CONICAL FLUIDIZED BEDS - CASE STUDY FOR A GAS SOLID SYSTEM INVOLVING WHEAT FLOUR AND ADDITIVE

Rajesh Katiyar

Associate Professor, Chemical Engineering Department, Harcourt Butler Technical University, Kanpur, India

---***---

Abstract - *Conical or tapered fluidized beds inherit certain valuable properties in comparison to columnar fluidized beds. They can handle particles of broad size distribution and also manage the particles which exhibit cohesive nature. The existence of higher gas velocity over the inlet grid would minimize the chances of bed getting de-fluidized, and with the comparative lower velocity at the outlet of the bed reduces elutriation of the solid particles during operation. Present investigation utilized two-dimensional conical bed with cone angle of 20.5°. Air has been used as the fluidizing medium. Solids taken for fluidization were commercial flour and mixture of crushed wheat with flour. Commercial flour of wide particle size range (1-355 μm) was used for experiments having certain degree of cohesivity. Particle size analysis of the commercial flour for the undersize of 63 μm was done by laser particle size analyzer of Galai, Israel. Crushed wheat used was of size range 495 to 1520 μm. Size determinations of crushed wheat particles was carried out by sieve analysis using standard screens. Studies were done towards estimating that how the fluidization of flour which is cohesive in nature, is improved by the addition of crushed wheat particles in different ratio.*

Key Words: **Conical fluidized bed, wheat flour, cone angle, pressure drop, fixed bed, fluidization velocity, Ergun equation, particle size, initial bed height, cohesivity.**

1. INTRODUCTION

During fluidization operation in a columnar bed with uniform particles, the drag force is constant at any position. This drag force decreases in the upward direction in a conical bed accompanied by the reduction in the superficial velocity of the fluid. Hence, particles of the lower parts of the bed would first be fluidized upon an increase in the flow rate, whereas the particles at the upper part of the bed tend to remain static. Thus the problems associated with conventional (cylindrical) fluidized beds are overcome by using conical fluidized beds. These problems faced by conventional columnar beds are possible in fluidization of wider size range of particles, entrainment of particles and limitation of fluidization velocity. Important fluidization operations of process industries handle particles of non-uniform size due to size reduction during chemical reactions (combustion or gasification) and attrition. Reduction in particle size would result in entrainment and non-uniform fluidization during operations in columnar beds. Conical beds help in these issues in which there is a gradual decrease in the superficial gas velocity with increasing cross-sectional area and height. Thus conical beds have found important application in the areas of incineration of waste materials, coating of nuclear fuel particles, crystallization, fuel combustion and gasification, roasting of ores, waste heat recovery and food processing areas [1,2,3]. The application of tapered fluidized beds for biochemical reactions and biological treatment of waste water have been emphasized and elaborated along with the advantages of the tapered beds over the columnar beds [4].

The voidage in a tapered fluidized bed of large apex (cone) angle is smaller and its dependence on velocity is less than that for a columnar (cylindrical) fluidized bed. Also, an intense exothermic reaction can be handled properly in a conical bed and the operations of conical bed are smooth without any instability. With existence of velocity gradient in the axial direction, unique hydrodynamic characteristics are established. The tapered angles of the conical beds have been found to affect the hydrodynamic characteristics of the bed unit [5,6]. Geldart group C particles showing cohesive nature may lead to plug flow and channeling during fluidization operation. Inter-particle adhesive forces cause agglomeration and bridging between agglomerates in these particles of pigments, flour, starch granules, etc. Attempts involving different techniques have been made in improving the fluidization quality of the cohesive particles by using external forces, by modifying the surface of particles or by addition of other particles [7,8].

The hydrodynamics characteristics for a conical bed with three different cone angles have been studied experimentally for a Geldart-D powder. The results observe three different flow regimes which are fixed bed, partially fluidized bed and fully fluidized bed (or spouting bed). These regimes depend on superficial gas velocity and regime ranges depend on cone angle and stagnant bed height [9]. Fine particles (of Geldart-A zone) for fluidization characteristics in gas-solid conical beds were studied for flow regimes and transition conditions with three different cone angles. Fixed bed and spouting bed regimes were observed successively in experiments with the increase of superficial gas velocity. In comparison with coarse particles (Geldart-D), in fine particles fluidization, the partially fluidized bed regime disappears, as an important observation [10].

