Mechanical Agitation of Bed In A Motor Driven Two-Phase Fluidized Bed Particle Seeder

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Abstract—**Solid-gas Fluidization generally pertains to particle-laden flows wherein seed particles of desired size are dispersed in a fluid volume inside a fluidized bed seeder. The present work includes numerical investigation of a simple non-reacting and non-restricted two-phase fluidized bed followed by the experimental analysis of a fabricated non-reacting two-phase fluidized bed seeder. Void fraction of the bed is maintained as 0.53 throughout the analyses owing to absence of chemical reactions. Considering the physical significance of a two phase system (namely particles and beads constituting the bed), agitation of the bed and initial turbulence required for smooth particle entrainment in the flow are of paramount importance, as their ineffectiveness adversely affects the flow physics and measures adopted explain the revamping done in this section. The major drawbacks of agglomerate formation and particle stagnation faced by a two-phase fluidized bed seeder are also relatively minimized. The following paper is presented with a view of articulating the benefits of the fabricated two-phase seeder and also the dependency of experimental analysis on the percentage of bed rise, which is obtained numerically.**

Keywords— **Fluidization, multi-phase flow, two-phase fluidized bed, agglomerate**

I. Introduction

Fluidization is an interdisciplinary research with the prime field being Fluid Mechanics. Particles are to be entrained in the flow in a proper manner such that they faithfully follow the flow. In fluidization, the prime focus is the particles used for seeding and fluidized beds ensure their proper entrainment in the flow without stagnation or momentum distortion. The effectiveness of this process depends on various critical parameters, like the gravitational settling velocity of the particle which in turn depends on its size and physical properties, superficial velocity of the fluid, void fraction, viscosity of the fluid and turbulence. [1] In a fluidized bed, fluidization occurs only when the following Stokes' Settling condition is satisfied:

$$w_s = \frac{2(\rho_s - \rho_f)gr^2}{9\mu}$$

for laminar flows, and

$$w_s = \left[\frac{3(\rho_s - \rho_f)g\,d_p}{\rho}\right]^{\frac{1}{3}}$$

for turbulent flows.

This implies that the velocity of the fluid from below should be far greater than the settling velocity of the particle, for laminar and turbulent flows respectively.

However, in two-phase packing, an additional restraint is imposed by the bead phase. Because of the restriction on the rise of the beads, the inlet velocity should be less than the settling velocity of the beads — this means that the velocity is closed on the domain.

$$V_{inlet}\ \varepsilon\ (W_{s,particle}, W_{s,bead})$$

On a broader perspective, fluidized beds can be classified into two categories based on the constituents that form the bed namely single–phase fluidized bed seeder and two-phase fluidized bed seeder. The latter has its own advantages and is lot more challenging to explore than the former and the subject of this work. Existence of two solid phases namely particles and beads in this type of Fluidized beds is a tricky characteristic as one phase (the particle) has to be carried with the flow and the other (bead) has to merely facilitate the process.

In such a scenario, it is imperative that the beads must be vastly dense than its counterpart. Particles, on the other hand, must be of very small size so that they trace the flow field faithfully. As a result, stainless steel balls (1mm diameter) and turmeric powder are used as beads and particles respectively in the present work and is further explained in the subsequent sections.

A major concern in a popular two–phase fluidized bed seeder is the potential back flow of particles during the agitation of the bed caused by the air flow from a counter flow pipe fit inside the seeder. [2] This problem is eradicated in the present work by the usage of motor-driven blades, which are housed inside the seeder via different transmission elements like gears, shafts etc. These motor–driven blades cause substantial agitation of the bed and preclude the potential back flow. Details on this are discussed in Section II. Furthermore, the fluid carries the particles due to pure vertical momentum thereby promoting high agglomeration rates due to the high particle surface charge combined with high particle–to–particle contact. [3]

