ISSN 0018-151X, High Temperature, 2018, Vol. 56, No. 1, pp. 61–69. © Pleiades Publishing, Ltd., 2018.
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HEAT AND MASS TRANSFER AND PHYSICAL GASDYNAMICS

Numerical Simulation of the Turbulent Upward Flow of a Gas-Liquid Bubble Mixture in a Vertical Pipe: Comparison with Experimental Data

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Received September 25, 2016

Abstract—The results of numerical simulation of the structure of a two-phase flow of a gas–liquid bubble mixture in a vertical ascending flow in a pipe are presented. The mathematical model is based on the use of the Eulerian description of the mass and momentum conservation for the liquid and gas phases, recorded within the framework of the theory of interacting continua. To describe the bubble-size distribution, the equations of particle-number conservation for individual groups of bubbles with different constant sizes are used for each fraction, taking the processes of breakage and coalescence into account. Comparison of the results of numerical simulation with experimental data has shown that the proposed approach enables the simulation of bubble turbulent polydisperse flows in a wide range of gas concentrations.

DOI: 10.1134/S0018151X18010078

INTRODUCTION

Investigation of the formation of bubbles and droplets in the flow of liquids or gases from apertures and nozzles is extremely important for the development of scientifically valid methods for calculations regarding a column apparatus in which the interfacial surface is created by dispersing a liquid or gas. Parameters that affect the process of bubble formation can be divided into design parameters, options related to the properties of gas and liquids, and performance characteristics. The properties of a system include the surface tension at the interface, density, viscosity, contact angle, and sonic velocity of a gas. The performance characteristics include the volume flow rate of the dispersed phase, the magnitude and direction of the velocity of the continuous phase, the height of the liquid level in the column, and the pressure drop and temperature [1, 2]. Gas-liquid turbulent flows in pipes are found in power equipment, nuclear-power engineering, and other fields [3–6]. A large number of works have been devoted to the experimental study of turbulent bubble flows [7–15]. Studies of both upward gas–liquid [7–11] and downward flows [12–15] are of particular interest. The existence of a region with anomalously high resistance values was experimentally observed during the gas–liquid mixture flow in pipes at low concentrations and low reduced velocities of the liquid phase [7]. In the upward gas–liquid flow, the distribution of a local gas concentration with sharply pronounced maxima near the pipe wall is implemented in many modes, when there is a significant increase in the shear stress on the wall [8–10]. For descendingflows, distributions of the local concentration of the gas phase are used, which are characterized by higher gas-content values near the center of the flow and decreasing ones near the channel walls [12]. In this connection, the characteristics of the ascending and descending bubble flows differ significantly [7–15]. The results of an experimental investigation of the descending bubble flow in a vertical pipe 15 mm in diameter were presented in [12]. The two-phase flow was formed by introducing gas into the liquid using a special mixer, which made it possible to obtain a gas–liquid flow with approximately the same dimensions of gas bubbles, the average size of which could vary in different modes. Along with experimental studies of gas–liquid flows, a large number of papers have been devoted to numerical simulations of two-phase bubble flows.

Different approaches are used to calculate polydisperse flows on the basis of the Eulerian continuum method, taking collision processes between the bubbles into account [16–42]. Approaches using the kinetic equation for the specific concentration of bubbles, that is, the population balance equation (PBE), are widely used [16–20]. One way to solve the PBE equation system is the multiple-size group (MUSIG) multifluid multistage approach, where the entire particle system is divided into separate groups (classes) in size. Then, a system of equations for the balance of mass, momentum, and heat is recorded for each group of particles with a certain fixed size [17, 18]. Approaches that are more economical from the point