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A DEM study of bubble formation in Group B fluidized beds with and without cohesive inter-particle forces

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Abstract

This paper presents a 2D soft-sphere discrete element method (DEM) simulation study of bubble formation in fluidized beds of Geldart Group B powders with and without externally imposed cohesive interparticle force. The effect of interparticle force on bubble formation and bubble characteristics is studied by inducing a single bubble at the centre of the distributor of a 2D bed that contains 36 000 mono-sized particles having a diameter of 500 μm and density of 1000 kg m^{-3}. It is observed that in the presence of externally imposed cohesive interparticle force, the bubble formation process not only requires a higher air velocity for its initiation, but it is also slower when compared to the case with no interparticle force.

Keywords: DEM simulation; Bubble formation; Interparticle force

1. Introduction

In gas–solid fluidization, bubbling is a common phenomenon. Bubbling promotes mixing of solids, resulting in improved bed homogeneity and heat and mass transfer. However, extensive bubbling is not desirable because it can cause back mixing and gas bypassing, thus reducing the efficiency of fluid–solid contact. Therefore, an understanding of the bubbling phenomenon is necessary for the design and development of processes involving fluidization. Many of the previous studies on bubbles in fluidized beds were based on a single rising bubble in a fluidized bed. The first systematic study of a fully developed bubble is due to Davidson (1961). The bubble in the Davidson model is circular in shape. Jackson (1963) and Murray (1965) improved the Davidson model to account for the wake formation. Rowe and Partridge (1963) and Rowe et al. (1964) experimentally verified the Davidson model. Models proposed by Davidson, Jackson and Murray can predict bubble characteristics but cannot predict bubble formation and bubble growth. On the other hand, it is difficult to determine pressure and voidage distribution around a bubble in a fluidized bed using experimental techniques.

In recent years numerical simulation techniques have been increasingly used for studying gas–particle systems. Most of the simulation techniques are based on either two fluid models (TFM) or discrete element method (DEM) models. In TFM both fluid and solid phases are treated as continuous phases. Simulations based on a TFM can provide information down to the resolution of the solid and fluid computation grids. In a DEM simulation, the particles are traced individually by solving Newton's equations of motion, while the fluid phase is treated as a continuum. Therefore, DEM simulation can provide information at the particle level. Using a TFM, Bouilard and Gidaspow (1991) studied bubble rise velocity and pressure profile in and around a 2D rising bubble. Kuipers et al. (1991) also developed a TFM for gas fluidized beds. These authors studied bubble formation and bubble detachment time and compared the results obtained from simulation with those obtained from experimental work. In another TFM-based simulation study, Kuipers et al. (1992) observed strong leakage of bubble gas during bubble formation stage. Nieuwland et al. (1996) extended the work of Kuipers et al. to investigate the effects of particle properties on bubble formation. However, through the comparative study of TFM and DEM simulations, Gera and Tsuji (1997) and Gera et al. (1998) observed that the TFM-based simulations were very sensitive to key parameters and therefore hindered observation of true bubbling characteristics of fluidized beds.

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Kawaguchi et al. (1995) studied a single rising bubble in a 2D fluidized bed using the DEM simulation and compared their results of the simulation with a theory of Collins (1965). However, the study of Kawaguchi et al. did not include a bubble formation stage. Mikami et al. (1998) used a DEM simulation to study cohesive powder behaviour in a fluidized bed by using wet powder and incorporating liquid bridge force in the simulation. However, these authors were not able to simulate a single bubble in the cohesive bed. Various researchers, e.g., Rietema (1973), Seville and Clift (1984), Rhodes et al. (2001b) and Valverde et al. (2003), have recognized the importance of interparticle force in bubble formation. However, there have been rather limited experimental and numerical studies of the effects of interparticle force on bubble formation and bubble characteristics. In this paper we present the results of a DEM simulation based study of the formation and rise of a single bubble in a fluidized bed. The aim of the study is to analyse bubble formation in a bed of Group B powders and to investigate the effects of externally imposed interparticle force on bubble formation.

