Improvement of turbulence models by direct numerical simulation of bubbly flow

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Highlights

- DNS simulation of bubbly flow in a vertical channel is conducted
- Turbulence balance equation is evaluated by DNS data
- Bubble induced turbulence model is derived based on DNS simulation

1. Introduction

Gas-liquid multiphase flow is commonly encountered in stirred tanks and other reactors. CFD simulation becomes more and more popular and effective to analyze and predict multiphase flow in reactors. The development of suitable models and numerical methods is hence quite important. For small-scale simulation of detailed turbulence and bubbles, direct numerical simulation (DNS) can be employed. For reactor scale simulation, the Euler-Euler two-fluid model is commonly used, coupled with the Reynolds-averaged Navier-Stokes (RANS) method. The two-fluid model is preferable for industrial multiphase flow simulation due to its simplicity. Therefore, high accurate model under the two-fluid method framework should be developed for industrial applications.

For gas-liquid flow, the presence of bubbles will affect the structure and intensity of local turbulence. There are two ways to introduce the effect of bubbles into liquid turbulence. One way is additional viscosity method, in which an additional viscosity due to bubble motion is added to calculate the effect viscosity [1]. The other way is an additional source term method, in which additional source terms are added to the turbulence kinetic and energy dissipation equations [2]. Both methods are widely used for gas-liquid simulations in stirred tanks and other reactors [3,4]. However, these models include empirical parameters, which are taken on various values in the literature.

In this work, bubble induced turbulence models are developed by direct numerical simulation of bubbly flow in a vertical channel. Based on the DNS results and statistical analysis, a bubble induced turbulence model is developed and validated. The model will be used to simulate practice gas-liquid flow in industrial reactors in future works.

2. Methods

Front-tracking method [5] is adopted to direct simulate the bubbly flow in a vertical channel. One fluid equation is the key of this method, by which the whole domain, including both the bubbles and the carrying liquid is solved. The last term represents the interface force in the equation which only existed at the interface. This equation can fully resolves the fluid flow around each bubble and accurately capture the movement and deformation of bubbles. The governing equation is solved by an explicit projection method on a fix and staggered grid. The time term is discretized by second order scheme and QUICK scheme is employed for the advection term.

3. Results and discussion

Bubble movement simulated by DNS is shown in Figure 1. It can be seen that the bubbles have deformed with the two phase flow. The vorticity in the channel by lamda2 methods is also shown. Some of the vortexes are generated by the wall, and some of them caused by bubbles. Besides, this bubbly flow is quite

different with the case of sphere bubbles. In that case, bubbles will move towards to the wall due to the lift force. But when bubbles deform, they will trend to move to the opposite direction. The turbulence equations evaluated by DNS data are shown in Figure 2. Each term in the equation can be calculated to obtain the source terms. By comparing with the term calculated by bubble induced model, the coefficient can be obtained.

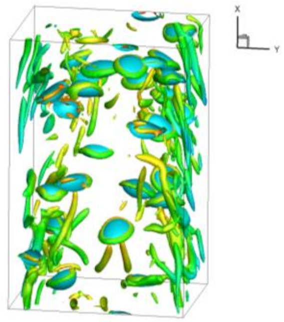

Figure 1. Distribution of bubbles and vorticity

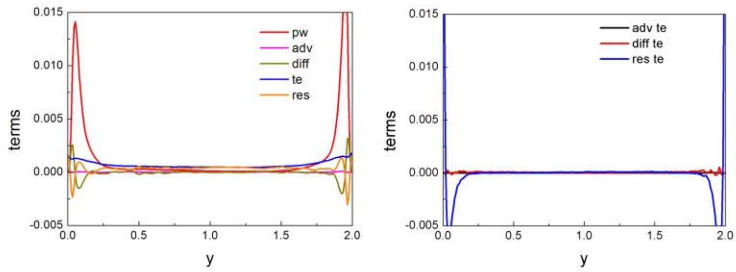

Figure 2. Evaluation of turbulence balance equations (left tk; right te)

4. Conclusions

A DNS simulation of bubbly flow in a vertical channel between two parallel walls is conducted. The DNS data is processed and analyzed to get available information. Based on the DNS data, the turbulence balance equations is evaluated and the bubble induced turbulence model with improved coefficients is developed. This is just a preliminary work and more cases with different DNS simulation parameters should be focused on in future to develop better turbulence models.

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Keywords

Direct numerical simulation; bubbly flow; turbulence models; two fluid model