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Twist Blade Distributor in Fluidization Systems: Part 2 – The Air Flow Characteristics

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ABSTRACT

This study examines the findings of numerical analysis studies that were conducted to determine how the arrangement of the blade distributors in a fluidization system affects the distribution of air flow distribution. In contrast to the conventional methods, which give the particle a swirling motion, the current fluidization systems produce a circular movement of a beds. Therefore, the influence of twist angle blade (60° and 100°) was investigated through to the horizontal inclination angle (15°) and radial inclination angle (10° and 12°) blade distributors. In a fluidization systems, the simulation was used to calculate and assess the performance outcomes of three velocity components: tangential velocity, axial velocity, and radial velocity. These components represent the flow of fluid inside the plenum fluidizations systems. According to the results of the numerical study that used a horizontal inclination of 15°, the velocity of the airflow in the fluidization systems may reach up to 8 m/s. This circumstance occurred because the air flow was quite near to the large opening area where the airflow was allowed to enter. This is due to the less of an interruption to the airflow when it enters the gap area between the two blades distributor.

1. Introduction

The term "fluidization" refers to the process of a fluid moving over a densely packed bed of solid particles at a specific velocity in order to produce drag forces that are sufficient to overcome each particle's weight. The particles will no longer rest on one another as a result, and as a result, they will act and flow like a fluid [1]. A vessel with a porous base is necessary for fluidization in order to distribute the fluid onto the bed. Previous researcher [2,3] have produced a summary of employing

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the fluidization systems application which give some idea to the new design that is being suggested for the blade distributor.

As an example of good current fluidization application is a Swirling Fluidized Bed (SFB). In most current fluidization systems, the rate of gas flow into the bed may be split into three main components as shown in Figure 1; axial velocity, radial velocity, and tangential velocity. In this current fluidization systems, the gas is injected horizontally into the bed at a certain blade angle. As in simple analyzing, the horizontal and vertical components of v sin θ and v cos θ, respectively, would be used to calculate the gas's velocity. In comparison to conventional fluidized beds, the SFB offer many key benefits. In the swirling field, no bubbles nor gas bypass exist. In addition, according to experiments done by the previous researcher [4] in SFB, the radial distance increases the velocity of swirling particles. However, the majority of prior research results have provided a generalized portrayal of fluidization events by describing the airflow distribution throughout the blades distributor without offering adequate detail on the effect of twist blade distributor for fluidized bed inside flow behavior. The present research is focused on the single-phase flow of current fluidization system through extensive CFD study, which simultaneously describes mixing behavior within the fluidization regime using different blade distributor design configurations.

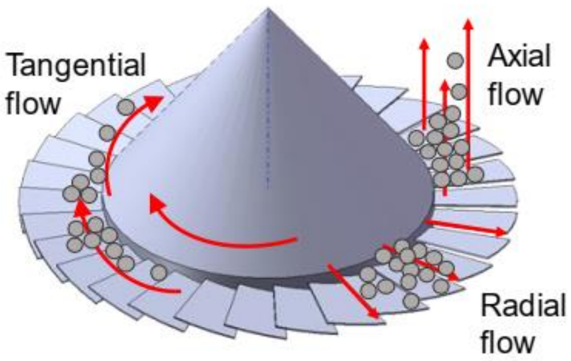


Fig. 1. Annular blade distributor of Swirling Fluidized Bed (SFB)

2. Methodology

2.1 Numerical Simulation Process

A flow chart of the research procedures could be refer as illustrated in the first manuscripts of Part 1 – The Computational Procedure. The final step in this study is referred to as the post-processing step using several of graphical methods such as grid, contour, vector, and line plots.

2.2 Description of the Current Fluidization Systems

The airflow distribution in current fluidization systems was investigated using ANSYS Fluent commercial CFD software. This ANSYS was used to create the computation domain and grid generation. As seen in Figure 2, the phase velocity was specified at the intake boundary of the plenum chamber as 2.25 m/s (0.22 kilograms per second mass flow rate), and the pressure outlet was set to atmospheric pressure (101,325 Pa). Consequently, the flow in this investigation is constant and incompressible.

