Mathematical Modelling for Hydrodynamic Studies of Spouted bed

B. Sahoo and A. Sahoo, Chemical Engineering Department, National Institute of Technology, Rourkela
Rourkela-769008, Orissa, India

***Abstract*—The hydrodynamic behavior of the spouted bed has been studied by considering the different system parameters (viz. static bed height, spout diameter, particle size, gas velocity, particle density). Experiments were carried out using a Perspex column of 4 inch diameter. Attempts have been taken to develop correlations for the bed expansion / fluctuation ratios by varying different system parameters with the experimentally measured values of the bed dynamics on the basis of dimensional analysis. The experimental values of the expansion and fluctuation ratios were compared with the calculated results. The percentage deviations were observed to be within -15 to +15. A computer programmed was also done for the calculations of these bed dynamics theoretically. Theoretical results thus obtained through computer programming are compared with the calculated values obtained through the developed correlations on the basis of dimensional analysis approach as well as with the experimentally observed values of bed dynamics.**

***Index Terms*—spouted bed, expansion ratio, fluctuation ratio, dimensionless analysis.**

I. INTRODUCTION

The spouted bed and spouting were coined at the National Research Council of Canada in 1954 by Gishler and Mathur [1]. These investigators developed this technique initially as a method for drying wheat. Spouted bed apparatuses are already used in some technical areas where intense contact of gas-particle systems is required. The spouted bed technique is a variant of fluidization. The gas is injected vertically through a centrally located small opening at the base of the vessel. If the gas injection rate is high enough, the resulting high velocity jet causes a stream of particles to rise rapidly in a hollowed central core within the bed of solids. This system is termed as a spouted bed, the central core is called a spout, and the peripheral annular region is referred to as the annulus. The term fountain will be used to denote the mushroom-shaped zone above the level of the annulus.

The use of spouted bed reactors for several chemical processes - coal carbonization, shale pyrolysis, ore roasting, cement clinker production, and thermal cracking of petroleum - has also received attention. The main advantage of spouted bed is that it is capable of performing certain useful cyclic operations on solid particles which cannot be performed in a fluidized bed due to its comparatively random particle motion. The other advantages of the spouted compared to other techniques of gas-particle contact is the possibility of achieving more intense heat- and mass-transfer conditions.

II. LITERATURE SURVEY

The spouting and its stability, operating condition, spouting bed height along with the changing phenomenon from spouting to bubbling, slugging etc. as shown in fig.(1) depends on many factors like effect of particle size, orifice size of spouting fluid, flow rate of fluidizing fluid, bed height and the density of particle used. For a given solid material contacted by a specific fluid in a vessel of fixed geometry, there exists a maximum spoutable bed depth H_m, beyond which the spouting action does not exists but it replaced by a poor quality fluidization. The minimum spouting velocity at this bed depth can be 1.25 to 1.5 times greater than the corresponding minimum fluidization velocity, $U_{mf.}$

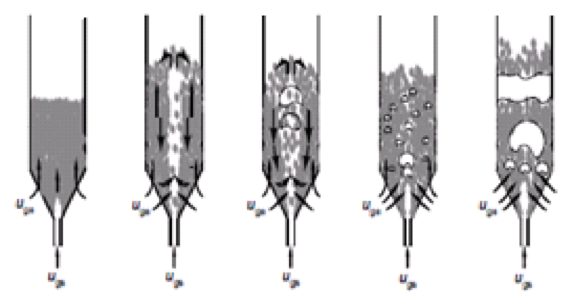


Fig.1: Spouting behavior of the bed

The bed expansion and fluctuation ratios are used to describe the characteristics of bed height during fluidization process as mentioned below.

$$R = \frac{(H_{\max} + H_{\min})}{2 * H_s} \quad (1)$$

$$r = \frac{H_{\max}}{H_{\min}} \quad (2)$$

An optical fibre probe was used to study the effect of operating conditions (base angle, gas inlet diameter, stagnant bed height, particle diameter and gas velocity) on particle velocity in the three zones of spouted beds: spout, annulus and fountain [2]. From the experimental and calculated values of particle velocities, maps of velocity vector throughout the bed have been drawn and zones of preferential solid cross-flow into the spout have been determined.

