FLOW VISUALIZATION IN A SWIRLING FLUIDIZED BED
Sulastri Sabudin¹*, Shahzada Khan Nawab Khan¹ and Mohd Faizal Mohideen Batcha¹

¹Energy Technologies Research Group (En-RG)
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Malaysia
*Email: sulastri@uthm.edu.my

ABSTRACT

A Swirling fluidized bed (SFB) is known to yield high a solid-fluid interaction which augments heat and mass transfer due to the swirling motion. Its distributor is known as annular blade distributor as it is constructed from blades that are truncated sectors and has an annular geometry. The annular blade distributor provides lateral momentum which is ideal for various industrial applications. However, the distributor is limited to shallow bed operation only due to momentum attenuation in the vertical direction. This limits the full potential of the bed. The present study attempts to remove this limitation by introducing the annular blade distributor with radial inclination. Qualitative flow assessment via flow visualization technique is reported on the effect of using such distributor blades. Fine seeding particles were injected upstream of the system to observe difference in using the annular distributor (0˚ inclination) and radially inclined distributor (13.5˚ inclination). The distributor pressure drop was also measured to quantify the energy loss associated with both distributors. The findings show that radial inclination of distributor blades in a SFB is capable in reducing the net centrifugal force generated inside the bed due to the intense swirling motion. As a result, the steep variation of momentum distribution in the bed is reduced, although a slight increase in the distributor pressure drop was noticed.

**Keyword:** Swirling fluidized bed; distributor; radial inclination; flow visualization; pressure drop.

INTRODUCTION

Flow visualization is one of the classical experimental techniques in which flow patterns are made visible to eye, particularly to obtain fundamental information on flow characteristics. Velocity distribution, flow separation and vortex formation with regard to surface and geometry of flow domain are some of the examples. Generally, in fluid motion, flow can be visualized through several methods such as the surface flow visualization method, optical method or the particle tracer method. The last method requires particles to flows freely in the fluid and when illuminated by sufficient lighting, images of the fluid which is now represented by the particles, can be acquired. However, this method is only feasible if the density difference between the particles and the fluid is negligible to ensure the particles truly represent the flow structure.

The swirling fluidized bed (SFB) has gained interest in research as well as in the industry since the last two decades. The SFB consists of an annular blade distributor which imitates the stationary guide vanes in a typical gas turbine system and provides angular momentum that results in fluidization as well swirling (Batcha et al, 2012 and Mohideen et al, 2012). This feature is highly desired in gas-solid contacting processes such as drying, combustion, gasification and catalytic cracking. Understanding the flow of swirling air is of great importance in improving the airflow design. Once the three-dimensional swirling flow is fully understood, the performance such as the pressure drop and velocity distribution can be improved by optimizing the device’s design.
A previous investigation on the SFB by Batcha and Raghavan (2011) revealed that despite the excellent hydrodynamic characteristics of the bed, the SFB has a limited range of air flow rate. Although the swirling motion reduces the vertical momentum that may cause elutriation of particles, it creates an intense centrifugal force which throws the bed material towards the outer bed periphery during operation and exposes the bare distributor at the inner periphery. As a result, bypassing of process gas without coming into contact with bed particles occurs. One way to overcome this drawback is to incline distributor blades in a radially inward direction. The numerical investigation of the flow has been addressed by Batcha et al. (2013). In this paper the flow visualization is addressed. The effect of flow distribution with a conventional distributor (0˚ inclination) and the one with radial inclinational (13.5˚ inclination) are assessed qualitatively via flow visualization. The SFB system and the distributor blades are depicted in Figure 1.

![Figure 1. Configuration of a Swirling Fluidized Bed (SFB) with: (a) conventional distributor (0˚ inclination) and (b) radially inclined distributor (13.5˚ inclination)](image)

**EXPERIMENTAL SET-UP**

The experimental set-up consists of a 25 hp blower, piping, pitot-static probe for velocity measurement and the SFB system. The velocity was varied by using a frequency controller which regulates the motor speed at the blower. Three inlet velocities were used in the present study: 1.06m/s, 1.64m/s, and 2.25m/s, which were measured at the air inlet pipe. These velocities were chosen in accordance to the experimental work by Batcha et al. (2012). Similar work was reported by Lackermeier et al. (2001). For the purpose of flow visualization, fine powder having an average diameter of 5 µm was injected upstream of the system, inside a sufficiently long pipe to ensure fully developed flow before entering the system. The injection of this powder was made after the system stabilized and the velocity reading was constant. This was absolutely necessary to ensure the fine powder will be well mixed in the flow stream. Apart from this, a sector of the distributor which consists of about 15 blades was painted dark to increase visibility and to create contrast between the powder and its background.
Upon the entrance of the seeding powder into the bed, images were acquired using Canon EOS 7D camera with aperture size of 3.5 – 6 mm and focal length of 1585 mm. The images was acquired at a speed of 60 frames per second. Similar as Takami Kai et al (2013), they used digital camera to study bed behaviour. Before the experiments began, the camera was first focused on 10 mm plane above the distributor which is the interrogation plane. Images acquired were then processed using Adobe Photoshop software. The experimental setup is shown in Figure 2 below:

