An Experimental and CFD-DEM Study of Spouted Fluidized Bed Heat Exchanger for Non-Spherical Particles

Project Summary:

In the present proposal conical spouted bed with draft tube will studied for non-spherical particles. Experiment and Numerical investigation will be carried out, and non-spherical particles will be generated using multi-sphere methods for numerical studies

The spouted bed is majorly used in the industrial process where the material is susceptible to thermal treatment. The spouted bed offers better mixing and regular circulation of particles, as compared to fluidized bed thus permitting the use of high-temperature fluid without the risk of thermal damage to solid particles. The hydrodynamics region for spouted bed cab characterized into regions: spout, fountain and annulus. Ordinary fluidized bed experiences an oscillatory, more random and more complex flow pattern, on the other hand, particles in the spouted bed move upwards through the spout and come down through the annulus. This particle circulation pattern is an advantage in drying/gasification processes to achieve a uniform heating. Hence, for applications involving particulate solids which are too coarse and uniform in size, spouted bed should be used.

In the current study experiments will be carried out for *Geldart Group D* spherical particles, in a spouted bed. A spouted bed with conical shape base with draft tube and cylindrical column will be investigated. Pressure drop will be measured along the riser and will be measured by a pressure sensor. High speed camera and infrared camera along with thermocouples will be used to measure the hydrodynamics of bed fluidization and data will be generated to validate the simulation results.

Detailed flow-field information cannot be obtained from experiments; hence numerical study will be done to understand the hydrodynamics and heat transfer characteristics between solid and fluid. A coupled Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) approach will be used to track solid-fluid interaction. Non-spherical particles will be modeled based on multi-sphere technique and soft collision model will be used to capture the inter collision of particles and with the bed walls. Novel design of draft tube will be studied for various non-spherical particles to achieve better mixing and fluidization.

The development and understanding of close loop spouted bed with draft tube will pave the way to efficient and commercial use of fluidization in agriculture industry for drying of seed or gasification of biomass industry. Numerical algorithms developed in the current study can be used to study various spouted bed application areas connected to ICAR, India and TERI, India labs.

Objectives:

1. Design and development of experimental procedure for conical shaped spout bed with draft tube to study various non-spherical particles.
2. Development of coupled numerical CFD-DEM algorithm to study spouted bed Fluidization.
3. Study of effect of particle shape on the fluidization and hydrodynamics characteristics in a spouted bed.

4. Development and design of Novel draft tube based on the spout shape for various non-spherical particles.

Keywords: Fluidized Bed, Spouted Bed, Draft Tube, CFD-DEM, Non-Spherical particle

Expected Outcomes:

- The project will have a vital role in understanding the hydrodynamics and thermal behavior of particles in a fluidized state. The work carried out in Objective 1, will give various industries to setup there SFBs with low cost experiment facilities with the use pressure scanners and high speed cameras. This will enable industries to visualize the formation of slugging or any other problems.
- The results obtained from Objective 2 and 3, can be used to do further research and help scale up the SFBs for large industrial process. The results obtained will be able to give insights into the effect of various parameters like: effect of different shapes on fluidization, effect of ratio of inlet jet diameter to particle diameter and fluid velocity on fluidization process, and effect of contactor angle on fluidization. Based on the results building of SFBs for processes which deals in coarse non-spherical particles, like pyrolysis and gasification will be easier.
- Results obtained from Objective 4 will be of great advantage in scaling up the SFB geometry for large industrial processes. Designs of draft tube based on particle shape will help to maximize the spouted bed height thus helping in scaling up the SFBs. Good draft tube design will be able to help better mixing of the particle and reduce the dependence of spouting and fluidization on the contactor angle or jet inlet diameter.

