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Original Research Paper

Numerical solution of gas–solid flow in fluidised bed at sub-atmospheric pressures

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ABSTRACT

Fluidised beds are characterised by excellent thermal and chemical uniformity and have a wide application range including heat and surface treatment, ore roasting and catalyst production. However, compared to other gas-based systems, to fluidise a particulate mass, a significant quantity of gas is required. To conserve gas there is potential to operate the fluid bed under low-pressure conditions. It is also observed that heat transfer remains constant with reduction in pressure. The present work has numerically studied the nature of hydrodynamics in fluidised bed at sub-atmospheric conditions and a new drag law is proposed to account for the increased mean free path of the fluid. A wide range of sub-atmospheric pressures were considered such that slip flow regime, which is characterised with $Kn \sim 1$, is applicable. An open source code (MFIX) is used to numerically solve the multiphase problem of a jet in the fluidised bed column with an immersed surface at vacuum pressure conditions. Bubbling fluidisation in shallow and deep beds are also solved. The new drag model takes into consideration the effect of slip flow to model drag force on the particles and the results of velocity distributions in the column and around the submerged surface is presented. The results of velocity distributions from the slip flow model are compared with the existing Gidaspow's model. Significant differences were observed in the simulation results of velocity distributions and flow structure in the fluidised bed under vacuum conditions.

1. Introduction

Fluidisation is the achieving of a fluid like behaviour for any solid granular entities with the help of a fluidising media, such as gasses and liquids. The fluidising medium displaces and suspends the solid granular particles from their static position, transferring the momentum and resulting in fluid like motion of the particles. These particles being fluid borne are free to move from one location to another in a seemingly random manner. It is this random motion of the particles that resembles the flow of a fluid and hence the name fluidisation. It is a commonly used phenomenon in chemical industries and is used in processes such as mineral cracking, heat treatment, surface engineering etc. Fluidisations phenomenon offers a processing environment with a wide spectrum of advantages. The ability to achieve uniformity of temperature, high solid–fluid mixing leading to high heat and mass transfer and continuous operation, make the use of fluidisation quite appealing.

To understand the complex multiphase flow behaviour inside gas–solid fluidised beds the mathematical models proposed mainly fall under four groups depending on how they treat each phase and the magnitude of the length scales. These are (1) Discrete Bubble model, (2) Two-fluid model, (3) Discrete Particle model and (4) Molecular Dynamics model. In other words, each of these models considers the gas–solid phases to be either Eulerian or Lagrangian [1]. Selection of these models depends mostly on the geometry to be modelled and the available computing resources. Of these, most popular are the Two-fluid models where the two phases are modelled as interpenetrating continua. Each of the two phases are modelled as separate fluid (gas and solid) and is solved by Eulerian method (classical Navier–Stokes equation). The solid–fluid coupling is given by drag force that appears in the momentum balance equation for each phase and is equal in magnitude but opposite in direction.

Operation of fluidised bed at various pressure ranges (sub-atmospheric to high pressures) offers advantages that make the use of fluidised bed reactors (FBR) even more appealing. In the literature, fluidised beds at high pressures have been studied extensively. A comprehensive review is given by Yates [2] on the effect of pressure and temperature on gas–solid fluidisation. Coal combustion and gasification are the primary areas of interest for high-pressure fluidisation. Although, high pressures greatly effects heat and mass transfer rates, certain heat sensitive materials such as thermolabile substances, used in pharmaceutical industry for coating and drying purposes, cannot be used at high pressures.

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