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HYDRODYNAMICS OF TWO-STAGE LIQUID-SOLID SEMI-FLUIDIZATION

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ABSTRACT
To develop the concept of two-stage semi-fluidization on hydrodynamic characteristics viz. the bed pressure drop and formation of the top packed beds, investigation have been carried out in a two-stage semi-fluidized bed with regular and irregular particles. Perspex column of internal diameter 2.54 cm with a 30 test section cm has been used for two stage study with water as the fluidizing medium. Glass beads and dolomite particles (0.1504 cm) have been used as solid phase material. Experimental parameter studied includes superficial liquid flow rate with constant bed expansion ratio. Mathematical modeling has been done for the bed pressure drop and the top packed bed height for two-stage semi-fluidization. Individual stage behavior and comparison of results have been made between single and the two-stage semi-fluidized bed with fixed amount of total solids and total volume of test section.

KEYWORDS: Two-stage Liquid–solid semi-fluidization, Bed pressure drop, Top packed bed formation, Regular and Irregular particles

INTRODUCTION
A unique technique of fluid solid contact is semi-fluidization, which combines fluidization and packed bed operation in a single vessel. This process has gained many attentions of the researchers starting from 1959 (L T Fan) [1] due to certain advantages over fluidized and packed bed operations. Semi-fluidization technique has immense applications in various fields of chemical and bio-chemical engineering processes [2-7]. By restrict the free expansion of a fluidized bed beyond minimum fluidization condition with the help of a top restraint in the column, semi-fluidized bed forms. This result in the simultaneous formation of a packed bed below the top restraint and a fluidized bed below the top packed bed formed. Minimum and maximum semi-fluidization fluid flow rates (or velocities) are the two extreme values of fluid movement for the course of semi-fluidization phenomena [8]. Single stage semi-fluidized bed functions within two restraints of a vessel (cylindrical or rectangular c/s section). The fluid passes through the bottom restraint and after proper contact with the movable and the stationary solids leaves the system through a top restraint. It is a single stage operation where the fluid properties, solid characteristics and vessel dimensions influence the performance of the semi-fluidizer.
The aim of the present work is to develop a two-stage liquid-solid semi-fluidization concept and mathematical models for the bed pressure drop and the top packed bed height formation using spherical particles. Investigation is being carried out in a 2.54 cm internal diameter Perspex column. The effect of the system parameters studied includes superficial liquid flow rate with constant bed expansion ratio and initial static bed height. The experimental data of two-stage semi-fluidization has been compared with that of a single stage operation.

SINGLE AND TWO-STAGE SEMI-FLUIDIZATION
In single stage semi-fluidization, solid material of certain height (H_s) is kept inside the vessel of effective height R×Hs (where R is bed expansion ratio [9]). The liquid flows through the vessel. The total effective height of the vessel is occupied by a part of the solids in stationary state at the top and the rest of the solids below the top stationary solids in fluidized form. Two single stages are connected in series for the two-stage semi-fluidization operation. In the present investigation, two-stage semi-fluidization test sections are created by splitting single stage semi-fluidization test section with different bottom and top volume ratio.

Let ΔP_{ts}, the total bed pressure drop and H_{pa-ts}, the total top packed bed formation for a particular superficial liquid flow rate in case of two-stage semi-fluidization. The overall performance of two-stage semi-fluidization may be planned as;

For constant bed parameters, fluid and particle properties,

(A) i) $H_{pa-ss} < \sum H_{pa-i} (= H_{pa-ts})$

ii) $\Delta P_{ss} < \sum \Delta P_i (= \Delta P_{ts})$

(B) i) $\Delta P_n = \sum \Delta P_i = \sum_{i=1}^{n} f(\text{vol. fr.}) \Delta P_n / n,$

ii) $H_{pa_n} = \sum H_{pa_i} = \sum_{i=1}^{n} f(\text{vol. fr.}) H_{pa_n} / n,$ *where n=2*

