Numerical Investigation of Bubble Characteristics in a Two-Dimensional Fluidized Bed

Kyung-Tae Kang
Cleaner Production Technology R&D Center
Korea Institute of Industrial Technology
Chonan, Korea

Jeong-Jin Kook and Seungho Park
Department of Mechanical Engineering
Hong-Ik University
Seoul, Korea

ABSTRACT

A numerical investigation using a commercial CFD program of the Inter-Phase Slip Algorithm has been carried out for detail characteristics of particle motions and bubble behaviors in a two-dimensional fluidized bed. The bed simulated has been operated with three different distributor geometries, such as bubble cap, nozzle, and perforated plate types. Experiments using a slit-type two-dimensional fluidized bed and a cylinder-type fluidized bed have been performed in order to confirm the simulation model. In addition, the numerical results are compared with the well-known correlation of bubble sizes and bubble rising velocities by Mori and Wen [1]. The simulation model that we applied is shown to be useful to understand the relation between bubble behaviors and distributor geometries.

Keywords : bubbling fluidized bed, bubble characteristics, CFD, distributor geometry, 2 dimensional fluidized bed experiment

INTRODUCTION

Fluidized beds are widely used in processing industry and solid fuel energy industry [1]. Recently fluidized beds are used for wastewater sludge incineration in Korea. One of major advantage of the fluidized bed incinerator is the uniform temperature inside the bed where wet sludge is dried and burnt because of high heat transfer rate in the fluidizing bed. In order to use the advantages of the fluidized beds, understanding of the bubble characteristics is needed.

Many studies [1, 2] concerning bubble characteristics have been done, but most of them are experimental works. Recently more studies using numerical analysis appears than before because of rapid development of computers.

In this paper, detail characteristics of particle motions and bubble behaviors in a two-dimensional fluidized bed are studied using a commercial CFD program and comparison with experiments using a slit-type two-dimensional fluidized bed and a cylinder-type fluidized bed have been performed in order to confirm the simulation model.

NUMERICAL MODELS

The fluidized bed is two-phase problem that may suppose the conveyance of large numbers of solid particles in gas by treating the solid particle phase as a separate fluid. In this study, commercial CFD program CFX ver.4.3 using the Inter-Phase Slip Algorithm (IPSA) of Spalding [3] has been used for solving the coupled equations of gas phase and solid phase. This solves the coupled equations in a segregated fashion, with the option of accelerating convergence using the Partial Elimination Algorithm (PEA) of Spalding, or the SINCE (Simultaneous Solution of Non-linearly Coupled Equations) method of Lo [4].

Interaction between particles and fluids occurs in the fluidized bed, so we use Particle Model which is Phases are labeled by Greek indices α, β, γ We denote the number of phases by N_P. The volume fraction of each phase is denoted γ_α.

There are the continuity equation :

$$\frac{\partial}{\partial t}(\gamma_\alpha \rho_\alpha)+\nabla \cdot (\gamma_\alpha \rho_\alpha \vec{U}_\alpha) = \sum_{\beta=1}^{N_p}(\dot{m}_{\alpha\beta}-\dot{m}_{\beta\alpha})$$

the momentum equation :

$$\frac{\partial}{\partial t}(\gamma_\alpha \rho_\alpha \vec{U}_\alpha)+\nabla \cdot \left\{\gamma_\alpha\left[\rho_\alpha \vec{U}_\alpha \otimes \vec{U}_\alpha - \mu_\alpha(\nabla\vec{U}_\alpha+(\nabla\vec{U}_\alpha)^T)\right]\right\}$$

$$=\gamma_\alpha(\vec{B}-\nabla P_\alpha)+\sum_{\beta=1}^{N_P} c_{\alpha\beta}^{(d)}(\vec{U}_\beta-\vec{U}_\alpha)+\vec{F}_\alpha$$

$$+\sum_{\beta=1}^{N_P}(\dot{m}_{\alpha\beta}\vec{U}_\beta-\dot{m}_{\beta\alpha}\vec{U}_\alpha)$$

and the algebraic constraint that the volume fractions sum to unity :

$$\sum_{\beta=1}^{N_p}\gamma_\alpha=1$$

There are usually given by algebraic constraints on the pressure, the simplest being that all phases share the same pressure field :

$$P_\alpha=P$$

Here, ρ is the fluid density, $\vec{U}=(U, V)$ the fluid velocity, p the pressure and μ the viscosity. $c_{\alpha\beta}^{(d)}$ is the inter-phase drag term between the continuous phase β and the disperse phase β and F_α is any inter-phase non-drag term. r_a is the volume fractions of the each phases.

