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A Comparative Study on Fluidization Characteristics of Coarse and Fine Particles in a Gas - Solid Fluidized Bed: CFD Analysis

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Abstract*— Hydrodynamics of a two - dimensional gas – solid fluidized bed are studied experimentally and computationally for coarse and fine particles. The experiments are carried out to observe the bed dynamics namely pressure drop across the bed, the minimum and maximum heights of the expanded bed which are attained during the fluidization process. CFD simulation is also carried out by using commercial CFD software package, Fluent 13.0. The model parameters such as Gidaspow drag model, 0.9 value of restitution coefficient of particles, 0.001 convergence criterion, and first-order discretization schemes has been used. The experimental and CFD simulated results are compared with each other for pressure drop variations and bed height changes. The comparison shows a close approximation between the simulated and experimental results. It is observed that the proposed model is able to capture the gas - solid flow features existing within the fluidized bed.

Keywords: **CFD Modeling, Gas – solid flow patterns, Pressure drop, Local voidage profiles.**

I. INTRODUCTION

Fluidization is one of the best ways of interacting solid particles with fluids. Some of the important variables affecting the quality of fluidization are fluid flow rate, particle size, density of bed materials, fluid density, static bed height and column diameter. Fluidized beds have found extensive industrial applications due to the advantage of better fluid - solid contact [1]. But the complex flow behavior of gas – solid flow in these systems makes flow modelling a challenging task. The mathematical complexities of the non - linear equations (for example defining the interpenetrating and moving - phase boundaries) make numerical solutions very difficult. CFD is one of the branches of fluid mechanics which uses both numerical methods and algorithms to solve and analyze problems that involve fluid flows. That is why CFD is said to be a very promising new tool in modelling hydrodynamics of fluidized bed. Thus with CFD modelling bed dynamics for fluidization process can be studied thoroughly. Coarse and fine particles behave differently in the fluidized bed. That is why it is essential to know fluidization characteristics of both coarse and fine particles before using these materials in the industrial units of fluidization process. The present work emphasizes on coarse and fine particle fluidizations both experimentally and computationally.

II. LITERATURE

As the particle size decreases the cohesive force of particles increases. The fine particles also exhibit problems like plugging, disrupting, agglomerating, bubbling, channeling [1]. As a result, the fluidization of fine particles becomes more difficult in comparison with the larger sized particles. Thus there is need for the development of a reliable technique to improve the quality of fluidization for fine particles. Proper fluidization may be achieved by use of external force or by altering the intrinsic properties of particles. Bed expansion using fine powders with high aspect ratio investigated [2]. Fluidization of fine particles [3] under reduced pressures where only the upper part of the bed is fluidized and the rest remained quiescent and also determined the minimum fluidization velocity. Experiments on the fluidization using fine particles (0.01-18.1 µm) where particle agglomerates are varied in sizes from the largest at the bottom of the bed to the smallest at the top [4]. Uniform fluidization of fine particles (≤ 50

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μm) by the hydraulic resistance of the bed [5] and measured the quality of fluidization as a function of its height and the rotational speed of the mixer used during the fluidization process. Investigation on the effects of vibration / sound amplifier / cross flow magnetic field on the quality of fluidization for fine particles [6] – [8].

Computational Fluid Dynamics (CFD) is a powerful tool to predict the fluid behaviour i.e. to predict the accurate flow and other characteristics of fluidized bed required for design, scale up and optimization purpose. CFD simulations of multiphase flow are based on either the Lagrangian – Eulerian (LE) or the Eulerian – Eulerian (EE) approach. In the EE approach is more appropriate for fluidized bed that forms the basis for popular gas – solid CFD codes, averaged equations for mass, momentum and energy are written for both the solid and fluid phases, with coupling terms that represent interphase interactions. Simulated fluidized beds have been carried out [9] by using the discrete element method for the particles and the finite volume method for the fluid. Experimental and computational studies have been conducted [10] for hydrodynamics of gas – solid flows in a fluidized bed reactor.