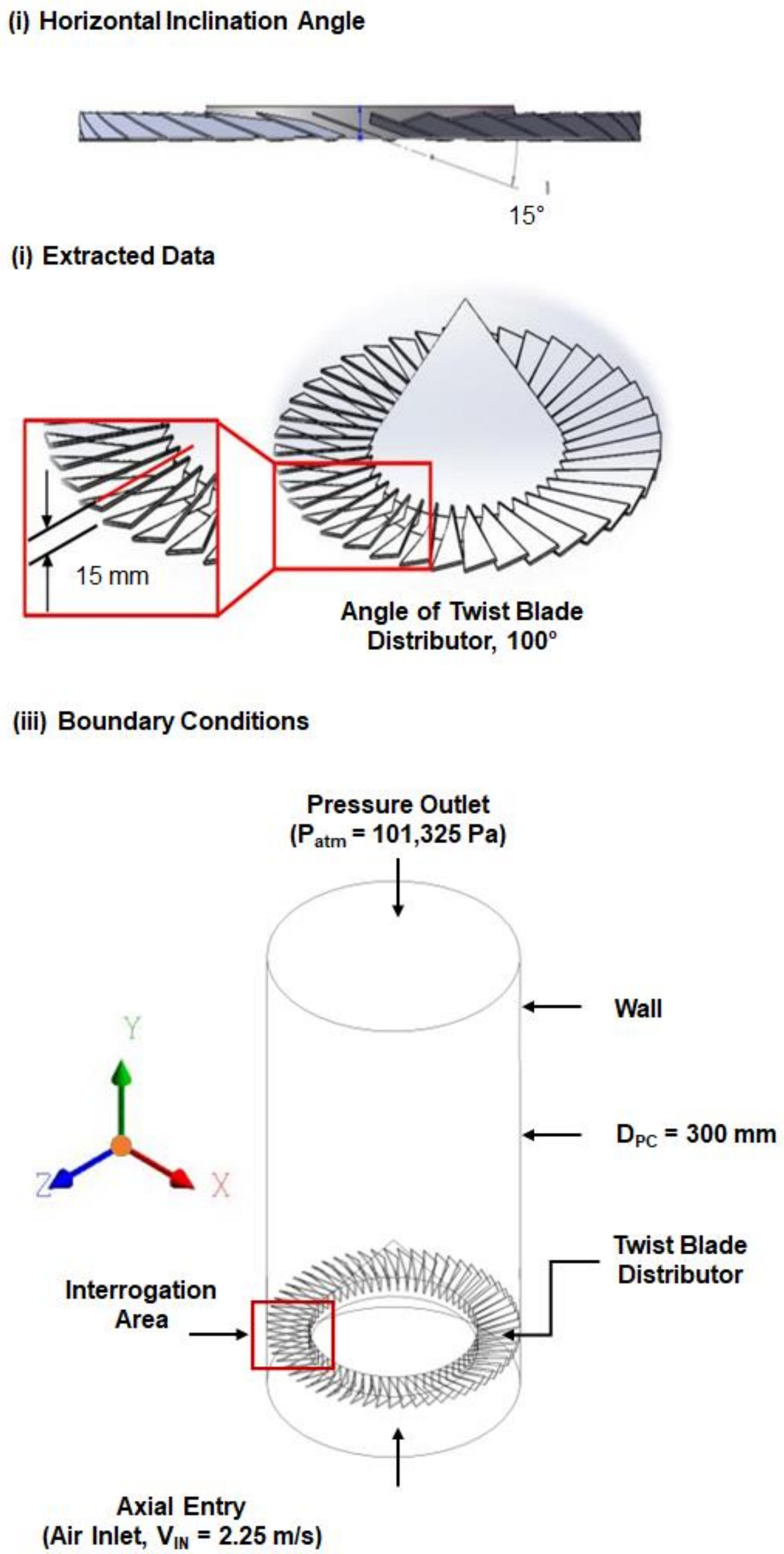
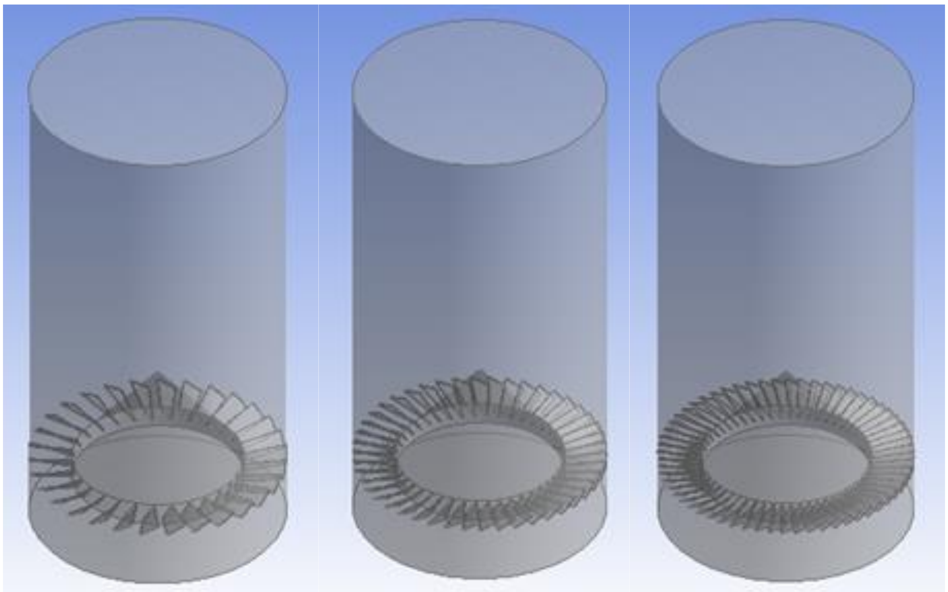


Fig. 2. Fluidization systems via twist blade distributor configuration

Consequently, the fluid element's density and time do not vary while air flows through the geometrical volume. In addition, the no-slip shear condition presupposes that the fluid velocity relative to the geometric boundary is zero. In addition, the wall motion was configured to be stationary. Figure 3 shows the placement of 30, 45 and 60 blade distributors at the centre of the current fluidization systems and airflow going through a 15° horizontal inclination angle. Therefore, the flow can be considered as an unconfined flow. The blade distributor dimensions are taken based on [5-8], and for validation purposes, the data was referred to [6,7]. In this study, three types of angles were used: radial inclination, horizontal inclination, and twist angle. A constant horizontal inclination of 15°, radial inclination of 10° and 12°, and twist angle of 60° and 100° were used, as shown in Table 1.



(a) (b) (c)

Fig. 3. Fluidization systems through various number of distributor models; (a) 30, (b) 45, and (c) 60

Table 1
Parametric study on plenum chamber configuration in fluidization systems

Case	Number of Blades	Horizontal Inclination	Radial Inclination	Twist Blade
1	30	15˚	10˚	60˚
2				100˚
3			12˚	60˚
4				100˚
5	45		10˚	60˚
6				100˚
7			12˚	60˚
8				100˚
9	60		10˚	60˚
10				100˚
11			12˚	60˚
12				100˚

According to prior research, blade inclination angle of 15° would results in a high tangential velocity and a high uniformity in velocity magnitude. Ratio between the current fluidization systems diameter to the radius blade distributor (50 mm) were utilized to get further information on the twist angle blade distributor arrangement.

