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Study on Multi-stage liquid-solid semi-fluidization with spherical particles

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Abstract

Multi-stage chemical process or operation gained the credit over single stage in many case. For getting advantage of multi-stage over single stage semi-fluidization on hydrodynamic characteristics investigation has been carried out in a Perspex column of 25.4 mm internal diameter. Glass beads are used as solid phase with water as the fluidizing medium. Stainless steel screens have been used as top and bottom grids as well as the intermediate restraints. Experimental parameter studied includes superficial liquid flow rate, no. of stages with constant bed expansion ratio. Mathematical study and graphical analysis have been done by introducing a new parameter "*D-power factor*" for multi-stage semi-fluidization. Total power analysis shows that the power consumption is less as compared to the single stage for identical bed conditions for multi-stage semi-fluidization.

Keywords: *Multi-stage, Liquid–solid system, semi-fluidization, Spherical particles, D-power factor*

1. Introduction

A distinctive procedure of fluid solid contact is semi-fluidization, which is a combination of fluidization (bottom part) and packed bed operation (top part) simultaneously occurring in a single vessel, initiated by L T Fan in 1959 [1], which gained maximum attention of the researchers [2-27]. The hydrodynamic parameters viz. the total bed pressure drop, the top packed bed height and minimum and maximum semi-fluidization velocities for single stage semi-fluidization has been developed for different types of system like based on phase: two phase (gas-solid, liquid-solid) and three phase, based on particle size: mono-size (irregular/regular), binary mixtures (homogenous/heterogeneous) and ternary mixtures (homogenous) for catalytic activity purposes. Semi-fluidization has its own pathway to be in the process or operation in the field of chemical, biochemical, metallurgy engineering, etc. Multi-stage semi-fluidization can also find its position in the queue as the single stage semi-fluidized beds are used starting from filtration unit to bio-reactor. Multi-stage semi-fluidization is achieved by connecting individual single stages in series (homogenous / heterogeneous) or splitting a single stage into several (equal or different) stages (homogenous) in terms of solid distribution and volume of individual test section.

The objectives of the present work is to study the hydrodynamics of multi-stage semi-fluidization (homogenous) viz. the bed pressure drop and the top packed bed height formation in liquid-solid system with spherical particles and total power consumption. The system parameters studied includes superficial liquid flow rate, no. of stages with constant bed expansion ratio and initial static bed height. The experimental data of different multi-stage semi-fluidization have been compared with that of a single stage operation.

2. Multi-stage semi-fluidization

Mathematical analysis

The power requirement for the system is taken as the basis for analysis and understanding the multi-stage phenomena. Considering the total solid height (H_s) of a single stage, which has to totally semi-fluidized by using liquid for a definite bed expansion ratio (R) to a total top packed bed height 'H_{pa}', the power (Po) required for total lift of the solid below the top restraint is the integral value with the onset semi-fluidization superficial liquid flow rate (Q_{osf}) as lower limit and the maximum semi-fluidization superficial liquid flow rate (Q_{msf}) as upper limit. Graphically it is the area under the curve, which is plotted between a new parameter superficial liquid flow rate and "*D-power factor*". *"D-power factor"* is defined as the product of semi-fluidized bed pressure drop (ΔP_{sf}) and dimensionless top packed bed height (H_{pa}/H_s), which is taking care of all bed responses. The top packed bed height and semi-fluidized bed pressure drop are only the function of superficial liquid flow rate, as other parameters like particle properties and bed properties are constant. When the stages are created by distributing 'H_s' height solid and total volume in equal proportion, the total formation of top packed bed height (summation of individual top packed bed heights) in multistage is greater than that of single stage for a particular superficial liquid flow rate, because of the solid weight is less than the buoyancy force provided in each stage by the liquid.

