

Effect of Non-Drag Forces on the Numerical Simulation of Bubbly Flow in a Bubble Column

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Accuracy of CFD simulation on the bubbly flow was investigated by considering different kinds of non-drag forces in a flat bubble column aerated from a single-orifice gas sparger by comparison with the experimental data presented by Pflieger et al. (1999). The simulated results reveal that the lift force model does not have significant effect, while the turbulent dispersion force model can give much better results.

1. Introduction

Bubble columns, as one of the most efficient multiphase reactors, are used in many important industrial fields. This is due to the simple construction, low operating costs and high transfer efficiency (Kulkarni et al., 2007). However, the hydrodynamics in the bubble column are affected by many factors and difficult to be described accurately. CFD is considered as a powerful tool to study the bubbly flow in the bubble column.

It is well-known that the bubble plume is a flow characteristic in a locally aerated flat bubble column. This phenomenon was simulated well by CFD and qualitatively proved with the experimental data (Becker et al., 1994). Sokolichin et al. (1999) have studied the applicability of closure models on the simulation. But non-drag forces were usually ignored in the previous works. Recently, it was reported that the drag force alone would not be sufficient to predict the local hydrodynamics correctly (Díaz et al., 2008) and the proper selection and description of non-drag forces are also of prime importance.

The aim of this work was to make an attempt to present a sensitivity analysis of different kinds of non-drag forces including the lift force and turbulent dispersion force. Effects of non-drag forces on the numerical simulation of bubbly flow hydrodynamics were simulated in a 2D flat bubble column equipped with a single-orifice gas sparger. The simulations were carried out based on two-phase fluid model.

2. Govern equations and models

Based on Euler-Euler approach, the momentum equation could be expressed as:

$$\frac{\partial(\alpha_k \rho_k \mathbf{u}_k)}{\partial t} + \nabla \cdot (\alpha_k \rho_k \mathbf{u}_k \mathbf{u}_k) = -\alpha_k \nabla p + \nabla \cdot (\alpha_k \mu_k (\nabla \mathbf{u}_k + (\nabla \mathbf{u}_k)^T)) + \mathbf{F}_{k,m} + \alpha_k \rho_k \mathbf{g} \quad (1)$$

$\mathbf{F}_{k,m}$ is the interphase force described by Olmos et al. (2003). Drag force was modeled as proposed by Clift et al. (1978) and the wall lubrication coefficient was set to 0.1.

Lift force with coefficient was given by following equation (Tomiyama et al., 1999):

$$\mathbf{F}_{l,g}^{LF} = -\mathbf{F}_{g,l}^{LF} = -C_L \alpha_g \rho_l (\mathbf{u}_g - \mathbf{u}_l) \nabla \mathbf{u}_l \quad (2)$$

Turbulent dispersion force was calculated by the model from Bertodano et al. (1991):

$$\mathbf{F}_{l,g}^{TD} = -\mathbf{F}_{g,l}^{TD} = -C_{TD} \rho_l k \nabla \alpha_g \quad (3)$$

C_{TD} is the turbulent dispersion coefficient with recommended value of 0.1.

As reported by Lucas et al. (2001), there was a fluctuating motion of single bubble caused by deformation, which increased with the Eötvös number. It brought an additional smoothing for the radial distribution of gas holdup, which was not covered by Eq. (3). For this reason a second dispersion force was introduced and modeled as:

$$\mathbf{F}_{l,g}^{TD,Eo} = -\mathbf{F}_{g,l}^{TD,Eo} = -C_{TD,Eo} \rho_l (Eo_d - 1) \nabla \alpha_g \quad (4)$$

According to the literature, $C_{TD,Eo}$ was $0.0015 \text{ m}^2 \cdot \text{s}^{-2}$ for $Eo_d > 1$ and zero for $Eo_d < 1$.

3. Computation Setup

In order to compare with the experimental results obtained by Pflieger et al., (1999), the numerical simulations were carried out in a 2D air-water flat bubble column with a rectangular cross-section (0.2 m×0.45 m×0.04 m). Gas was introduced through a single-orifice gas sparger, in the centre of which located a hole with diameter of 1 mm. The whole transient simulations were done with the superficial gas velocity of 0.3 m/s.