Explanation:

For 'Part A'

i) The impact of total weight of solids acting downward in two-stage is less than single stage due to intermediate restraint. So a particular liquid superficial flow rate forms top packed bed in a single stage is less than in two-stages taken together.

ii) For a particular amount of solids the buoyancy force required is high in single stage. The total weight of solid in single stage is distributed in two stages in two stage semi-fluidization. The required superficial liquid flow rate is less than that of single stage to lift the solid particles. So the overall formation of the top packed bed height is more compared to a single stage which causes more total bed pressure drop. That is because about 99% of semi-fluidized bed pressure drop is contributed by the top packed bed [8].

For 'Part B'

i) The bed pressure drop occurs due to lifting of solids form fluidizing and packed bed sections. As the liquid supply is continuous, equal liquid superficial velocity is experienced in each stage. The buoyancy force required for semi-fluidization in each stage as per the weight of the solid and the bed expansion ratio. The total bed pressure drop is the summation of individual bed pressure drops. If the conditions of the stages are different, they contribute to overall is a function of volume fraction of test section or weight fraction of solids in the test section (as R is constant) rather only volume fraction of test section or weight fraction of solids. If the conditions of the stages are same, the contribution of an individual stage to overall is proportional to its volume or weight fraction value.

ii) As mentioned above, the superficial liquid flow rate being same for the stages, the top packed bed form in each stage will also be same if similar operating conditions are maintained. With varying operating conditions varying, the minimum and maximum semi-fluidization flow rates are also varying which result in different packed bed height for the two stages. The total top packed bed height is the summation of individual top packed bed formed in the stages. If different conditions are maintained in the stages, the contribution of individual stage to the overall is a function of volume fraction or weight fraction of solids. If similar conditions are maintained in the stages, they contribute to the overall is proportional to its volume or weight fraction value.

MATERIALS AND METHODS

Schematic view of the experimental setup is shown in Fig. 1. The experimental semi-fluidized beds comprise test section, restraints of special design to create stages, liquid distributor and disengagement section. Recirculation is achieved with pump (0.5 HP) and liquid storage tank (30 lit.) and the flow measured with calibrated liquid rotameter (max. 600 LPH). The scope of the experiment is presented in Table 1. Dummy column is used for feeding solid particles in the test sections. the solid materials are feeding into the test section with bed expansion ratio twice the initial static bed height

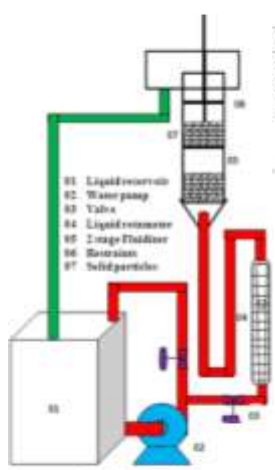

Fig 1: Experimental Setup

Table 1: Scope of the Experiment

System:	Liquid-Solid
Column diameter, cm:	2.54
Properties of bed materials:	Bauxite (Irregular) and Glass Beads (Regular)
Size cm, (BSS):	0.1504, (-8+10)

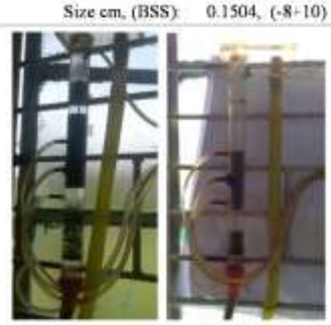

Fig. 2: Two stage Semi-fluidized bed

(R=2H_s). Then the liquid is pumped to the column at a desired flow rate using a liquid rotameter. To

ensure steady state in operation at least two minutes are allowed before each reading. The reading of the bed pressure drop and top packed bed height for each liquid flow rate are then noted. The procedure is repeated for the single and the two-stage semi-fluidized beds. Fig 2 shows pictorial views of the two stage semi-fluidized bed for irregular and regular particles.

