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HYDRODYNAMIC STUDIES IN TWO-PHASE STIRRED FLUIDIZED BED WITH THREE TYPES OF IMPELLERS

Article Highlights

- Stirring the bed provides the required energy to breakdown interparticle bonds
- Stirring enhances the performance of fluidization and reduces the minimum fluidization velocity
- Using three types of impellers provides efficient mixing
- Pressure drop and power increase with increase in gas velocity and stirrer speed
- Fluidization performance is enhanced in the stirred bed

Abstract

Fluidized beds are extensively used in petrochemical, chemical process industries, pharmaceutical, food and biotechnology industries. They are preferred to process materials with a wide range of particle size distribution and offer even temperature distribution and excellent heat and mass transfer. To improve the quality of the fluidized bed, mechanical stirring can be employed along with aeration. Hence, an attempt was made to study the hydrodynamics of stirred fluidized bed using air-water system. The characteristics of the fluidized bed can be well understood by studying its hydrodynamics. Pressure drop is one of the vital factors which affect the performance of fluidized bed. Hence, the effects of gas velocity and stirrer speed on pressure drop and power were studied for both stirred and unstirred bed conditions. It was observed that pressure drop and power increases with increase in gas velocity and stirrer speed. Also, the pressure drop and power are lower for the stirred bed condition than the unstirred bed condition.

Keywords: hydrodynamics, stirred fluidized bed, stirrer speed, gas velocity, two-phase system.

In the fluidized bed, excellent fluidization quality is necessary for gas-solid contact, heat and mass transfer. But often it is very difficult to maintain fluidization due to particle agglomeration [1]. Though aeration of the bed gives better fluidization, too much aeration leads to slugging and bubble formation. So, mechanical stirring can be employed along with aeration in fluidized beds for improving fluidization performance. Particle size distribution plays a major role in easiness on which the particle gets fluidized and withstand fluidization. Generally, fine particles agglomerate and defluidize the bed [2]. So, a mechanical stirrer [3] can be employed and the bed can be operated at higher gas velocities to eradicate agglomeration.

Mechanical agitation enhances the performance of fluidized bed with respect to gas-solid contact in heat transfer, catalytic reaction, homogeneous mixing of powders [4]. Stirred fluidized bed is an excellent device for solids blending (Leve 1960). Stirring decreases porosity and minimum fluidization velocity, controls sticking of particles and overheating in case of sticky materials [5]. Various efforts were made to alter the particle and bubble behaviour by external means inside a fluidized bed. Acoustic fields are used to improve the fluidization quality of cohesive powders [6]. Also, ferromagnetic particles are exposed to magnetic fields and they alter the way the bed fluidizes, extending the bubble free operation in fluidization

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state [7]. Agitated fluidized bed dryer is used to dry oil palm frond particles [8]. Inter-bond properties of fibre prevent flow of air within the bed and agitation of the bed results in reducing the bond, thereby the state of fluidization is attained [9]. Furthermore, using special methods like gas injection also improves the fluidization quality. Use of a rotary distributor can improve solids mixing and bubble distribution in fluidized bed [10]. The use of a distributor reduces bubble channelling and stimulated particle radial dispersion in the fluidized bed. Fluidization of nanoparticles can be significantly improved by both vibration and stirring [11]. Addition of a stirring device into the fluidized bed reduces the dead zone of gas-solids fluidized beds [12]. The particle mixing and fluidization quality can also be improved by inclined injection of the fluidizing air [13].

Stirred fluidized beds find application in the recovery of lysozyme from chicken egg white [14,15], operations related with particle separation [16], etc. The application of fluidized beds can be extended to wet and sticky materials and drying of granular materials [17] by introducing vibration in the fluidized bed. Some applications of agitated beds are fluidization of bentonite particles [18] and phosphor particles [19], drying of apple pulp [20] and pharmaceutical products [21].

Due to extreme agglomeration and channelling, the improvement in fluidization requires a design that should be capable to offer high levels of energy in the entire bed volume. Hence, mechanical stirring is employed to overcome the difficulties in a conventional fluidized bed. Stirring the bed offers the required energy to break the interparticle bonds, eradicate channelling and reduces agglomeration. Very few studies have been reported on hydrodynamics in a stirred fluidized bed. Therefore, the present study deals with the hydrodynamic studies in a stirred fluidized bed with three types of impellers using air-water system. The three types of impellers used are pitched blade upflow, pitched blade downflow and Rushton turbine. The effects of gas velocity and stirrer speed on pressure drop and power were studied.

