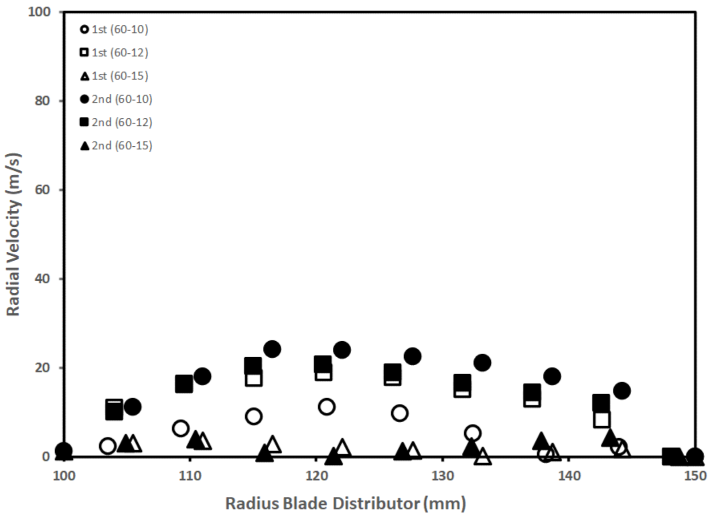
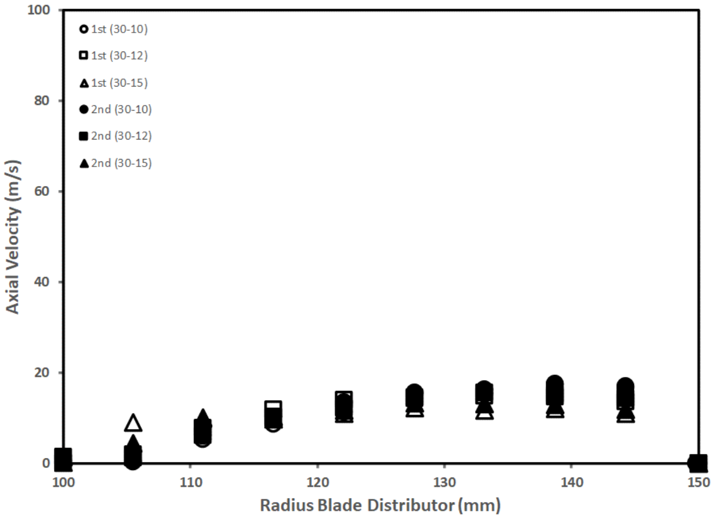


(c)

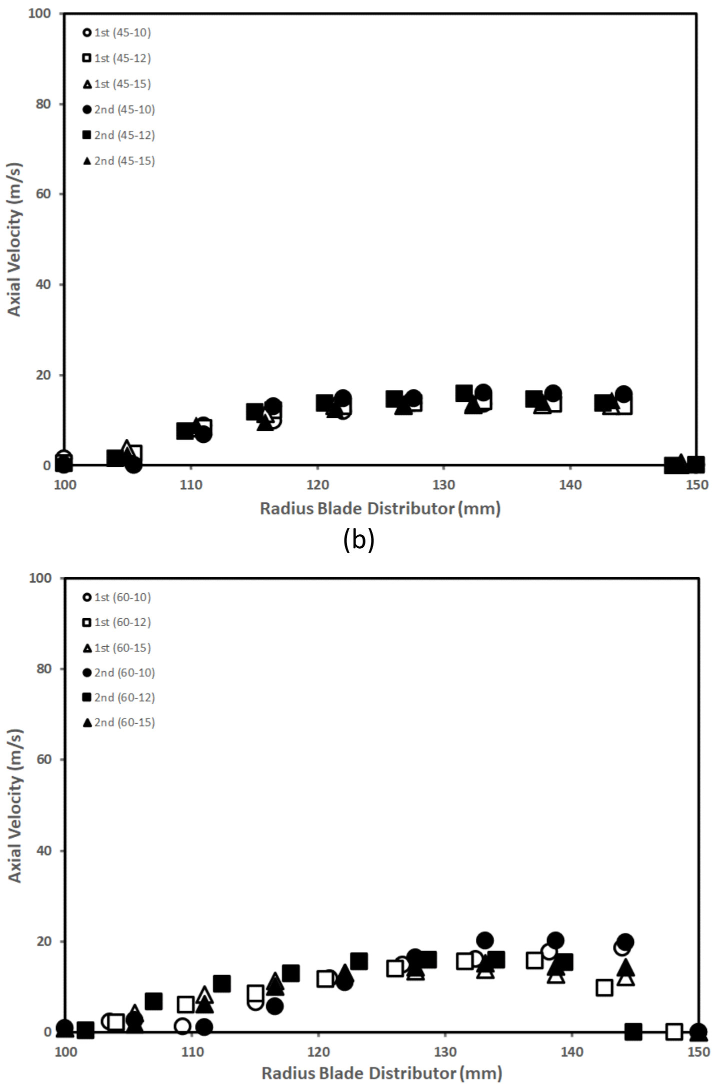
Fig. 5. Comparing the radial velocity of blades number of 30, 45, and 60 with different blade angle 10°, 12°, and 15° at first and second stage blade distributor

