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Investigation on the effect of geometrical parameters on the performance of a venturi type bubble generator

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ABSTRACT

The venturi type bubble generator adopted in the fission gas removal system for the liquid-fuel thorium molten salt reactor plays a crucial role in strengthening the mass transfer rate. Aiming at clarifying how these three main geometrical parameters, including the injection hole diameter, injection hole number, and divergent angle, influence the bubble size distributions, an experimental study is carried out. The bubble size distribution is extracted from the images captured by the high speed visualization. Post processing algorithm is developed to detect the bubble edges and compute their Sauter mean diameters for each flow condition. By changing the value of each geometrical parameter, the variation of the bubble size distribution is obtained and discussed. It is shown that the injection hole diameter and number basically have little effect on the bubble size distribution while the divergent angle is proved to be sensitive. Finally, the reasons that account for the bubble size variation with three geometrical parameters are explained by the bubble turbulence breakup theory.

1. Introduction

The Molten Salt Reactor (MSR) is one of the candidates of Generation IV reactors. The liquid-fuel thorium molten salt reactor (TMSR) proposed by Shanghai Institute of Applied Physics (SINAP) is a typical molten salt reactor. One of the prominent features of TMSR is that the fuel can be burned up completely. It is realized by the gas removal system which can remove the neutron poisonous gases such as ^{135}Xe and ^{85}Ke. The first off-gas system was proposed in the development of the Molten Salt Breeding Reactor (MSBR) by Oak Ridge National Laboratory (ORNL) (Flynn et al., 1966). The basic principle of the off-gas system is to inject helium bubbles into the liquid salt. The ^{135}Xe and ^{85}Ke will be transferred into the helium bubbles by turbulent diffusion and then stripped off from the salt by a gas-liquid separator (Yin et al., 2016; Yin et al., 2015). The first step to achieve this is to develop the micro bubble generators. A feasible and simple bubble generator firstly developed by Kress (1972) from ORNL is the venturi type bubble generator, by which large bubbles can be broken into very small bubbles. The bubble breakup mechanism attracts interests from many researchers. Fujiwara et al. (2007) and Uesawa et al. (2012) investigated the bubble breakup phenomenon by visualization and other measurements and concluded that the bubble breakup can be due to the pressure shock induced by the transition from supersonic flow to subsonic flow. However, for the venturi-type bubble generator proposed for off-gas system in MSRs, the bubble breakup mechanism is ascribed to the turbulence from the liquid phase that split the gas-liquid interphase. Based on the turbulence breakup theory (Uesawa et al., 2012), Kress (Kress, 1972) also developed a correlation relating the volume averaged bubble diameter to the Weber number and the Reynolds number based on the experimental data. Yin et al. (2015) added the effect of the gas volume ratio to the correlation and pointed out the volume averaged bubble diameter has a linear dependence on the gas volume ratio. Gordiychuk et al. (2016) also investigated how air and water flow rates as well as the air inlet size influence the size distribution of micro bubbles for a venturi type bubble generator and concluded that the bubble size is inversely proportional to the water flow rate and the increase in the air/water ratio results in the increase of the bubble size. However, the influence of air inlet size is not determined and also no flow pattern under different air inlet size is available. Besides the air inlet size, there are other key geometrical parameters including the air inlet number, the divergent angle of the venturi tube concerned in the design of the bubble generator. In order to quantify how the air inlet size, the air inlet number and the divergent angle influence the bubble size and clarify the detailed flow pattern evolution with the variation for each geometrical parameter, a systematic experimental study was carried out in present study.

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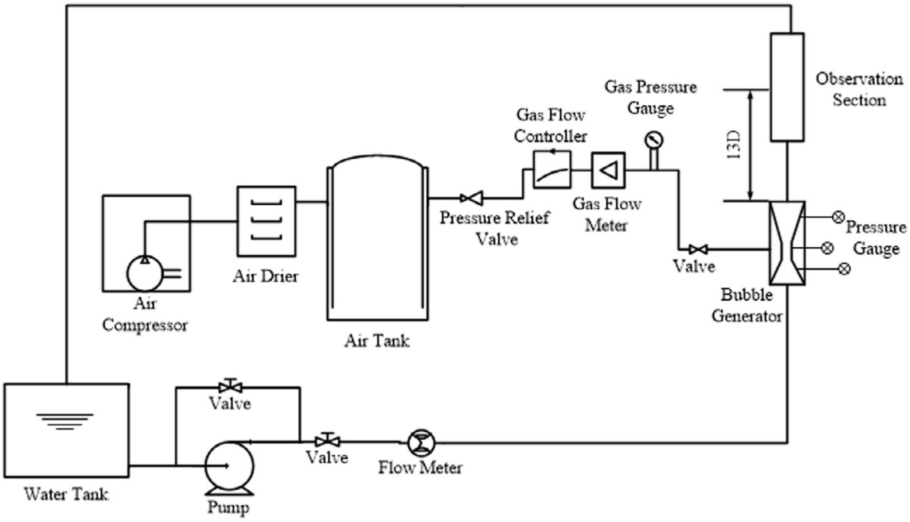

