Flow regime mapping of liquid-solid inclined fluidized beds

K. Ashok Kumar, K. Sarath Chandra, T. Bhargavi, K.V. Ramesh*

Abstract— **Experiments were conducted to identify the angle of inclination of a fluidized bed so that the fluidizing condition could be retained. Experimental set up has been specifically fabricated for this purpose with a provision for measurement of angle of inclination accurately. Further studies were also conducted to identify different flow regimes that appear by using visual inspection technique. It was observed that apart from fixed and fluidized beds three other regimes viz., channel flow, counter flow and circulatory flow were prominent. The angle of inclination with horizontal axis was found to be approximately 70 degrees to retain fluidizing conditions.**

Index Terms— **Fluidization, inclination, fluidized bed, flow regimes.**

I. Introduction

The unit operation in which solid particles exhibit a fluid like behavior by suspending in a fluid is known as fluidization. The fluidized beds have some unusual characteristics that led to their wide adaptability in industry. The advantages include good mixing, isothermal conditions, slow response to abrupt changes in operating conditions, high heat and mass transfer rates, ease of handling etc. their disadvantages are non-uniform residence times, pulverizing of solids, erosion of pipes and vessels etc. the applications are in coal gasification, synthesis reactions, metallurgical and other processes, heat exchange, coating metal objects with plastic, drying of solids, adsorption, carrying out catalytic reactions, combustion and incineration, carbonization, activation of carbon, calcinations, roasting of ores, bio-fluidization etc [1]. The behavior of bed and the interaction between solids and fluid depend on the type of flow regime in the bed. Based on the type of solids and fluid, different flow regimes have been identified viz., particulate, bubbling, slugging, turbulent, churning, aggregative etc. it is also reported that slight inclination of the column has large effect on the performance of fluidized beds [2]. This can be attributed to the resolution of forces acting on the particle. It is well understood that the forces that act on the vertical fluidized bed are collinear; upward buoyant and drag forces and downward gravitational force. If the fluidized bed is inclined, for the solid particle to be suspended in the fluid, the net force acting in the upward vertical direction plays the role. Although buoyant and gravitational forces do not change with inclination, the drag force must be resolved so that its vertical component is considered in force balance. This is the reason for the cause of a different behavior of inclined fluidized beds.

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Inclined fluidized beds often occur inadvertently in connecting pipe lines in which a two-phase fluid-solid flow is sent from one operation to another operation. Therefore, it is essential to understand the behavior of such fluidizing columns. If this phenomenon were not understood properly, the improper installation of connecting pipe lines may get clogged and may be subjected to severe erosion leading to frequent maintenance problems. Although, studies in this direction are compelling, to the knowledge of authors, very few investigations were only carried out on inclined fluidization.

Odea et al [3] investigated the effects of inclination of fluidized beds. Four different powders were used as bed material and air was the fluidizing medium. Angles between 45 to 90 degrees to the horizontal were considered. There flow regimes viz.,, packed bed, channel initiation and channeled bed were observed. Mixing behavior of solid particles within an inclined fluidized bed was studied by Chaikittisilp et a al [4] using discrete element method simulation. Angles of zero to 30 degrees inclination from vertical axis has been considered. 4 mm particles in a 15 cm dia column were studied using air as the fluid. It is reported that 10 degree inclination gives enhanced degree of mixing of solid particles when compared with other inclinations and also with straight vertical bed. Yakubov et al [5] studied the dynamics and structure of a liquid-=solid fluidized bed in inclined pipes using silica gel as solid and water as fluid. Angles from horizontal to vertical were considered. Particle flow patterns and expansion process of bed were investigated. Several modes were observed; packed bed, first fluidization, second fluidization and hydro-transportation. The particles employed were appeared to be spherical in shape. Anil Kumar et al [6] investigated fluidized beds in helical coils. They employed glass balls as solids and water as liquid. For a minimum pitch to diameter ratio of 2.5, formation of fluidized bed was observed. This corresponds to an angle of 68.9^o to the horizontal. for pitch to diameter ratios of less than 2.5, the glass balls simply rolled out along the walls of te coil. Therefore, it is revealed that flow regime mapping has not been reported so far, hence the present study is attempted in this direction.

II. Procedure

The experimental test rig employed for carrying out the present studies has been very carefully fabricated. A schematic sketch of the experimental unit used in the present study has been shown in Fig.1. The unit consisted of a feed tank, a globe valve for regulating the flow rate through the bed, an acrylic column of 1-in diameter as test section, a wire mesh for holding fluidizing solids and ensuring uniform distribution of water, and an exit section. A mechanical linkage is provided so that the fluidizing column can be arranged with given angle. A provision has been made in order to measure the angle accurately. Sand particles of 0.5 mm were used as bed material in the present study. The transparency of the acrylic column facilitated the visual observations on flow patterns. The flow rate of the liquid was very accurately measured by volume displacement technique.

