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ABSTRACT
Electrification of particles due to frequent particle-particle and wall-particle frictional contacts is a well-known phenomenon in fluidized beds. Charged particles exert repulsive or attractive forces to each other and this leads a dramatic change in the hydrodynamic behavior of the bed. Mixing of particles in fluidized beds is vital for good heat and mass transfer in the bed. Discreet element method (DEM) is a promising tool for predicting mixing of particles in gas solid fluidized beds. DEM simulations were conducted with 1500-micron polyethylene particles with charges ranging from 0.0 to +50 pC with and without negative charged particles. The electrostatic forces change bubble size, formation and detachment time of bubbles. As a result, the solid axial diffusivity is affected by appearance of electrostatic forces. The results showed that axial diffusivity of particles is reduced as the electrostatic effects are increased within the bed.

INTRODUCTION
Particulate systems are widely used in the physical and chemical processes. Gas-solid fluidized bed is an ideal method for the processes that a good contact between phases is needed such as drying, coating, combustion, oxidation and polymerization. In addition, the overall hydrodynamics of fluidized bed suggest that there is a good mixing in solid phase that enhance the bed uniformity during operation. However, some issues arise when gas-solid beds are in operation. One of the most well-known phenomena in beds is electrification of particles due to particle-particle and particle-wall contacts (1).Thus, particle charging caused by frequent particle-particle and wall-particle collisions which are unavoidable in fluidized beds. Electrostatic charges can affect fluidization behavior, including bubble hydrodynamics and particle mixing. If the electrostatic charge on particles reaches a critical value, particles adhere to the reactor wall and wall sheeting happens (2).

Effect of electrostatic forces on hydrodynamic of fluidized bed has been studied in experiment for many years. Boland and Geldart investigated the mechanism of charge generation in fluidized beds (3). Triboelectric charging of powders was recently reviewed by Matsusaka et al. (4). While the Electrostatic Phenomena in fluidization systems was reviewed generally by Bi (5). Lim et al. studied the pneumatic transport of granular materials through an inclined and vertical pipe in the presence of an electrostatic field using the discrete element method (DEM) coupled with computational fluid dynamics (CFD). They assumed a constant charge for all particles and simulated the motion of particles by second Newton's law (6). Jalalinejad et al. simulated the injection of single bubbles into a fluidized bed of charged particles using Two Fluid Model (TFM) (7).

In this study, the effects of electrostatic charge on the bubble shape in a single bubble injection regime and axial mixing of particles in freely bubbling gas-solid fluidized beds were investigated using a 3D CFD-DEM code. This in-house code solves momentum and continuity equations for fluid phase and Newton's laws of motion for solid particles (8).

DEM is a numerical method for studying the dynamics of particular systems. This method was first introduced by Cundall and Strack for soil mechanics (9). In this method motions of individual particles are governed by contact and non-contact forces acting on them and each particle is considered as a separate system.Collisions betweenparticleswithparticles andwalls are evaluated by the linear spring-dashpot model (9) in soft-sphere approach, and Electrostatic forces are calculated by Coulomb'sLaw as non-contact forces between particles.

For multi-phase flow simulation, DEM is coupled with Navier-Stokes equations which describe gas phase motion. In this approach, the gas phase is considered as a continuous phase and solid phase are considered as discrete particles (10). In this case, additional forces act on particles such as drag, pressure, and lift forces. The governing equations are described here in [11, 12, 13, 14) for more details. The motion of the continuum gas phase for each computational cell is governed by the Navier-Stokes equations. Equations of gas and solid phases are coupled together through porosity and particle-fluid interaction force (14).

RESULTS AND DISCUSSION

The simulation conditions are reported in Table 1. A pre-defined charge on each particle was assumed. Each particle can carry a maximum amount of charge on itself that is a function of particle diameter and relative permittivity of the material (15). For a polyethylene particle of 1.5 mm diameter and relative permittivity of 2.3, the maximum possible charge on the particle is 300 pC. In mono-charged bed, particles with positive charge of 50 pC were simulated and in the bipolar charged bed, particles with 50 pC negative and positive charges were considered. Simulations were performed with two different fluidizing regimes namely single bubble injection with 90000 particles and freely bubbling regimes with 75000 particles.