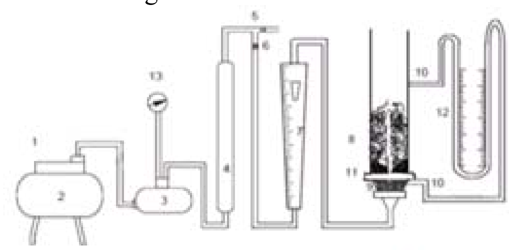
A group of authors were compared the time, frequency and phase space analyses of pressure measurements in different spouted beds [3]. The experiments were carried out in different constructions of spouted bed apparatuses, operated under ambient conditions and under different spouting regimes. A treatment technique using the Fast Fourier Transformation of measured pressure fluctuations was developed to create plots describing the bed behaviour evolution from fixed to slugging bed. At the beginning of stable spouting the amplitude of pressure fluctuations is uniform and small.

A novel annular spouted bed had been developed consisting of two homocentric upright cylinders with different diameters [4]. The nozzles and V-shaped deflectors were located in the bottom of annular space between the inner and outer cylinders. The effects of hold-up, bed material, total flow rate and nozzle structure on the hydrodynamic characteristics of the novel annular spouted bed were investigated. The results show that there exist three different zones for the particle flow in the annular spouted bed: the moving packed zone, the dense-phase spouted fluidizing zone and the dilute-phase zone. With the increase of hold-ups, the height of the dense-phase spouted fluidizing zone tends to increase in the annular spouted bed, while the moving packed zone is only limited within the V-shaped deflector

A group of authors carried out an experimental investigation to evaluate the stable spouting regime in conical spouted beds using four particle mixtures: a reference (monoparticles), a binary mixture and two ternary mixtures with flat and Gaussian distributions respectively, using a high- viscosity Newtonian fluid and glycerol [5]. The mixtures were selected for particle diameters (d_p) ranging from 1.09 to 4.98mm and particle diameter ratios (d_{pL}/d_{pS}) ranging from 1.98 to 4.0. Experimental data show that pressure fluctuation signals of the bed, as indicated by changes in their standard deviations, provide suitable information to identify the range of operational conditions for stable spouting. For glycerol in the spouting regime, the standard deviation is noted to increase with increasing glycerol concentration due to the growth of inter particle forces.

III. EXPERIMENTATION

The experimental set-up as shown in Fig-2 consists of many parts such as an air compressor of capacity 25 kgf/cm^2, an air accumulator for storing the compressed air from compressor, a rota meter in the range of 0 to 200 Nm3/hr, a fluidized bed column of diameter 10cm, four different diameters of distributor plates, a U-tube mercury manometer and valves like gate valve and globe valve.



1.	Compressor	2.	Recevier
3.	Contact pressure tank	4.	Silica gel tower
5.	By pass valve	6.	Line valve
7.	Rotameter	8.	Spouting
9.	Calming section	10.	Pressure tapping
11.	Distributor	12.	Manometer
13.	Pressure gauge		

Fig.2: Experimental set-up

The experiment has been carried out to describe the characteristics of bed height during fluidization. The distributor plates of spout diameter of 2.5, 3.0, 3.5, 4.0cm were used. These plates were made up of card boards by making a hole at the centre. This plate is tightly attached to the column with the help of the gasket, so that there is no leakage of air. The screen of very fine size was put to prevent the backflow of bed materials below the distributor. The rota meter was used for measuring the air flow rate passing to the column. A U-tube manometer was used for measuring the pressure drop across the bed with the mercury as the manometric fluid.

The experiments were carried out by passing air through the distributor plate by varying the different system parameters as discussed in scope of the experiment (Table-1). The bed expanded bed heights and bed manometer readings were noted down at different flow rates of the supplied air.