Mathematically,

For differential power requirement $d(Po)$:

"*D-power factor*" required is: $D= \Delta P_{sf}\times(H_{pa}/H_s)= f(Q_{sf})$

For total height H_{pa}/H_s =1,

Total power required for single stage ($n=1$),

$$Po_1 = \int_{Q_{osf1}}^{Q_{msf1}} f_1(Q)\,dQ ,$$

Total power required for two stages ($n=2$),

$$Po_2 = 2 \times \int_{Q_{osf2}}^{Q_{msf2}} f_2(Q)\,dQ$$, and so on…

Total power required for 'n' stages,

$$Po_n = n \times \int_{Q_{osfn}}^{Q_{msfn}} f_n(Q)\,dQ,$$

For n = finite but large or infinity, the upper and lower limits are nearly equal ($Q_{osf} \approx Q_{msf}$) which yield 'a constant power requirement' for lifting of definite height of solid for semi-fluidization which is the power requirement at onset semi-fluidization (≈ minimum fluidization).

When maximum no. of stages created the condition of semi-fluidized bed cumulatively leads to onset semi-fluidization at which power required is: $Po_n = Po_{osf} = Po_{mf}$

Again, $Po_1 > Po_2 > Po_3 > Po_4 > Po_5 > \ldots\ldots > Po_n$

In semi-fluidized region, the bed pressure drop is approximately a linear function of superficial liquid flow rate. The slope of total bed pressure drop increases as no. of stages are increases but the limits of semi-fluidization decreases ($Q_{osf1} > Q_{osf2} > Q_{osf3} > \ldots Q_{osf(n-1)} > Q_{osfn}$, and $Q_{msf1} > Q_{msf2} > Q_{msf3} \ldots > Q_{msf(n-1)} > Q_{msf(n-1)}$), which decrease the total power requirement (area under the curve).

The same can be applicable to fractional top packed bed formation (H_{pa}/H_s<1), whether in single or multi-stage.

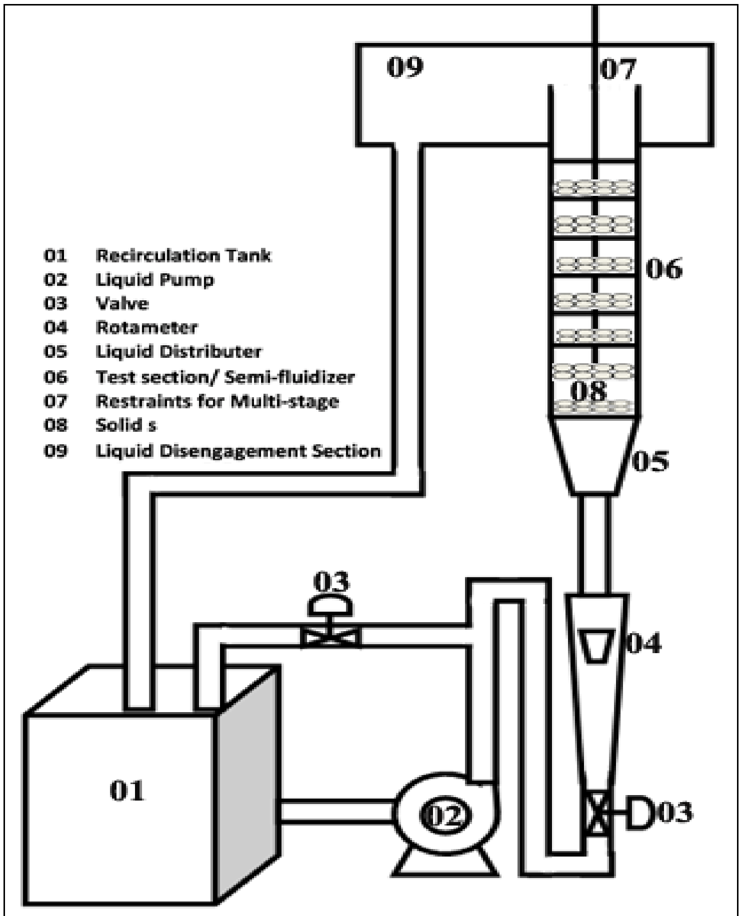

Fig. 1: Experimental setup

3. Material and methods

Schematic view of the experimental setup is shown in Fig. 1. Investigations have been carried out in 25.4 mm internal diameter Perspex column. The experimental semi-fluidized beds consist of test sections, restraints (stainless screen of 40 BSS) 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).

