The Modification of Two-Fluid Momentum Equations for Two-Dimensional Bubbly Flows.

Ali Sadeghi , Yoon Sang hee, Kim Byoung Jae*
School of Mechanical Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, South Korea
**Corresponding author: bjkim@cnu.ac.kr*

1. Introduction

The two-fluid model is widely used to predict the multiphase flows. The problem is that the conventional two-fluid momentum equations shows unphysical results which is the overestimation of the velocity profiles of the dispersed phase when fully developed [1].

In this study, we are trying to modify the momentum equations to address this issue which would be especially important regarding the safety of nuclear systems, and to show that the modified momentum equations predict the void fraction profile well.

2. Methods and Results

2.1 Reference Calculations

Conventional momentum equations are given as follows:

$$\frac{\partial}{\partial t}(\alpha_g\rho_g\mathbf{u}_g)+\nabla\cdot(\alpha_g\rho_g\mathbf{u}_g\mathbf{u}_g)=-\alpha_g\nabla p$$
$$+\nabla\cdot\left[\alpha_g(\mu_g+\mu_g^t)(\nabla\mathbf{u}_g+\nabla\mathbf{u}_g{}^T)-\alpha_g\frac{2}{3}(\mu_g+\mu_g^t)(\nabla\cdot\mathbf{u}_g)\mathbf{I}-\alpha_g\frac{2}{3}\rho_g k_g\mathbf{I}\right] \quad (1)$$
$$+\mathbf{F}_i+\alpha_g\rho_g\mathbf{g}$$

$$\frac{\partial}{\partial t}(\alpha_l\rho_l\mathbf{u}_l)+\nabla\cdot(\alpha_l\rho_l\mathbf{u}_l\mathbf{u}_l)=-\alpha_l\nabla p$$
$$+\nabla\cdot\left[\alpha_l(\mu_l+\mu_l^t)(\nabla\mathbf{u}_l+\nabla\mathbf{u}_l{}^T)-\alpha_l\frac{2}{3}(\mu_l+\mu_l^t)(\nabla\cdot\mathbf{u}_l)\mathbf{I}-\alpha_l\frac{2}{3}\rho_l k_l\mathbf{I}\right] \quad (2)$$
$$-\mathbf{F}_i+\alpha_l\rho_l\mathbf{g}$$

2.2 Proposed Equations

The momentum equations suggested by [2] are as follows:

$$\frac{\partial}{\partial t}(\alpha_g\rho_g\mathbf{u}_g)+\nabla\cdot(\alpha_g\rho_g\mathbf{u}_g\mathbf{u}_g)=-\alpha_g\nabla p$$
$$+\alpha_g\nabla\cdot\left[(\mu_l+\mu_l^t)(\nabla\mathbf{u}_l+\nabla\mathbf{u}_l{}^T)-\frac{2}{3}(\mu_l+\mu_l^t)(\nabla\cdot\mathbf{u}_l)\mathbf{I}-\frac{2}{3}\rho_l k_l\mathbf{I}\right] \quad (3)$$
$$+\mathbf{F}_i+\alpha_g\rho_g\mathbf{g}$$

$$\frac{\partial}{\partial t}(\alpha_l\rho_l\mathbf{u}_l)+\nabla\cdot(\alpha_l\rho_l\mathbf{u}_l\mathbf{u}_l)=-\alpha_l\nabla p$$
$$+\alpha_l\nabla\cdot\left[(\mu_l+\mu_l^t)(\nabla\mathbf{u}_l+\nabla\mathbf{u}_l{}^T)-\frac{2}{3}(\mu_l+\mu_l^t)(\nabla\cdot\mathbf{u}_l)\mathbf{I}-\frac{2}{3}\rho_l k_l\mathbf{I}\right] \quad (4)$$
$$-\mathbf{F}_i+\alpha_l\rho_l\mathbf{g}$$

These equations were realized in FLUENT with the help of UDF.

3. Results and Discussion

3.1 Verification

Verification simulations were carried out for the two-dimensional fully-developed bubbly flow in a channel. Figure 1 shows the test channel. Air-water flow enters a 2 m long and 5 cm wide channel with the initial velocity of 1 m/s and the inlet void fraction is 0.05. The gravity is not considered.

The standard k-ε is used as the turbulent model the schiller-Naumann model is used for the drag coefficient and the Frank-et-al model is used for wall lubrication force, bubble diameter is considered as constant, and equal to (3 mm).

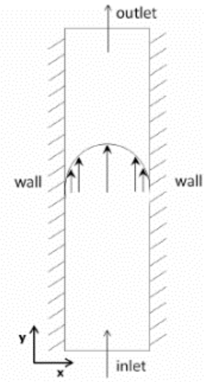


Fig. 1 Bubbly flow in a channel

Figure 2 shows the velocity profiles at the outlet. For the conventional momentum equations, the air velocity is predicted to be higher than the water velocity. However, for the modified momentum equations, the air velocity is predicted to be the same as the water velocity, which is physically correct when the flow is fully-developed without the gravity effect. This result confirms that the proposed momentum equations are well implemented.