The drag exerted on an immersed body by a moving fluid arises from two mechanisms only. The first is due to the viscous surface shear stress, and the second is due to the pressure distribution around the body. The total drag force is expressed in terms of the non-dimensional drag coefficient:

$$C_D=\frac{D}{\frac{1}{2}\rho U^2 A}$$

Here, D is the magnitude of the drag force, and A is the projected area of the body in the direction of flow. Drag coefficient is function of Reynolds number and is determined experimentally. It is classified three distinct regions varying Reynolds number, which are Stokes region, viscous region and inertial region. Also, drops and bubbles become distorted in the inertial region and the distorted particle regime may be preferred. The Gidaspow modification for high particle concentrations takes the form of a multiplying factor to drag factor for all regimes. This factor is:

$$E = (1 - r_{\beta})^{p}$$

where the power p is constant, -1.65 in the present paper.

Parameter	Value	Unit
Size(length*height)	0.13*0.5	m
Bed height	0.3	m
No. of grid	26*70	
Particle diameter	0.6	mm
Voidage	0.42	
Density of solid	2600	kg/m^3
Density of air	1.2	kg/m^3
Viscosity of air	1.8e-5	m^2/s

Table 1 Parameters of the calculation

In the present study, computer is used AMD's Athlon 850 CPU and 512RAM on the Windows NT 4.0(SP 6).

EXPERIMENTAL APPARATUS

The cylinder type fluidized bed (see Fig. 1) is consisted of a transparent plastic cylindrical body 0.26m in diameter and 2m in height with a 16 bubble-cap type nozzles. The bed height is 30cm and particles are sand (D_P = 0.67-0.75). The bubble size on the bed surface has been recorded by the video camera with mirror, which is analyzed later.

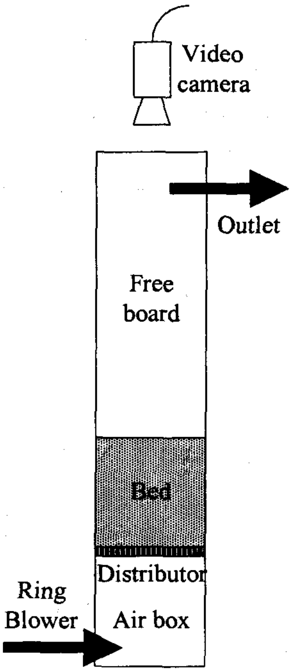


Fig. 1 Schematic diagram of lab-scale fluidized bed

The slit-type 2-D fluidized bed has 0.26m(width)×0.02m(depth)×0.3m(height) size and same particles, and the bubble rising motion is taken by video camera through a transparent plastic front wall of the bed. Flow meter used experiments are calibrated orifice in the lab-scale fluidized bed and Dwyer RMB series rate-master flowmeter (200*/min*) in the 2-D fluidized bed.

In this experiment, we use three types of nozzle on the distributor, i.e. perforated, nozzle and bubble cap type, which are shown in

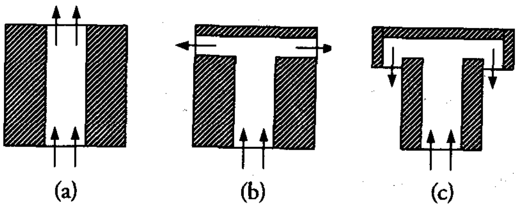


Fig. 2 Diverse type of nozzles on the distributor
(a) perforated, (b) nozzle, (c) bubble cap

Fig. 2. Bubble size or rising velocity are measured using VCR image analysis.

