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Numerical investigation on the bubble separation in a gas-liquid separator applied in TMSR

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ABSTRACT

The fission gas removal system plays a critical role in the development of the Thorium Molten Salt reactors. An axial gas-liquid separator is adopted in the gas removal system. To predict the bubble trajectories in swirling flow is essential for designing such gas-liquid separator, since the separation efficiency is closely related to the bubble trajectory. In this paper, we proposed a numerical method to predict the bubble motion. This method is a modified Lagrangian approach in that the velocity of the continuous phase is obtained by approximating the velocity profiles from CFD. Combing the known velocity distribution with explicit mathematical expression and the force model for a single bubble, a mathematical model to calculate the bubble motion is well posed. Calculations with various bubble sizes and Reynolds numbers were carried out. By comparing the simulation results with the experimental data, we concluded that the numerical results agree well with the experimental data. The maximum error of the separation length is less than 10%, which is accurate enough for the determination of the dimension of the separator.

1. Introduction

Molten salt reactors are engaging more and more interests in the Generation IV reactors. One advantage of the liquid fueled Thorium Molten Salt Reactor (TMSR) is that the fuel can be burned up deeply with the use of fission gas removal system. The bubbling degassing approach proposed by Oak Ridge National Laboratory (ORNL) (Molten-Salt Reactor Program, 1972) shown in Fig. 1 can be adopted to remove fission gases effectively. In this approach, small helium bubbles as shown in Fig. 1(a) are injected into the coolant in the primary loop, in which mass transfer as shown in Fig. 1(b) of the fission gases from the salt coolant to the bubbles will take place. Then the bubbles of helium and fission gas mixture can be removed by an axial type gas-liquid separator (Neesse and Dueck, 2007; Davidson, 1988) shown in Fig. 2.

The gas-liquid separator shown in Fig. 2 consists of a swirl vane, a swirl chamber, and a recovery vane. When the bubbly flow passing through the swirl vane, bubbles will be concentrated and an air core is formed (Yin et al., 2015) due to the centripetal force acting on the bubble surface. In this way, the bubbles are degassed from the liquid phase. For a successful separation, it must be guaranteed that all bubbles with different sizes enter into the air core, that requires the axial distance (defined as Separation length) taken by bubbles moving from the periphery of the swirl chamber to the center is less than the swirl chamber length. Thus, an accurate and fast numerical approach to predict the separation length is preferred for the separator design.

The gas-liquid two-phase flow is very complex in that the bubbly flow and stratified flow coexist with intense gas-liquid interfacial area variation due to bubble coalescence and breakup. To numerically simulate the flow by two-fluid models such as the full Eulerian, Eulerian-Lagrangian models (Brennan, 2006; Sripriya et al., 2007; Najafi et al., 2005) is still challenging and time consuming. In this paper, we are aiming to develop an alternative method to predict the bubble's motion, which can avoid the difficulties induced by the two-phase flow simulation. A closely relevant work dealing with bubble's trajectory in swirl flow was carried out by Magaud (Angilella et al., 2003). In his mathematical modeling and experiments on the behavior of an isolated bubble in swirling flow, the liquid velocity profile was assumed as a solid-body rotation supposed to a uniform axial velocity, based on which the interface forces including the drag force, the lift force, the virtual mass force, and the turbulence dispersion force were implemented on the isolated bubble. Since the axial velocity component used in the Magaud's model is assumed to be constant, one issue to be addressed is to take non-uniform distribution the axial velocity component of the swirl flow into consideration. In addition, the circumferential velocity cannot be approximated by