Table 1: Scope of the Experiment

System:	Liquid-solid
Column diameter, mm:	25.4
Bed expansion ratio:	2.0
Bed materials:	Glass beads
Size, mm	1.504

The scope of the experiment is presented in Table 1. Accurate weight of solid material is feeding in the test sections. After feeding the solid material into the test sections, the liquid is pumped into the column at a desired flow rate using a liquid rotameter. To ensure steady state operation, at least 2 minutes are allowed before each reading. The reading of the total and individual bed pressure drop are taken from U-tube monometer reading and the top packed bed height for each liquid flow rate are by normal graph sheet. The procedure has been repeated for the single and multi-stage beds.

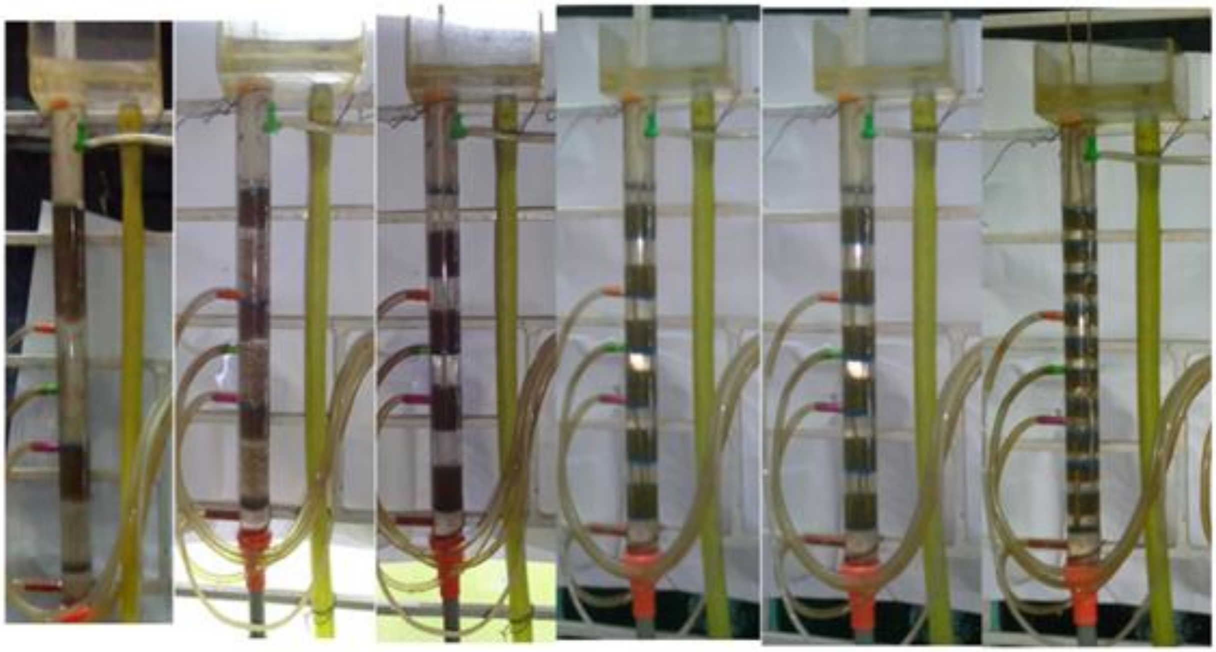

Fig. 2. Multi-stage Semi-fluidized beds

Fig 2: shows pictorial views of different multi-stage (2, 3, 6 and 10) semi-fluidized beds.

4. Results and Discussions

Based on the theoretical formulation and experimental investigation of the hydrodynamic parameters for the semi-fluidized bed viz. the semi-fluidized bed pressure drop and height of the top packed bed formed have been studied for multistage semi-fluidization. As no. of stages increases the dependant variables (responses) of the systems i.e. bed pressure drop and top packed bed height are approaching toward linear form from higher order polynomial function. More precisely if only semi-fluidization is taken into consideration i.e. from onset semi-fluidization to maximum semi-fluidization, the total bed pressure drop is nearly a linear function of superficial liquid flow rate.