RESULT AND DISCUSSION

Comparison between Computational and Experimental Result

Figure 3 shows experimental results of cylinder type cold-flow fluidized bed and 2-D cold-flow fluidized bed, Mori and Wen' s empirical formula and our simulation results. Bubble size is smaller in simulation results than in the others. The bubble size of simulation of perforated plate type distributor is smallest, but that of bubble cap type distributor is similar to other results.

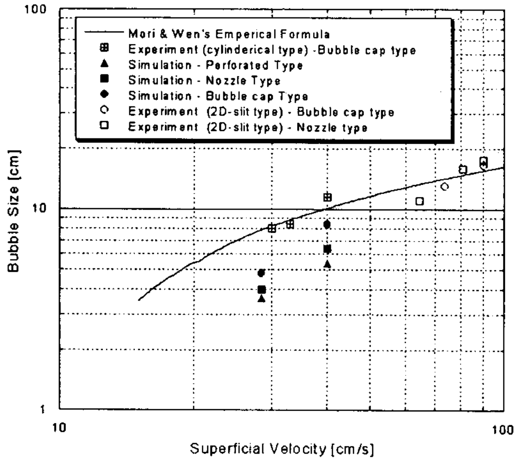


Fig. 3 Comparison between simulation, experiment and Mori and Wen' s formula.

Transient Solution

Figure. 4 shows the transient result of bubble movement at fluidized bed with bubble cap type distributor. The right side of the figure is the symmetry plane. The velocity of nozzle inlet is 10m/s. The line indicates the volume fraction between particles and air, and the arrows displays velocity of particles. The air forms bubble at 5-10cm high above nozzle. The generated bubble goes up through particles and breaks at the bed surface after 0.4-0.5sec. After the bubble comes to the bed surface, particles are dispersed with air bubble fall at bed surface.

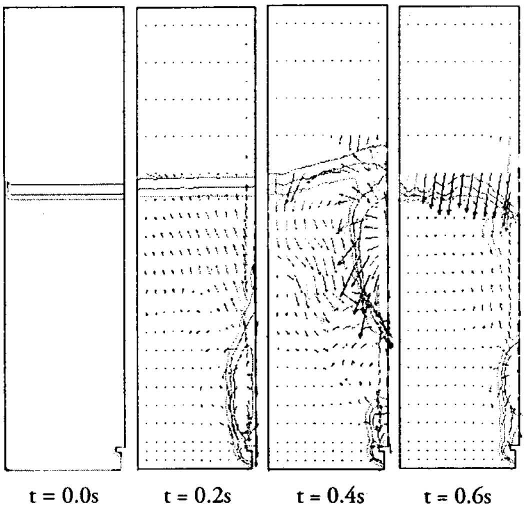
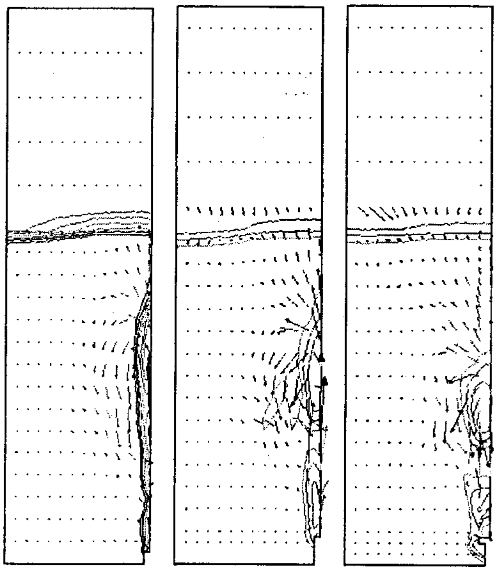
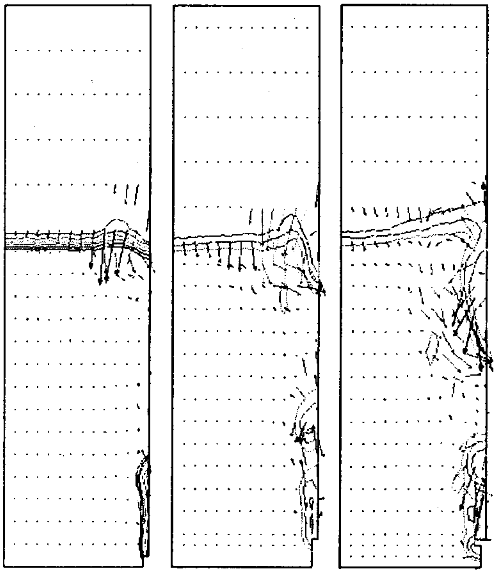