Table 1 Simulation Conditions

Bed Properties				**Particle Properties**	
For Single Bubble Regime		**For Axial Diffusivity**		**Material**	**Polyethylene**
Width	0.3 m	**Width**	0.15 m	**Diameter**	1.5 mm
Height	1 m	**height**	1 m	**Density**	900 kg/m^3
Depth	0.003 m	**Depth**	0.01 m	U_{mf}	0.45 m/s
$N_{particles}$	90000	$N_{particles}$	75000		
Jet velocity	15 m/s				

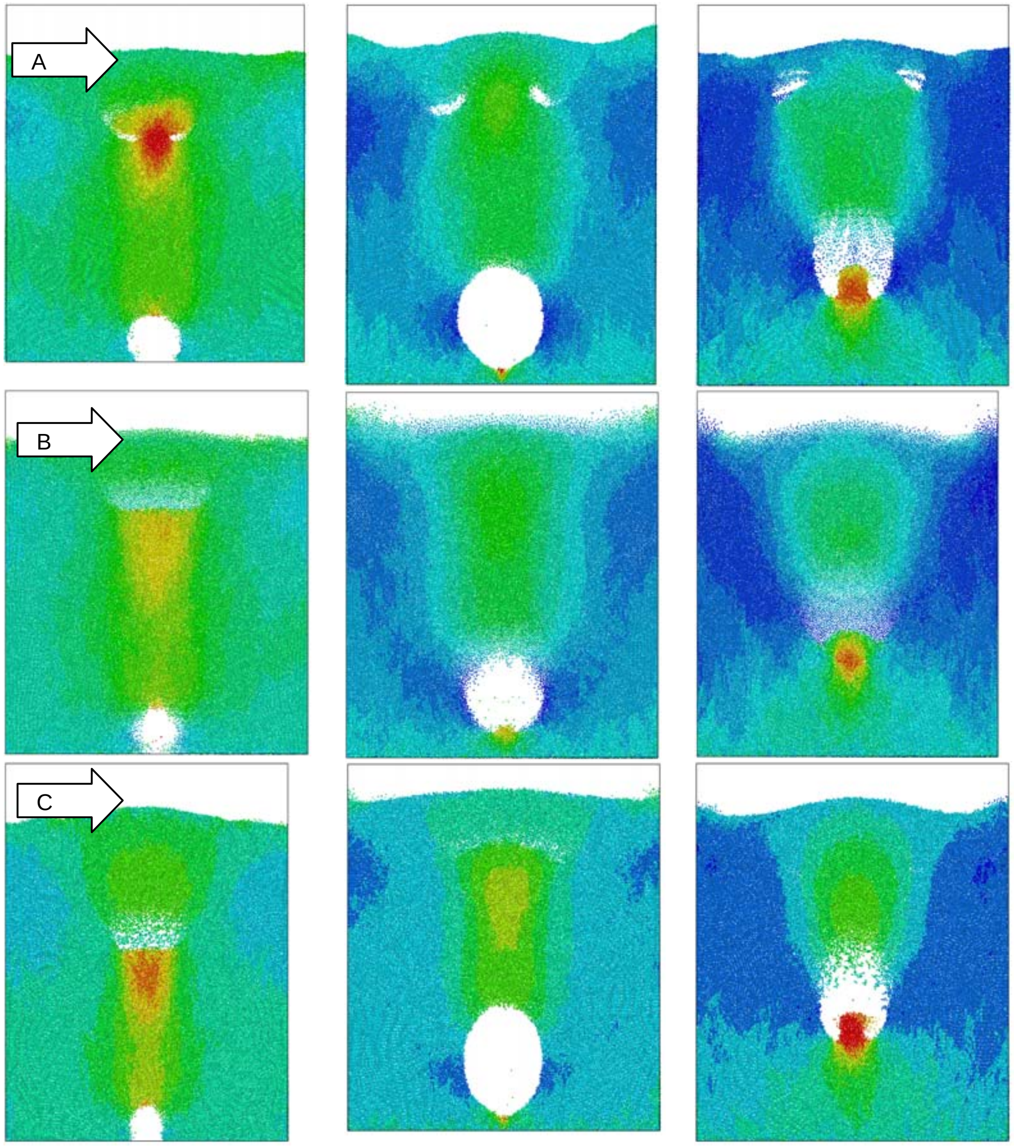

Figure 1 Bubble formation and motion in a bed with (A) neutral, (B) mono-charged (q=50 pC) and (C) bipolar charged (q=50 pC with 40% negative and 60% positive charged particles) particles

Bubble Hydrodynamic in Single Bubble Injection Regime

Fig. 1 shows bubble formation and bubble rise in the single bubble injection regime in a bed with(A) neutral, (B) mono-charged (q=50 pC) and (C) bipolar charged (q=50 pC with 40% negative and 60% positive charged particles) particles. Particles are colored according their vertical velocities. The snapshots in each column of this figure belong to the same time. Thus, the results can be assessed in terms of bubble dynamic and transition in these three cases. As it can be seen, the electrostatic forces between mono-charged particles results in smaller bubble in the bed. Repulsive force between particles in the emulsion phase pushes particles inside the bubble. As a result, particles pour into the bubble, which form a larger cloud phase around bubbles and diminish the clear interface between bubble and emulsion. Comparing the bubble formation and detachment in neutral and mono-charged beds shows that bubble formation and detachment occurs earlier in the later bed (Figs. 1A and 1B). Fig. 1C shows that by enhancing bipolar