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Review Article

Effect of Initial Bed Height and Liquid Velocity on the Minimum Fluidization Velocity (U_{mf}) and Pressure Drop for the Bed of Semolina Particles in Liquid-Solid Fluidization

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Abstract: The successful and economical design, scale up and operation of a fluidized bed reactor depends upon the true prediction of its bed hydrodynamics. The present research has been carried out to study the hydrodynamics behavior of bed of semolina particles in liquid solid fluidization. The prime objective of this research work is to study the effect of liquid superficial velocity and variation in static bed height on the minimum fluidization velocity and pressure drop. Liquid-solid fluidization is characterized by the uniform expansion of bed particles, therefore it is known as particulate fluidization. In liquid solid fluidization, there is no bubbling phase, that is the main cause of uniform bed expansion. Liquid-solid fluidization has extensive field of applications, i.e. in hydrometallurgy, waste water treatment, biochemical processing and food technology. Minimum fluidization velocity and pressure drop are important hydrodynamic parameters in the design and scale up of fluidized bed reactors. The experimental work was carried out in a column made up of acrylic having 60mm outer diameter and 2mm wall thickness and was 1000mm long. Manometers were used to observe the pressure drop variations across the bed. The minimum fluidization velocity was found to be 0.404mm/sec. It has been found that the minimum fluidization velocity is not affected by the variations in the initial static bed height. Semolina particles being sticky solids offer slightly greater pressure drop. Pressure drop becomes constant when fluidization is achieved.

Keywords: Pressure Drop, Liquid-Solid Fluidization, Minimum Fluidization Velocity, Bed of Semolina Particles

1. Introduction

Liquid-solid fluidization is such a technique in which solids are suspended by the upward flowing liquid. The term fluidization is generally related to two or three phase systems, in which bed of solid particles are fluidized by a gas or liquid flowing in the opposite direction to the gravitational force. The fluidized bed can be explained as a packed bed through which fluid (liquid or gas) flows at a high velocity such that the bed is loosened and the particle fluid mixture acts as a fluid [1]. Liquid solid fluidization is extensively used in the fields of hydrometallurgy, biochemical processing, food technology, water treatment, etc. The unit operations involved are ion exchange, crystallization, adsorption, cell culturing and enzyme catalysis, etc. If the density of the particles is smaller than the flowing fluid, then the fluidization is achieved by downward flow of liquid. Hydrodynamics characteristics are very important in designing and optimizing a fluidized bed reactor because hydrodynamics describe the behavior of the bed when fluid is passed through it [2]. Liquid solid fluidization is also known as particulate fluidization because of uniform expansion of bed. Fluidization is preferred on the other contacting techniques due to high heat and mass transfer rates. Winkler was the first who successfully developed the first fluidized bed in 1921. In 1942, the first large scale industrial implementation of fluidization technique was made in fluidized catalytic cracking of crude oil. In the 1970's, the first circulating fluidized bed (CFB) for coarse particles was commercialized by Lurgi [3]. In 1980s circulating fluidized bed combustion was commercialized and polypropylene production in fluidized beds. As the fluidized bed is getting developed, its utilization in coal combustion and the current interest in the use of fluidized bed reactors for waste utilization and the applications of multi components fluidized beds are on the rise. There are many well known operations that utilize this technology, like coal carbonization, ore roasting, cracking, Fisher Tropsch synthesis, reforming of hydrocarbons, gasification, coking, aluminum production and coating preparations [5]. The main reason for the success of fluidization technique is due to its ability to perform a number of unit operations like coating, drying, mixing, granulating, heat transfer, leaching and mass transfer. When fluid (liquid) is passed through the fixed bed of solid particles at lower flow rates, the fluid pass through the bed voidages without changing the fixed bed state. When velocity is further increased, the bed particles starts to expand, and on further increase in fluid velocity, a stage will come at which upward acting drag force becomes equal to downward acting forced, i.e. weight of particles, at this stage particles are incipiently fluidized. Fluid velocity at this stage is called as Minimum fluidization velocity. Further increase in the velocity causes the bed particles to expand and move vigorously (fluidized condition). In past years, bed hydrodynamics with sticky particles was not studied. Therefore the main objective of this research is to study the bed hydrodynamics by using sticky particles like semolina particles [6]. We have employed the bed of semolina particles in liquid solid fluidization. Solid particles used in fluidization are classified by the Geldart for the convenience of researchers [7]. In this classification, the various solids particles (powder) are divided into four groups according to their properties, sizes and densities. In group A, the particles with small sizes (d_p= 30-150μm) and having densities in range of <1500 kg/m^3 are classified. In group B, the particles with large sizes (d_p= 150-500 μm) and having densities in range of 1500-4000 kg/m^3 are classified. In group C, the particles with very small sizes (d_p<30 μm) and having low sphericity e.g. talc are classified. These particles are not easy to fluidize and they give rise to channeling more often. In group D, these particles are either of very large size or more denser e.g. lead shot [9].