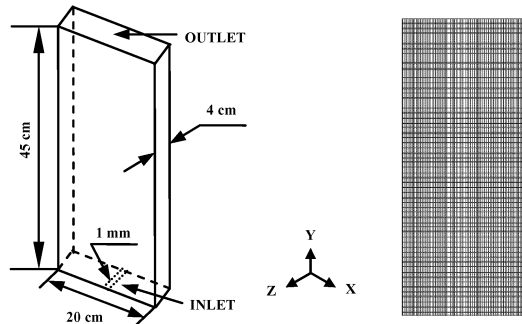


Fig. 1 Geometry and mesh configurations of two-dimensional flat bubble column

Commercial software CFX 4.4 was used. The walls of bubble column were set to no-slip boundary. Degassing boundary was used for the outlet surface. The average bubble size was set to 2 mm. A uniform grid having 60×60 cells and a time step of 0.001 s were used in all simulations, which were proved to give satisfactory results.

4. Simulated Results and Discussion

4.1 Effect of lift force model

The simulated distributions of gas holdup with and without lift force model are given in Fig. 2-a. It can be qualitatively seen that the simulated flow states are similar to the visual observation by Pflieger. As shown in Fig. 2-b, vortical eddies caused by bubble plume and descending liquid flow along the sidewalls of bubble column are found, which also agree with the experiment. The simulated results are almost independent on the addition of lift force model except enlarging the amplitude of bubble plume.

Fig. 3 shows the computational results monitored at $h=0.3$ m. It is found that the lift force affects the radial distribution of gas holdup and liquid velocity clearly. Bubbles gather at the center of bubble column and the radial profile is approximately axisymmetric without the lift force model. With adding the model, it seems that bubbles are driven away from the axis and spread over the cross section of bubble column.

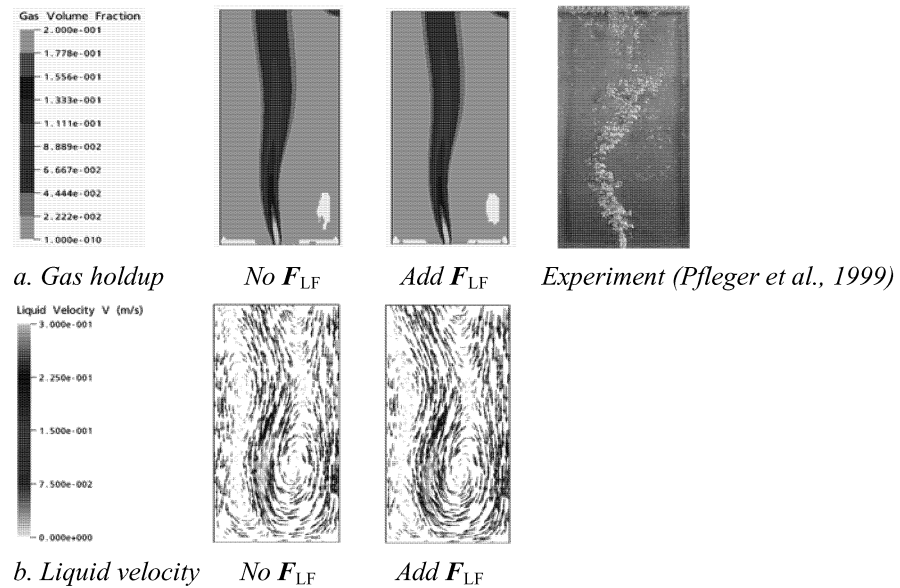
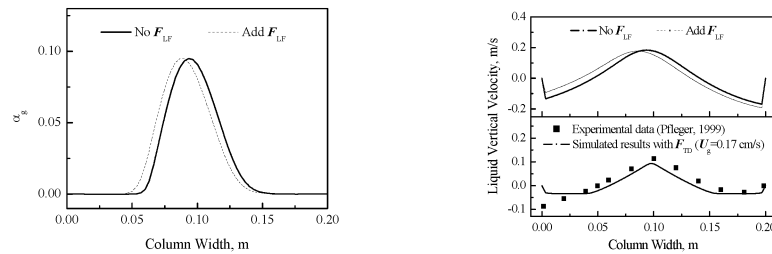


