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Editorial

Hydrodynamics and Heat Mass Transfer in Two-Phase Dispersed Flows in Pipes or Ducts

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Two-phase gas-liquid and gas-dispersed flows are frequently encountered in energy, nuclear, chemical, geothermal, oil and gas and refrigeration industries. Two-phase gas-liquid flows can occur in various forms, such as flows transitioning from pure liquid to vapor as a result of external heating; separated flows behind a flow sudden expansion or constriction; and dispersed two-phase flows, where the dispersed phase is present in the form of liquid droplets or gas bubbles in a continuous carrier fluid phase (i.e., gas or liquid). Typically, such flows are turbulent with a considerable interfacial interaction between the carrier fluid and the dispersed phases. The interfacial heat and mass transfer is very important in the modeling of such flows. The variety of flow regimes significantly complicates the theoretical prediction of the hydrodynamics of the two-phase flow. It requires the application of numerous hypotheses, assumptions, and approximations. Often, the complexity of the flow structure makes it impossible to theoretically describe its behavior, and so empirical data are applied instead. The correct simulation of two-phase gas-liquid flows is of great importance for safety and the prediction of energy equipment elements.

Therefore, understanding and controlling such flows demands study of the transport phenomenon in different macro- and microscales. Currently, the fast development of computer facilities allows numerical or experimental investigations of two-phase gas–liquid and gas-dispersed flows to be carried out in complicated flows of geometry; this can be considered an effective method to solve the abovementioned tasks.

This Special Issue presents papers related to various aspects of hydrodynamics and heat mass transfer in two-phase gas–liquid and gas-dispersed flows in pipes or ducts. These findings can also be used in basic sciences and in a vast range of applications. We consider the main goals to have been successfully reached. Authors from Russia, China, the USA, the UK, India and Singapore have published their recent contributions in this Special Issue. Here, we present 11 papers (2 are reviews and 9 are articles). Three papers from this list are feature papers in this Special Issue. We are happy to see that all papers present findings characterized as unconventional, innovative, and methodologically new. We hope that the readers of *Water* can enjoy and learn about the experimental and numerical study of two-phase flows using the published material and share their results with other researchers.

The main goals of this Special Issue were to present recent advances in experimental and numerical studies of hydrodynamics and heat mass transfer in two-phase gas–liquid and gas-dispersed flows in pipes or ducts for engineering and natural systems. These findings can be very useful for researchers and engineers in heat transfer and heat exchanger communities. The following paragraphs provide a short overview of the published articles.

Review paper [1] presents a comparative analysis of the capabilities of various experimental techniques for studying droplet entrainment in annular gas–liquid flows. Entrainment occurs due to the break-up of small-scale ripple waves propagating on top of large-scale disturbance waves. This process must be studied in two planes simultaneously;

the instantaneous film thickness must be measured over an area, together with the parameters of the entrained droplets. This goal cannot be achieved with conductance probes, optical visualization, or Planar LIF. Re-emission or absorption techniques accompanied with side-view visualization are suitable for this purpose. To reduce the errors caused by optical distortions, usage of X-ray or near-infrared radiation is recommended.

A review of the experimental and numerical methods used for the investigation of two-phase annular flow in vertical pipes, mainly in the last two decades, is provided by [2]. The variety of measured methods and numerical simulations are compared to highlight their advantages and challenges. Experimental techniques were summarized and their advantages and limitations were shown to readers. The advantages and deficiencies of the numerical model are presented and discussed. Many previous theoretical or empirical models considered the gas flow as one of the dominating mechanisms; they did not consider the effect of gas superficial velocity in the formulas. These models did not predict the annular flows well without the gas stream in the core zone of the pipe.

The authors of [3] proposed a method for modifying the inner surface of a mini-channel by applying a laser pulse on the outer wall of the channel. The boiling of R-125 in the vertical channel with a diameter of 1.1 mm and length of 50 mm was studied at varied pressures and flow rates in channels with modified surfaces. A significant increase in the heat transfer coefficient and critical heat flux was found. The increase in pressure leads to a reduction in the effect of wall modification on the heat transfer coefficient. The results of this study can be used for the development of advanced heat exchange devices based on mini-channels.

