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# Experimental Investigation on Segregation of Binary Mixture of Solids by Continuous Liquid Fluidization

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**Abstract.** Segregation of binary mixture of solids was experimentally investigated in a continuous liquid fluidized bed with water as the fluidizing medium. The feed is a uniform mixture of particles of equal composition of different size but same density. Experiments were conducted to study the effect of feed rate of solids and liquid superficial velocity on entrainment and discharge rate of solids, and purity of top and bottom products. The fluidization behavior was observed through pressure drop measurement. The results indicate that the purity of the top of product decreases and the purity of the bottom product increases with increasing liquid superficial velocity.

**Keywords:** Segregation, liquid fluidized beds, binary solids mixture

## 1. Introduction

When a mixture of solids that differ in either density and/or size is subjected to fluidization, the particles tend to segregate. Separation of solids by fluidization seems to be an attractive option as there are no moving parts, easy installation, easy solids handling and space reduction. Segregation of solids by fluidized beds finds applications in several processes such as separation of coal from mined impurities and beneficiation of minerals. While substantial number of publications has appeared in literature on segregation occurring in gas fluidized beds [1]-[3], the literature pertaining to liquid fluidized beds are limited. Measurements of particle segregation with different size and different density in liquid fluidized bed was reported on batch mode [4], [5] and on semi-batch mode [6]-[8]. However, there is no reported information on segregation of binary mixture of solids in liquid fluidized beds by continuous mode. Continuous separation of solids depends on constitutive properties of solids, feed properties, feed composition and operating variables of the bed.

The present paper deals with segregation of binary mixture of solids in a continuous liquid fluidized bed with water as the fluidizing medium. Experiments on the fluidization behavior of size segregation with uniform composition (50% fines-50% coarser) of solids and one size ratio are conducted at various liquid velocities and solid feed rates. While the operating variables are feed rate of solids and liquid superficial velocity, the measured variables include pressure drop across the column, entrainment rate of solids, discharge rate of solids, purity of top product and purity of bottom product.

## 2. Experimental

### 2.1. Experimental Setup

The schematic diagram of experimental setup is shown in Fig. 1. The setup consists of a Perspex column with an id of 72 mm and 3 m length. A perforated plate with 13% free area was used as the distributor and a fine mesh was used above the perforated plate to prevent the draining of particles through the perforated plate. A calming zone (8) was provided for uniform distribution of water to the column. Two collection tanks

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(9) each at the top and bottom were used for continuous removal of solids without disturbing the bed conditions in the main column. A cylindrical hopper (5) was used for feeding the binary mixture of solids to the column and pre-calibrated scales were used to control the solids flow from hopper to the main column. Water flow rate was measured by calibrated rotameters (4).

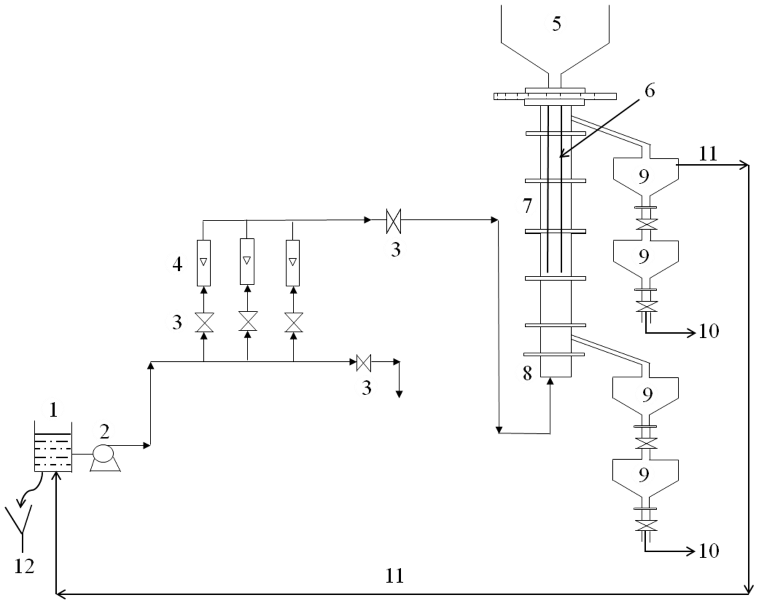


Fig. 1: Experimental setup. 1.water tank, 2. Pump, 3. Valve, 4. Rotamter, 5. Solid feeding tank, 6. Feed pipe, 7. Main column, 8. Calming section, 9. Solid collection tank, 10. Solids outlet, 11. Recycle water, 12. Drain