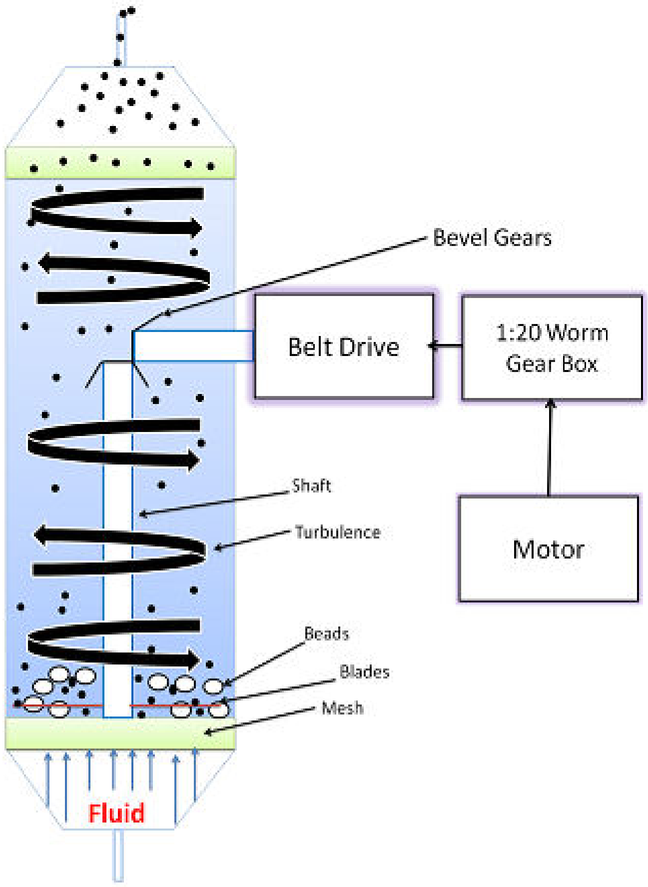

Fig. 1. Schematic of the Seeder Setup

This is overcome by the usage of stainless steel mesh in the following work which has a dual function of having the particles & beads and triggering the much needed turbulence in the flow downstream for enhancing particle laden flow.

The focal objectives of the following paper are to highlight:
1) Problems in the existing agitation mechanism (counter flow pipe) and the use of a new mechanism (motor-driven blades) for agitation of the bed.
2) Positive effects of using motor-driven blades for experimental analysis.
3) Numerical significance of bed rise during agitation and its requirement for the experimental analysis.

II. MECHANICAL AGITATION OF THE BED USING MOTOR-DRIVEN BLADES

The mechanical agitation system consists of a motor, coupled with gear and belt drives, mounted on bushes. The mechanical agitation is caused by blades inside the seeder, transforming the vertical momentum of the flow over the radial direction and causing the agitation by the combined effects of the lift and rotation. Figure 1 shows the Schematic of the Experimental Test Setup. The rotation of blades is significant in ascertaining the level of agitation as it depends on the orientation of the blades and the speed of rotation. Inclined

Fig. 2. The Mechanical Agitation Setup, with Blade Mounting

alignment of the blades, facing upwards is a requisite for enhanced agitation. This also creates a swirl flow which enhances the particle lifting. [4]

A. Design Considerations

Design of the agitation mechanism is a bottom–up strategy as the central objective of this mechanism is to rotate the blades at the desired speed in order to generate the essential swirl for better particle entrainment. As seen in the diagram, components of agitation mechanism consist of blades, shafts, gears, reduction drives and motor. Acceptable blade speed is determined by trial and error method and found to be in the range of 75-90rpm. Exclusive blade profile is not separately designed due to time constraints. Instead, knives (daily-use knives without the handles) with their sharp edges are used as blades.

The blades are present exactly at the center of the bed to provide uniform agitation to the beads. Knives exhibit a “cutting” effect at high rotational speeds and as a result low speed and high torque of the blades are desired inside the seeder.

B. Turbulent Regime

When the fluid comes in contact with the bed, turbulent nature of the flow is essential to lift the particles in a random manner throughout the bed to preclude particle stagnation. The transition of the flow to turbulent takes place through the mesh placed inside the seeder. Three meshes of varying grades are stacked in layers, above the seeder base to ensure proper and sustained turbulence as the fluid reaches the bed. Moreover, a very fine grade mesh is the topmost layer as it forms the bed comprising of particles and beads. Apart from the three meshes stacked on top of each other from the seeder base, another mesh is placed near the seeder outlet to create a counteracting turbulence and ensure fine particle dispersion. Essentially, this mesh is employed to eliminate the swirl of the flow caused due to the internal rotating members. Hence, local turbulence is essential for randomness throughout the bed.