The influence of the discrete representation of the continuous bubble size distribution on the flow structure inside the bubble column, as well as comparison between the polydisperse and monodisperse approaches, is shown in [4]. The authors use the Euler–Euler approach to model the bubble flow dynamics. The turbulence of the carrier phase was modeled by the k-ω SST model, considering the effect of additional turbulence production due to the presence of bubbles. The population balance model was used to model the bubble size distribution. The main aim of the paper was to propose and assess the most compact discrete representation of the bubble size distribution capable of predicting complex flow structure inside the bubble column reactor. The authors have shown that the new hybrid discrete representation with only four classes of bubbles can capture the flow behavior inside the column; additionally, with the increasing bubble size, the monodisperse approach can be sufficient to predict important multiphase parameters, such as the volume fraction of the dispersed phase or the specific interfacial area density.

An experimental study of the movement of bubbles after injection from a single capillary in an inclined pipe was performed [5]. The high-speed shadowgraph method and image analysis procedure are utilized. The dependencies of the velocity and average size of gas bubbles on the angle of inclination of the pipe at various distances from the place of gas injection are obtained. A map of regime parameters has been constructed, according to which various flow regimes are classified. The regime parameters were obtained, under which chains of bubbles were formed; no coalescence of the bubbles occurred. This demonstrates that the increase in the gas flow rate leads to the coalescence of bubbles and the destruction of bubble chains.

A Reynolds-averaged Navier–Stokes (RANS) Euler–Euler simulation of flow, turbulence and heat transfer of droplet-laden flow in a ribbed duct was carried out in [6]. The carrier phase turbulence was predicted using the elliptical blending second-moment closure by observing the presence of droplets. The authors show that the mean and fluctuational flow structures undergo significant modification in comparison with the straight duct. The significant augmentation in the level of turbulent kinetic energy (up to 2 times) and heat transfer (almost 2.5 times) in the ribbed duct two-phase mist flow, in comparison with the single-phase rubbed flow, was predicted.

In the experimental and numerical studies of swirling flows in an aerial vortex reactor [7], it was found that, similar to the case of two rotating liquids, a strongly swirling jet is formed at the reactor axis and the entire flow takes on the structure of a miniature gas–liquid tornado. The aerating gas only interacts with the liquid through the free surface. It was also revealed that the radial velocity component slips at the interface. Moreover, despite the difference in density being more than three orders of magnitude, the spiral air flow converging to the reactor axis forms a divergent vortex motion of the liquid medium. This feature causes an intensification of the interphase mass transfer due to the high-speed motion of the aerating gas.

The authors of [8] combine laser treatment and hot wire chemical vapor deposition (HW CVD) for the change wettability of single-crystal silicon surface. The wetting properties varied from supehydrophilic to superhydrophobic. The influence of contact angle on the spreading of falling water droplets for a Weber number of up to 40 was measured. A new approach for the generalization of experimental data was suggested. The authors of [9] investigated the effect of gravitational forces on the rate of evaporation of a water droplet deposited on a structured surface. The comparisons were made between the dynamics of evaporation of a sessile and suspended droplet. This was carried out by using a bifilar surface with a seat and an experimental setup with a rotary mechanism. The authors showed and hypothesized about the differences in the dynamics of evaporation for sessile and suspended droplets.

The authors of [10] utilized the HW CVD method to the fabrication of highly efficient hydrophobic separation membranes by depositing fluoropolymer coatings with different wetting properties. The separation of emulsions of water and commercial crude oil was studied. It was shown that membrane-wetting properties affect the rate and efficiency of the separation. The incensement in water contact angle and decrement in the pore size of membranes lead to higher separation efficiency. The optimal parameters for the use of membranes for separating emulsions were found. The highest efficiency is achieved when separating membranes with a superhydrophobic coating (water contact angle = 170°) and the minimum pore size (40 μm). It was shown that the proposed membranes can easily be washed and reused with close-to-original properties.

The effect of wall proximity and surface tension on the single and rising bubble path in still water close to the wall was numerically studied in [11] using OpenFOAM based on the Volume of Fluid (VOF) method. The authors found that bubble motion and rising close to the wall increases the drag and leads to an early transition from rectilinear to the planar zigzagging regime. The bouncing motion of gas bubbles in pure water was studied. The authors revealed the bubble motion in the spanwise direction is insignificant and the bouncing motion is two-dimensional.

The advanced underpinning physics of the mechanism is summarized in several groups, including wavy liquid film, droplet behavior, entrainment and local void fraction. Unsteady annular two-phase flow has not been widely experimentally and numerically studied and is not well understood. The current understanding of unstable annular flow is generally derived from the steady-state case. Therefore, the investigation of unsteady annular flow and the transient region of a stable flow is recommended with particular focus on the wavy liquid film, gas core and entrained droplets.

All of the abovementioned reviews and research papers have demonstrated the importance and usefulness of two-phase gas-liquid and gas-dispersed flow studies, using both measurements and numerical simulations for science and a range of applications.

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