The feed inlet pipe (6) was placed up to a distance of 1400 mm from the top discharge sections. Two pressure taps were located, one above the distributor plate and the other near to the top discharge section, to measure the overall pressure drop across the column by differential manometer. Top and bottom discharge sections (9) were respectively used to measure the entrainment and discharge rate of solids. Table I shows the physical properties of the solids used in the present study. The solids used were glass beads with a density of 2490 kg/m$^3$. The terminal velocity and the minimum fluidization velocity of the particles are respectively calculated using Haider and Levenspiel [9] and Wen and Yu [10] equations.

Table 1: Physical Properties of Solids of Present Study

| Screen size, mm | Average particle diameter, mm | Terminal velocity, m/s | Minimum fluidization velocity, m/s |
|---|---|---|---|
| -2.36+2.0 | 2.18 | 0.274 | 0.0238 |
| -4.0+3.35 | 3.67 | 0.372 | 0.0386 |

## 2.2. Experimental Procedure

Water at particular flow rate was introduced into the column and pre-well mixed solids from hopper were allowed into the column through pre-calibrated scale at a specific solids flow rate. The column was allowed to attain the steady state and the steady state was confirmed by constant pressure drop in the manometer. Steady state was also confirmed by mass balance of top and bottom solids flow rates with the feed rate of solids. After the steady state was attained, the top and bottom flow rates of solids were measured and samples were collected from the top and bottom flows to measure the purity. The range operating variables uses in the present study are given in Table II.

Table 2: Range of Operating Variables Investigated in the Present Study

| Variable | Range of study |
|---|---|
| Liquid flow rate, m/s | 0.16 - 0.36 |
| Solids flow rate, kg/hr | 106 - 148 |
| Feed composition | 0.5 |

## 3. Results and Discussions

Purity of flotsam or top product is defined as the ratio of amount of fine particles in the sample to the total amount of sample collected in the overflow and the purity of jetsam defined as the ratio of amount of larger particles in the sample to total sample collected in the underflow [1].

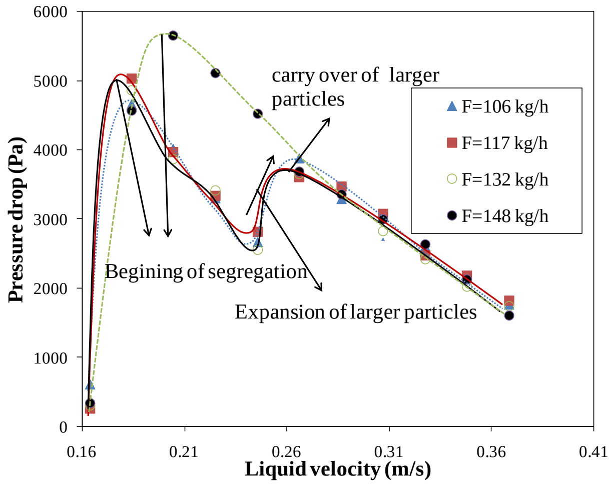


Fig. 2: Variation of pressure drop with liquid velocity for different solids feed rate

Fig. 2 to 6 show the pressure drop profile, entrainment rate and discharge rate of solids for uniform composition of different sized particles at different solids feed rates. It is evident from Fig. 2 that the bed pressure drop reaches a maximum, decline and reaches a maximum again before leveling off. If the liquid velocity (close to the transport velocity of the fine particles) is increased slowly, slow expansion of fine particles takes place and pressure drop increases. If the liquid velocity is increased further (greater than the transport velocity of the fine particles), the beginning of segregation occurs and the entrainment of solids starts. This point is called “segregation velocity”. For higher solids feed rate, segregation velocity occurs near the transport velocity of the fine particles.