2. Hydrodynamics and modeling

Development of a model for maximum pressure drop at incipient fluidization condition of a conical fluidized bed has been carried on the basis of Ergun equation [4]. Theoretical model for minimum fluidization velocity and pressure drop in a packed bed of spherical particles for gas-solid systems in a conical vessel has been developed by the authors [3]. Solid-liquid fluidization characteristics in a conical bed were studied and theoretical models for the prediction of minimum fluidization velocity and maximum pressure drop have been formulated for the spherical particles [1]. With the studies carried out on conical fluidized beds, models were developed for gas-solid systems for spherical coarse particles and spherical fine particles [9,10].

Researchers have determined the factors affecting minimum fluidization velocity and maximum pressure drop. Investigations have been carried out regarding fixed bed pressure drop calculations, flow regimes, incipient condition of fluidization, void distribution and bed expansion calculations. An empirical dimensionless correlation has been developed for predicting the minimum fluidization velocity and maximum pressure drop for regular and irregular particles in gas-solid systems. Parameters taken into consideration are particle diameter, particle density, tapered angle, porosity and sphericity. Bed height has not been considered and authors have compared the applicability of the model developed with existing models from literature [6].

3. Materials and methods

3.1 Experimental set-up

Experimental set-up and procedure are similar as has been described in earlier communication [11]. Details of set-up and experimental procedure are provided here as well. The fluidization columns were fabricated from perpex material sheet to allow visual observations of the fluidization. The experiments were performed with two-dimensional column having tapering angle of 20.5°. The thickness was 1.7 cm and height was 0.5 m. The cross-section at bottom of the column was 2.75 x 1.7 cm.

To measure the pressure drop through bed, pressure tap was installed on the wall along the centerline of the column immediately above the distributor. The tapping was connected to U tube manometer. Gas distributor was a polymer type mesh. Air was supplied by a blower whose speed was varied by a variable voltage supplier. Gas flow rate was determined by means of venturi-meter which was connected to the U tube manometer. Provision of measuring the bed height was through a graduated scale. The materials utilized for fluidization were commercial flour and crushed wheat. Their properties were studied as described later. Crushed wheat has been used as an additive.

3.2 Material used for fluidization

Commercial flour was taken and its particle size analysis was done. Flour was first sieved and undersize fraction of 63 µm was analyzed by laser particle size analyzer of Galai, Israel, which is a suspension type particle analyzer working on diffraction principle. The oversize of 63 µm was analyzed by sieve analysis. Hausner's ratio (HR) was determined for complete flour as well as for flour of undersize of 63 µm. For complete flour the average value of the HR was 1.4047 for four estimations. The average value of HR for flour of undersize of 63 µm was found as 1.6487 for four estimations. Crushed wheat which was used as additive was analyzed by sieve analysis. Volume surface mean diameters were determined and for complete flour it was found to be 70.73 µm, whereas for crushed wheat it was 868 µm.

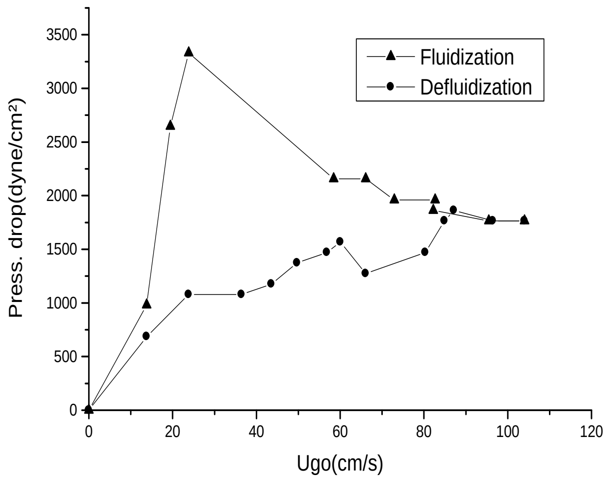
3.3 Experimental procedure

The experiments were carried out under ambient conditions. For conducting experiments, the conical bed was charged with material to a fixed bed height. Initially the bed was fully fluidized by increasing the flow rate of air and subsequently the flow rate was gradually reduced to zero to a stage where the material was settled to form a fixed bed. This was the initial fixed bed height and the procedure was used to obtain reproducible results.