4.1 Hydrodynamics of Multi-stage Semi-fluidization

4.1.1 Semi-fluidized bed pressure drop

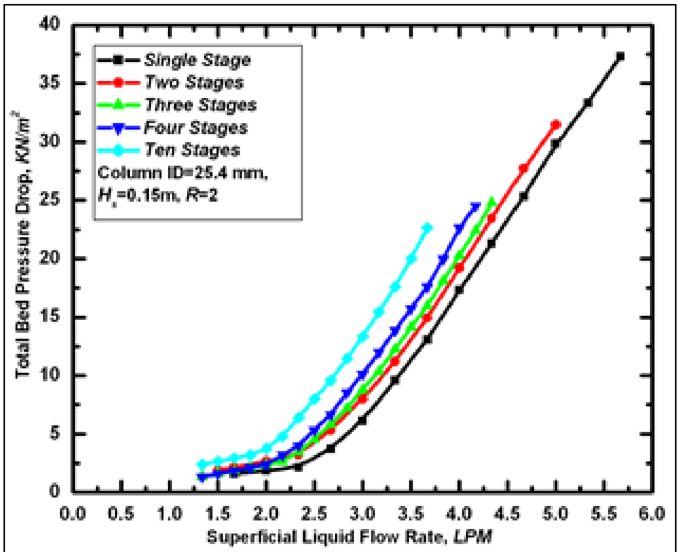

Fig. 3a. Comparison of Total Bed Pressure Drop

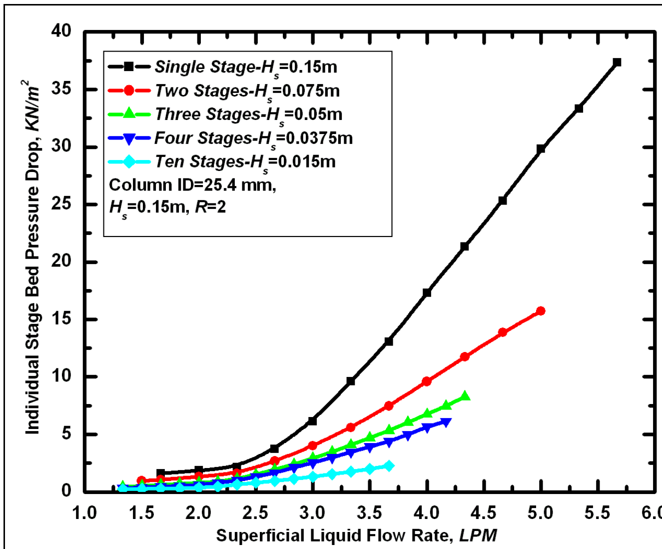

Fig. 3b. Comparison of Individual Stage Bed Pressure Drop

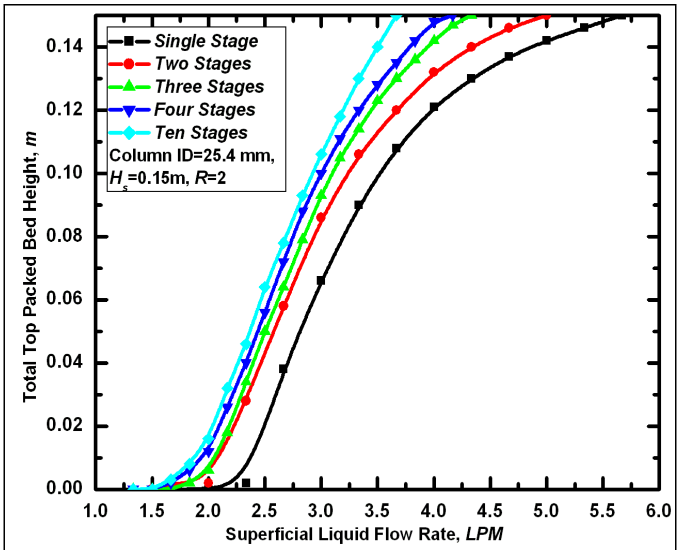

Fig. 4a. Comparison of Total Top Packed Bed Formation

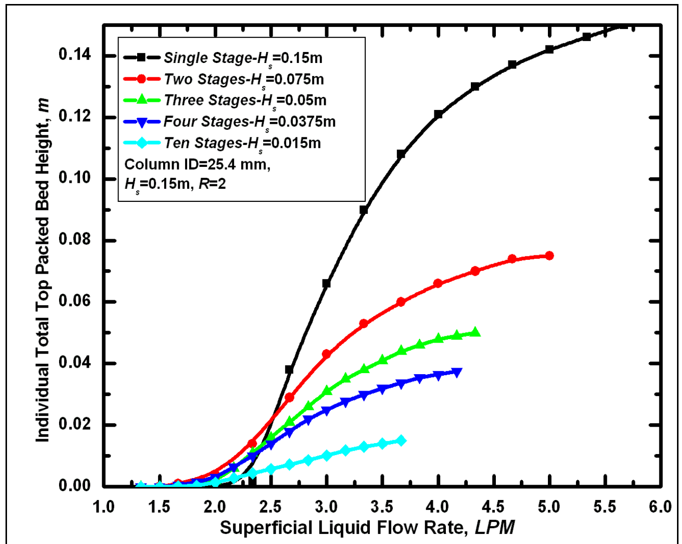

Fig. 4b. Comparison of Individual Total Top Packed Bed Formation

The total bed pressure drop with superficial liquid flow rate of water in a single stage is compared with multi-stage units in Fig. 3a for an initial static bed height of 0.15 m. The total bed pressure drop for multi-stages is higher than that of a single stage irrespective of the no. of stages for a particular superficial liquid flow rate due to maximum top packed bed formation as evidence from Fig. 3a. As the total weight of solids are distributed by the intermediate restraint(s) in multistage the accumulation of solid at the individual top restraint(s) are more for a particular superficial liquid flow rate compared to single stage. Fig. 3b shows the individual stage bed pressure drop with superficial liquid flow rate for different multi-stage units. Single stage shows maximum bed pressure drop compared to multistage due to maximum formation of top packed bed for a particular superficial liquid flow rate as the maximum solids are available as compared to multistage.

4.1.2 Height of top packed bed formation

Comparison of the formation of total top packed bed height with superficial liquid flow rate in single and multi-stage units has been shown in Fig. 4a. The total top packed formation increases for a particular superficial liquid flow rate due to distribution of solid weight decreases as no. of stages increases.

Cumulative formation of top packed bed height is more in multistage as compared to single stage for a particular superficial liquid flow rate. Fig. 4b shows the individual stage top packed bed formation with superficial liquid flow rate for different multi-stage units. In multistage semi-fluidization the minimum and maximum limits of operation are less as compared to single stage. This is due to lesser requirement of buoyancy force to lift up the solids in multistage as compared to single stage.