Increasing the velocity further, the coarser particles also fluidize and some of the coarser particles attempt to entrain out of the column along the fine particles. But the coarser particles remain in suspension due to lack of sufficient drag. Hence the pressure drop increases under these conditions and the bed is in vigorous mixing mode. The coarser particles can neither go up nor settle down to bottom and strong internal circulations establish in the column. If the liquid velocity is close to the transport velocity of coarser particles, fine particles go out of the bed immediately taking along with them some of the coarser particles.

The interaction between particles becomes less and particles behave independently in the bed. At this condition, uniform fluidization or particulate fluidization occurs and the solid holdup is least. If the velocity is increased beyond the transport velocity of coarser particles, no particles present in the bed and bed look like pneumatic transport column. This analysis identifies the level of segregation for this particular composition.

Fig. 3 shows the variation of entrainment rate of solids with liquid velocity at different solids feed rate. The entrainment rate increases with increasing liquid velocity for any solids feed rate. With increasing solids feed rate, the amount of solid particles entering the column also increases and this results in higher entrainment rates. When the liquid velocity approaches the transport velocity of the coarser particles, entrainment rate reaches a maximum and levels off. This phenomenon is similar to the segregation of solids observed in continuous fast fluidized beds [1].

The variation of discharge rate of solids with liquid velocity for different solid feed rates, as shown in Fig. 4, indicates that the discharge rate of solids decreases with increasing liquid velocity. Excepting at low liquid velocities, the discharge rate of solids are independent of solids feed rate. On the other hand, there is considerable difference in entrainment rate of solids for different solids feed rates. This means that the holdup of the column decreases with increase in solids feed rates. The discharge rate of solids is close to zero if the liquid velocity approaches the transport velocity of the coarser particles.

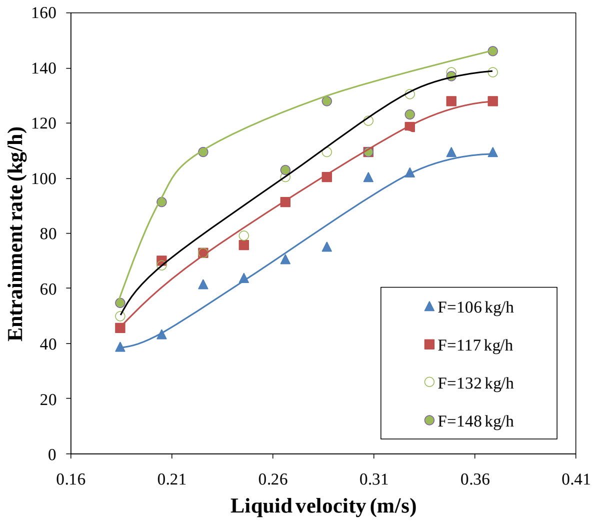


Fig. 3: Variation of entrainment rate of solids with liquid velocity or different solids feed rate

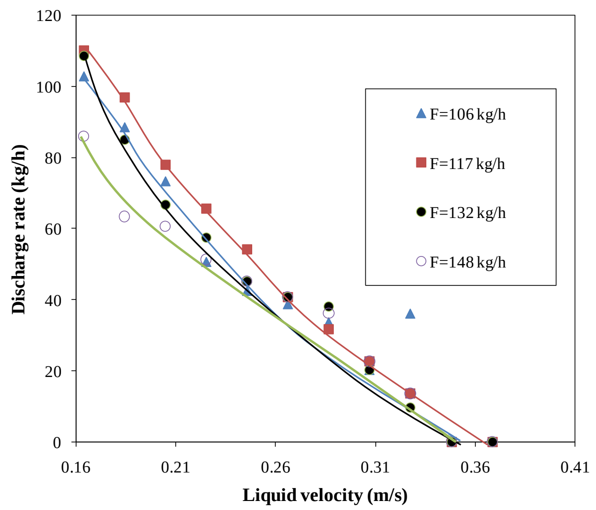


Fig. 4: Variation of discharge rate of solids with liquid velocity for different solids feed rate

Fig. 5 shows the variation of purity of the top product with liquid velocity for different solids feed rates. The purity of the top product decreases with increasing liquid velocity. At low liquid velocity, fine particles alone attain sufficient velocity to entrain out of the column and hence the purity of the top product is high. With increase in liquid velocity further, carryover of coarser particles along with fine particles increases and hence purity of the top product decreases. This observation is similar to that observed in fast fluidized beds [1].