RESULTS AND DISCUSSION

Based on the theoretical formulation and experimental investigation of the prediction of hydrodynamic parameters for the semi-fluidized bed viz. the semi-fluidized bed pressure drop and the height of top packed bed have been studied for two-stage semi-fluidization. The mathematical functions are symmetrical for this investigation as the two stages are similar. When the stages are not equal with each other the mathematical function and limits of integration vary.

Semi-fluidized bed formation in individual stage

As the superficial liquid flow rate increases beyond minimum fluidization superficial liquid flow rate, the upward movement of solids forms a packed bed below the top restraint of individual stages. The formation of top packed beds for bottom and top stages as function of superficial liquid flow rate is shown in Fig. 3 and Fig. 4 for irregular and regular particles respectively. The minimum and maximum limits of semi-fluidization are different for different volume fraction of stages as evident from Fig. 3 and 4. When the same static bed height solids with constant bed expansion ratio (*R=2*) are compared with their individual counterpart (as single stage) and it is found that the bed behaviors are changing which are shown in Fig. 5 (irregular particles) and Fig. 6 (regular particles) respectively.

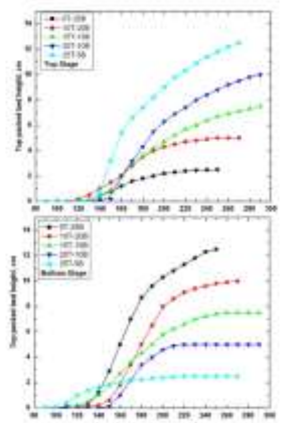

Fig. 3: Formation of Top Packed Bed in two stage semi-fluidization with irregular particles

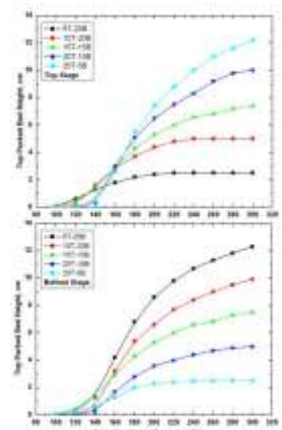

Fig. 4: Formation of Top Packed Bed in two stage semi-fluidization with regular particles

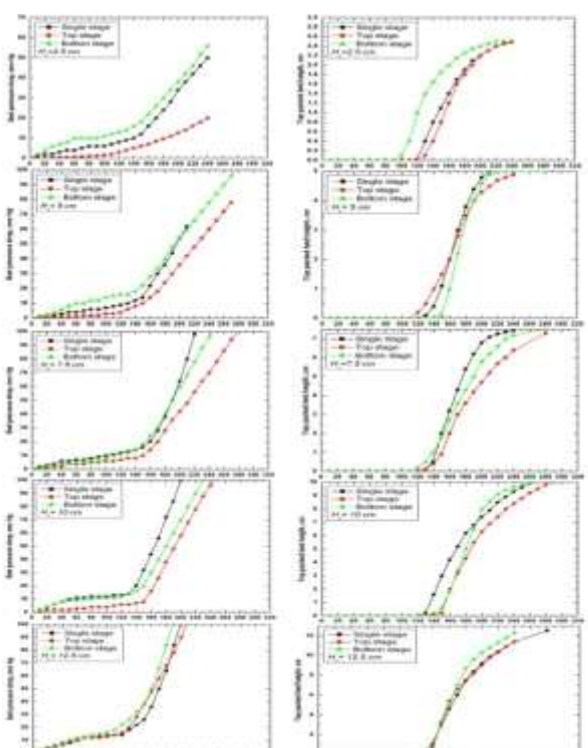

Fig 5: Comparison of Bed responses of single stage at different conditions for various initial static bed height of irregular particles