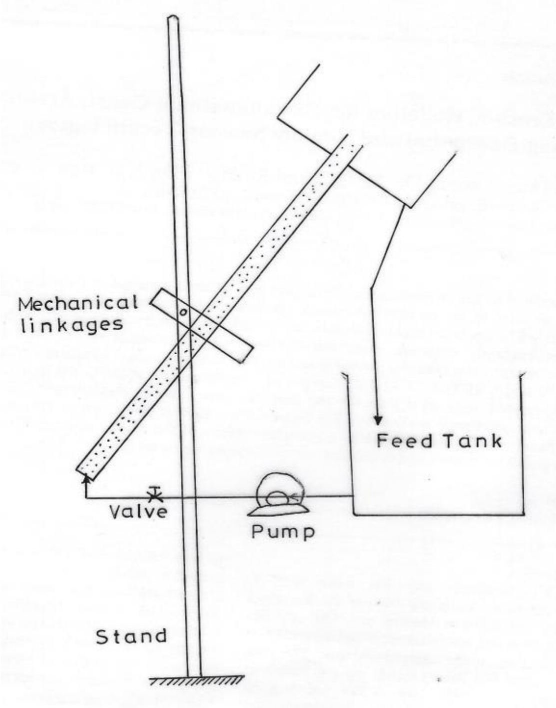

Fig.1. Schematic diagram of the experimental setup

III. RESUILTS AND DISCUSSION

Initially experiments were conducted with sand particles. Sea sand is screened to the desired size and was thoroughly cleaned several times until it loses its salinity. The sand was then dried so that it exhibits free flowing properties. Then the sand was subjected to particle analysis using a set of BSS standard sieves and the desired fraction is obtained. The test column was filled with known amount of sand so that one can obtain the bed porosity data.

Prior to the beginning of the present study the fluidizing experiment was conducted to verify whether the experiment reproduces earlier published results. In this regard studies were conducted on minimum fluidization velocity and bed porosity. It is found that the minimum fluidization velocity data agreed well with the Ergun equation[7] and the bed porosity data agreed that of Richardson-Zaki equation[8].

Studies now conducted by changing the angle of the fluidizing column, by considering that vertical column is 90 degrees and horizontal column is zero degrees. Different types of flow regimes appeared. For a given particle size Fig.2 presents these flow regimes. A close examination of the plots of this figure reveals that mainly the regimes that appeared are fixed bed, fluidized bed , channel flow, counter flow and circulatory flow of particles. It is observed that once the minimum fluidizing conditions appears, it is the channel flow that comes first. Here, the liquid forms a channel and the remain solid bed will be stationary. Once the velocity is increased at a given angle, there appears a counter flow regime where in, elutriation of particles appear in the liquid dominated channel that moves away from the bottom of the bed and solid bed movement towards the bottom of the bed. As the velocity of the fluid is further increased, this movement of the two zones becomes faster and a circulatory flow of solid particles appear, which is labeled as circulatory flow. At higher angles, it is the fluidized bed that closely resembles. A close examination of these regimes in Fig.2 further reveals that the true fluidizing condition could be maintained only over a small angle variation with y-axis.

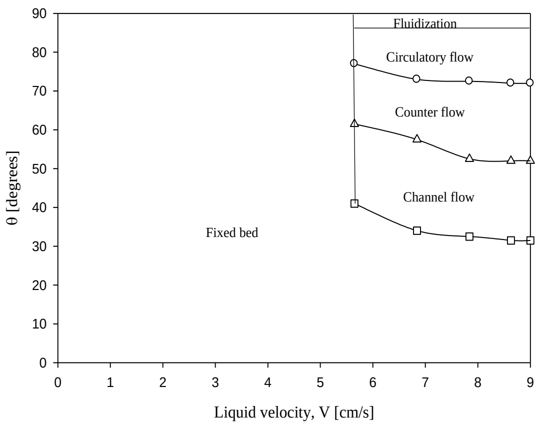

Fig.2. Flow regime mapping for inclined fluidized bed for sand particles of size 1.5 mm

IV. CONCLUSION

Five types of flow patterns were observed in inclined fluidized bed. These are fixed bed, channel flow, counter flow, circulatory flow and fluidized bed. The angle of inclination with horizontal axis was found to be about 70 degrees in order to sustain fluidizing conditions. These findings will be highly helpful in the design of inclined pipe connectors in process industries.

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