Regimes of Fluidization

In the hydrodynamics studies of two phase liquid solid fluidized bed, the most significant factor is the contacting regime. Hydrodynamics is actually the study of behavior of bed when fluid is passed through it at varying flow rates [12]. In liquid fluidized beds, the flow regimes are limited as compared to gas fluidized beds. Flow regimes in the two phase (liquid-solid) fluidized system mainly depends upon the liquid velocity. By increasing the fluid (liquid) velocity which is defined as liquid superficial velocity, the two phase (liquid-solid) system will undergo different flow regimes [10]. Bed remains intact when liquid velocity (U_l) is lower than that of the minimum fluidizing velocity (U_{mf}). When liquid superficial velocity is increased further than the min. fluidization velocity, then the two phase liquid solid system enters into the regime of conventional fluidization, where exist clear and obvious boundary between the dense region (at bottom) and freeboard region (at top). In that regime, the increasing liquid velocity causes the denser phase to expand further and consequently the denser-dilute phase boundary is raised. As the velocity if liquid is further increased, the denser-dilute phase boundary becomes hazy (unclear) and as a result the height of the denser phase is increased. And few particles start to get entrained out of the solid particles bed. At this stage, the two phase fluidized bed is shifted from conventional to circulating fluidized bed [11]. By increasing the liquid solid density ratio, this transition becomes more clear. When velocity of liquid becomes sufficiently high, huge quantity of particles are entrained out of the solid bed and solids circulation rate become increased sharply. Fig. 1 shows the map of solid bed transition into different flow regimes. And the transition of these flow regimes can be find out by flow regime map in the form of dimensionless particle size and liquid superficial velocity. The regime of conventional fluidization and fixed bed is determined by the min. fluidizing velocity (U_{mf}).

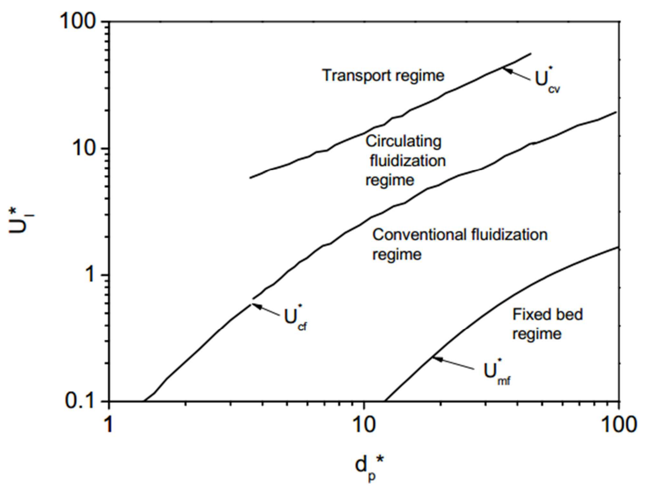

Fig. 1. *Flow Regime Map for liquid solid Fluidization.*

The prime objective of the current study is to predict the hydrodynamics of two phase liquid-solid fluidized bed using semolina particles as a bed material. The current research was conducted by studying the variation of a key hydrodynamics parameter "pressure drop" with liquid superficial velocity and effect of static bed height on "minimum fluidization velocity". Pressure drop and min. fluidizing velocity are the significant hydrodynamics factors that are used mainly for the determination of hydrodynamics behavior of the bed. Many researchers have determined the hydrodynamics behavior of a fluidized bed using different particles but there is insufficient research data on the hydrodynamics behavior of a fluidized bed using sticky particles, so this topic has been selected by us. We used semolina particles which are sticky particles and then we studied the hydrodynamics behavior for bed of semolina particles in liquid-solid fluidization.