Origin of the Proposal

Fluidization is a process in which solid particles are made to behave like a fluid-state by passing a fluid, at a high velocity, through the particles. An effective fluidized mechanism is required in many industrial processes like combustion, blending, gasification, drying, biomass-pyrolysis, coating, etc. Depending upon the size of the particles and the application area various fluidization devices are used. Spouted Fluidized Beds (SFBs) are majorly used in drying or bio-mass pyrolysis processes where the size of the particles is big and the shape of the particle is not spherical. Typical SFBs consist of a conical base followed by a cylindrical column and the fluid enters from a slot. SFBs have three distinct regions: the central core ***Spout***, the surrounding annular region the ***Annulus***, and the solid above the bed entrained by the spout and then falling into the annulus is referred to as a ***Fountain***. SFBs were first proposed by [1] to couple gas with coarse solids and since then many researchers have worked on various types of SFBs. Due to high thermal and mixing efficiency, it becomes important to understand the physical mechanism of the energy and mass transfer.

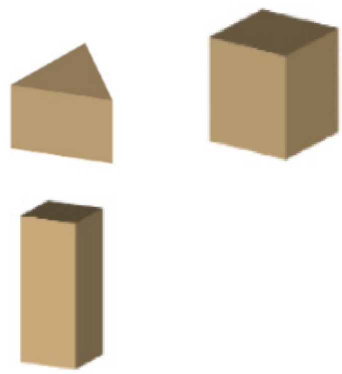
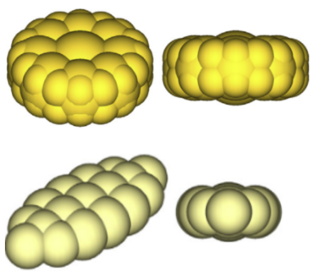
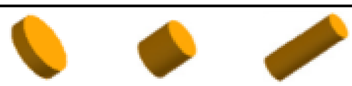
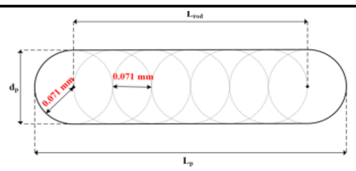
Many industrial processes involve a closed-loop SFB (CSFB) consisting of three main components: the spouted bed with draft, blower with heater and temperature control, and cyclone separator. Solid-fluid interaction only takes place in the spouted bed and the cyclone separator. Hence it becomes important to study both the components to understand and increase the efficiency of the CSFB. The hydrodynamic characteristics in the spouted bed majorly depend on the fluid velocity, particle size, density, and shape. Effect of these parameters can be studied by performing experiments or numerical simulations. Experiments can be performed using various techniques like X-ray tomography, electrical capacitance tomography, particle image velocimetry (PIV), infrared thermography (IR), etc. Among these, PIV coupled with digital image analysis (DIA) is one of the most used experimental procedures. All the techniques mentioned are very expensive techniques. Another way is to perform numerical simulations to understand the fundamental of transfer mechanism of multiphase flow. As the SFBs involve interaction between solid particles and fluid, numerical strategies are broadly classified into two categories discrete or continuum based in regards to solid particles. In the continuum approach, the solid particles are treated as continua, and in the discrete approach, solid particles are treated as discrete elements. The discreet approach, known as CFD-DEM, to model the particles is majorly used due to the theoretical rationality of it. Majority of the studies performed on SFBs are done under cold operating conditions and very few deals with the inner thermal state of SFBs. Further, scaling up SFBs possess challenges due to dependence on particle to inlet jet diameter ratio and contactor angles for conical SFBs. To overcome these problems draft tubes are used, but till now the designing of the draft tube has only considered spherical particles.