2.3 Numerical Model

As a result, in this study, the similar condition setting as prior researchers [8,9] was used. The Reynolds Averaged Navier Stokes (RANS) turbulence equation of the (Re-Normalization Group) RNG methods based on model transport equations for the turbulence kinetic energy (*k*) and its dissipation rate (*ε*), also known as the RNG *k-ε* model, has been chosen in the FLUENT environment. This turbulence model had been comparable to others semi-empirical model. Details on the solving processing that specify solution methods and selected discretization schemes had been emphasized in the previous manuscripts (Part 1 – The Computational Procedure).

2.4 Governing Equation

The current study's governing equations are three-dimensional momentum and continuity equations in cylindrical coordinates that were solved for Newtonian, incompressible fluid in steady flow [10].

2.4.1 Continuity equation

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

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

2.4.2 Momentum equation

(x direction)

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

(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 discusses the investigation's results from the numerical analysis. In this work, the tangential, radial, and axial velocity distributions were examined. Data were extracted on a horizontal plane, 15 mm above the distributor, since this was the appropriate place to analyze the airflow characteristics.

3.1 Velocity Distribution Analysis

The current investigation used blades with specified numbers of 30, 45, and 60 via various plenum chamber configurations (Table 1). In subtopic 2.2, the modelled geometry has been described (Part 1 – The Computational Procedure). When air enters the distributor, it is deflected by the blade, causing a swirling motion. This will have an effect on the mass in the outermost section of the column due to centrifugal force. Using tangential velocity, radial velocity, and axial velocity, the velocity distribution may be classified.

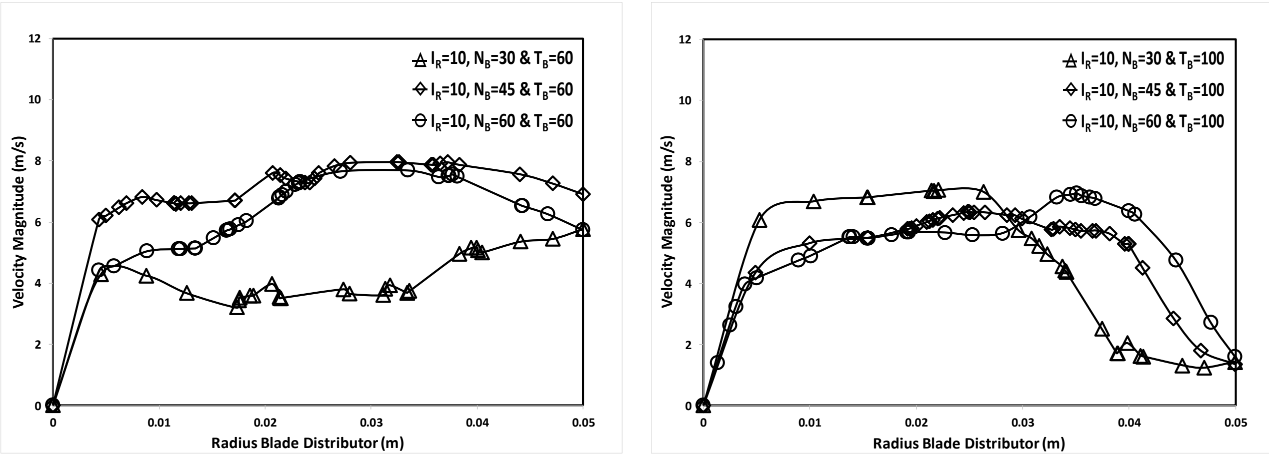
In real industrial application, these three velocity components can be characterized as tangential velocity would produce a swirling effect in plenum fluidization systems, whereas axial velocity component would create fluidization on the bed. While the radial velocity component is caused by the centrifugal force that makes swirling gas move into the wall plenum. Figure 1 illustrates the annular blade distributor of Swirling Fluidized Bed (SFB). The tangential velocity serves as the primary component throughout the study because it captures the velocity of the swirling air in the annular region of the system. Tangential velocity will provide the swirling effect, whereas axial velocity creates the fluidization effect. The following section will provide further information on these velocity components. There were a total of 12 case studies examined, and the data of the extracted velocity components varied based on the configuration of the plenum chamber. In future by doing the statistical analysis, the optimum configuration and parameter will be determined as previous study [11-13] have be done.

3.2 Velocity Magnitude Analysis

The three (3) velocity components—tangential, axial, and radial—that made up the velocity magnitude were described. This velocity component may be described as the air passing the distributor blade as it was inserted axially. As a result, the annular blade distributor is causing a swirling in the air flows. Additionally, the swirling effect contributes mass to the air at the column's outermost edges via centrifugal force, causing the flow to now be resolved by the three (3) velocity components. The selected horizontal inclination angle of 15° in each case was developed based on the most recent fluidization study. As the distributor reaches and induces spinning, the air is deflected by the distributor blade and enters the current plenum fluidization systems axially. The flow would split into three (3) velocities components as mentioned earlier due to the centrifugal swirling effect of the air at the base.