Fig. 3. The Mesh Setup at the base of the Bed, without the Gear Setup

III. NUMERICAL ANALYSIS

The commercial CFD Software ANSYS Fluent is used for the numerical analysis of the Seeder. Due to paucity of computational resources, the fluidized bed was modeled neglecting the agitation mechanism used. The problem setup was carried out in 2-D, which gave an appreciable result equivalent to the 3-D counterpart. Since, the setup is axisymmetric, the 2-D model gives an axial mid-section profile that can be extended to the 3-D model. The next approximation is the absence of seed particles in the flow. The seed particles are assumed to be finely ground (to approximately 20 microns size), under which circumstances, they are assumed to faithfully follow the flow. On the other hand, beads are of steel and each having a diameter of 1mm.

A. Problem Setup

The Eulerian multi-phase model is used for simulating the numerical model. It solves a set of n momentum and continuity equations for each phase. Coupling is achieved through the pressure and interface exchange coefficients. The Fluidized bed equation solved is:

$$\frac{\Delta P}{L} = g(\rho_s - \rho_f) = \frac{1.75 \rho u_f^2}{d_p \varepsilon^3} + \frac{150\mu(1-\varepsilon)u_f}{d_p^2 \varepsilon^3}$$

This model is coupled with realizable k - ε model, which provides the turbulence (with the turbulence in the actual setup being initiated by the wire-mesh attached below the solid phase bed). The mixture k - ε model solves coupled turbulence along with the momentum and continuity equations for each phase separately. [5] The Syamlal–O'Brien Drag Law is used for the bead phase. [6]

B. Solver Settings & Constraints

Eulerian Multiphase model and k – ε Turbulence models are coupled; the solver is a Pressure-Velocity coupled solver, the

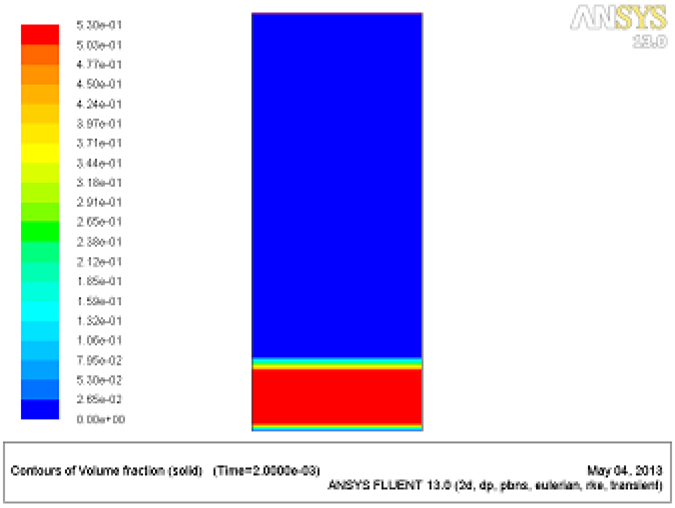

Fig. 4. Initial Contour of the Bed, 2nd Time Step

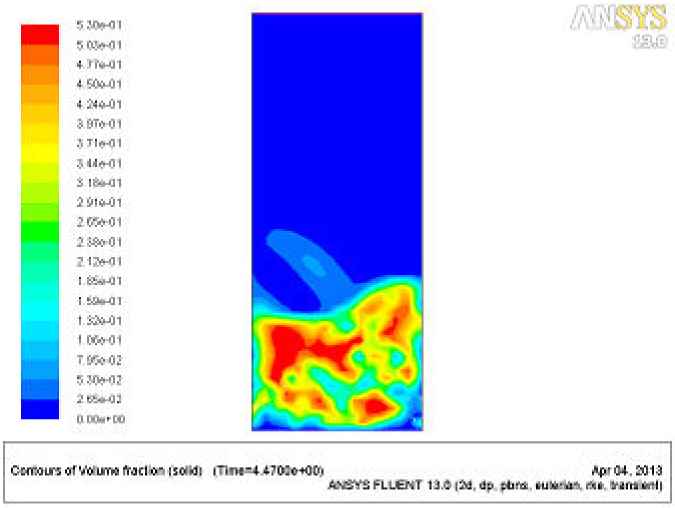

Fig. 5. Contour at 4:470s, showing the gas escape and agglomerates

Phase-coupled SIMPLE Solver. The Gradient uses a Least Square Cell-based Solver, while the Momentum, Volume Fraction, Turbulence Kinetic Energy and the Turbulence Dissipation Rate are all solved using First Order Upwind methods. First Order Implicit transient case formulation with Standard Initialization is used.