MATERIALS AND METHODS

The photographic view experimental setup is shown in Figure 1. The acrylic column is 1 m in height with 0.05 m internal diameter and 0.06 m outside diameter. U-tube manometer is used to measure the pressure drop across the column. A compressor driven by 5 hp motor is used to supply air. Water is drawn from the surge tank located at the bottom through a motor. Water flow rate and air flowrate are measured by flow meters with a range of 0-5 L/min and 0-10 L/min, respectively. The stirrer is 1 m in length and 0.06 m in diameter and it is rotated by a Tullu motor with a speed regulator. Three different impellers namely, Rushton turbine (1 no.), pitched blade upflow (1 no.) and pitched blade downflow (4 nos.) are used for stirring the bed and are placed at equal distance. The diagrammatic view of impellers and its location in stirrer is shown in Figures 2 and 3, respectively. Compressed air and tap water were used as gas and liquid phases, respectively. Table 1 shows the specifications of the experimental setup.

Figure 1. Photographic view of the experimental setup.

Using the above laboratory setup, hydrodynamic studies on two phase stirred fluidized bed were carried out using an air-water system. Water pumped from the surge tank flowed at a continuous flow rate of 2 L/min. Air from the compressor was introduced at the bottom of the column. The gas velocity was varied from 0.02 to 0.09 m/s. Stirrer speed was varied from 600-1400 rpm and the speed were measured by a digital tachometer. A differential manometer with carbon tetrachloride as manometric fluid was used to measure pressure drop across the column. Power is calculated as the product of volumetric flow rate and pressure drop. The effect of gas velocity and stirrer speed on pressure drop and power was studied without and with stirrer.

RESULTS AND DISCUSSIONS

Hydrodynamic studies are vital to understand the design and operation of fluidized bed. The charac-

Figure 2. Stirrer with impeller.

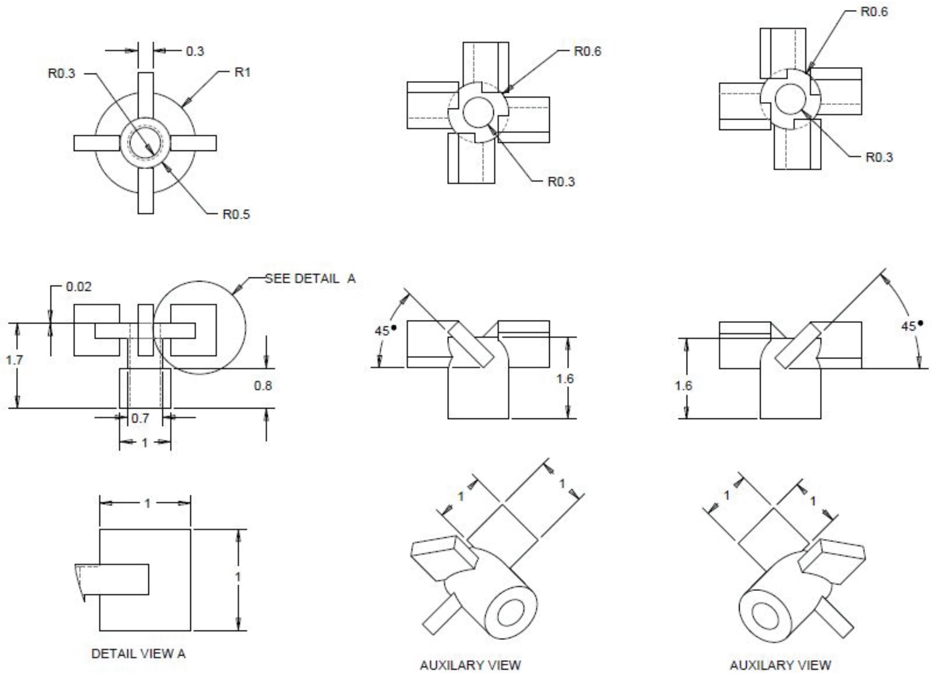

Figure 3. Schematic view of impellers.

Table 1. Specifications of the experimental setup

Acrylic Column	
Column height	1 m
Inner Diameter	0.05 m
Outer diameter	0.06 m
Wall thickness	0.005 m
Stirrer details	
Stirrer height	1 m
Stirrer diameter	0.06 m
Impeller types	
Rushton turbine	1 no.
Pitched blade down flow 45o	4 nos.
Pitched blade up flow	1 no.
Rotameter	
Gas	0-10 L/min
Liquid	0 - 5 L/min

teristics of fluidized bed can be enhanced by understanding the hydrodynamics. The most important parameter which affects the fluidization quality is the pressure drop, which measures the drag in combination with phase holdups and buoyancy. Pressure drop controls the slug formation and channelling.