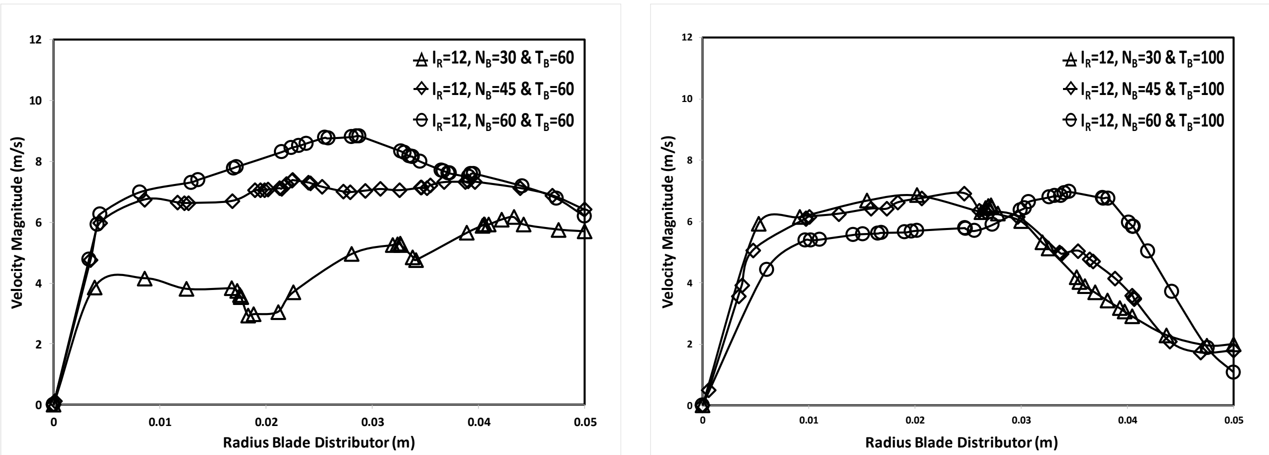
Based on the findings of this study, it can be concluded that, for a given blade angle at two distinct twist blade angles (60° and 100°), the velocity magnitude tends to have a right-leaning shape. It is crucial to distinguish the distribution of velocity at a specific peripheral using the annular blade type, which indicates the distinct location on the plane 15 mm above the distributor at 60° and 100° twist angles. In addition, distributors with numerous blades contribute to the uniform velocity (in area 10 mm – 30 mm) of the system, as seen in Figure 4 and Figure 5. As the twist angle lowers, the resultant velocity of high air flows is uniformity, as shown by the graph in Figure 4 to Figure 5. It displays the velocity distribution of the velocity magnitude for each scenario.

In this situation, the number of 45 blades distributor with a 60° twist angle has a smaller velocity deviation than other cases. The resultant velocity tends to diverge more when the twist angle is reduced. Nonetheless, as shown in Figure 4, the number of 60-blade distributors used to spread velocity magnitude is disproportionately high compared to that of others. This condition is due to the particles or solids within a fluidized bed may have been dried or otherwise impacted, uniformity in velocity magnitude is crucial in a fluidized bed with turbulence.



(a) (b)

Fig. 4. Velocity magnitude for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 10°

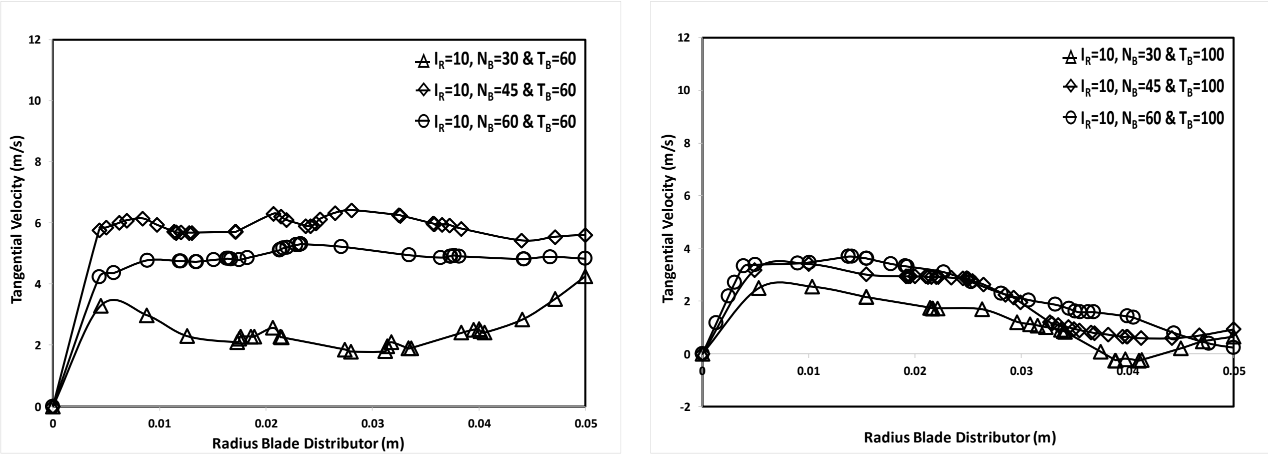


(a) (b)

Fig. 5. Velocity magnitude for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 12°