Fig. 4 The rising of bubble at bubble cap type distributor.



a. perforated b. nozzle c. bubble cap

(a) bubble behaviors at 0.4 sec



(b) bubble behaviors at 0.6sec

Fig. 5 Different bubble rising phenomena due to distributor type.

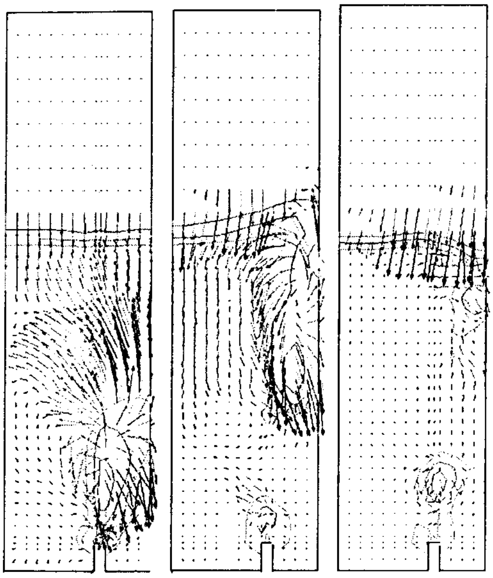


Fig. 6 The bubble behavior of two nozzles

Diverse Distributor Type

Different air distributor shows different bubble rising velocity and bubble size. Figure. 5 shows various bubble motions when nozzle velocity is 7.5m/s. Generally, bubble size is greater in the bubble cap type distributor than in the perforated type. But, the bubble rising velocity has opposite tendency of the bubble size. Bubble comes to bed surface with perforated and nozzle type distributor at 0.5-0.6sec, but with a bubble cap type distributor does over 0.6sec. In the case of a bubble cap type distributor, bubble diameter is larger than others, so bubble rising velocity is slower than others. Perforated type distributor shows it is like as channeling like bubble behavior.

Two Nozzle Effect

Figure. 6 shows the result of bubble behaviors with two nozzles at the nozzle. The nozzle velocity is 5m/s. The bubble is formed near the distributor, rises, and is merged with opposite side bubble in the middle of the bed. Bubble is larger than the same superficial velocity of the one nozzle. So, the bed mixing intensity is strengthened.

CONCLUSION

The bubble flow between particles and air in the fluidized bed are numerically calculated by CFD program. The simulated result shows similar tendency with other empirical relations and experimental results. Bubble characteristics like bubble size or bubble rising velocity are different from each others varying distributor types. A bubble is shown to be combined with other bubble at the two nozzles distributor simulation result.

In the future, the effects of various particle size and density will be studied. Three phases problem including other phase like sludge will be investigated.

REFERENCES

1. Kunii, D. and Levenspiel, O., *Fluidization Engineering, 2nd* ed., Butterworth-Heinemann, MA, U.S.A., 1991.
2. Horio, M. and Nonaka, A., "A Generalized Bubble Diameter Correlation for Gas-Solid Fluidized Beds," *AICHE Jounal,* Vol. 33, No. 11, pp. 1865-1872, 1987.
3. Spalding, D.B., "The calculation of Free-Convection Phenomenon in Gas-Liquid Mixture," *ICHMT Seminar*, Dubrovink, 1976.
4. Lo, S.M, "Mathematical of a multi-phase flow model," AERER 13432, 1989.