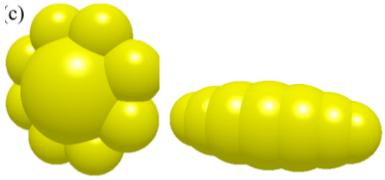
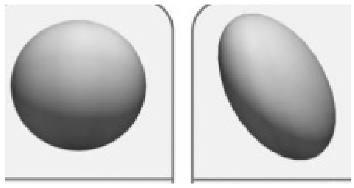
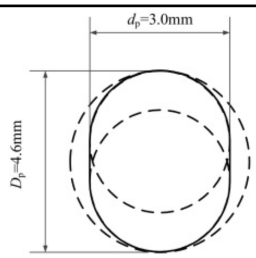
Based on the above-mentioned facts, in this project hydrodynamic characteristic along with the heat transfer mechanism between solid and fluid will be studied for a SFB. Experiments will be performed for a CSFB at atmospheric conditions and the inner thermal state will be calculated using thermo-couples and infrared camera. To investigate the solid-fluid interaction CFD-DEM modeling will be used in a conical spouted bed with non-spherical particles. Draft tube will be used to enhance the efficiency of mixing process and will be designed based on the spout shape for various non-spherical particles, so that scale up of the SFBs can be achieved.

Review of the status of Research and Development in the subject

Due to the high fluid-solid interactions in spouted bed, it has found more applicability in industrial processes including greater heat and mass transfer [12, 13]. Understanding the physical characteristics of fluidization in a spouted bed is important to unearth the mass and energy transfer phenomenon between the fluid and solid particles. Based on the research carried over the years, spouted bed has high heat transfer and mixing performance when compared to traditional Fluidized bed [14, 15]. Hence, spouted beds are majorly used for processes comprising high energy transfer, such as drying [16, 17], gasification [18, 19], coating [20-22], energy conversion [23], and pyrolysis [24-26]. Experimental investigations were carried out by many researchers [27, 28] for spouted bed to understand the hydrodynamics of fluidization process and heat transfer.

Further various numerical simulations have been performed using CFD-DEM for spouted fluidized beds [28-31]. All these studied performed, used spherical particle shapes various types of fluidized bed. Conversely phenomenon such as rolling of particle, porosity deviation and segregation of particle mixtures for highly non-spherical particle can't be accounted by using spherical shaped particle. Therefore, studies of various non-spherical particles were also considered and are performed which are mentioned in the table below:

Author's	**Particle Shape**	**Type of Geometry/Bed**	**Remarks**
Liu et al. (2021) [32]		Simulation were performed for Flat Fluidized Bed	Polyhedral particles showed higher degree of motion and mixing as compared to spherical particles for same fluidization gas velocity.
Liu et al. (2021) [33]		Simulations were performed for Rolling Cylinder	Compared multi-polyhedron and multi-spherical methods for generating both the shapes.
Liu et al. (2020) [34]		Simulations were performed for Flat-Bed Spouted Bed	Compared the effect of L/d of the particle and found for L/d =1 highest Fountain height was achieved
Esgandari et al. (2021) [35]		Simulations were performed for Flat-Bed Spouted Bed	Used multi-sphere method to create the particle, found better fluidization and high fountain height.

Dianyu et al. (2022) [6]		Simulations were performed for Flat Spouted Bed	Prolate-spheroid formed the biggest bubble during spouting and highest fountain height
Atxutegi et al. (2021) [36]		Simulations were performed for Conical Spouted Bed with draft tube	Ellipsoidal particle showed higher degree of homogeneity in mixing because of: 1. Orientation of largest face perpendicular to the axis of bed in fountain region 2. Alignment of major axis with contactor wall in annulus region while falling downward.
Wang et al. (2021) [37]		Simulations were performed for Flat-Bed Spouted Bed	Instability in the fountain and annulus region was studied for non-spherical particle. Mutli-sphere technique was used to create different particle shape
Hoosdaran et al. (2021) [38]	Spherical Partcle	Conical Shaped Spouted Bed	Biomass fast pyrolysis was investigated by CFD modeling with experimental validation. Provided the numerical strategy for heat transfer mechanism.
Brito et al (2021) [10]	Speherical Particle	Conical Shaped Spouted Bed with draft tubes	Designed and tested draft tube depending upon the shape of the spout for spherical particles

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