2. Experimental Setup and Method

The experimental set up consist of a transparent column which is made-up of acrylic with dimensions of 60 mm internal diameter with a maximum height of 1000 mm and a wall thickness of 2 mm. Liquid (water) enters into the column from bottom through distributor, distributor ensure the uniform flow of water into the column. Distributor has perforates in a pattern of triangular pitch. A pump of 0.5 hp is used to pump the water through the column. Rota meter is used to control the flow of liquid and three manometers are used to measure the pressure drop at different points across the bed. A reservoir tank is used to store the fluid. A known quantity of semolina particles was loaded through the provision in the column. The pump was started to fill the column with the liquid and then initial static bed height was noted. Then liquid (water) was allowed to pass through the column and the velocity of fluid was increased till the onset of fluidization. During this operation, the pressure drop was observed in manometers with the varying fluid flow rates. In the next experimental run, the static bed height was changed and same above stated procedure was repeated. Schematic diagram of the experimental set up is shown in Fig. 2.

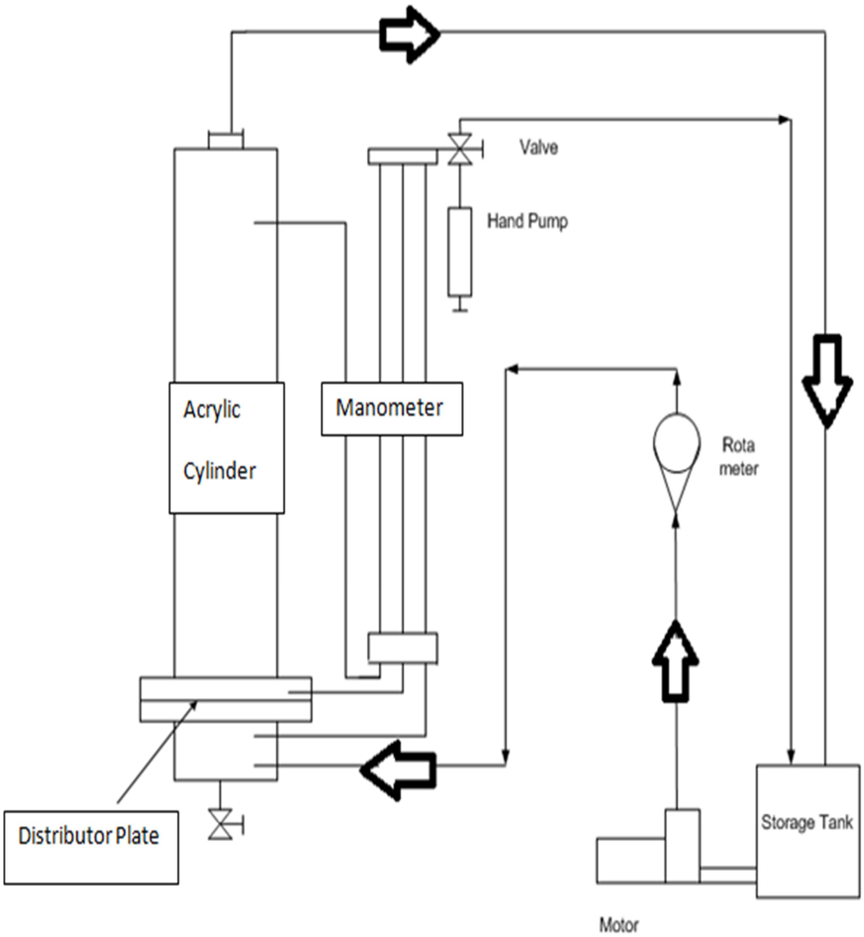

Fig. 2. *Schematic diagram of experimental set up.*

3. Results and Discussion

3.1. Minimum Fluidization Velocity

Minimum fluidization velocity is the liquid superficial velocity at which bed of solid particles becomes incipiently fluidized and at this velocity the upward force (drag force) becomes equal to the downward force (weight of solids). Minimum fluidization velocity is a important parameter in the design of a fluidized bed reactor. The equation used for the determination of U_{mf} is the Ergun equation which is based on a assumption that the drag force of the liquid flowing with a superficial velocity (U_{mf}) is equal to the weight of solid particles in the bed.

$$U_{mf} = \frac{d^2{}_p(\rho s\text{-}\rho f)g}{150\mu_f}\left(\frac{\varepsilon^2{}_{mf.}\ \emptyset^2{}_s}{1\text{-}\varepsilon_{mf}}\right) \qquad (1)$$