IV. RESULTS

Correlation is done for finding out the values of expansion ratio and fluctuation ratio by changing different system parameters, which are as follows:

$$R = 0.014\left(\frac{H_s}{D_c}\right)^{-0.006}\left(\frac{d_p}{D_c}\right)^{-0.241}\left(\frac{D_i}{D_c}\right)^{0.181}\left(\frac{\rho_s}{\rho_f}\right)^{0.759}\left(\frac{U_o}{U_{ms}}\right)^{0.487} \quad (3)$$

$$r = 0.002\left(\frac{H_s}{D_c}\right)^{-0.046}\left(\frac{d_p}{D_c}\right)^{-0.369}\left(\frac{D_i}{D_c}\right)^{0.204}\left(\frac{\rho_s}{\rho_f}\right)^{0.807}\left(\frac{U_o}{U_{ms}}\right)^{0.683} \quad (4)$$

TABLE-I

SCOPE OF THE EXPERIMENT

materials	Hs/Dc	Dp/Dc	Di/Dc	Uo/Umf	ρs/ρf
glass beads	0.8	0.033	0.25	1.25	2211.809
glass beads	1.2	0.033	0.25	1.25	2211.809
glass beads	1.6	0.033	0.25	1.25	2211.809
glass beads	20	0.033	0.25	1.25	2211.809
Al balls	0.8	0.026	0.25	1.25	2211.809
Al balls	0.8	0.022	0.25	1.25	2211.809
Al balls	0.8	0.017	025	1.25	2211.809
Al balls	0.8	0.033	0.3	1.25	2211.809
mustard	0.8	0.033	0.35	1.25	2211.809
mustard	0.8	0.033	0.4	1.25	2211.809
mustard	0.8	0.033	0.25	1.15	2211.809
mustard	0.8	0.033	0.25	1.35	2211.809
sago	0.8	0.033	0.25	1.5	2211.809
sago	0.8	0.033	0.25	1.25	2211.809
sago	0.8	0.033	0.25	1.25	2530.459
sago	0.8	0.033	0.25	1.25	1030.928
sago	0.8	0.033	0.25	1.25	1255.858

V. DISCUSSION

The hydrodynamic study of the materials (such as glass beads, Al balls, sago and mustard seeds) was done using spouted fluidized bed. The expansion and fluctuation ratios of the materials are calculated by the equations (1) and (2).

Several experiments were carried out by varying the parameters like density, static bed heights (8, 12, 16, and 20), spout velocity, particle diameter and spout diameters etc. For each experiment the graphs of pressure against the superficial gas velocity were plotted as shown in “fig.3”. From those graphs it was observed that with increase in velocity, pressure in the bed gradually increases and goes to the maximum but the bed height remains constant. In the middle part the pressure decrease and in that case the bed height also at constant level. By further increasing the air velocity the pressure drop almost remain constant and at that time the bed was fluidized completely. The corresponding velocity at which the pressure drop is constant is noted as the minimum spout velocity.

From the above plots the minimum superficial velocities are obtained we see that in the case of glass beads of size (-5+6) the minimum spout velocity ranges from 42 to44, size (-6+7) the velocity ranges from 40 to 42 and for (-7+8) and (-8+12) it ranges from 38 to 40 and 32 to 36 respectively due to the weight of the solids and the height of static beds. These variations of spout velocity are due to the particle size.

Then effect of various system parameters (like H_s/D_c , D_i/D_c , U_o/U_{mf} , ρ_s/ρ_f , d_p/D_c) on expansion and fluctuation ratios were described by the logarithmic graphs in “fig.4” and “fig.5”.