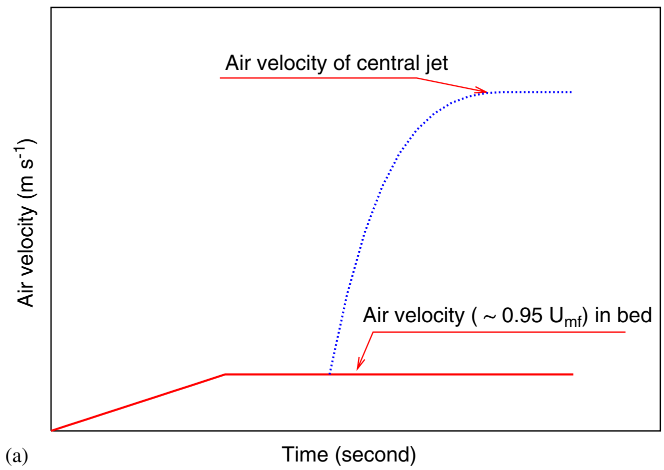
2. DEM simulation

In the current study, we use a DEM simulation based on the soft sphere model proposed by Tsuji et al. (1993). In this model it is possible to estimate the interaction forces with multiple particle contacts. The soft sphere model was also used by Mikami et al. (1998) and Kuwagi et al. (2000) to study the behaviour of a fluidized bed in the presence of a liquid bridge force, and by Rhodes et al. (2001a) to study the cohesive behaviour in fluidized beds. Table 1 gives details of the parameters used in our DEM simulation. The particle spring constant is the key parameter. Tsuji et al. (1993), Mikami (1988) and Rhodes et al. (2001c) recommended a particle spring constant of 800 $N\,m^{-1}$ for DEM simulation. We have used a spring constant of 800 $N\,m^{-1}$ in our simulations, as recommended by Tsuji et al. (1993) and Mikami (1988). Our choice of spring constant is based on the fact that the values of minimum bubbling velocity obtained by DEM simulations remain almost constant for spring constants beyond 800 $N\,m^{-1}$, (Pandit, 2004). The restitution and friction coefficients given in Table 1, 0.9 and 0.3, respectively, are considered to be realistic values and have been widely used in DEM simulations of bubbling beds (e.g., Tsuji et al., 1993; Mikami, 1988). In the present study, we use a 75 mm wide 2D rectangular bed containing 36 000 mono-sized spherical particles. The bed particles are 500 μm in diameter and 1000 $kg\,m^{-3}$ in density.

To induce a single bubble in the bed, we followed the experimental method of Rowe et al. (1964) in their study of cloud formation around a single rising bubble in a 2D fluidized bed.

Table 1
Some parameters used in the DEM simulation

Fluidizing gas	Air	Coefficient of friction	0.3
Air viscosity	1.77×10^{-5} Pa s	Coefficient of restitution	0.9
Air density	1.15 $kg\,m^{-3}$	Normal spring constant	800 Nm^{-1}



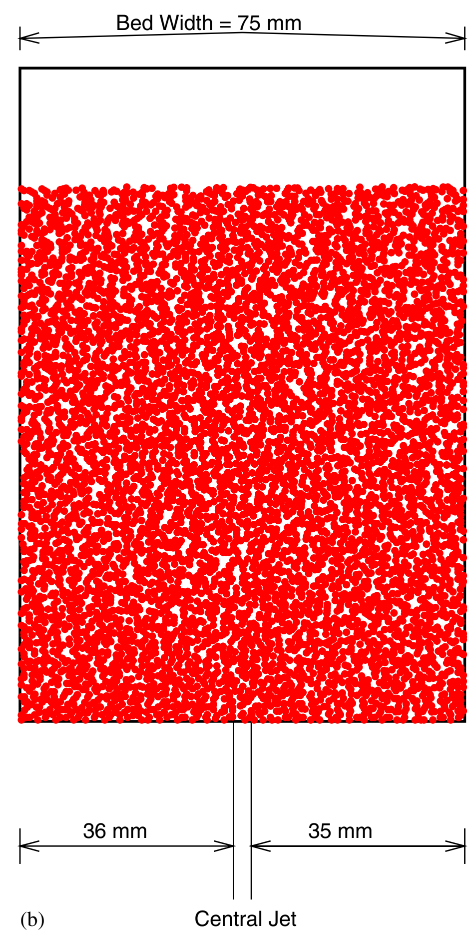


Fig. 1. Air velocity variation scheme to induce a single bubble in the bed: (a) variation of air velocity; (b) location of central jet.

To generate the bubble, these authors first introduced air at the maximum possible velocity without bubble formation, which was then followed by introduction of a pulse of gas at the centre of the bed. Fig. 1 depicts the air velocity variation scheme for inducing a bubble in the bed. First, the air velocity to a fixed bed was increased gradually to U_0. U_0 was approximately 0.95 times the minimum fluidization velocity. The air velocity was maintained at this value for about 1 s. After this, a jet of 4 mm