![Experimental set-up for Flow Visualization](image)

**Figure 2.** Experimental set-up for Flow Visualization

**RESULTS AND DISCUSSION**

For conventional distributor blades (0° radial inclination), it was observed that air containing the fine powder enters the bed through the narrow gaps of the distributor blades. The flow was initiated mostly from the outer region of the blades, nearby the bed wall. It was also observed that the air flow was uniformly distributed from the outer periphery of the distributor, before quickly progressing towards the middle section of the bed. With the larger amount of flow mass at the outer periphery of the bed, (indicated by the thicker concentration of the seeding powder at this location) it can be deduced that significant amount of centrifugal force is generated due to the swirling flow of the air, even at the relatively low velocity, i.e. 1.06 m/s. These can be seen from Figure 3, (a) to (c).
As the air was continuously introduced inside the bed, more air flows towards the bed core until the bed was occupied by the flow. This was evident as the blades gradually vanished as a result of thicker seeding powder concentration in the bed as seen in Figure 3 (d) to (f). Similar findings were obtained with air velocities of 1.64 m/s and 2.25 m/s. They are not presented here due to space limitations. Higher velocities naturally created even higher centrifugal force inside the bed and hence delayed development of flow towards the bed core. In actual industrial applications such as drying, the flow distribution from the outer bed periphery to the core is not preferred due to the lack of uniformity in solid-gas contact inside the bed. As a consequence, the particles at outer periphery may tend to have higher heat and mass transfer in comparison to the particles near the core and result in non-uniformity and reduction of quality of the final product.

To investigate the possibility of reducing the intense centrifugal force which causes maldistribution of air inside the bed as mentioned above, a set of distributor blades with radial inclination of 13.5° was introduced. With the same concentration of seeding powder and velocity (1.06 m/s) as tested with conventional distributor, the images in Figure 4 (a) to (f) depict the flow characteristics of the radially inclined distributor. From Figure 4 (a), the initiation of air flow inside the bed seemed somewhat similar the conventional distributor with flow progressing from the outer periphery of the distributor. Interestingly, the flow develops faster towards the core, as seen shown in Figure 4 (b) and (c). Progressively the flow covered the whole bed quickly in comparison to the conventional distributor (Figure 4 (d) to (f)).
Several important remarks can be made from these observations. Firstly, the radial inclination of distributor blade was able to modify the flow structure inside the bed. The presence of radial velocity component towards the bed core can be seen. This velocity component counterbalances the intense centrifugal force generated due to the swirling motion of air. Secondly, much faster flow development to the bed core which was indicated by thicker seeding powder concentration suggests that axial velocity distribution (perpendicular to the figure) was also reduced. As a result, angular momentum inside the bed can be sustained much longer, to ensure better solid-gas contacting and mixing inside actual system.

Although the radial inclination of distributor blades provides apparent advantages, the change in distributor blade geometry may inflict higher energy loss in the flow. To quantify the amount of energy loss, distributor pressure drop measurements were made for both conventional distributor as well as the radially inclined distributor. Figure 5 compares the distributor pressure drop for both distributors. These pressure drops were static pressure difference between inlet and outlet of the distributors respectively.

Figure 4. Flow development for the radially inclined distributor (13.5° radial inclination)
From Figure 5, it was found that the distributor pressure for both distributors are almost identical, suggesting that introduction of radial inclination on the distributor blades did not have any significant change on the pressure drop. As such, the operating cost will not differ between the two distributors but the radially inclined distributor will have advantage as discussed earlier.

CONCLUSION

Flow visualization using fine powder is capable of providing the distributor flow characteristics in a swirling fluidized bed. The qualitative evaluation is useful in assessing the distributor’s performance. It was found that radial inclination in annular distributor blades modifies the flow characteristics by proving inward momentum which is necessary to counterbalance the intense centrifugal force generated inside the bed during actual operations. This feature will further improve the overall performance of the swirling fluidized bed. The radially inclined distributor also did not exhibit any proportionate increase in pressure drop in comparison to the conventional distributor.

ACKNOWLEDGEMENTS

The authors would like to extend their deepest appreciation to Universiti Tun Hussein Onn Malaysia (UTHM) for providing the equipment and facilities to conduct the research. Sincere thanks also conveyed to Ministry of Higher Education (MOHE) for sponsoring this research under Fundamental Research Grant Scheme (vot 0731).

REFERENCES