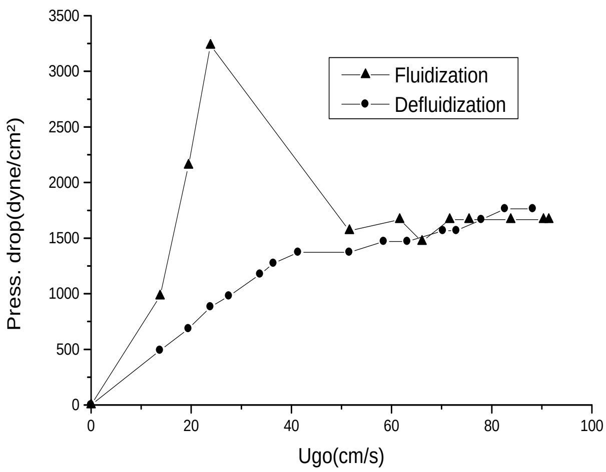
During the performance of an experimental run, the flow rate of air through the column was increased incrementally. When a stable state was established after each increment, records were made of the readings on the manometers. An experimental run was initiated by increasing the flow rate to fluidize the bed and then by decreasing the flow rate to defluidize it. Visual observations were made during the experiments in addition to the pressure drop and flow rate measurements. Gas velocity has been expressed on the basis of inlet area of the bed and manometer readings corresponding to bed pressure drops have been plotted against corresponding superficial velocities at the inlet.

4. Results and discussion

Fluidization behavior of pure flour was studied in conical bed at different stagnant heights. The experimental pressure drop versus velocity data obtained from the two-dimensional tapered fluidized bed with cone angle of 20.5° follows the pattern as shown in plots 1, 2 and 3. These plots show the fluidization as well as de-fluidization behavior for a stagnant bed height of 5 cm, with approximate weight of flour amounting to 20 gram. It is important to note that in 5 runs among the total 14 runs which were performed, the material fluidized properly. Fluidization was not proper and channeling took place at low superficial gas velocity in 9 experimental trials. In the increasing fluid velocity cycle, the pressure drop reached a maximum value and then decreases, approaching a nearly constant value. In the decreasing fluid velocity cycle, however, the pressure drop decreases almost continuously and the peak is not recovered.

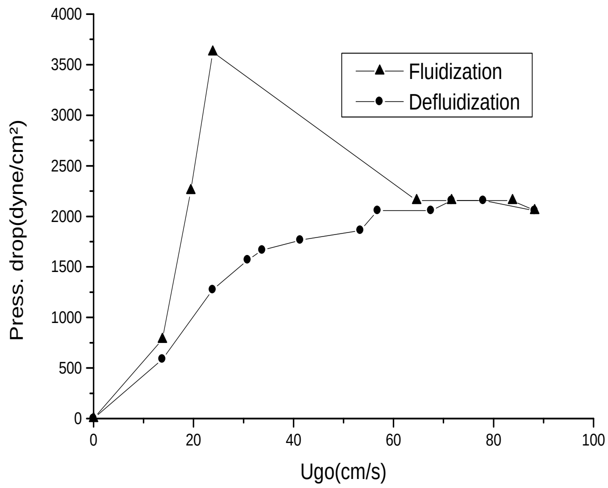


Plot -1: Effect of superficial gas velocity on pressure drop in conical bed for flour