The governing equations of the gas - solid flow include the conservation of mass, momentum, and energy which is based on the Eularian – Eularian (EE) model are used for CFD simulation. The volume fractions of the phases sum to one i.e.

$$\varepsilon_g + \varepsilon_s = 1 \qquad (1)$$

The continuity equation for gas and solid phases in the absence of inter-phase mass transfer are respectively given as

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g\right) + \nabla\left(\varepsilon_g \rho_g u_g\right) = 0 \qquad (2)$$

$$\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s\right) + \nabla\left(\varepsilon_s \rho_s u_s\right) = 0 \qquad (3)$$

The conservation of momentum for the gas and solid phases are described by

$$\frac{\partial}{\partial t}\left(\rho_g \varepsilon_g u_g\right) + \nabla\left(\rho_g \varepsilon_g u_g u_g\right) = -\varepsilon_g \nabla p + \nabla \tau_g + \rho_g \varepsilon_g g + F_{i,g} \qquad (4)$$

$$\frac{\partial}{\partial t}\left(\rho_s \varepsilon_s u_s\right) + \nabla\left(\rho_s \varepsilon_s u_s u_s\right) = -\varepsilon_s \nabla p - \nabla p_s + \nabla \tau_s + \rho_s \varepsilon_s g + F_{i,s} \qquad (5)$$

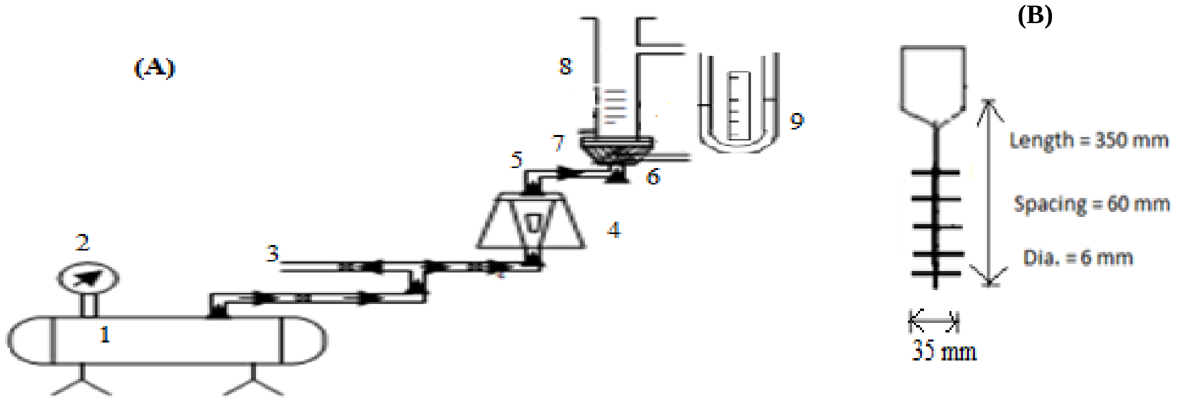
III. EXPERIMENTATION

The fluidization characteristics of coarse / fine particles are studied in a cylindrical column which is made up of Perspex material as shown in Fig. - 1(A). A wire mesh and filter cloth with openings of 40 microns are used as the distributors for coarse and fine particles respectively. Distributors are tightly attached to the column. Gasket is used in between two faces of flange, so that there is no leakage of air. The calming section is packed with spherical glass beads of size 5 mm for uniform distribution of fluid to avoid channeling. The Rotameter and U-tube manometer are connected to the fluidizer as shown in Fig. - 1 (A) for measuring the flow rate of air and the pressure drop across the bed respectively. A stirrer (rod promoter) is used inside the column to provide constant agitation to the bed of fine particles. This rod promoter is hanged from the top of the column and is allowed to rotate by a 5-hp motor as shown in Fig. - 1(B).

The material is taken inside the bed upto certain height. Air is used as the fluidizing medium and then supplied from the bottom of the column through the distributor till all the bed materials fluidize at the ambient condition. The air flow is increased gradually, Rotameter and manometer readings are noted down for air flow rate and bed pressure drops respectively. The expanded bed heights both maximum and minimum are also noted down at each flow rate of air for both coarse and fine particles. The scope of the experiments is given below in Table-1.

Table – 1: Scope of Experiment for Coarse / Fine Particles

MATERIALS	H_S, cm	d_p, microns	U_0/U_{mf}, m/s
Dolomite (Coarse Particles)	20	$750 * 10^{-6}$	0.7
			0.8
			0.9
			1.0
Alumina Powder (Fine Particles)	16	$63 * 10^{-6}$	0.04
			0.06
			0.08
			0.10



1. Compressor; 2. Pressure gage; 3. By pass valve; 4. Rotameter; 5. Control Valve; 6. Calming section with glass bead packing; 7. Distributor; 8. Fluidizer; 9. U tube manometer

Fig. - 1: Schematic of Experimental unit and Stirrer.