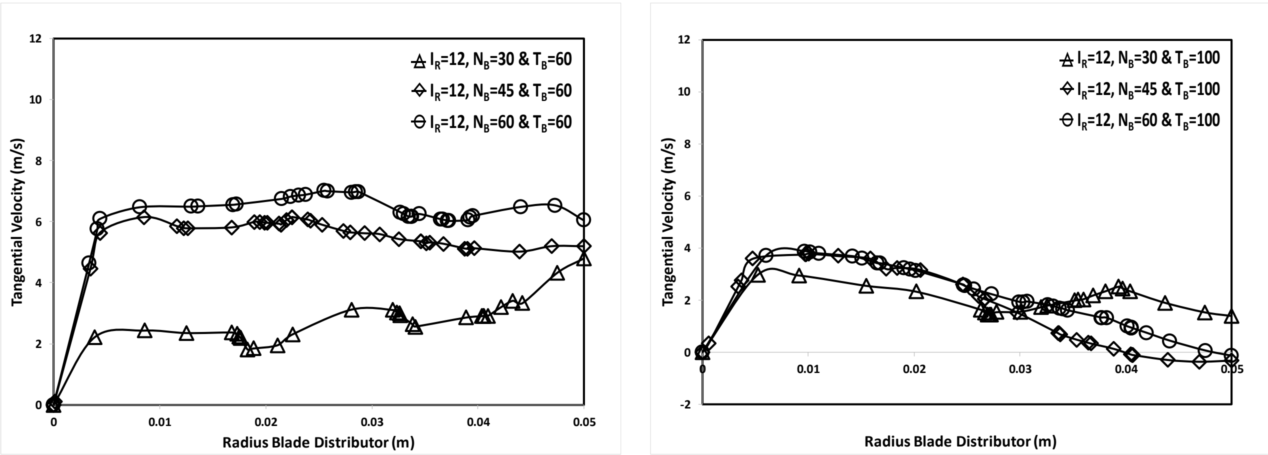
3.3 Tangential Velocity Distribution

Tangential velocity is the main velocity component of current fluidization systems. It represents the velocity of the air in the annular region of the bed. The tangential velocity profile will be given by comparing data according to the variation annular blade distributor number and the influence of twist blade angle on swirl generation. The tangential velocity data that were retrieved from all parametric case studies are displayed in Figure 6 and Figure 7. Different axial entry plenum fluidized bed did not demonstrate any peculiar velocity characteristics. It seems that the flow was occurring as expected. Similar trends were seen between the current research condition and the prior study [14] on the twist blade distributor.



(a) (b)

Fig. 6. Tangential velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 10°



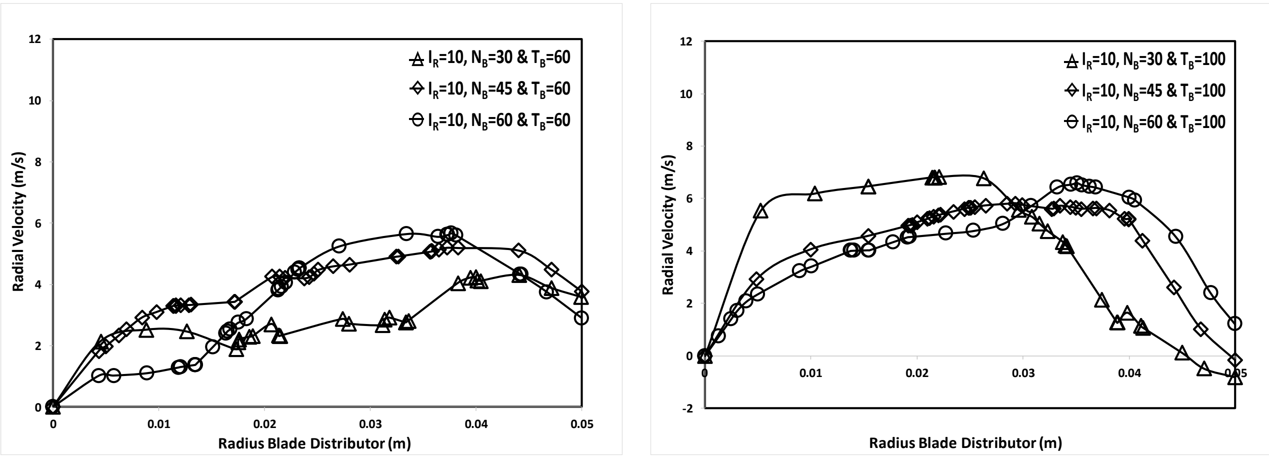
(a) (b)

Fig. 7. Tangential velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 12°

Along the radius, it tends to become greater as you approach closer to the bed wall. However, at the wall itself, the air velocity is zero because there is no slippage, which creates shear motion, at the stationary wall. For the same reasons as in the preceding sections, higher blade angles improve airflow uniformity. Lower blade angles result in a greater horizontal velocity component, which explains why tangential velocity numbers are greater. It was also evident that an increase in the number of blades leads to a reduction in flow uniformity while increasing tangential velocity. This was because there was a smaller proportion of open surface, which increased the airflow's amplitude and tangential velocity component [14]. The characteristics of the air velocity component and the velocity magnitude distribution graph show the same pattern (Figure 4). In most of the diagrams, velocity uniformity has developed. Once the low velocity (2.25 m/s) supply is introduced, it has been demonstrated that the airflow will generate whirling circumstances. The air flows in the plenum fluidized bed arrangement are capable of exerting centrifugal force and moving toward the wall.