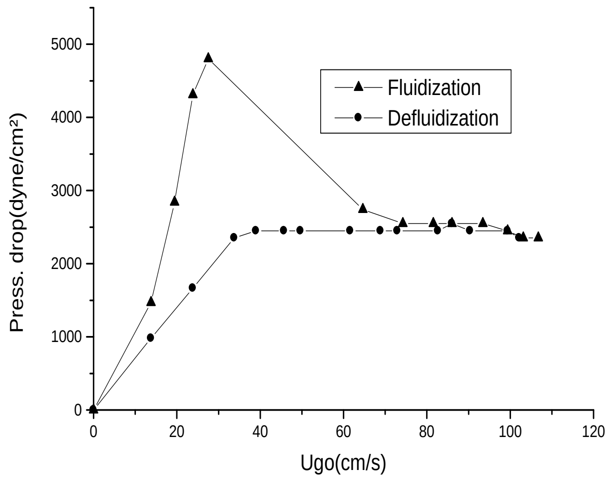


Plot -2: Effect of superficial gas velocity on pressure drop in conical bed for flour

In the coarse particle fluidization, three distinct regimes were observed in the increasing fluid velocity cycle [11]. These regimes are of fixed bed, partially fluidized bed and fully fluidized bed. In the case of fluidization of flour, for the cases where it could be fluidized, the regime of partial fluidization has not been identified and observed. Thus during increasing fluid velocity cycle, after the fixed bed regime the initiation of fully fluidized bed regime takes place.



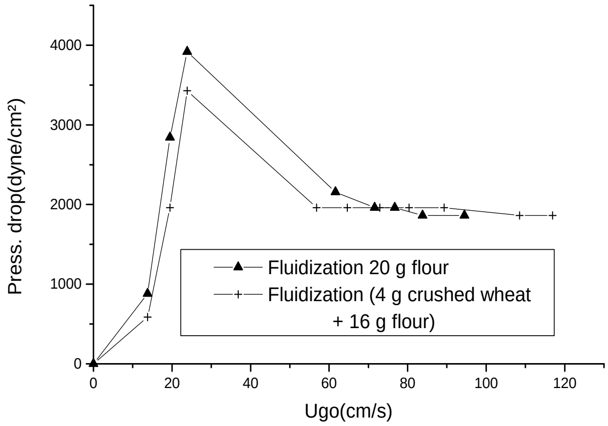
Plot -3: Effect of superficial gas velocity on pressure drop in conical bed for flour



Plot -4: Effect of superficial gas velocity on pressure drop in conical bed for flour (bed height of 6 cm)

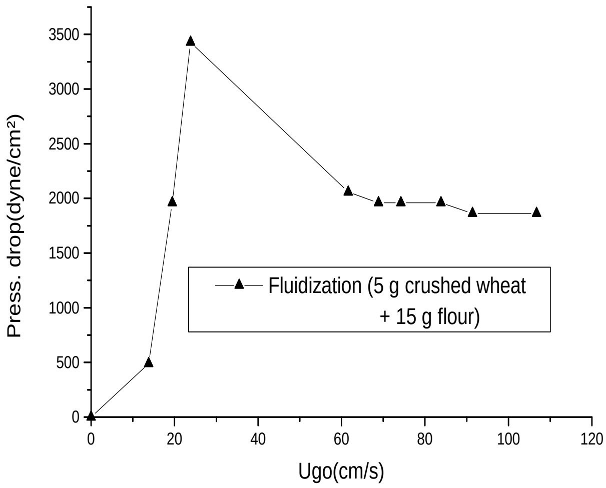
Plot 4 is showing the fluidization behavior as well as the de-fluidization behavior for a stagnant bed height of 6 cm and approximate weight of flour amounting to 25 gram. It was observed that difficulty of fluidization increased with increased bed height and proper fluidization could be achieved even with more less number of times. When height of the flour bed was increased from 5 cm to 6 cm, pressure drop as well as minimum fluidization velocity increased.

For smooth fluidization of flour, crushed wheat was added to it in different ratios. Observation was made regarding the settling of crushed wheat at bottom along with the value of superficial gas velocity. Any entrainment of flour out from the bed was also noticed for these ratios. After these preliminary runs, crushed wheat was added in three different proportions for stagnant bed height of 5 cm and total weight of 20 gram. The proportions of crushed wheat were 15%, 20% and 25% amounting to 3, 4 and 5 gram with flour quantities of 17, 16 and 15 gram respectively.