Fig. 1. The schematic map of the test loop.

2. Experiment setup

2.1. Overview of the experimental loop

The performance of bubble generators was tested in the two-phase flow test loop shown in Fig. 1 previously used by Yin et al. (2015). Besides the pumps, valves and pipes used for tap water transportation, the test loop consists of two key units including the bubble generation unit and bubble separation unit. An axial gas-liquid separator similar with the hydro-cyclone (Sripriya et al., 2013) introduced by Baowei (Baowei et al., 2014) was used to remove the dispersed bubbles. The bubble generation unit consists of an air compressor with auxiliary air drying facility, a smart gas flow rate controller which can produce a designated gas flow rate automatically, and the venturi type bubble generator concerned. The air was injected into the throat region of the venturi tube through small holes and large bubbles were formed near the injecting position and broken into small bubbles by the turbulence. With the gradual balance of bubble breakup and coalescence, the bubble size distribution approaches a steady state. To capture the steady bubble distribution, the measurement window made of acrylic plastics was installed downstream of the bubble generation with 15D the axial distance. The high-speed camera (Phantom V1210) was used to take images both at the measurement window and the bubble generator. The data taken from the downstream window with relatively high resolution was used to analyze the bubble size while the data taken from the bubble generator with relatively low resolution was used to explain the bubble breakup process qualitatively. Two LED panels were arranged in a backlight configuration to provide a uniformly illuminated background. In order to correct the optical distortion resulting from venturi shape, a square box illustrated in Fig. 2 made of acrylic plastics was installed around the bubble generator.

Fig. 2. Configuration of the venturi-type bubble generator with the additional square glass box.

2.2. Configuration of the bubble generator

As shown in Fig. 3, the venturi type bubble generator consists of the convergent portion, throat portion, and divergent portion. In the throat region, several holes are drilled in such a way that the air can be introduced by connecting the hole to the air supply system. Each hole is controlled by a separate valve and the gas injection is under the constant volumetric flow rate mode. Larger bubbles are firstly formed near the injection hole and broken into smaller bubbles in the divergent portion by strong turbulence. The bubble formation process indicates that the geometrical parameters affecting the performance of the bubble generator are the diameter of the holes d_i, the hole number N, and the divergent angle β. To investigate the effects of these three key geometrical parameters on the bubbling performance, three groups of bubble generators listed in Table 1 were designed and manufactured. The group G1 focused on the variation of the injection hole diameter, which varies from 1 mm to 3 mm. In group G2, the number of the holes varies from 1 to 3 while keeping the injection hole diameter and the divergent angle be constant. Attention was given to the divergent angle in group G3 with fixed injection hole diameter and number (see Table 2).

2.3. Test runs

In the experiment, the deionized water was used as the liquid phase and the air was taken as the air phase. Targeted for the application of TMSR, the volumetric flow rate of water was controlled ranging from 5 m^3/h to 20 m^3/h, namely the Reynolds number defined by the bulk water velocity and the diameter of the venturi tube inlet ranging from 47,000 to 188,000. The gas flow rate controlled by the smart flow controller ranges from 0.005 m^3/h to 0.101 m^3/h. The variation range of the volumetric flow rate for the two phase was selected in such a way that the gas volume ratio defined in Eq. (1) (Where q_l is the water volumetric flow rate, and q_g is the gas volumetric flow rate.) varies from 0.1% to 0.5%, which guarantees the two-phase flow is in a dispersed bubbly flow and also satisfies the requirements of TMSR.

$$\alpha = q_g/(q_g + q_l) \tag{1}$$

2.4. Image processing method

The measurement challenge is to accurately quantify the geometrical parameters of individual bubble captured by the camera. According to the experimental study by Fu (Broeder and Sommerfeld, 2007), the phenomena of bubbles overlapping in acquired images can