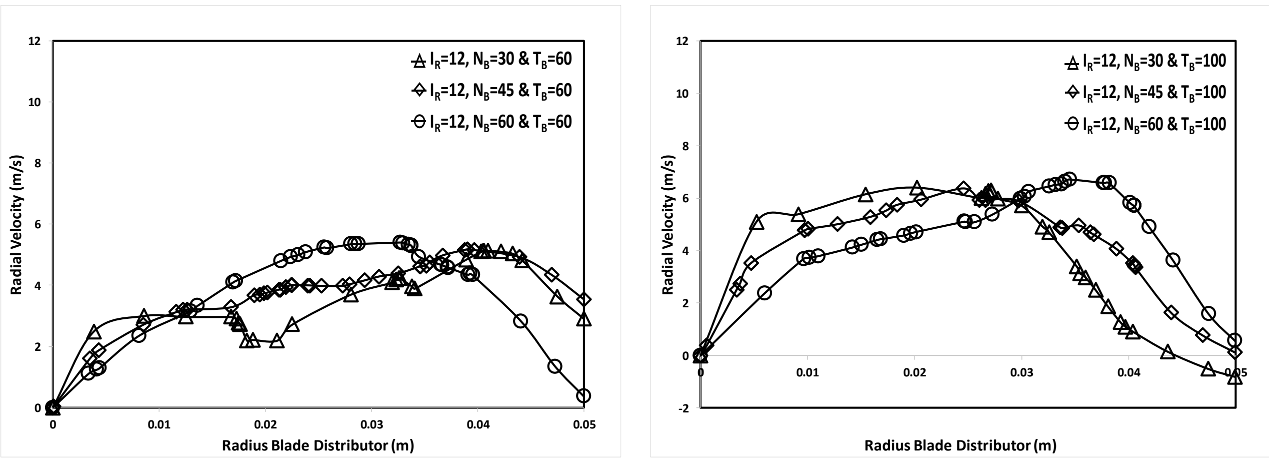
3.4 Radial Velocity Distribution

Radial velocity is one of the essential components of the swirling motion of the fluidized bed. It indicates the velocity of the air pushed against the bed wall as it passes from the cylinder base of the centre body to the wall of the plenum fluidization systems with the radial blade distributor. The flow distribution of the radial velocity profiles is distinct and distinctive because it achieves low radial velocity at high-angle blades. As the angle of the blades rises, centrifugal force exerts its influence on this system. A greater tangential velocity will increase the radial velocity, which is caused by the tangential velocity component. As a result of the high tangential velocity, an increasing amount of air is pushed to the bed's wall in proportion to the decreasing angle of the blades. The radial velocity profile for each setup is shown in Figure 8 and Figure 9. The overall tendency of the radial velocity distribution was revealed by the findings of the velocity magnitude. The velocity rises as it passes through the cylinder base and onto the outer blade distributor. As a consequence, the graph is right-leaning and skews toward the bed wall.



(a) (b)

Fig. 8. Radial velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 10°

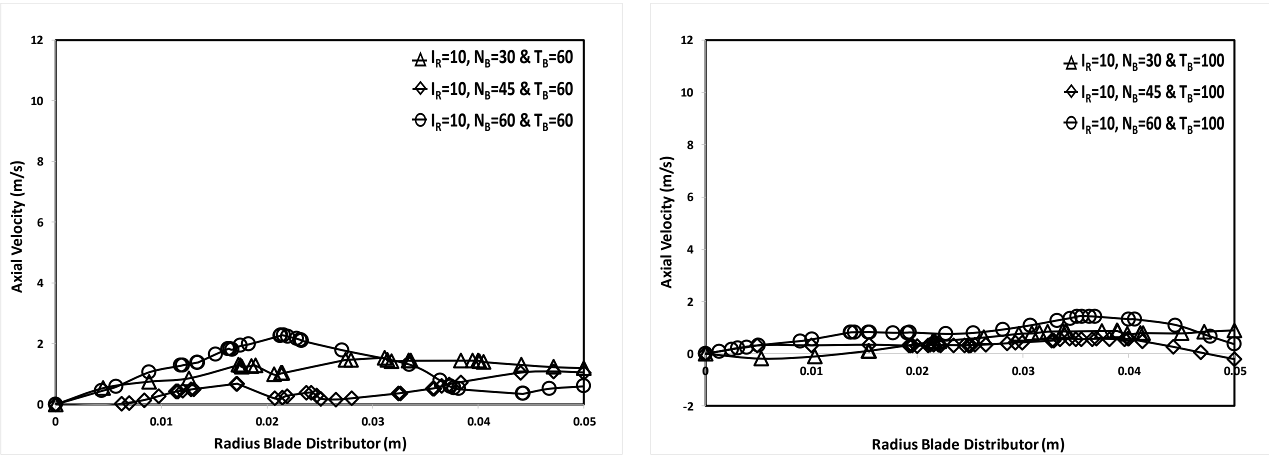


(a) (b)

Fig. 9. Radial velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 12°

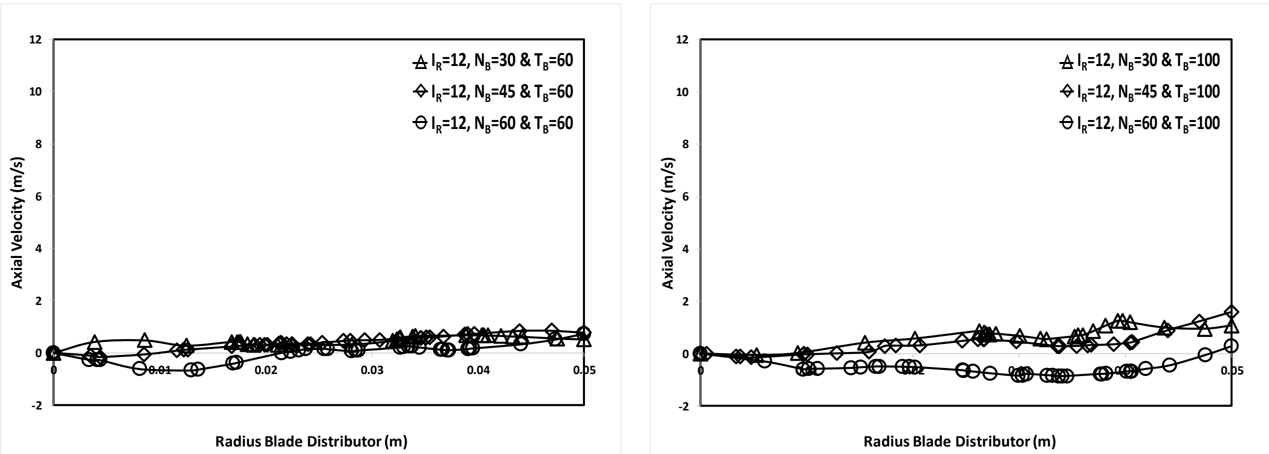
3.5 Axial Velocity Distribution

Axial velocity is an important element of fluidization velocity. The vertical, downward, or upward airflow is determined by the velocity of the particles, which is represented by this velocity component. As demonstrated in Figure 10 and Figure 11, the magnitude of the axial velocity is proportional to the blade angle, with greater blade angles resulting in greater magnitudes. This is due to the increased vertical velocity component of the blade opening. In addition, it was evident that the axial velocity had negative values, suggesting a negative pressure gradient in the middle of the bed, which is again the result of centrifugal force. As the angle of the blade decreases, reverse airflow generation is likely to occur near the central body.



