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Original Research Paper

Improvement on particulate mixing through inclined slotted swirling distributor in a fluidized bed: An experimental study

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ABSTRACT

Previous studies show that excellent particulate mixing in a fluidized bed can reduce the operating cost during fluidization. Therefore, this paper investigates enhancement of particulate mixing in a fluidized bed by using novel inclined slotted swirling distributor. To reduce the cost of pumping power, small size, low pressure blower is used in the study. Moreover, Geldart group B bed materials with different bed aspect ratios and distributor designs viz., perforated plate, circular edged slots (90°) and novel swirling (45°) distributors are used. The novel distributor with 45° inclined slots was found to be effective at enhancing the circulation rate. Swirling flow pattern of the bed materials in a clock-wise direction is obvious in shallow bed, and two-layer transversal-lateral circulation motions are observed in deep bed. It can be concluded from the study that excellent particulate mixing as per rotated distributors is made possible by novel swirling-type distributor without the implementation of electric motor and mechanical rotation.

1. Introduction

Intense mixing between bed particles and fluidizing gas that give rise to high heat and mass transfer is the most important feature of fluidized beds. The efficient operation of chemical reactions and combustion depends considerably on the gas-particle mixing in the fluidized bed. The major factors which may influence the intensity of mixing include, fluidized particle velocities, particle size distribution, bed aspect ratio, and arrangement of the gas flow through the distributor [1]. The flow pattern and mixing caused by these factors are the primary interest of this study.

Practically, distributors for gas distribution system in a fluidized bed have taken a variety of designs. The designs are classified into two physical forms: static and rotating distributors. The distributors are later grouped based on the direction of air entering into the distributor, viz., normal direction (perforated-type distributor, tubular), lateral direction (multi-vortex tube, tuyere, and bubble caps) and inclined direction (swirling-type distributor). Fluidized bed with rotating distributor on vertical and horizontal axes has been extensively studied as industrial solution in improving the quality of fluidization [2–6]. It has been reported that the radial dispersion of particles resulted from the rotation motion of the distributor improving the radial and axial mixing inside the bed [3,7]. Furthermore, elimination of the aggregates and defluidized region at location just above the distributor can be achieved by using rotating distributors [8].

Recently, swirling-type distributor has gained remarkable interest in many fluidized bed applications [9–14]. The dispersion behavior of particles and increased lateral mixing can be achieved by the swirling-type distributor without implementation of electric motor and mechanical rotation of distributors. The inclined entrainment of gas through the distributor produces two velocity components: the vertical component causes fluidization and the horizontal components – responsible for swirling motion in bed [15,16]. Swirling motion produced by using helical-type gas distributors promotes lateral dispersion and significantly improves the fluidization quality compared to a plain nozzle without spiral [9]. Therefore, viable designs of air distributors that can contribute in improving lateral mixing in fluidized bed are essential.

Considering most of the fluidization processes were operated with pressurized air as working fluid, an attempt has been made in this study to investigate the hydrodynamics and mixing pattern of fluidized bed operated by a low pressure blower. Different sizes of Geldart group B bed materials with different aspect ratios were investigated. The bed materials: alumina and river sands selected for this study have industrial importance as an inert material for combustion of fuel in Fluidized Bed Combustion (FBC). To gain an insight of the hydrodynamics of these materials, fluidization at ambient temperature and pressure was applied. Effect of different

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distributor designs viz., perforated plate and circular edged slotted distributor from our previous study [17] were also investigated. The distributor consists of 8 air slots with 6.5 mm diameter and 29 mm long circular edged openings extended to the peripheral of the distributor. The air angle of attack was perpendicular (90°) to the plate. In this study, a novel swirling distributor was introduced by modified the angle of attack into the circular edge openings with 45° inclined air intakes. The performance and applicability of all distributors were evaluated.