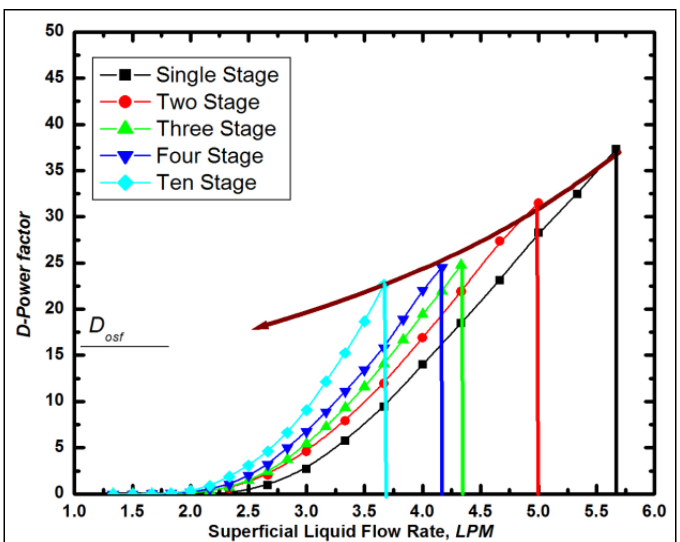

Fig. 5. Comparison of Power Requirement

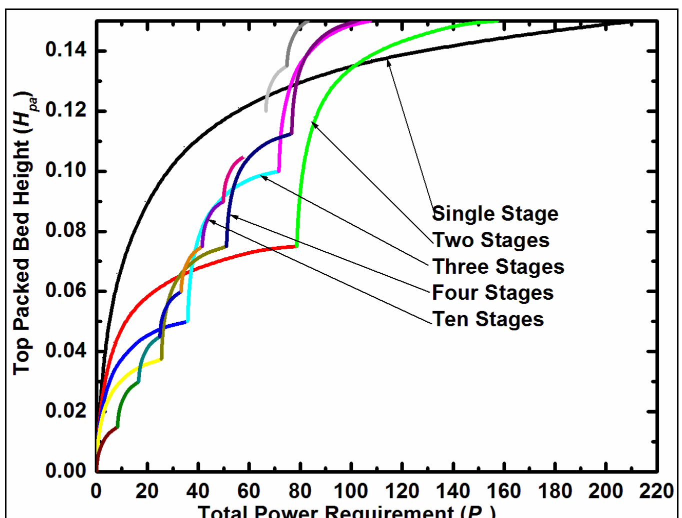

Fig. 6: Cumulative formation of top packed bed height w.r.t total power for H_{pa}/H_s=1

4.2 Analysis
Fig. 5 shows the '*D-power factor*' for *n=1* to *n=10* with superficial liquid flow rate. For the total top packed bed formation, the multi-stage is favorable than that of single stage as the area bounded by the curves are goes on decreasing with increase in no. of stages for a fixed amount of solid particles. Fig. 6 shows the cumulative total power requirement of multistage with respect to formation of top packed bed height (for $H_{pa}/H_s=1$). By knowing individual *D-power factor* of a system, no. of stages can be obtained graphically for a particular total power (for $H_{pa}/H_s<1$). For a particular top packed bed height the multistage is always better than single stage as evidence from Fig 6. The total power requirement of single and multi-stage can be computed from this plot. For infinite no. of stages in '*D-power factor*' is a constant value i. e. D_{osf} ($=D_{mf}$) at Q_{osf} ($=Q_{mf}$). The slope of the bed pressure drop and the individual top packed bed height lines are approaching zero as the no. of stages increase in the multi-stage semi-fluidization, as evidenced by Fig. 3b and 4b respectively.

5. Conclusion
As a large amount of investigations have been carried out by many researchers for different types of system for single stage semi-fluidization, the *D-power factor* can be easily obtained from the developed correlations. No. of stages can be obtained by knowing maximum power of the multistage system. Total power analysis shows that the power consumption is less as compared to the single stage for identical bed conditions for multi-stage semi-fluidization. Hence the developed mathematical and graphical approaches can be used for interpretation of single and that of multi-stage semi-fluidization bed design for liquid solid system.
The present study may useful to develop multi-stage semi-fluidized bed processing units depending on the requirements in the processes.