(a) (b)

Fig. 10. Axial velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 10°



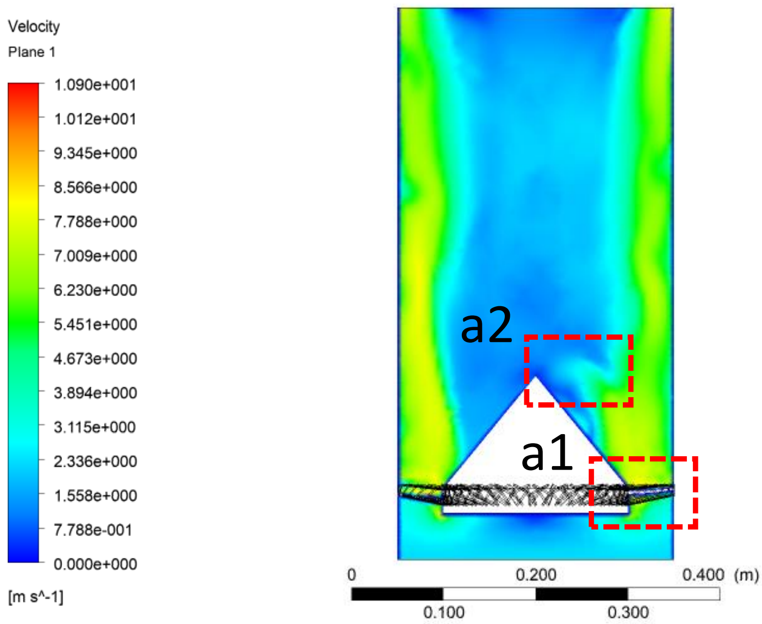
(a) (b)

Fig. 11. Axial velocity for blade numbers, N_B (30, 45 and 60) with different twist blade angle, (a) T_B = 60° and (b) T_B = 100° via radial inclination, I_R = 12°

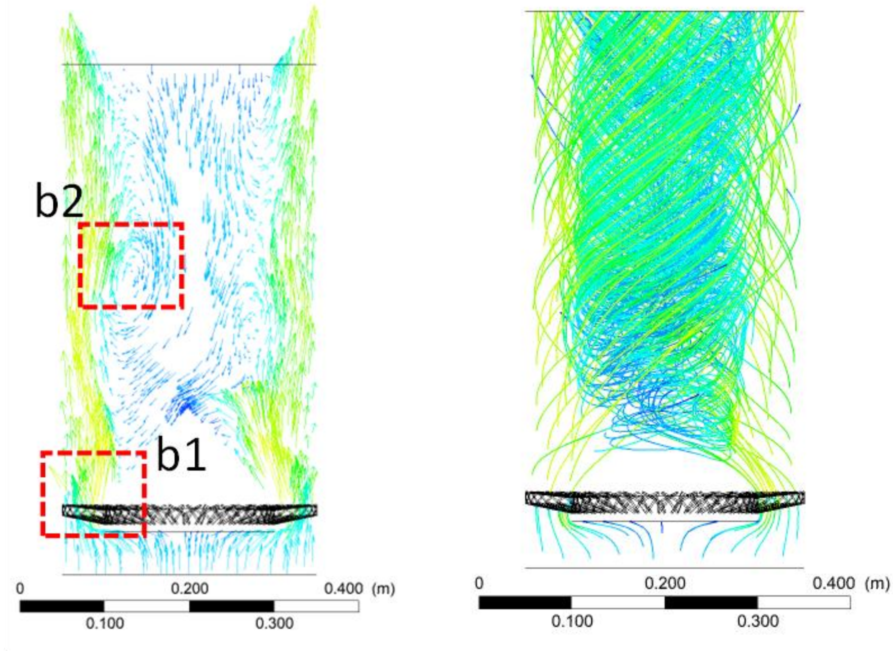
3.6 Air Flow Behaviour

In fluidization parlance, the cylinder or plenum under consideration had a variable velocity distribution that involves underflow and no overflow of fluid. The comprehensive study by [15,16] & [6,7] investigated the air flow distribution of tangential entry plenum chamber in which PIV experimental data were compared to the right simulation of RNG *k-ε* model and found to be in excellent agreement with simulation results. Furthermore, the same prototype of current fluidization systems had shown that the tangential velocity reflects the swirling air's velocity in the annular region and increases as it gets closer to the bed's wall. In the current study, visualization images of the air distribution in various regions of the most recent research on fluidization systems are presented. These images show the symmetry of the velocity contour, vector velocity, and the flow streamline.

Although the tangential flow is steady, the small vortex is still occurred along with the plenum chamber height. Therefore, this region was marked as 'a' in velocity contour and 'b' in velocity vector at selected figures. The longer striations near the bed's wall indicate the average velocity at all cases involves at horizontal inclination angle 15° (Figure 12). Furthermore, according to the studies of Batcha *et al.*, [17], the tangential flow is mostly swirling as far as flow structure goes, with the exception of the vortices that typically form near to the distributor. To the current study same condition can also be seen in this study, namely on a1 and b1 in the Figure 12. Moreover, the distributor of the coast radial bed and practically all parameter stages of the vortices may be seen in a limited area. In this area, the flow is highly irrational and resembles a free vortex as shown in a2 and b2. These circumstances may be due to the geometry of the blade angle prevents airflow past the distributor. The vortex is still there and being forced by the component with the highest velocity in this region. This airflow behaviour is most closely similar to the study conducted on horizontally inclined distributors.



(a) (b)



(c) (d)

Fig. 12. Annular blade distributor for blade number, 45 with twist blade angle, 60° via radial inclination, 10°; (a) velocity legend, (b) velocity contour, (c) velocity vector and (d) velocity streamlines

4. Conclusions

Numerical analysis is a useful tool for deciphering the complicated airflow phenomena in current fluidization systems, particularly in terms of velocity magnitude, which includes all three velocity components axial, tangential, and radial. This velocity magnitude reflects the annular blade distributor configuration's particular design, which allows for excellent mixing. As results, number of blade distributor, 45 with twist blade angle, 60° via radial inclination, 10° was considered to be the best in terms of tangential and axial flow uniformity based on the current setup. A large magnitude of air velocity will result in a high tangential air velocity and so on will be results in superior fluidization systems as a consequence of the systems' ability to generate the tornado effect, which may accelerate processes such as drying.