charged particles the shrunk bubbles recovered and due to appearance of attractive forces that exist between negative and positive particles. Bubble size and shape is almost the same in neutral and bipolar beds. However, there is a great difference between them. Particles pour as individuals from the bubble roof in the neutral bed, while, they pour as clusters in the bipolar bed (third column).

Axial Diffusivity in Freely Bubbling Regime

Since the motion of particles in the bed is mainly governed by bubble motion and size, it is expected that the mixing properties of particles is also affected by electrostatic force. Axial diffusivity of particles (D_z) was computed based on Mostoufi and Chaouki (16).

Fig. 2 shows the axial diffusivity of particles at different heights of the bed for a bed with neutral particles and for a bed with charged particles. For both cases, the axial diffusivity of particles is larger at higher heights than that in distributor zone. Small and weak wakes are formed beneath small bubbles in the distribute zone that induce low particle motion there. However, at higher heights, larger bubbles are formed due to coalescence, which possess strong wakes. This leads to high particle motions and consequently larger diffusivities. Electrostatic forces between particles reduce the diffusivity of particles markedly. As it was shown in the previous figure, repulsive force between particles reduces bubble size and forms a cloud around bubble. Therefore, the diffusivity of particles reduces.

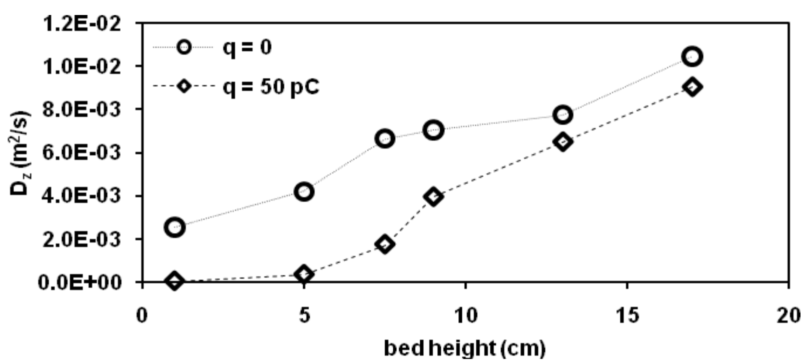

Figure 2: Axial diffusivity of particles for neutral and mono-charged bed as a function of height, U_0 = 1.2 m/s