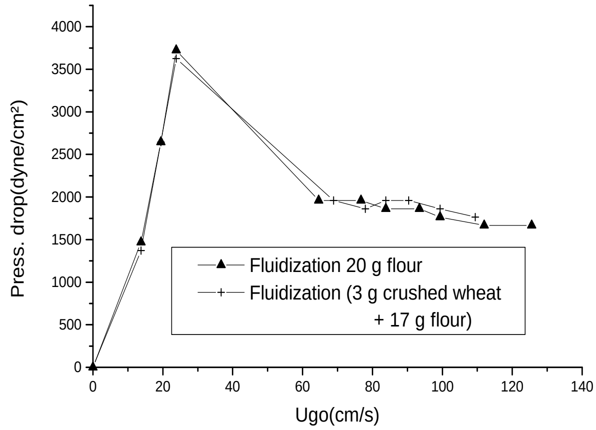


Plot -5: Variation of bed pressure drop with superficial velocity showing effect of additive

Fluidization of mixture of crushed wheat as additive and commercial flour was compared with fluidization of plain flour. When compared with plain flour (20 gram total weight), the maximum pressure drop was reduced in the case when crushed wheat was mixed as an additive in commercial plain flour. These observations are clear from plots 5 and 6 as shown. As can be observed from plot 5, with 4 gram crushed wheat in 16 gram of flour, the fluidization characteristic remain almost similar, whereas the maximum pressure drop has been reduced. This is also established with the fluidization parameters observed as shown in plot 6 during the increasing fluid velocity cycle. Here the amount of additive crushed wheat is 5 gram in 15 gram flour. As an important finding, reduction in pressure drop is observed with the addition of additive.



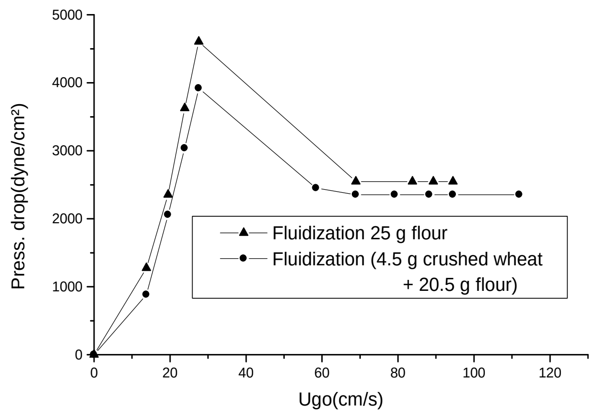
Plot -6: Variation of bed pressure drop with superficial velocity showing effect of additive



Plot -7: Variation of bed pressure drop with superficial velocity showing effect of additive

At 15% mixture of crushed wheat as additive in flour, the fluidization behavior of plain flour alone was nearly similar to that of the mixture with additive. This observation becomes clear as shown in plot 7. With the proportion of 30% of crushed wheat in the mixture, it was observed that the additive starts settling at bottom and with the further increase in the superficial gas velocity chances of flour getting elutriated out from the bed initiates. With these observations, it becomes clear that the additive can be added for improvement in operational characteristics within a specific quantity range.

The reduction in pressure drop has been further observed with the total weight of 25 gram. In this 15% crushed wheat was added as additive. Here the mixture composed of 4.5 g crushed wheat and 20.5 g flour. This mixture was fluidized and results were compared with plain flour (25 gram total weight). Here also it was further established that the maximum pressure drop was reduced when crushed wheat was mixed as an additive to plain flour as shown in plot 8.