Fig. 2 Effect of lift force model on the simulation of bubbly flow

The peak of gas holdup moves to the left as seen in Fig. 3-a. The reason is that the smaller bubbles tend to transfer to the walls of column under the action of lift force. Fig. 3-b presents that the simulated liquid vertical velocity agree well with the experimental data and show a qualitatively correct of fluid circulation in the experimental condition. As a result, the lift force model used here has no significant effect on simulating the bubble plume in a single-orifice bubble column, which agrees with Díaz et al. (2008).



a. Gas holdup radial distribution

b. Liquid velocity radial distribution

Fig. 3 Effect of lift force model on the radial profile of hydrodynamic parameters

4.2 Effect of turbulent dispersion force model

It can be seen intuitively that bubbles move upwards directly and do not show the

distinct horizontal swing without the turbulent dispersion force as shown in Fig. 4.

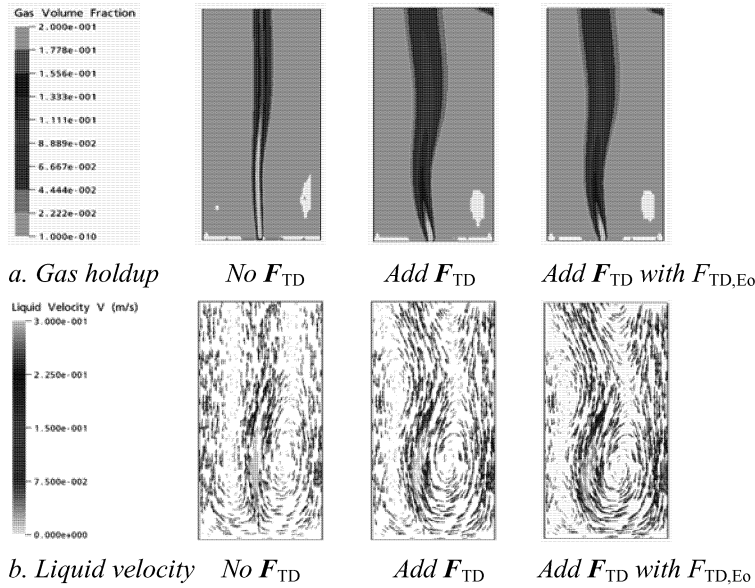


Fig. 4 Effect of turbulent dispersion force model on the simulation of bubbly flow

Contrarily, with the consideration of turbulent dispersion force, the fluid dynamic movement is similar to the experimental observation and takes on the clear bubble plume. This may be explained by the action of turbulent dispersion force for distributing the bubbles over the cross section. However, it is found that the additional dispersion force model given by Lucas et al. (2001) do not bring significant change here.

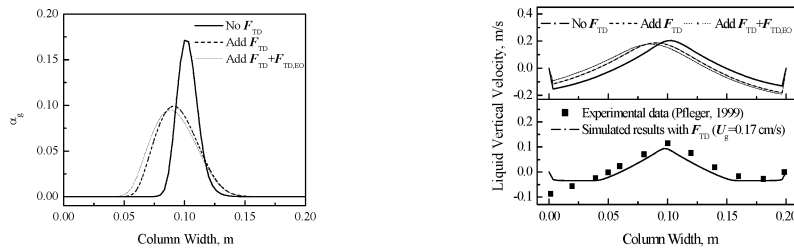


Fig. 5 Effect of turbulent dispersion force model on the hydrodynamic parameters

As shown in Fig. 5, the radial profile of gas holdup becomes flatter with the consideration of turbulent dispersion force model than without that. The peak of liquid vertical velocity moves leftward, while with the additional dispersion force both curves

only move to the left appreciably. It can be attributed to the fluctuating movement of bubbles and the turbulent dispersion force prevents bubbles accumulating within a small region close to the centerline. Due to the additional dispersion force mainly acts on the larger bubbles ($d_b \geq 6$ mm) pointed by Lucas et al. (2001), the obvious change can not be found with the average bubble diameter of 2 mm in the present work.

5. Conclusion

Effects of non-drag forces (lift and turbulent dispersion) on the simulation of bubbly flow in a centrally aerated flat gas-liquid bubble column were investigated. It reveals that the additions of lift and additional dispersion force model do not have significant effect, while the turbulent dispersion force model can give much better results.

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