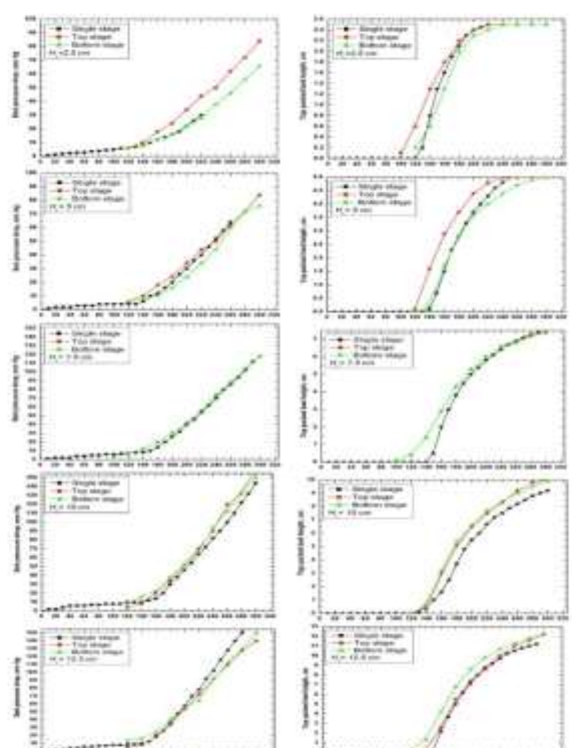

Fig 6: Comparison of Bed responses of single stage at different conditions for various initial static bed height of regular particles

Semi-fluidized bed pressure drop

Fig. 7 shows the variation of total bed pressure drop with superficial liquid flow rate of water in single and two-stage unit for an initial static bed height of 15 cm for irregular and regular particles. From Fig. 7, it is observed that the total bed pressure drop for two stages is higher than that of a single stage irrespective of the position of intermediate restraint for both irregular and regular particles. The variation of the total bed pressure drop for regular particles for different intermediate restraint positions are less compared to the irregular ones. Individual stage contribution on the total bed pressure drop is a functional value of volume or weight fraction, which is clear from Fig. 8. The contribution of individual stage is approximately a constant (0.5) for volume or weight fraction (0.5) for regular particle as is evident from Fig. 8. When the volume of bottom stage is less compared to the top one, the contribution is higher due to the faster formation of top packed bed in the stage. When the volume of bottom stage is higher than the top one, the contribution is still dominating but not as previous was in the case. For this situation with regular particles, the contribution is less than that of the top stage, because of in regular particle the formation of top packed bed is regular packed which contributes to the less pressure drop as compared to the top stage due to formation of top packed bed height to initial static bed height ratio is more.

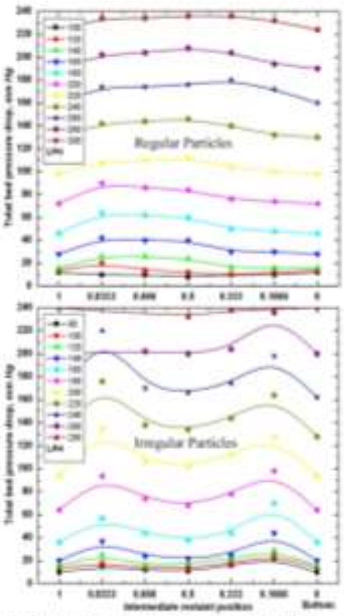

Fig. 7: Total bed pressure drop at different superficial liquid flow rate varing intermediate restraint position