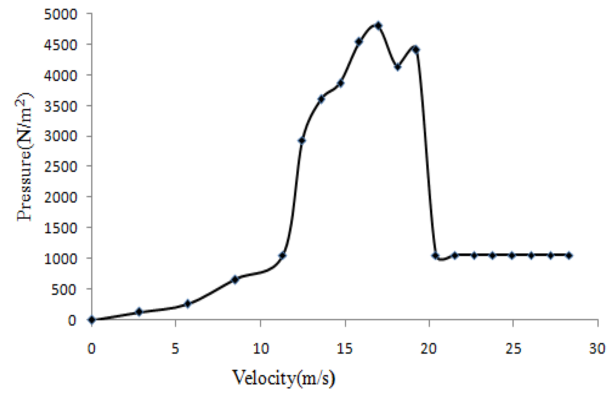


Fig.3: Pressure drop profile

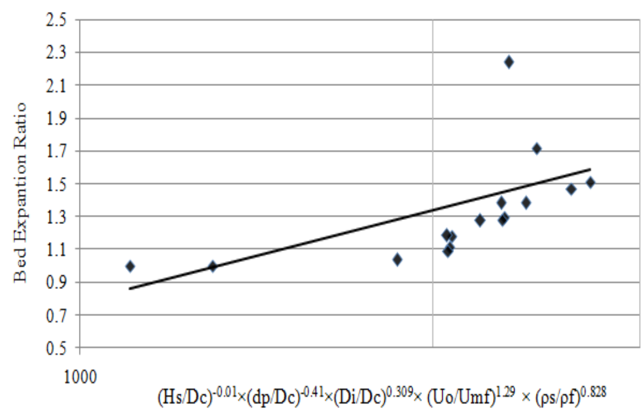


Fig.4: Correlation plot for Expansion ratio

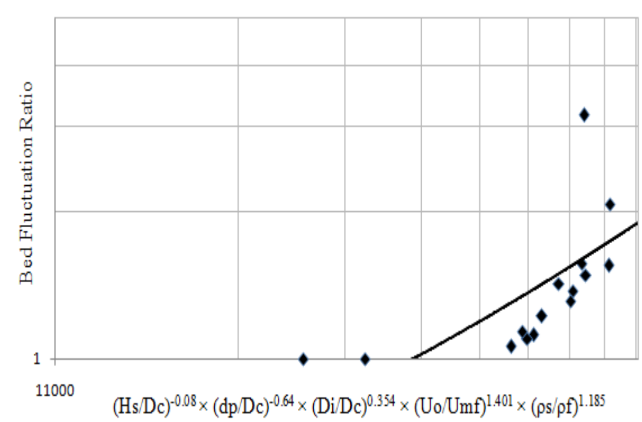


Figure-5: Correlation plot for Fluctuation ratio

From the above figs it was observed that with the increase in the static bed height, the expansion and the fluctuation ratios first decrease and then increase. In the case of particle size with the decrease in size the expansion and fluctuation ratio first increase and then decrease. With the increase in spout diameter the expansion ratio increases but the fluctuation ratio first increases, then decreases to some values and again increases. In the case of rising values of flow rate the expansion as well as the fluctuation ratio both increase. With the decrease in particle density, the expansion and fluctuation ratios show no clear trend.

Correlations were developed for the bed expansion and fluctuation ratios on the basis of dimensionless analysis approach by varying different system parameters (eq.3 and eq.4). The overall changes in values of expansion and fluctuation ratios were observed from the developed correlations. With the increase in static bed height and particle size, both the expansion and fluctuation ratio decease but with the increase in spout diameter, flow rate, and density of particle the expansion and fluctuation ratios increase. Calculated values of bed expansion and fluctuation ratios obtained through eq^n-1 and 2 are compared against the experimental values. The standard deviations were found to be 8.45 and 9.98 respectively. Again the calculated values of bed expansion and fluctuation ratios obtained through computer programming which are compared with those obtained from experimentation as well as those calculated by dimensionless analysis method in "Fig.6(A)" and "(B)". For the computer programming a flow chart was developed represented by (flow chart.1).