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Nomenclature

TMSR	Thorium Molten Salt Reactor
Re	Reynolds number
R	radius of swirl chamber
z^*	z/R, dimensionless characteristic of axial distance
$r*$	r/R, dimensionless characteristic of radial distance
V_0^*, V_1^*, V_2^*	dimensionless characteristic tangential velocity
R_1^* & R_2^*	dimensionless characteristic vortex radii
a	radius of bubble
d	bubble diameter
m_d & V_d	the mass and volume of a single bubble
ρ_d	density of air
v_d	velocity of the bubble
F	integral force
F_p	pressure gradient
F_d	drag force
F_g	buoyancy force
F_l	lift force
F_{m}	added mass
a_d	integral acceleration
C_d	drag coefficient
C_l	lift coefficient
C_m	added-mass coefficient of a particle in an in viscid fluid
SL	separation length
Experiment SL	separation length of experiment result
Simulated SL	separation length of simulation result
Ab	air core boundary

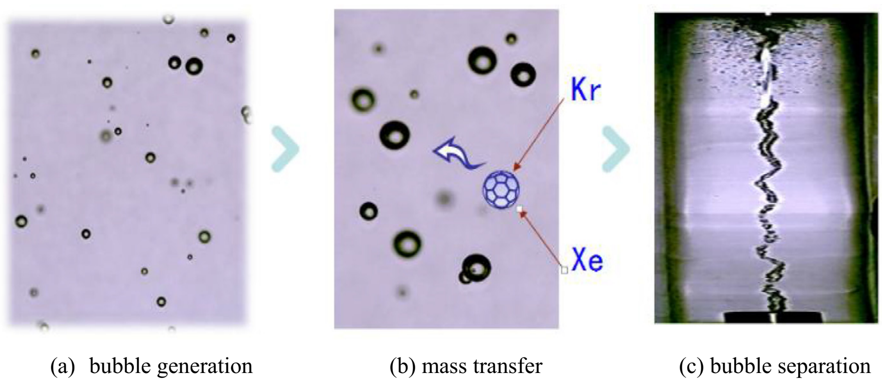

Fig. 1. Fission gas removal process (a) bubble generation (b) mass transfer (c) bubble separation.

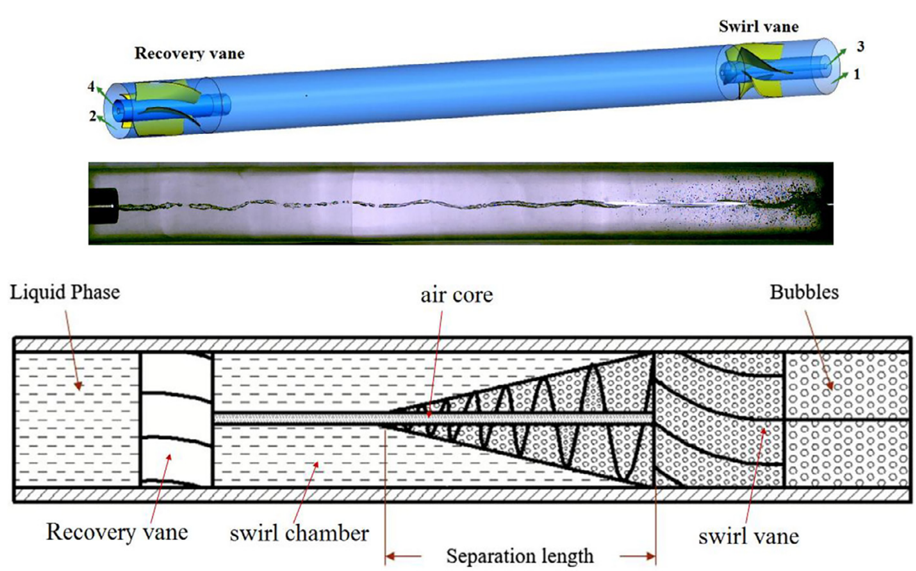

Fig. 2. A typical flow pattern for the gas-liquid separator.

the solid rotation due to that the swirl flow is not generated by rotating the walls of the swirl chamber used by Magaud (Angilella et al., 2003) but by the guiding of the swirl vanes. Thus, by incorporating the exact velocity profiles in the gas-liquid separator, a modified mathematical modeling approach was developed to predict the motion for the isolated bubble, in which the influences induced by bubbles' interaction was neglected because of the low void fraction of the gas phase. Then the model was