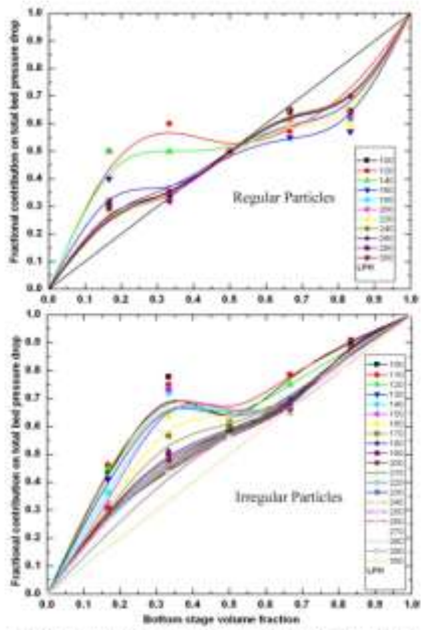

Fig. 8: Fractional contribution of bottom stage on total bed pressure drop

Height of top packed bed formation

Fig. 9 shows variation of the formation of top packed bed height with superficial liquid flow rate in single and two-stage units for an initial static bed height of 15 cm. When the two-stage total top packed bed height is compared with that of the single stage, it is found that the latter case has lower value than the former one which is evident from Fig. 9. The contribution of individual unit on total top packed bed is approximately proportional to volume or weight fraction for most except at initial conditions of semi-fluidization shown in Fig. 10 for both irregular and regular particles.

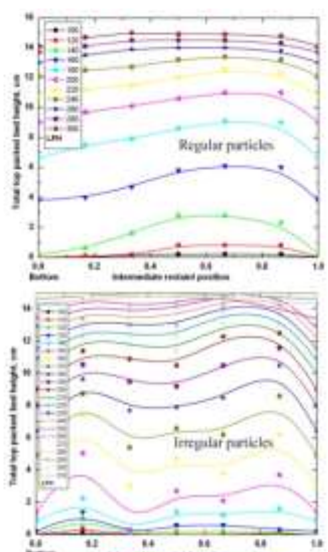

Fig. 9: Total top packed bed height at different superficial liquid flow rate varing intermediate restraint position

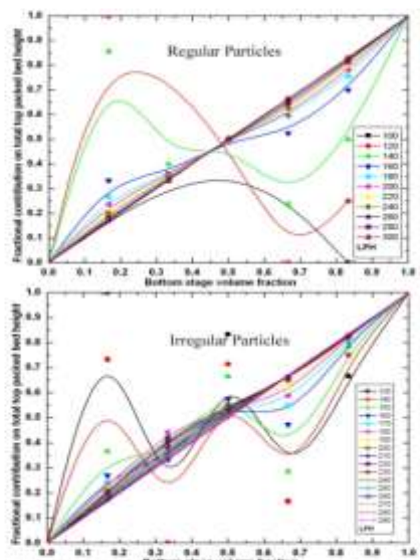

Fig. 10:Fractional contribution of bottom stage on formation of total top packed height

CONCLUSION

A comparative study is being initiated with respect to hydrodynamic behavior of single and two-stage semi-fluidized beds. Like other two-stage operations or processes, semi-fluidization can also be used in two-stages due to its advantage on certain hydrodynamic characteristics. The bed responses approach towards that of an individual single stage as the initial static bed height increases. The results of present investigation for the prediction of bed pressure drop and the formation of the top packed bed height for different bed volume with varying amount of solids in each

stage gives an idea about the solid distribution between the stages. A particular amount of solid can be semi-fluidized with less superficial fluid flow rate in a two-stage system as compared to a single stage one for a definite ratio of packed to fluidized bed formation. It is found that for a definite liquid flow rates the top packed bed formation for two-stage is more than that for a single stage and thus emphasizing the validity of the developed model over the range of the operating parameters investigated. The present study will throw new light to specific bed dynamics of a two-stage semi-fluidized bed operation which can be of specific relevance in case of the design of reactor system for fast heterogeneous catalytic reactions where promoters along with catalysts are used to enhance the reaction rate for optimum conversion viz. Haber-Bosch process, Synthesis of Sulphur trioxide.

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NOMENCLATURE
B *Bottom Stage*
H *Height*
R *Bed expansion ratio*
T *Top Stage*
Vol. fr. *Volume fraction*
Greek letters
Δ *Difference*
∑ *Summation*
Subscripts
n *No. of stages*
pa *Top packed bed*
s *Solid*
ss *Single stage*
ts *Two stage*
i *Individual*

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