3.5 Axial Velocity Distribution

One of the important factors in the velocity for fluidization is axial velocity. The vertical, downward, or upward airflow flows with the particle's velocity, which is represented by this element. As demonstrated in Figure 6, the axial velocity magnitude is proportional to the blade angle, with larger blade angles providing bigger magnitudes. This is essentially a result of the blade opening's increased vertical component of velocity. Additionally, it was obvious that the axial velocity also exhibits negative values, showing an unfavourable pressure gradient at the core of the bed, again induced by centrifugal force. As the angle blade lowers, it may be stated that reverse air flow creation is likely to happen near to the centre body.



(a)



(b)

(c)

Fig. 6. Comparing the axial velocity of blades number of 30, 45, and 60 with different blade angle 10°, 12°, and 15° at first and second stage blade distributor

3.6 Air Flow Behaviour

The same prototype of the Swirling Fluidized Bed, which has various parameter analyses proposed by Sreenivasan and Raghavan [4], has been continued by several researcher Batcha *et al.,* [5], Ashri [9], Roslan *et al.,* [14] and many more. Moreover, Ashri [9] has proposed an advanced of SFB systems which Multi-Stage SFB which has double stage of annular distributor and the distance difference for both are 350 mm. The researcher had state that the same conditions of bed pressure drop occurs at the both stages. Therefore, the present study, visualisation pictures of the air distribution at selected parameter on current fluidization systems are shown in Figure 7. These graphics exhibit the symmetry of the velocity contour, vector velocity, and the flow streamline. Here, it is apparent in the region of the blade where the air was moving at a high velocity just after it had crossed the distributor gap. The high velocity continues to flow around the SFB system plenum wall. This enhances the earlier [5,6,8] discoveries that the tangential velocity indicates the swirling air's velocity in the annular zone and the air flow is generally swirl as far as flow structure goes closer to the bed's wall.

Furthermore, as shown in Figure 7 at the area a1, when the velocity plane starts to rise, this high velocity starts to decrease and the flow develops faster towards the SFB plenum centre. A different circumstance occurs at 2nd stage blade distributor in the area a2, where the high velocity is still form at near to the bed’s wall. This high velocity is still form, due to the consistent swirling motion that already occurs in the stage area (1st and 2nd stage of blade distributor), this condition leads in high velocity profile close to the bed’s wall.