The minimum fluidization velocity in our case comes out to be 0.404 mm/sec. When initial static bed height was changed in the next experimental run, the U_{mf} was the same. Therefore we can say that minimum fluidization velocity does not depends on the initial static bed height, it depends on the size and density of the particles. If the density of the particles are higher, then it requires greater upward forced to suspend and act like a fluid. In our case (bed of semolina particles), the bed particles are heavier than the flowing liquid, i.e, water, therefore they are fluidized by the upward flow of fluid and due to their cohesiveness (since semolina particles are sticky particles) a greater upward drag force is required for fluidization. That is why value of U_{mf} comes out relatively higher in our case. Knowledge of minimum fluidizing velocity (U_{mf}) is used to evaluate the range of operating conditions and the energy requirement for a fluidized bed reactor.

3.2. Pressure Drop Profile

Pressure drop is the most important parameter used for the determination of hydrodynamics of a two phase fluidized bed. Pressure drop is the key parameter which has a decisive role in the economical and efficient operation of a fluidized bed reactor. The Pressure drop is observed through manometers across the bed. These manometer provides the pressure drop in term of pressure head and then we converted it into Pascal. The observation data collected at different static bed heights is given below:

Table 1. *Pressure Drop at different static bed Heights.*

Liquid Superficial Velocity	ΔP_2 (H=5.0cm)	ΔP_4 (H=6.0cm)	ΔP_6 (H=7.0cm)
m/sec	Pa	Pa	Pa
$1.75*10^{-4}$	1264.2	1940.4	2234.4
$2.109*10^{-4}$	2058	2067.8	2479.4
$2.46*10^{-4}$	2940	2508.8	2665.6
$2.81*10^{-4}$	3773	3165.4	3057.6
$3.16*10^{-4}$	4419.8	3792.6	3459.4
$3.52*10^{-4}$	4949	4312	3841.6
$3.86*10^{-4}$	5831	5272.4	4625.6
$4.21*10^{-4}$	6183.8	5654.6	5301.8
$4.57*10^{-4}$	6242.6	5664.4	5497.8
$4.92*10^{-4}$	6272	5684	5517.4
$5.27*10^{-4}$	6272	5684	5521.2