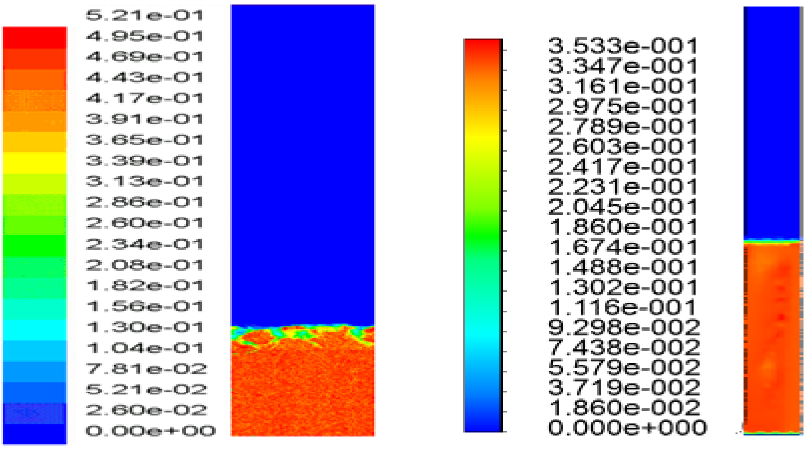
IV. RESULTS AND DISCUSSION

The CFD software package, FLUENT 13 is used to simulate a gas - solid fluidization. Eulerian granular multiphase model is used for modelling the transition nature of bubbling fluidized bed where gas and solid phases are treated as continua interpenetrating and interacting with each other and everywhere in the computational domain. CFD simulation parameters are given in Table – 2. The assumptions like isothermal non-reactive, no lift force, no mass transfer between gas and solid phase, constant pressure gradient and constant density of each phase are considered for CFD simulation.

Table – 2: Parameters used in CFD Simulation for Coarse and Fine Particles

Sample	Dolomite	Alumina Powder
Particle size	$750.1 * 10^{-6}$ m	$63 * 10^{-6}$ m
Particle density	$2.89 * 10^{-3}$ kg/m^3	640 kg/m^3
Initial static bed height	0.20 m	0.16 m
Static bed voidage	0.5	0.9

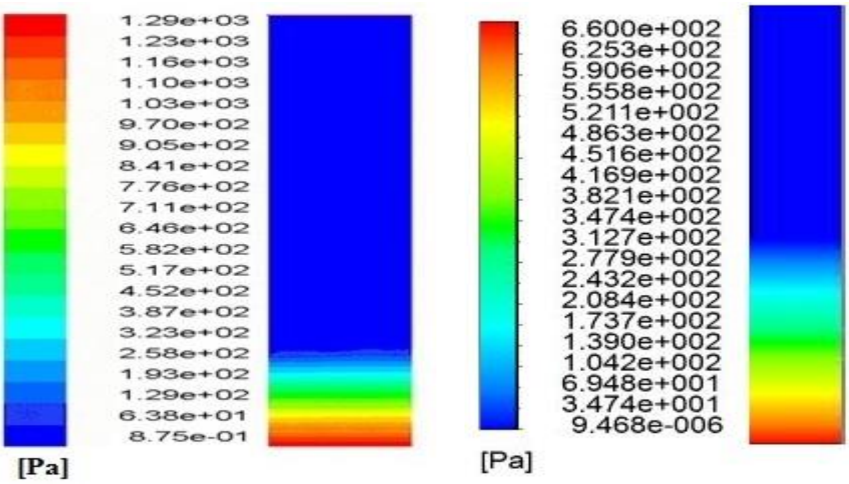
The hydrodynamic behaviors of fluidized bed are analyzed by monitoring the contour plots for volume fraction of bed materials, static pressure of bed, velocity magnitude of fluid etc. The volume fraction of solid phase are also represented in the form of contour plots as shown in Fig. - 2. The contour plot of solid particles (dolomite and alumina powder) illustrated that bed is in fluidized condition. The contour plot of fine particles illustrates that gas hold up is more than the fluidized solid (i.e. volume fraction of solid is less compared to coarse solid particles) in two phase region i.e. gas – solid phase.



COARSE PARTICLES **FINE PARTICLES**

Fig. - 2: Contours of volume fraction of bed materials for coarse and fine particles.