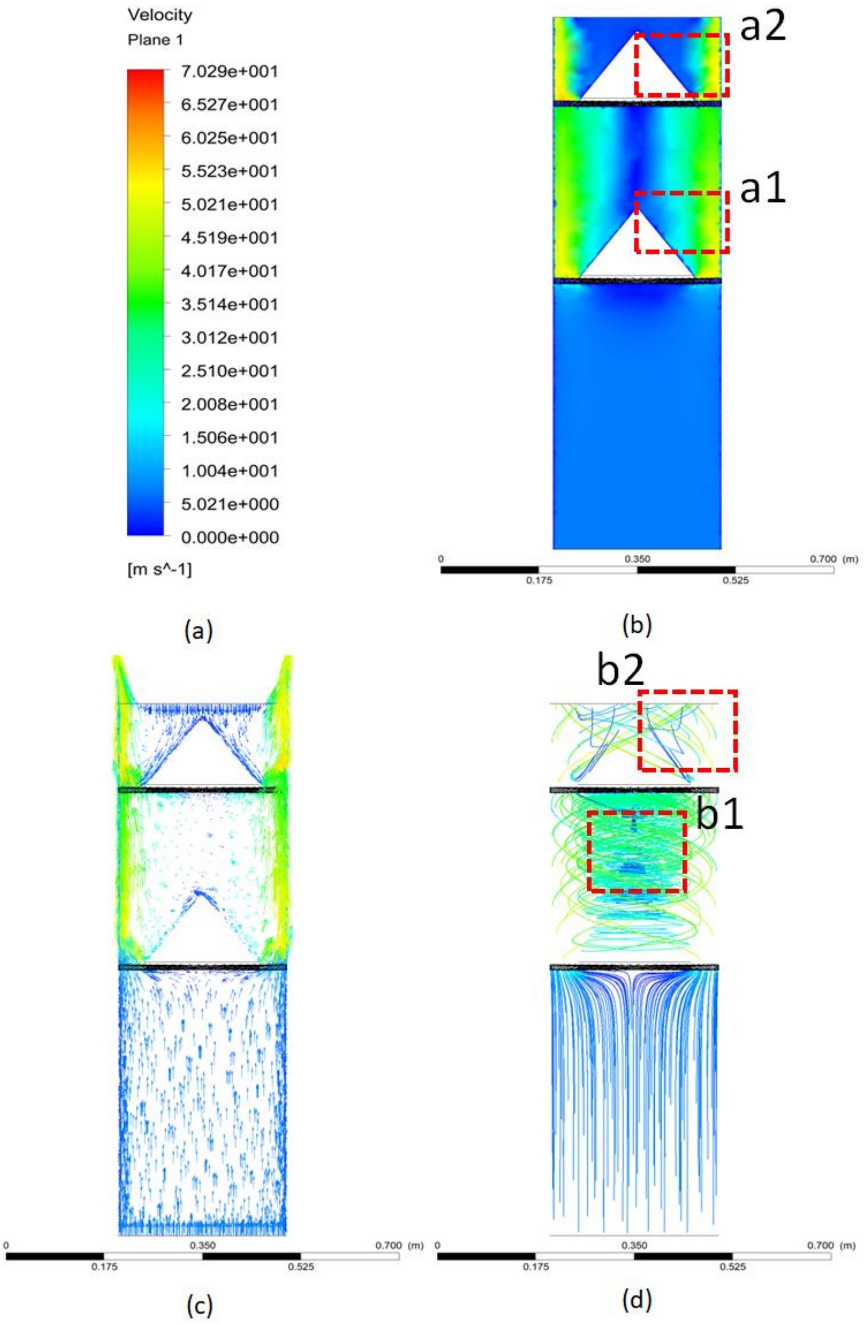


Fig. 7. Multi-Stage SFB with number of blades distributor, 60 via blade angle; (a) velocity legend, (b) velocity contour, (c) velocity vector and (d) velocity streamlines

Moreover, by looking at the streamlines image in the area b1, there are strong swirling motion are still remaining event the plane was increase after 1st stage condition. Here it can be seen of the low velocity is develops in the middle of the SFB systems. The air flow increasingly centralized just after the air flow pass through 1st stage of blade distributor until next stage of blade distributor. This condition it's opposite to the image at the area b2 were, a very low swirling motion to be just after the high stage of blade distributor. This can be concluded that, when airflow passes the high stage blade distributor, its velocity profile will tend to be low as well as kinetic energy. As was done in earlier studies [15–17], the ideal configuration and parameter will be identified in the future via statistical analysis.

4. Conclusions

This paper explains the velocity distribution in a Multi-Stage Swirling Fluidized Bed (SFB). To this end, a single-phase numerical study using ANSYS Fluent commercial CFD software is performed to obtain a proper visualization of the air flow behaviour. It is discovered that the Multi-Stage SFB prediction model the pressure drop and solids velocity throughout a broad range of operational circumstances. It is determined that the Multi-Stage SFB prediction model accurately predicts the velocity distribution throughout a broad range of operating circumstances. Flow variables such as tangential velocity, radial velocity and axial velocity are computed and examined. The numerical analysis indicates that a stable uniformly in area blade radius of 110 mm – 140 mm. During the case study, with increasing blade numbers and low blade angle, the increasing centrifugal forces to the bed's wall and increasing on tangential velocity and radial velocity. As result in current study, high uniformity of tangential velocity in fluidization systems (number of blades, 60 & blade angle, 15°) will result in a better Multi-Stage SFB system since it will have generated the tornado effect, which may aid in accelerating drying processes.

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