C. Simulation Results

The simulation is carried out with a time step size of 0.001s. The initial contour of the bed is displayed as a volume fraction contour in the figure. The bed height is 15cm, with the entire chamber height being 56cm, with a diameter of 25cm. Figure 4 is generated at the second time step of 0:002s, at the start of the simulation. Figure 5 shows a high dispersion of the solid in the bed region, with random distribution of the gas volume and smaller agglomerate regions of the solid. The top part of the bed also shows a clear picture of gas release from the bed region. Figure 6 shows a bed rise of more than 100%, with the

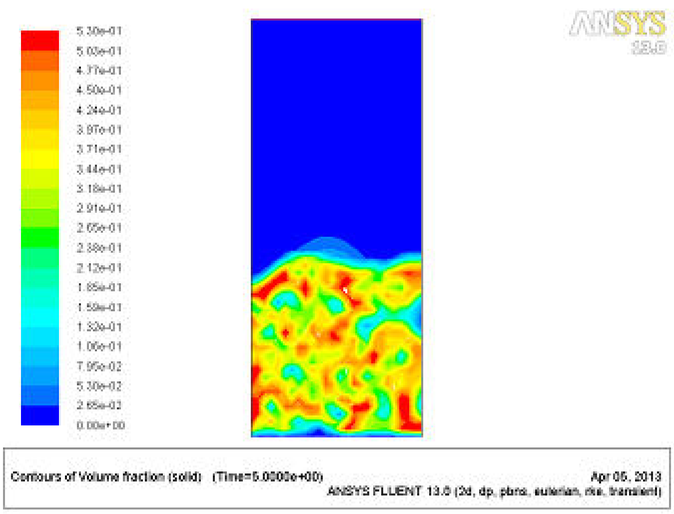

Fig. 6. Contour at 5:000s, showing a 100% bed rise

gas hold up and dispersion delineated. Higher gas hold–up is usually a necessity for particle entrainment into the flow, since sufficient time is required for momentum transfer between the phases. [7] The bed rise is a prerequisite for determining experimental data as it decides the position of the elements of the agitation mechanism. Details on this are discussed in the next section. Also, it imposes a constraint to the speed of rotation of the blades. As seen earlier, the bed rise is solely due to the incoming fluid flow in the numerical model analyzed here.

IV. EXPERIMENTAL ANALYSIS

The two-phase fluidized bed seeder, shown in figure 7 is used for determining experimental data. As described earlier, experimental analysis delineates the spraying of a solid (the particle) over a surface and hence determines the fineness in their dispersion. From the discharge of the compressor, the velocity at the seeder inlet is calculated and shown in table I. The pressure at the seeder outlet is atmospheric pressure.

As the fluid flows vertically upwards through the seeder, along with the particles, its pressure energy is converted to kinetic energy and the flow, entrained with particles, comes out of the seeder outlet at atmospheric pressure.

To carry out the experimental analysis, proper positioning of various elements of the agitation mechanism is mandatory. Bevel gears, which are mounted on the shafts, have to be installed at a proper height from the seeder base. The height is calculated from the numerical simulation of the bed rise in the contours of solid volume fraction discussed in the previous section. The percentage of bed rise gives the idea of the maximum height reached by the steel balls on a numerical basis. The height of fixture of the bevel gears is then arbitrarily taken as 1.5 times the height numerically reached by the steel balls due to the additional rise that comes from the presence of motor-driven blades. After the installation of the gears at the required height, the experimental output is determined.

Fig. 7. Experimental Test Setup

TABLE I
COMPRESSION POWER VS DISPERSION

S.No	Mass flow rate (kg/s)	Inlet Velocity (m/s)	Outlet Pressure (bar)	Dispersion Area (sq m)
1	0.0024	0.0634	1	10.54
2	0.0051	0.1347	3	24.63

The experimental output is the measure of fineness of particle dispersion on a filter paper considered here. In the present work, dispersion area obtained experimentally directly reflects the fineness in particle dispersion.

Turmeric powder is used as particles for two main reasons namely its fine size and visibility. Moreover, it also turns red in water which further aids in examining the flow field in a general view. Also, due to the ease of visibility, its fineness in dispersion is also calculated with considerable ease.

A. Compressor Power vs. Particle Dispersion

The fineness in particle dispersion of the seeder on the filter paper surface is compared by using two compressors of starkly different power.

From figure 8, the biased particle dispersion is clearly observed due to its large concentration on the center of the filter paper surface. This is accounted for the inadequate pressure at the inlet of the seeder, which in turn causes particle stagnation in the bed, thereby serving as a hindrance for smooth particle entrainment in the flow.