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References
1. Fan LT, Yang YC, Wen CY. Semi-fluidization: Mass transfer in semi-fluidized beds, AIChE J. 1959; 5:407-409.
2. Fan LT, Wen CY. Mechanics of semi-fluidization of single size particles in solid-liquid systems, AIChE J., 1961; 7:606-610
3. Kurian J, Raja Rao M. Hydrodynamics of semi-fluidized bed, Indian Journal of Technology, 1970; 8:275-284
4. Roy GK, Sarma KJR. Relation between maximum semi-fluidization and minimum fluidization velocity in liquid-solid systems, J. I. of the Inst. of Engrs., (India), 1974, 54.
5. Roy GK, Saratchandra HN. Liquid-Solid Semi-fluidization of Heterogeneous mixtures—II, Prediction of Minimum Fluidization Velocity, Chemical Engineering Journal, 1976; 12:77.
6. Dash J, Roy GK. Liquid-Solid Semi-fluidization of Homogeneous Mixtures—II, Prediction of Maximum Semi-fluidization Velocity, Indian Chemical Journal. 1976.
7. Dash J, Roy GK. Liquid-Solid Semi-fluidization of Homogeneous Mixture—I, Prediction of Onset Semi-fluidization Velocity. Indian Chemical Journal. 1977, 1.
8. Chern SH, Muroyama K, Fan LS. Hydrodynamics of Constrained Inverse Fluidization and Semi-fluidization in a Gas-Liquid-Solid System, Chemical Engineering Science, 1983; 38:1167-1174.
9. Chern SH, Fan LS, Muroyama K. Hydrodynamics of Co-current Gas- Liquid-Solid Semifluidization with Liquid as the Continuous Phase. AIChE J., 1984; 30:288-294.
10. Fan LS, Matsuura A, Chern SH. Hydrodynamic characteristics of a gas-liquid-solid fluidized bed containing a binary mixture of particles. AIChE J., 1985; 31:1801-1810
11. Murthy JSN, Roy GK. Semi-fluidization: a Review, Indian Chemical Engineer, 1986; 29(2):1-14.
12. Ho TC, Yau SJ, Hopper JR. Hydrodynamics of semi fluidization in gas-solid systems, Powder Technology, 1987; 50:25-34.
13. Mydlarz J. Prediction of the packed bed height in liquid-solid semi-fluidization of homogeneous mixtures. The Chemical Engineering Journal. 1987; 34:155-158.
14. Biswal KC, Sahoo SN, Verma P, Murthy JSN, Roy GK. Dynamics of Gas-Solid Semi-Fluidization of Binary Homogeneous and Heterogeneous Mixtures, Chemical Engineering Journal. 1990; 70:61-64
15. Dias SMM. Extractive fermentation of ethanol by immobilized yeast cells. NTIS. Report, Dept. Engg, Tech. Univ. Lisbon, Lisbon, 1991, 218.
16. Is'emin RL, Zaitseva NA, Osipov AD, Akol'zin AP. Formation of nitrogen oxides and deposits on the heating surfaces of boilers with semi-fluidized bed furnaces fired with low grade coal. Promyshlennaya Energetika, 1995; 2:37-38.
17. Kim SJ, Hwang KR, Cho SY, Moon H. Simultaneous Removal of Cyanide and copper Ions in a Semi-Fluidized Ion Exchanger Bed. Korean Journal of Chemical Engineering. 1999; 16:664-669.
18. Kim SJ, Hwang KR, Cho SY, Study on Ion-Exchange Behavior of Cu-CN Complexes. J Chem. Eng. Japan. 2001; 34:193-198.
19. Ho TC, Kobayashi N, Lee YK, Lin CJ, Hopper JR, Modeling of mercury sorption by activated carbon in a confined, a semi-fluidized, and a fluidized bed. Waste Management, 2002; 22:391-398.
20. Singh RK, Maharathy AK, Mahapatra AK. Prediction of Pressure Drop in Three-phase Semi-fluidized Bed for Non-spherical Particles. Chemical Engineering World, 40 2005; (9):86-88.
21. Jena HM, Roy GK. Meikap BC. Experimental hydrodynamic study of three phase semi fluidized bed, Indian Chemical Engineering Congress, 2006.
22. Dehkissia S, Baçaoui A, Iliuta I, Larachi F. Dynamics of Fines Deposition in an Alternating Semi-fluidized Bed. A.I.Ch.E. Journal, 2008; 54:2120-2131.
23. Schubert M, Larachi F. Phase Holdups in Three-Phase Semi-fluidized Beds and the Generalized Bubble Wake Model, Department of Chemical Engineering, Lava University, Quebec, Canada, G1V 0A6, Ind. Eng. Chem.

Res., 2009; 48(18):8393-8401.
24. Chayjan RA. Modeling some drying characteristics of high moisture potato slices in fixed, semi fluidized and fluidized bed conditions, Journal of Agricultural Science and Technology. 2012; 14:1229-1241.
25. Samal DK**,** Mohanty YK, Roy GK. Hydrodynamics of liquid-solid semi-fluidized bed with irregular homogenous ternary mixture. Powder Technology, 2013; 235:921-930
26. Samal DK**,** Mohanty YK, Roy GK. Prediction of bed pressure drop and top packed bed formation in gas-liquid-solid semi-fluidized bed with irregular homogenous binary mixtures; Korean J of Chemical Engineering. 2013; 30(6):1326-1334
27. Samal DK**,** Mohanty YK, Roy GK. Hydrodynamics of Liquid-Solid Semi-fluidized Bed with Regular Homogenous Ternary Mixture; J Bioprocessing Biotechniques; DOI: dx.doi.org/10.4172/2155-9821.1000151 (2014)