Effects of gas velocity and stirrer speed on pressure drop

Figure 4 shows the effect of gas velocity on pressure drop for various stirrer speeds. It is observed from the figure that pressure drop increases with gas velocity and stirrer speed. This is because when air is pumped from the bottom of the column larger size bubbles will be produced. The bubble reaches the top of the column quickly due to higher buoyancy force, hence the fractional holdup is low for an unstirred bed. At low gas velocity, the bubble size is larger. Further increase in velocity leads to breakage of bubbles, its size gets reduced and due to lower buoyancy force the bubble reach the top of the column very slowly. At higher velocity, the pressure drop should be constant, but due to slugging and channelling the pressure drop increases to some amount. By increasing the velocity further, the pressure drop

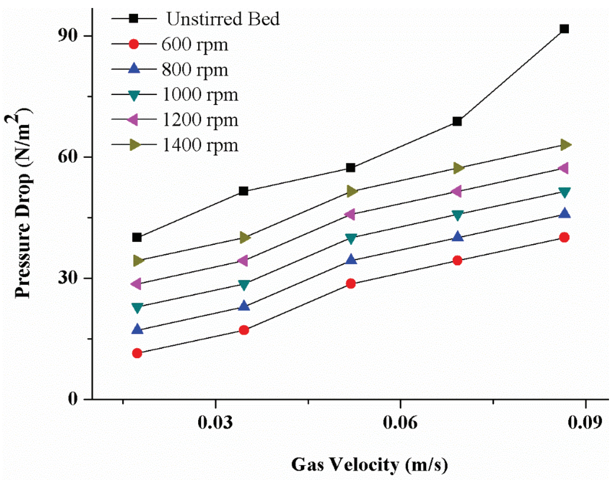

Figure 4. Effect of gas velocity on pressure drop for various stirrer speeds.

inside the column also increases. Pressure drop is lesser in the stirred bed than in unstirred bed conditions, since the stirred bed reduces bubble size thereby resulting in reduction of the bulk density and the same is confirmed from the graph.

Figure 5 depicts the effect of stirrer speed on pressure drop for various gas velocities. It is observed that on increasing the stirrer speed the pressure drop increases. This effect is due to the fact that bulk density of the fluid in the column is inversely proportional to the fractional holdup. Further increase in stirrer speed results in increase in fractional hold up and there is decrease in bulk density of the fluid in the column. The stirrer is designed in such a way that the pitched blade downflow impeller is placed at the top of the column, which pushes the liquid down the column resulting in an increase in pressure drop.

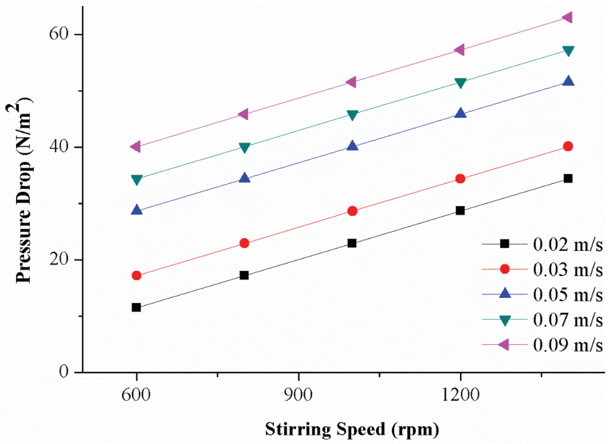

Figure 5. Effect of stirrer speed on pressure drop for various gas velocities.

Two observations were made from the experimental results: one is reduction in bubble size and the other is downflow of the fluid at a higher stirrer speed. The reduction in bubble size reduces the bulk density of the fluid. The downflow of fluid at higher velocity is mainly due to the type of blade. In axial flow impellers, when the particle is pushed up there will be increase in bed density or when the particle is pushed down there will be decrease in density; these effects are mainly due to blade type [22]. In this study, the stirrer has pitched blade downflow impeller at the top, hence the effect of downflow is greater which increases the pressure drop, on increasing the stirrer speed. The outcomes are in good agreement with the study on effect of agitation in fluidized bed done by Reed III and Fenske [23], in which they stated that pressure drop rises due to agitation by the stirrer. Thus, the pressure drop increases with increase in stirrer speed.

Effects of gas velocity and stirrer speed on power

The effect of gas velocity and stirrer speed on power is depicted in Figures 6 and 7. It is observed that power increases with increase in gas velocity and stirrer speed. At low gas velocity, the bubble size will be relatively large and it reaches top of the column quickly and hence the power requirement is low. When the gas velocity increases, the power requirement is also high. Similar report was reported by Leva *et al.* in studies on pressure drop and power requirement in stirred fluidized bed [24]. The requirement of power for stirring the aerated bed depends on the stirrer design and sense of operation [24]. Also, reduction in inter-blade distance rises the power requirement [3]. In the present study, three types of impellers are used, namely, pitched blade downflow, pitched blade upflow (4 nos.) and Rushton turbine. The impellers are positioned at equal distance. The power requirement for stirring depends on the arrangement