VI. CONCLUSION

The calculated values of the bed expansion and fluctuation ratios were compared with the experimentally observed values and with values obtained through computer programming. The percentage of deviations is approximately between +15 to -15. The standard deviations for the bed expansion and fluctuation ratios were found to be 8.45 and 9.98 respectively which validates the developed correlations. This indicates that these correlations can be used suitably over a wide range of parameters. This results in good applicability of the developed correlations for design of industrial spouted bed reactors where these can be used as basis of designs.

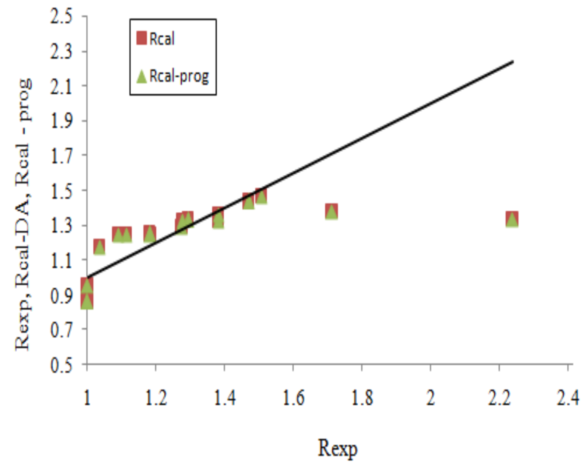


Fig.6(A): Plot of R-exp versus R-exp, R-cal and R-programming

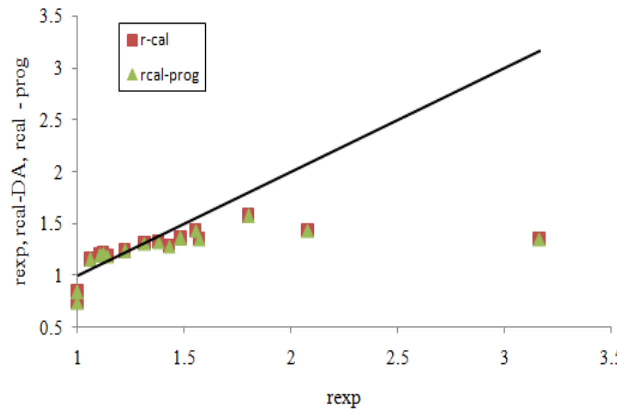


Fig.6(B): Plot of r-exp versus r-exp, r-cal and r-programming

VII. NOMENCLATURE

Hs	:	Static bed height
Dc	:	Column diameter
Di	:	Spout diameter
dp	:	Particle diameter
ρ_s	:	Particle density
ρ_f	:	Air density
Uo	:	Velocity of air
Umf	:	Minimum spout velocity
R	:	Expansion ratio
r	:	Fluctuation
max	:	Maximum values
min	:	Minimum values
avg	:	Average
exp	:	Experimentally observed values
cal	:	Calculated values
cal-DA	:	Calculated value by Dimension less Analysis
cal-prog	:	Calculated value by MATLAB programming

REFERENCES

[1] Gishler, P. E., K. B. Mathur, “Method of contacting solid particles with fluids”, U. S. Patent No. 2,786,280 to Nat. Res. Council of Can., Brit. Patent No. 801, 315, 1954.

[2] Ozalar, M., M. J. S. JoseM. A., Izquierdo, A.O. Salazar and J.Bilbao, “Effect of operating conditions on solid velocity in the spout, annulus and fountain of spouted beds”, chemical Engineering Science. 56, 2001, pp. 3585-3595.

[3] Piskova, E. and L. Morl, “Characterization of spouted bed regimes using pressure fluctuation signals”, Chemical Engineering Science. 63, 2008, pp. 2307-2316.

[4] Guoxin, H., L. Yanhong, and G. Xiwu, “Spoutable bed height and pressure fluctuation of a novel annular spouted bed with V-shaped deflector”, Powder Technology. 185, 2008, pp.152-163.

[5] Bacelos, M. S. and J. J. Freire, “Flow regimes in wet conical spouted beds using glass bead mixtures”, Particuology. 6, 2008, pp.72-80.

1. FLOWCHART: (MAT LAB Programming)