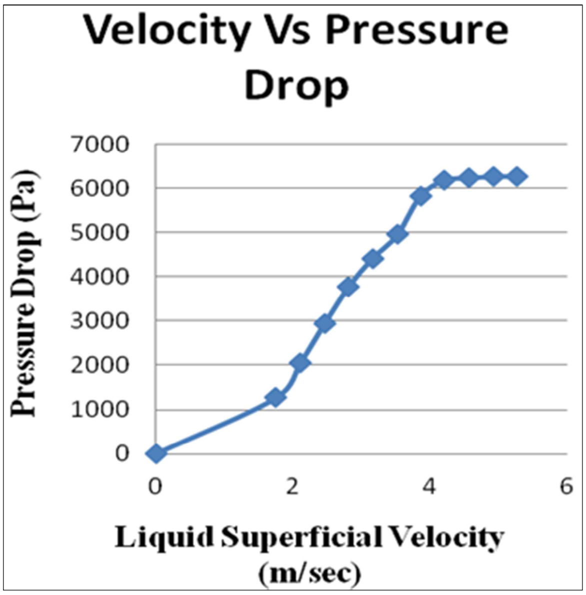

Fig. 3. *Pressure Drop variations (At static bed height =5cm).*

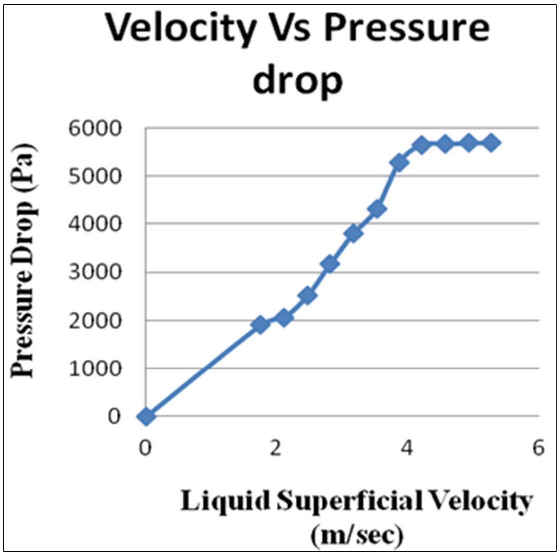

Fig. 4. *Pressure Drop variations (At static bed height=6cm).*

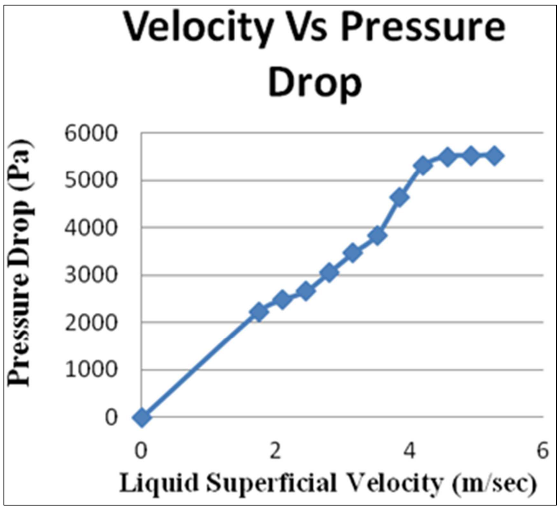

Fig. 5. *Pressure Drop variations (At static bed height =7cm).*

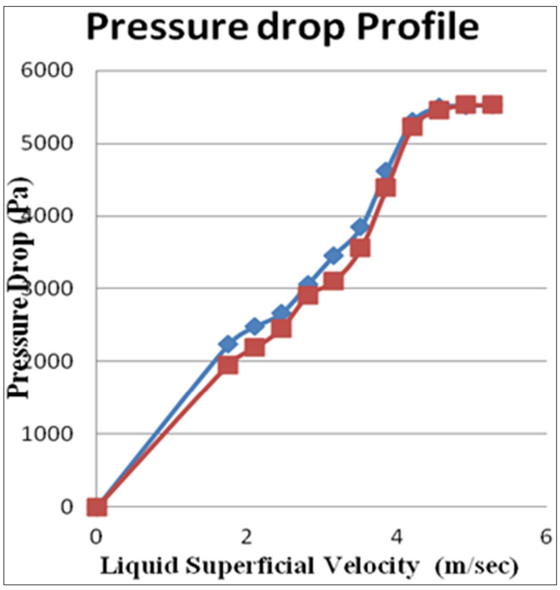

Fig. 6. *Pressure Drop variations for the fluidization and de- fluidization.*

Pressure drop increases with the increase in liquid superficial velocity till the onset of fluidization, once fluidization is achieved, the pressure drop becomes constant. The same trend is shown in Fig. 3 to Fig. 6. Semolina particles are the sticky particles and they offer more pressure drop than any other type of particles (sand etc.) due to their cohesiveness. Because when fluid is passed through the bed of semolina particles, they remain intact as a fixed bed, and hence more pressure is lost in making the sticky bed particles to fluidize. When bed is fluidized, the pressure drop becomes constant because the resistance for the fluid (liquid) decreases significantly. With the increase in the liquid superficial velocity, the bed voidage also increases due to the expansion of bed particles, this causes the pressure drop to increase till fluidization state reached. Fig. 6 demonstrate the pressure drop variations for fluidization and de-fluidization i.e. pressure drop profile when liquid flow rate is increased from zero to U_{mf} and then pressure drop profile when liquid flow rate is decreased from U_{mf} to zero.

4. Conclusions

The minimum fluidization velocity (U_{mf}) was found independent of initial static bed height (solid loadings) and it depends upon the particle density and particle diameter. U_{mf} is the key factor in the design and scale up of a fluidized bed reactor. The particles in the bed remain fixed till the minimum fluidizing velocity is achieved. Pressure drop in case of bed of semolina particles is high due to the cohesiveness of the semolina particles. Pressure drop increases till the minimum fluidization velocity is reached and then upon further increase in liquid velocity above U_{mf}, the pressure drop remains constant. Further increase in the liquid superficial velocity above the U_{mf} leads to particles vigorous motion, that is the main cause of turbulence and better mixing in the fluidization technique. Pressure drop is the important parameter in determination of hydrodynamics because it enables us to determine the energy losses and friction factor which are helpful in predicting the stable flow conditions necessary to operate the fluidized bed reactors efficiently for a given operation. Liquid-solid fluidization is now widely used technique which is extensively used in the hydro metallurgy, waste water treatment and especially in bio-processing.

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