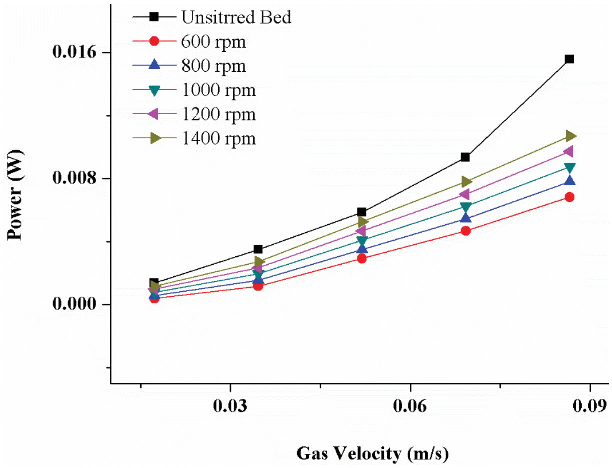

Figure 6. Effect of gas velocity on power for various stirrer speeds.

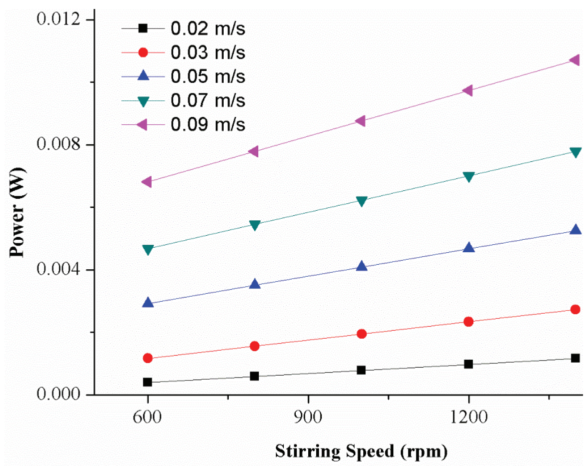

Figure 7. Effect of stirrer speed on power for various gas velocities.

and types of impellers. Power is directly proportional to the third power of stirrer speed and hence, power increases with the increase in stirrer speed. Also, the total power consumed in a stirred vessel increases with the pressure drop [25]. This is in good agreement with the results reported by Joshi and Sharma [26]. Although mechanical agitation increases the power consumption it significantly enhances the quality of fluidization [20].

CONCLUSIONS

Hydrodynamics study in a two-phase stirred fluidized bed was carried out using an air-water system. The effects of gas velocity and stirrer speed on pressure drop and power were studied for stirred and unstirred bed conditions. It was observed that the pressure drop and power increases with increase in gas velocity. This is due to the fact that at higher gas velocity the bubble size will be reduced and would take a longer time to reach the top of the column due to a lesser buoyancy force, which results in increase in pressure drop across the column. With the increase in stirrer speed, both the pressure drop and power increase; this effect is mainly due to the arrangement of impellers. On comparing stirred and unstirred conditions of the bed, it is evident that though pressure drop and power are increased in the stirred bed more than in the unstirred bed, the fluidization performance is enhanced in the stirred bed.

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NAUČNI RAD

ISTRAŽIVANJE HIDRODINAMIKE DVOFAZNIH FLUIDIZIRANIH SLOJEVA MEŠANIH TRIMA VRSTAMA MEŠAČA

Fluidizirani slojevi se široko koriste u petrohemijskoj, hemijskoj procesnoj industriji, farmaceutskoj, prehrambenoj i biotehnološkoj industriji. Poželjni su za obradu materijala sa širokim spektrom raspodele veličine čestica i nude ravnomernu raspodelu temperature i odličan prenos toplote i mase. Da bi se poboljšao kvalitet fluidizovanog sloja u sistemima vazduh-voda, može se primeniti mehaničko mešanje. U ovom radu, proučavana je hidrodinamika fluidizovanog sloja u sistemu vazduh-voda sa mehaničkim mešanjem. Karakteristike fluidizovanog sloja mogu se objasniti proučavanjem njegove hidrodinamike. Pad pritiska je jedan od važnih faktora koji utiče na performanse fluidizovanog sloja. Otuda su proučavani uticaji brzine gasa i brzine obrtanja mešača na pad pritiska i snagu u slojevima sa mešanjem i bez mešanja. Zapaženo je da se pad pritiska i snaga povećavaju sa povećanjem brzine gasa i brzine obrtanja mešalice. Takođe, pad pritiska i snaga su manji za sloj sa mehaničkim mešanjem.

Ključne reči: hidrodinamika, fluidizovani sloj sa mehaničkim mešanjem, brzina mešača, brzina gasa, dvofazni sistem.