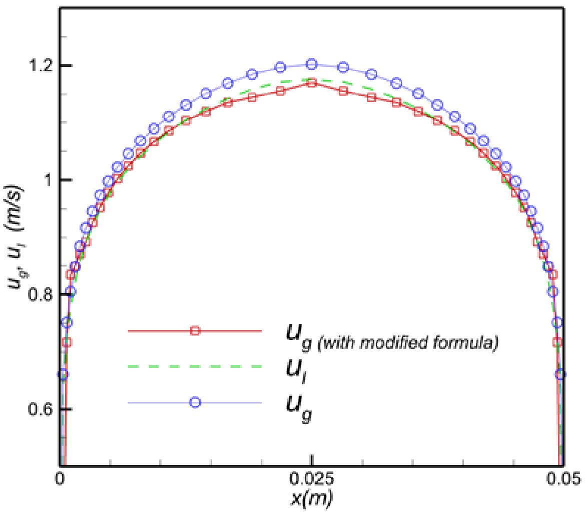


Fig. 2 Velocity profiles for air (conventional and proposed equations) and water (u_l: water velocity, u_g: air velocity, u_g (with modified formula): air velocity using the modified equations)

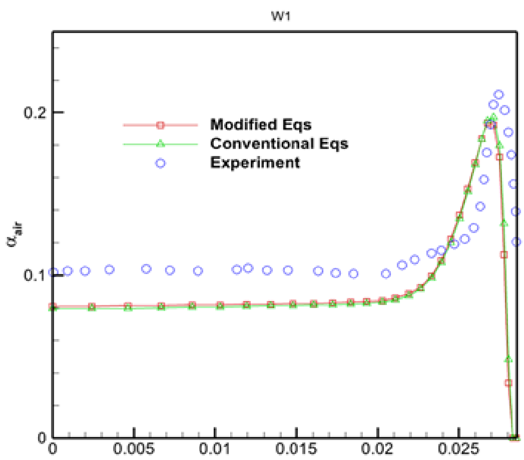
3.2 Wall-Peaked Volume Fraction of air

We extended the proposed equations to the axi-symmetric domain and simulated bubbly flows in vertical pipes. Three experimental data were used for validation. Wang et al. (1987) (W1, W2, W3) [3,4]. Experimental conditions are given in Table 1.

Table 1. Experimental conditions of Wang's experiment

Data	j_w [m/s]	j_a [m/s]	α [-]	d_B [mm]
W1	0.71	0.1	0.100	3.0
W2	0.94	0.4	0.202	3.0
W3	0.43	0.4	0.383	3.0

It is clearly seen that the proposed momentum equations predict well the void fraction profiles near the wall. Fig(3)



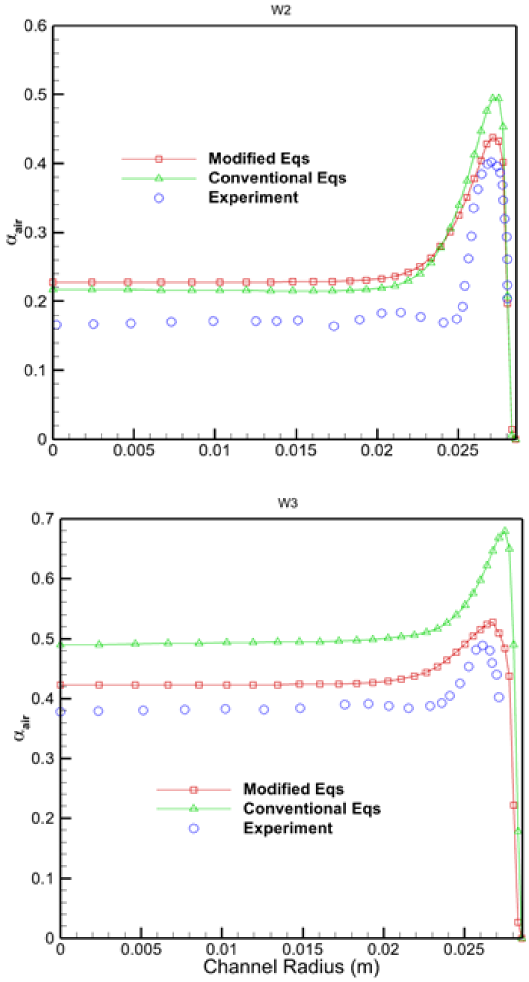


Fig. 3: wall-peaked volume fraction of air for (W1, W2, W3)

3. Conclusions

The accurate prediction of the bubbles velocities in a multiphase flow regime is crucial specially for safety measures in nuclear power systems however the standard conservation equations show unphysical results which is higher velocities for the dispersed phase. With suggested equations for the conservation of the momentum, the velocity profile of bubbles shows physical results for both laminar and turbulent regimes.
In the continuation of the study, other characteristic of flow properties has been investigated.
The wall-peaked volume fraction of the dispersed phase is the interest of the current study which is showing more accurate results according to the experimental data.
Regarding the promising results of the new formulation for the Eulerian multi-phase model, studies on the other flow characteristics and validations will be conducted in future.

Acknowledgments

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