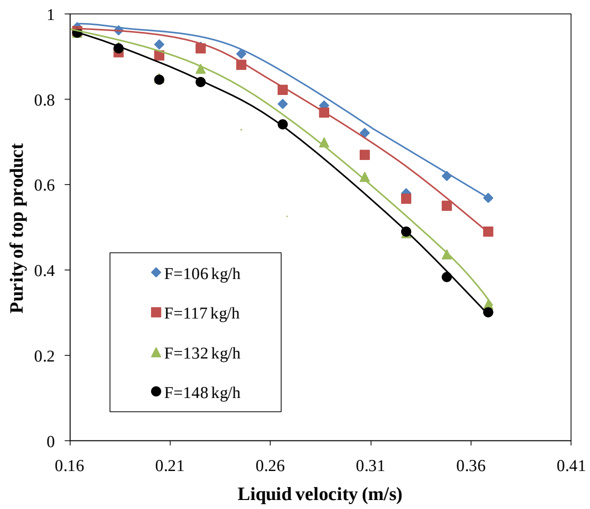


Fig. 5: Variation of purity of top product with liquid velocity for different solids feed rate

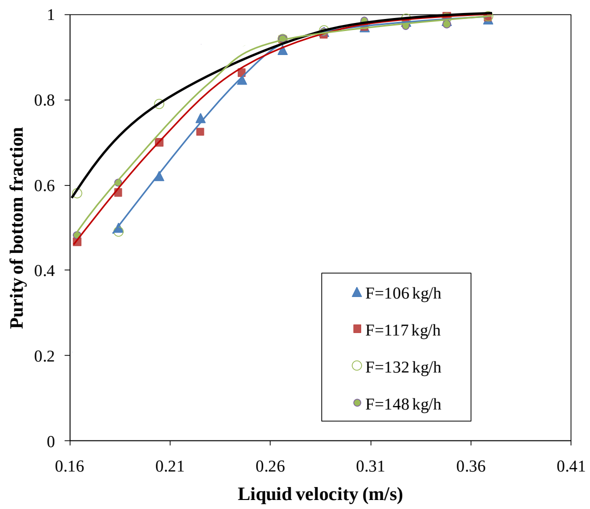


Fig. 6: Variation of purity of bottom product with liquid velocity for different solids feed rate

Fig. 6 shows the variation of purity of the bottom product with liquid velocity for different solid feed rates. The purity of the bottom product increases with increasing liquid velocity. At low liquid velocity, some of the fine particles settle down to bottom and hence the purity of bottom product is low. If the liquid velocity is increased further, entrainment of fine particles increases and hence the purity of the bottom of the product increases. At low liquid velocities, the purity of the top product is high and the purity of the bottom product is low. On the other hand, the purity of the top product is low and the purity of the bottom product is high at higher velocities.

## 4. Conclusions

The segregation behavior of binary mixture of solids of uniform composition with particles of different size in continuous liquid fluidized bed has been reported with new approach. The pressure drop data, entrainment and discharge rate of solids and mass fraction distribution of fine and coarser particle in overflow and underflow was obtained. The analysis of above data indicates the dependency of particle segregation on solids feed rate. The entrainment rate of solids and purity of bottom product increases with increase in liquid velocity. On the other hand, the discharge rate of solids and purity of top product decreases with increasing liquid velocity. Beyond a certain liquid velocity, no effect of solids feed rate is observed on the discharge rate of solids and purity of the bottom of the product.

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