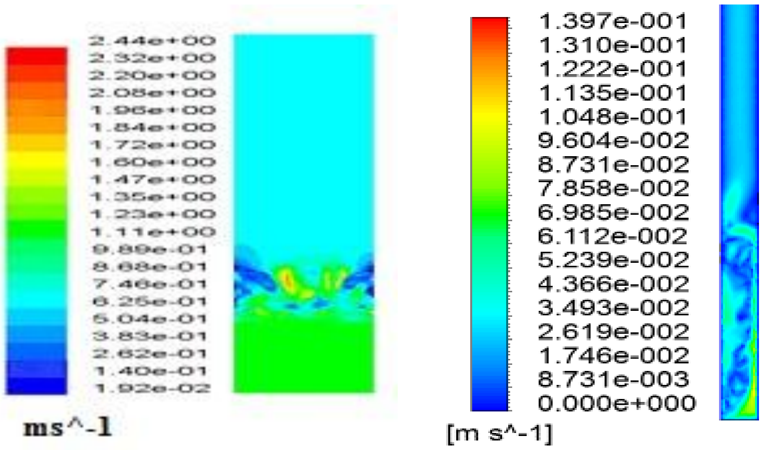
Contours of static pressure for bed materials as showed in Fig. - 3. It is observed that static pressure decreases from 1.29 $*10^3$ Pa to 3.23 $*10^2$ Pa and $6.6*10^2$ Pa to 1.73 $*10^2$ Pa for coarse and fine particles respectively. Once the bed is perfectly fluidized, the static pressure of bed material decreases from bottom to top of bed.



COARSE PARTICLES **FINE PARTICLES**

Fig. - 3: Contours of static pressure of bed materials for coarse and fine particles.

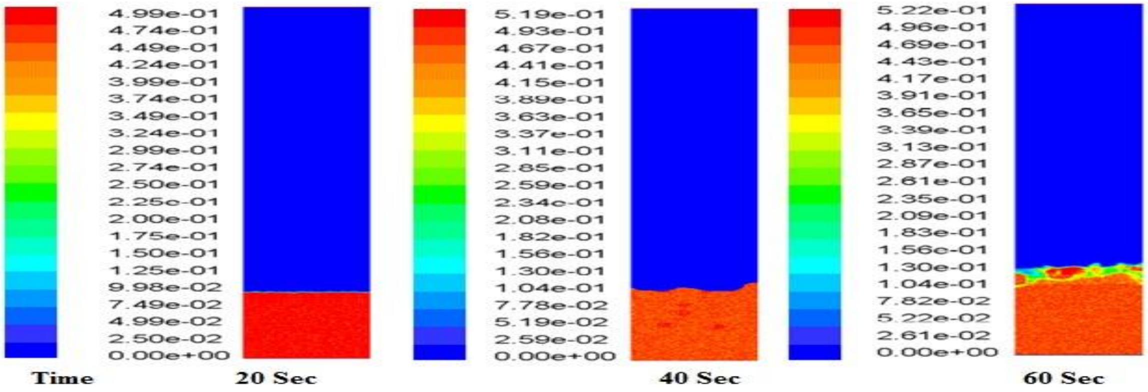
Contours of velocity magnitude vary with superficial velocity of air as shown in Fig. - 4. It is observed that the superficial velocity of air decreases from bottom to top of the bed materials i.e. from 1.11 m/s to 0.38 m/s and 0.052 m/s to 0.017 m/s for coarse and fine particles respectively. It means that bed materials of the column obstruct the movement of air, thereby decreasing the magnitude of air velocity. Finally the air moves upward throughout the column, after achieving fluidization condition.