Whereas, in figure 9, the particle dispersion is smooth and fine throughout the surface of the filter paper. This is accounted for the increased compressor power which relatively minimizes particle stagnation and ensures uniform lifting of particles throughout the bed thereby enhancing the fineness in particle dispersion by increasing the dispersion area. The areas of dispersion in table I are seen from the outlet at 5seconds exposure of the filter paper to the outlet. Apart from the smooth particle entrainment and fine particle dispersion, particle deposition on the internal elements of the agitation mechanism is found to be more significant in the

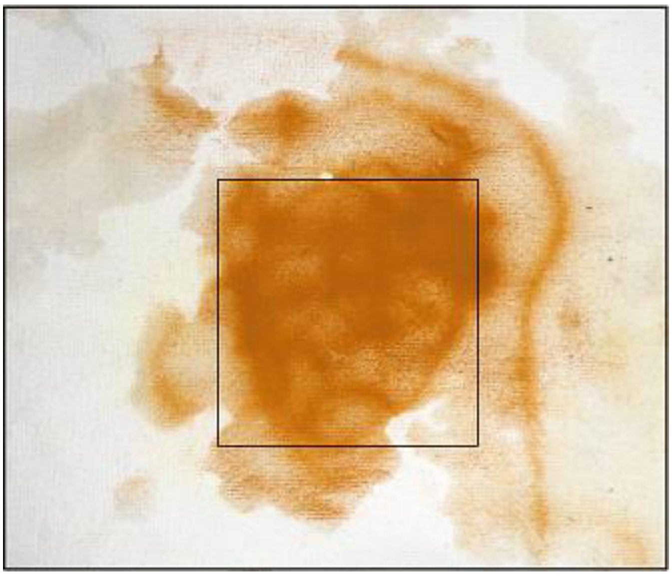

Fig. 8. Non-uniform Particle Dispersion with low-power compressor

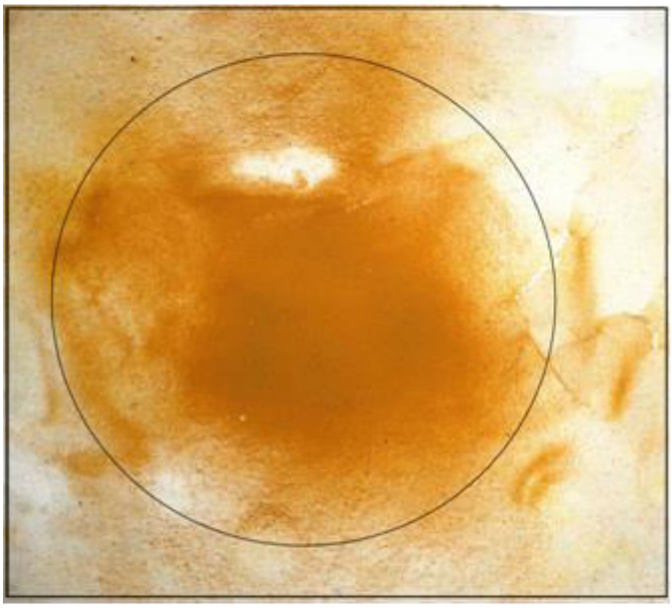

Fig 9. Uniform Particle Dispersion with a high-power compressor

latter than in the former. This demands periodic cleaning of the internal elements of the seeder.

V. CONCLUSION

The problems faced by a conventional two-phase fluidized bed seeder are tackled by revamping the mechanism used for agitation of the bed, as well as the base of the bed. The transformation of vertical momentum across the radial direction takes place due to the motor-driven blades, which is the net effect of the agitation mechanism on the flow. This momentum dispersion improves the bed rise.

The particle dispersion is enhanced as a function of increased dispersion over a larger area. The base of the bed which is made up of a series of meshes of different grades creates a local turbulent regime in an otherwise slug flow, facilitate random particle entrainment in the flow and simultaneously preclude particle stagnation in the bed. The percentage of bed rise as obtained from the simulations is used as a parameter to design the agitation mechanism.

Lastly, the performance of the seeder is compared using two compressors of varying pressures, and it is found that higher-power compressors provide more bed agitation, more bead friction, and hence, a greater dispersion area, with the concern being consequent increased particle deposition on the internal parts of the seeder leading to cleaning at regular intervals.

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