Acknowledgement
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References
[1] Sheng, Tan Chee, Shaharin Anwar Sulaiman, and Vinod Kumar. "One-dimensional modeling of hydrodynamics in a swirling fluidized bed." *International Journal of Mechanical & Mechatronics Engineering* 12, no. 6 (2012): 13-22.
[2] Haron, N. S., J. H. Zakaria, and MF Mohideen Batcha. "Recent advances in fluidized bed drying." In *IOP Conference Series: Materials Science and Engineering*, vol. 243, no. 1, p. 012038. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/243/1/012038
[3] Paulose, M. M., V. N. Narayanan Nampoothiri, and P. S. Sreejith. "Hydrodynamic study of swirling fluidized bed and the role of distributor." PhD diss., School of Engineering, 2006.
[4] Mohideen, M. F., and V. R. Raghavan. "Experimental studies on a swirling fluidized bed with annular distributor." *J. Appl. Sci* 11, no. 11 (2011): 1980-1986. https://doi.org/10.3923/jas.2011.1980.1986

[5] Mohideen, Mohd Faizal, Binod Sreenivasan, Shaharin Anwar Sulaiman, and Vijay Raj Raghavan. "Heat transfer in a swirling fluidized bed with geldart type-D particles." *Korean Journal of Chemical Engineering* 29, no. 7 (2012): 862-867. https://doi.org/10.1007/s11814-011-0255-6

[6] Nawi, Mohd Al-Hafiz Mohd. "Aerodynamics of a Swirling Fluidized Bed." PhD diss., Universiti Tun Hussein Onn Malaysia, 2013.

[7] Mohideen Batcha, Moho Faizal. "Aerodynamics and Hydrodynamics of a Swirling Fluidized Bed With Sloped Distributor." Phd Diss., Universiti Teknologi Petronas, 2015.

[8] Hafiz, M. A., Mohd Faizal Mohideen Batcha, and Norzelawati Asmuin. "Effect of plenum chamber depth in a swirling fluidized bed." In *IOP Conference Series: Materials Science and Engineering*, vol. 50, no. 1, p. 012021. IOP Publishing, 2013. https://doi.org/10.1088/1757-899X/50/1/012021

[9] Othman, Safiah, Abas A. Wahab, and Vijay R. Raghavan. "Numerical study of the plenum chamber of a swirling fluidized bed." In *Proceedings of International Conference on Mechanical and Manufacturing Engineering*, pp. 21-23. 2008.

[10] Versteeg, Henk Kaarle, and Weeratunge Malalasekera. *An introduction to computational fluid dynamics: the finite volume method*. Pearson education, 2007.

[11] Hazwan, M. H. M., Z. Shayfull, M. A. M. Nawi, M. Ahmad, Mohamad Syafiq AK, and A. M. Roslan. "Warpage optimization on battery cover using genetic algorithm (GA)." In *AIP conference proceedings*, vol. 2129, no. 1, p. 020195. AIP Publishing LLC, 2019. https://doi.org/10.1063/1.5118203

[12] Shayfull, Z., M. H. M. Hazwan, M. A. M. Nawi, M. Ahmad, Mohamad Syafiq AK, and A. M. Roslan. "Warpage optimization on battery cover using glowworm swarm optimisation (GSO)." In *AIP conference proceedings*, vol. 2129, no. 1, p. 020100. AIP Publishing LLC, 2019. https://doi.org/10.1063/1.5118108

[13] Ibrahim, M. I. F., M. U. Rosli, Muhammad Ikman Ishak, M. S. Zakaria, Mohd Riduan Jamalludin, C. Y. Khor, WM Faizal WA Rahim, M. A. M. Nawi, and Suhaimi Shahrin. "Simulation based optimization of injection molding parameter for meso-scale product of dental component fabrication using response surface methodology (RSM)." In *AIP Conference Proceedings*, vol. 2030, no. 1, p. 020078. AIP Publishing LLC, 2018. https://doi.org/10.1063/1.5066719

[14] Zulkifli, R. M., M. A. M. Nawi, M. I. Ishak, M. U. Rosli, S. N. A. Termizi, C. Y. Khor, and M. A. Faris. "Influence of Twisted Blades Distributor Towards Low Pressure Drop in Fluidization Systems." In *Intelligent Manufacturing and Mechatronics*, pp. 703-711. Springer, Singapore, 2021. https://doi.org/10.1007/978-981-16-0866-7_59

[15] Othman, Safiah, Abas A. Wahab, and Vijay R. Raghavan. "Validation by PIV of the numerical study of flow in the plenum chamber of a swirling fluidized bed." *Cfd Letters* 2, no. 2 (2010): 85-96.

[16] Abd Latif, Muhammad Lutfi, Mohd Al Hafiz Mohd Nawi, Wan Azani Mustafa, Mohd Sharizan Md Sarip, Mohd Aminudin Jamlos, Masniezam Ahmad, Ku Mohammad Yazid Ku Ibrahim, and Hazizul Hussein. "Numerical analysis of velocity magnitude in a swirling fluidized bed with spiral blade distributor." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 59, no. 1 (2019): 38-44.

[17] Batcha, Mohd Faizal Mohideen, M. A. M. Nawi, Shaharin Anwar Sulaiman, and Vijay R. Raghavan. "Numerical investigation of airflow in a swirling fluidized bed." *Asian Journal of Scientific Research* 6, no. 2 (2013): 157-166. https://doi.org/10.3923/ajsr.2013.157.166