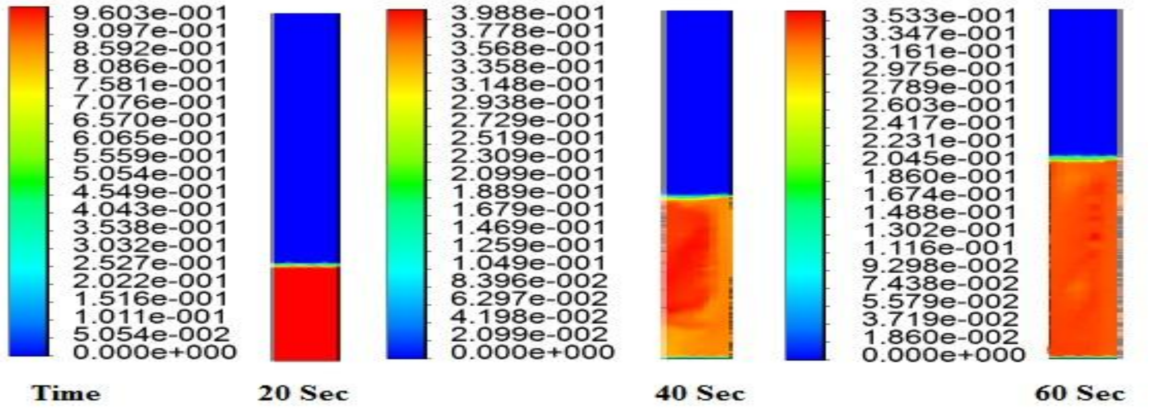
COARSE PARTICLES **FINE PARTICLES**

Fig. – 4: Contours of velocity magnitude of fluid for coarse and fine particles.

Contour plot for variation of bed height or volume fraction of the bed materials with time and gas flow rate as shown in Fig. – 5 and Fig. – 6 respectively. It is observed that bed height of bed materials gradually increases with time at constant air velocity for both cases and also the bed expands with increase in superficial velocity of fluid in both of the cases.

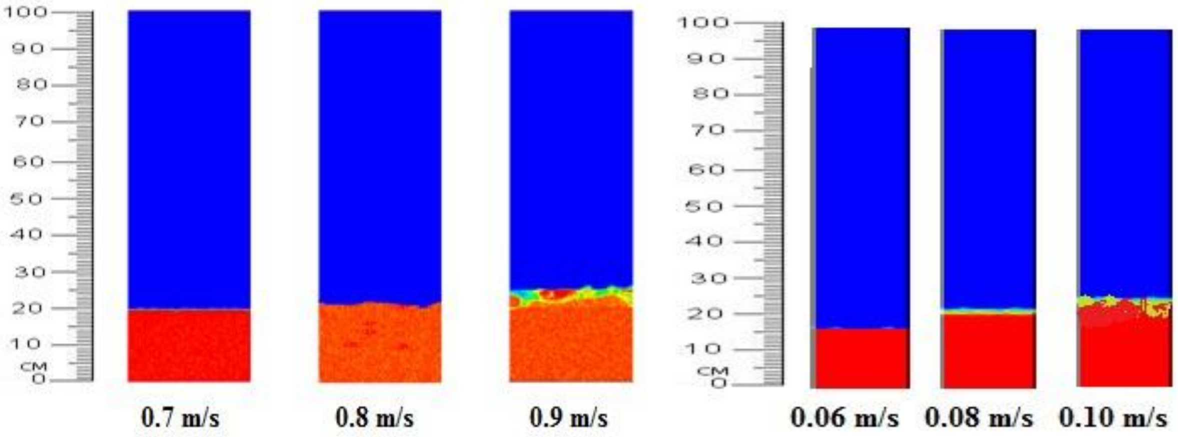


COARSE PARTICLES



FINE PARTICLES

Fig. - 5: Contours of variation of bed height / volume fraction of solids.