Plot -8: Variation of bed pressure drop with superficial velocity showing effect of additive

5. CONCLUSIONS

For the coarse particles fluidization, the experimental results have shown that the bed cone angle and the particle bed height are the main factors influencing the regime transition. Three different flow regimes that are observed are fixed bed, partially fluidized bed and fully fluidized bed in the increasing fluid velocity cycle. In the decreasing fluid velocity cycle the pressure drop decreases continuously. The results have been already elaborated by the author [11]. For the case of fluidization of flour, when the runs were carried out for plain flour alone, it was observed that proper fluidization was achieved at nearly 40% of the total runs carried out including preliminary trials. In the cases where proper fluidization was not achieved, there was plug formation, bed disruption with subsequent fluidization, or initial channeling and pressure drop fluctuations.

Under the cases when flour fluidized smoothly, the regimes which were observed were fixed bed and fluidized bed. Partially fluidized bed regime disappeared in these cases. The fluidization of flour was smooth and there was decrease in pressure drop when crushed wheat was added to it in the proportions ranging from 15% to 25%. It was observed that the circulation in beds of the mixture along with additive was more extensive and more rapid and it appeared to offer less resistance to flow than flour alone. Thus additive has improved the fluidization characteristics of somewhat cohesive and fine character material.

Studies can also be carried out at different cone angles of the two-dimensional tapered bed. A comparative study can also be carried out in a three dimensional bed. With the useful results obtained the set-up can be scaled up for detailed analysis and further results in terms of application. The material produced by first break grinding, the first step in flour milling can be taken up for fluidization and entrainment studies.

ACKNOWLEDGEMENT

Technical suggestions received from Prof. D. Subba Rao and Prof. B. P. Mani, who have been with IIT, Delhi are acknowledged herewith. Co-operation received from staff of fluid flow lab as well as powder technology lab of chemical Engineering Department, IIT, Delhi is duly acknowledged.

REFERENCES

[1] Y. Peng, L. T. Fan, "Hydrodynamics characteristics of fluidization in liquid-solid tapered beds", Chem. Engg. Science, vol. 53(3), 1997, 2277-2290.

[2] D. C. Sau, S. Mohanty, K. C. Biswal, "Prediction of critical fluidization velocity and maximum bed pressure drop for binary mixture of regular particles in gas-solid tapered fluidized beds", Chemical Engg. and Processing, vol. 47, 2008, 2114-2120.

[3] K. C. Biswal, T. Bhowmik, G.K. Roy, "Prediction of pressure drop for a conical fixed bed of spherical particles in gas-solid systems", The Chem. Engg. Journal, vol. 29, 1984, 47-50.

[4] Y. F. Shi, Y. S. Yu, L. T. Fan, "Incipient fluidization condition for a tapered fluidized bed", Ind. Engg. Chem. Fundam., vol. 23, 1984, 484-489.

[5] K. Ridgway, "The tapered fluidized bed- a new processing tool", Chem. Process Engg., vol. 6, 1965, 317-321.

[6] D. C. Sau, S. Mohanty, K. C. Biswal, "Minimum fluidization velocities and maximum bed pressure drops for gas-solid tapered fluidized beds", Chemical Engg. Journal, vol. 132, 2007, 151-157.

[7] T. Zhou, H. Li, "Force balance modeling for agglomerating fluidization of cohesive particles", Powder Tech., vol. 111, 2000, 60

[8] T. Zhou, H. Li, "Effect of adding different size particles on fluidization of cohesive particles", Powder Tech., vol. 102, 1999, 215

[9] S. Jing, Q. Hu, J. Wang, Y. Jin, "Fluidization of coarse particles in gas-solid conical beds", Chem. Engg. and Processing, vol. 39, 2000, 379-387.

[10] S. Jing, C. Guobin, M. Fan, B. Yu, J. Wang, Y. Jin, "Fluidization of fine particles in conical beds", Powder Tech., vol. 118, 2001, 271-274.

[11] R. Katiyar, “Conical fluidized beds – Case study for a gas solid system involving coarse particles”, International Research Journal of Engg. and Tech., vol. 4(10), 2017, 864-869.

BIOGRAPHY

Author is M.Tech. and PhD from IIT, Delhi, India. His research areas are focused on product development, particle processing, natural products extraction and towards up-gradation of material and composite properties.