2. Experimental setup and procedure

2.1. Fluidized bed setup

The fluidized bed experiments were conducted by using a laboratory scale cylindrical silica glass column which has 108 mm internal diameter, 5 mm thickness and 260 mm length. The schematic of the experimental setup is shown in Fig. 1. Air was supplied by low pressure, 1HP steel sirocco blower (VENZ™ model SC-362) with maximum capacity of 0.22 m^3/s. The low pressure blower used to supply air flow through the distributors is used to save energy. Moreover, the speed of the blower was controlled using inverter drive speed controller. The air flow to the plenum chamber was controlled by Toshiba™ VSF11 AC inverter drive speed controller that controls the speed of the blower between 0 and 50 Hz speed range. An orifice meter was installed 13*D* downstream of the plenum chamber along a 3″ diameter PVC pipe line to measure the air flow rate by the mean of pressure difference. The distributor pressure drop was measured by locating static pressure taps in the air plenum chamber 50 mm below the distributor (P1) and 10 mm just above the distributor (P2). The total pressure drop i.e. the sum of distributor and bed pressure drops was measured by taking the pressure difference across pressure tap P1 and Tap P3 located at top of the glass column. The differential pressure readings across the orifice, distributor and bed were logged by using AZ Instrument™ 82012 differential digital manometer with a resolution of ±1 mmH$_2$O and ±1.0% accuracy. The digital manometer was linked to the computer for real time data logging via the devices' interface.

Three different designs of air distributors made from aluminum with 115 mm diameter, *D*, and 8 mm thickness, *t*, were used in the experiment. The first fabricated distributor was perforated distributor plate consisting of $N = 89$ holes (each 4 mm diameter, d_o) arranged in evenly spaced concentric axes as shown in Fig. 2a. This distributor was considered as a reference distributor for conventional fluidized bed. The second distributor used in the experiment is circular edged distributor (see Fig. 2b) from our previous work [17]. The distributor consists of $N = 8$ air slots with 6.5 mm wide and 29 mm long circular edged openings extended to the peripheral of the distributor. The air angle of attack was perpendicular to the plate (90°). The distributor geometry was further modified to introduce a novel swirling distributor by making the circular edge openings inclined at 45° from the air intake as depicted in Fig. 2c. The opening ratio, β, for both 90° and 45° distributors is 13%. The geometric parameters and the schematics of the distributors are presented in Table 1 and in Fig. 2 respectively.

2.2. Bed materials classification

The bed materials used in the experiments were alumina grit and river sand particles due to their industrial importance as an inert material for combustion of fuel in Fluidized Bed Combustion (FBC). The alumina grit were obtained from the manufacturer (Seeka Bumi Engineering) whereas river sand was retrieved from nearby river and sieved using 80-0200/06 ELE sieve shaker. The river sand was first cleaned and dried to eliminate the dust and oil. Then, Tyler standard mesh size was used for the characterization of the river sand particles size. Normally, the particle size distribution of the bed materials has to be known in order to determine the effect of bed material size on the performance of the fluidized bed. However, the average size of the particles alone does not accurately describe the size distribution of the particulate samples [18]. According to Han [18], instead of particles average size, describing the median size of the particles as well as the

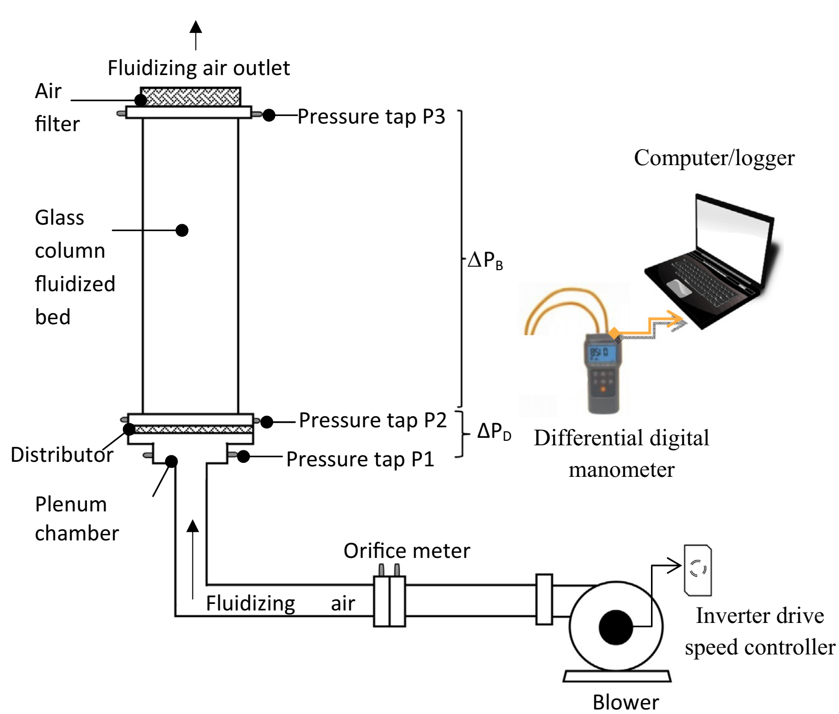

Fig. 1. Schematic of the fluidized bed setup.