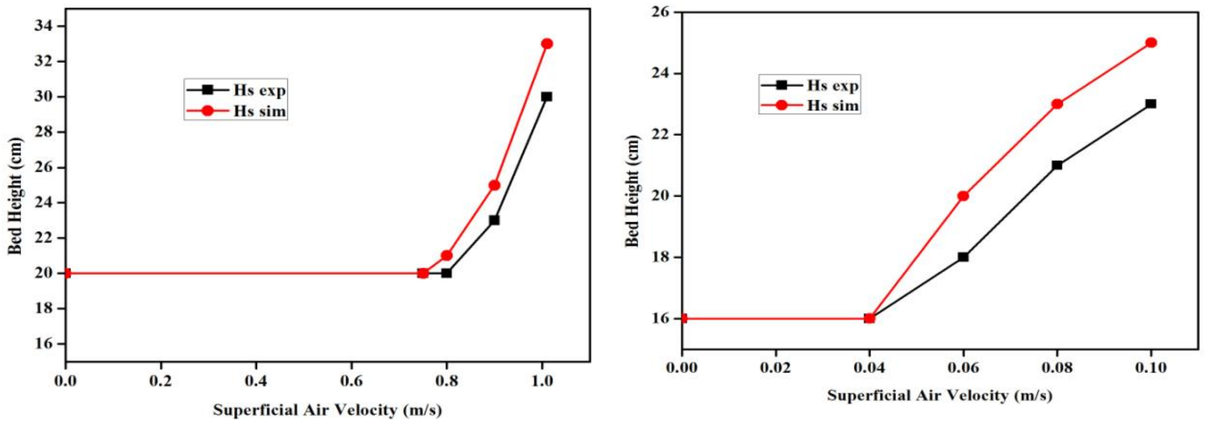


COARSE PARTICLES

FINE PARTICLES

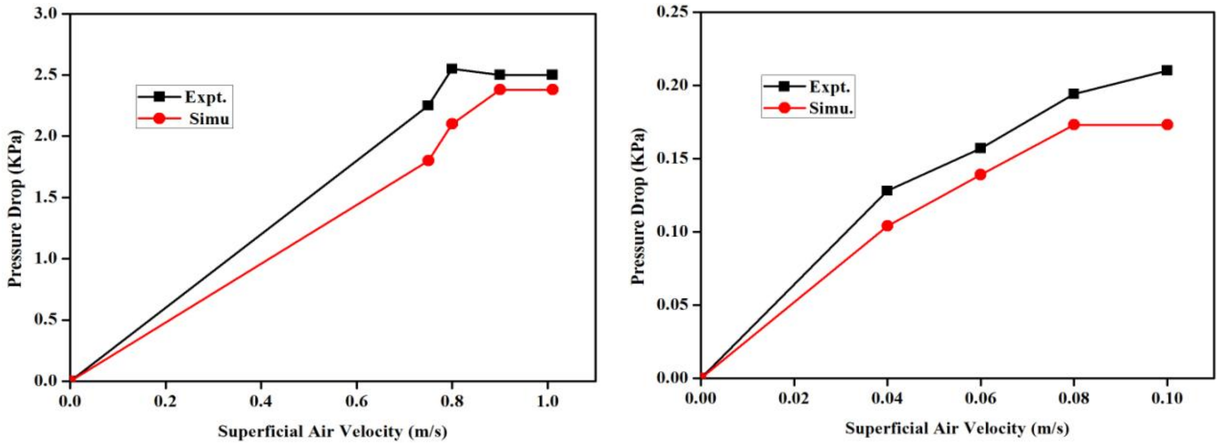
Fig. - 6: Variation of bed height with superficial velocity for coarse and fine particles.

Comparison plot of bed height and pressure drop with superficial air velocity for coarse and fine particles is shown in Fig. -7 and Fig. - 8. The bed height in both cases monotonically increases with superficial velocity and the bed pressure drop increases with increase in superficial velocity up to certain limit after which it remains constant when all the bed materials are fluidized. Similar trends are also observed in simulation of coarse and fine particles for both of the cases. It is also found that simulated results are in good agreement with experimental results with a - 5.3% and - 6.38% deviation (approx.) for bed height and 9.48% and 13.8% deviation (approx.) of pressure drop for coarse particles and fine particles respectively.



COARSE PARTICLES **FINE PARTICLES**

Fig. -7: Variation of bed height with superficial air velocity.



COARSE PARTICLES **FINE PARTICLES**

Fig. - 8: Variation of pressure drop with superficial air velocity for coarse and fine particles.

V. CONCLUSION

Flow behaviors for coarse and fine particles are studied both experimentally and computationally using a commercial CFD software package, FLUENT 13. Computational study is conducted for the same system and information about both flow related phenomena for the gas - solid fluidization is also obtained. These models can suitably be scaled up for pilot plant units or for industrial uses. The knowledge of bed dynamics also gives the fundamentals for optimum design of fluidized bed reactor, gasifiers and combustors, especially in the fixation of bed heights for such units. The experimental and CFD simulated results are compared with respect to pressure drop and bed height variation with superficial gas flow rates (i.e. inlet gas velocity). The result also shows that there is a better agreement between the CFD simulated and experimental results. Thus the knowledge on fluidization characteristics of coarse and fine particles will give information for improving the performance / efficiency of industrial fluidization unit.

NOMENCLATURE

ϵ	Volume Fraction
ρ	Density of Fluid, kg/m^3
u	Velocity, m/s
τ	Stress-strain Tensor, Pa
g	Acceleration due to Gravity, m/s^2
F	Force

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