Fig. 3 shows the effect of superficial gas velocity on axial diffusivity. The axial diffusivity increases with increasing gas velocity in the bubbling bed. Generally, it can be concluded that any change that causes an increase in bubble size enhances the diffusivity. Effect of bipolar charged particles on axial diffusivity is depicted in Fig. 4. When the percentage of negatively charged particles increases the bubble size also increases, and the diffusivity of particles approaches to that of neutral bed.

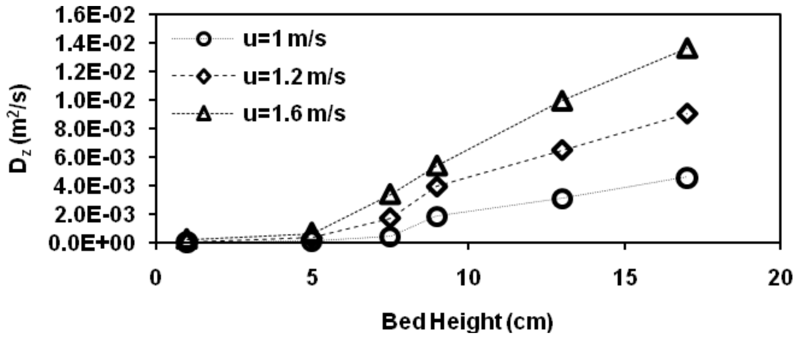

Figure 3: Axial diffusivity of particles at different gas velocities for a bed ofmono-charged particles as a function of height, q = 50 pC

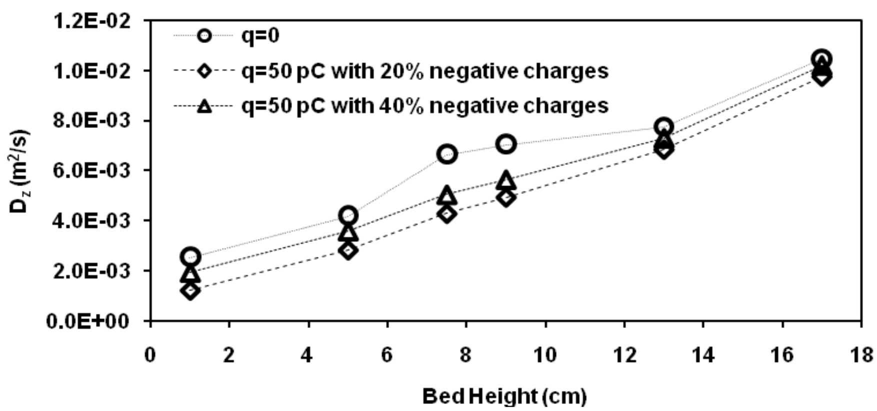

Figure 4: Axial diffusivity of particles at different gas velocities for a bed of bi-polar charged particles as a function of height, q = 50 pC

CONCLUSIONS

A 3D CFD-DEM code was used for investigating the bubble hydrodynamics in a single bubble injection regime and the axial diffusivity in a freely bubbling regime. Bed with pre-defined charge on each particle was assumed for this purpose, including neutral, mono-charged (q=50 pC) and bipolar charged (q=50 pC with 40% negative and 60% positive charged particles) particles. Results showed that bubble size in mono-charged bed is smaller than neutral bed and the shrunk bubbles recovered in bipolar case. Particles pour as individuals from the bubble roof in the neutral bed while, they pour as clusters in the bipolar bed. The axial diffusivity of particles increased at higher heights and higher superficial gas velocity and decreased by adding mono-charged particles into the bed. When the percentage of negatively charged particles increased the diffusivity of particles approaches to that of neutral bed.

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