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Editorial

Latest Progress and Applications of Multiphase Flow and Heat Transfer

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1. Introduction

Multiphase flow and heat transfer are critical in both traditional and emerging area of engineering research [1] and are widely involved in industrial processes and academic studies [2,3], including petrochemical engineering [4,5], chemical engineering [6,7], nuclear engineering [8–10], mechanical engineering [11,12], and ocean engineering [13,14], as well as renewable energy [15,16], energy storage [17,18], and cleaning coal technology [19,20], etc. With the rapid development of various interdisciplinary subjects and technologies, the novel technologies and innovative applications of multiphase flow and heat transfer are proposed and developed in an endless stream and show great potential. On the other hand, studies of multiphase flow and heat transfer commonly couple various physical processes, such as phase change [21,22], interface evolution and interaction, physical or chemical reactions, multiscale coupling analysis, spatiotemporal transient dynamics, and multicomponent flow and mass transfer. Although a lot of studies and great efforts have been performed to understand the complicated multiphase flow and heat transfer phenomena and to reveal new mechanisms and theories, there are still many issues that need to be clarified from both theoretical and applied aspects of this important field [1]. Correspondingly, the methods, algorithms, and modeling of numerical simulation also pose great challenges with regard to accurately capturing and predicting the heat transfer behavior of multiphase flow.

This Special Issue aims to provide a top-notch platform to introduce the latest progress and various applications in the area of multiphase flow and heat transfer. The scope of this Special Issue includes the aspects of theoretical derivation and analysis, model development and simulation, and experimental investigation and engineering applications, with hopes to be invaluable for scientists and researchers interested in multiphase flows. Generally, seven articles in this Special Issue cover the latest research advances in academia (mainly from the universities or institutes) and industry, such as KBR in the US and CNNC in China. The contributed scientists are from nine countries, including the USA, Russia, Germany, Belgium, Serbia, Australia, Colombia, Japan, and China. Moreover, I would like to express my gratitude to all authors who have contributed to this Special Issue.

2. An Overview of Published Articles

The first article by Mr. Li et al. from the Northeastern University of China and Prof. Tu from the Royal Melbourne Institute of Technology (RMIT) University of Australia conducted a numerical study on spontaneous steam condensation in a nozzle. A wet steam model with entropy generation rates was proposed in the study, considering three different mechanisms, including viscous dissipation, heat transport, and phase change. Different geometric parameters of the nozzle (like throat radius, divergent section expansion angle, and divergent section length) were designed, and the effects on the spontaneous steam condensation were discussed. In addition, the performance of the nozzle was also studied by comparing the mass flow rate, total entropy production, and liquid mass fraction. The calculated results demonstrate that increasing the throat diameter or reducing the expansion

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angle of the divergent section restrains steam condensation. The irreversible energy caused by steam condensation results in energy waste and weakens the nozzle's performance.

The second article is also an international collaborative work related to the two-phase flow in petroleum engineering. Researchers from Asia (Saudi Arabia and Kuwait), Europe (Russia, Serbia, Germany, Belgium), and South America (Colombia) propose a non-invasive method to identify the flow pattern and to determine the volume percentage of two-phase flow in a scale-laden petroleum pipeline by employing artificial intelligence technologies. In the tested petroleum pipeline, a dual-energy gamma source emits photons, and two detectors are placed in front of the gamma source at a 45-degree angle to the center of the pipe: one is for transmitted photons and the other one is for scattered photons. The Monte Carlo N-Particle code (MCNP) is employed to analyze the flow patterns at different volume percentages as well as to calculate the scale thickness inside the pipe. The feature extraction technique of the time domain is adapted to extract time characteristics, like skewness, kurtosis, and 4th-order moment. Finally, the flow patterns and the volume percentages are identified by the two designed multilayer perceptron neural networks.

Researchers of the third article are from Japan (Tokyo Institute of Technology and Tokyo University of Agriculture and Technology) and Indonesia (Institut Teknologi Nasional Bandung), focusing on the hydrodynamic fingering induced by gel formation. They conduct Hele–Shaw cell displacement experiments for a miscible fluid system by using skim milk and an aqueous citric acid solution. The effects of gel film formation on fingering instability are discussed and investigated, and a mathematical model is developed for the sequential growth of gel film formation at the fingertip. The results show that mixing skim milk with the aqueous citric acid solution causes the formation of gel film, which leads to interface instability. The diffusion of citric acid causes the formation of gel film to thicken over time. As the flow increases, the width of the fingers remains constant while the finger number increases linearly before the fingers merge. Based on the interaction between the diffusion of citric acid and the elongation of the fingertip, a mathematical model of sequential film thickness growth is developed for a bubble-like fingertip structure. The model is helpful for providing us with a better understanding of the fundamental growth mechanism of the bubble-like fingertip.

The fourth article written by scholars from academia (Louisiana State University and University of Texas at Austin) and industry (KBR) in the USA focuses on the influence of porous media on the interaction between wave-induced sloshing and the dynamics of the floating body, which is very important to the structural vibration control in civil and ocean engineering. A numerical algorithm that couples fluid computation (for sloshing fluid and ambient waves) and rigid-body dynamics (for the floating platform) is proposed. The Eulerian–Lagrangian method is employed to calculate the hydrodynamic in both the pore-flow domain and the pure-water domain. The Newmark time integration method is adopted for the rigid body dynamics to ensure numerical stability. The modeling freedom of the sloshing fluid is reduced, and the numerical process is fast and inexpensive. According to the frequency response analysis, the effectiveness of the porous media is verified for reducing the vibration and mitigating the sloshing response. It is believed that the porous media will reduce the hydrodynamic pressure and improve the integrity of the liquid container.

In the fifth article, Li et al. from the Xi'an Jiaotong University of China develop a high-accuracy flow pattern identification method for air–water two-phase flow in the porous media by combining signal feature extraction technologies and machine learning technologies. According to the differential pressure signals of two-phase flow in porous beds, three parameters related to time domain characteristics, including the mean, standard deviation, and range of the signals, are analyzed and extracted using a statistical method. In addition, the time–frequency domain features of the signals are also extracted with the empirical mode decomposition (EMD) method. Then, machine learning technologies, such as the support vector machine (SVM) and BP neural network, are adopted to train and construct different flow pattern identification models based on extracted signal feature parameters. In the end, an online and high-accuracy intelligent system is established to identify the flow patterns in porous media.

The sixth article focuses on the enhanced heat transfer characteristics of spherical heat storage related to phase change thermal storage technology. Researchers from the Inner Mongolia Agricultural University and Inner Mongolia Agricultural University of China designed and constructed a test system of melting spherical heat storage units to experimentally study the melting characteristics of a CuO-paraffin wax composite in a spherical heat storage unit. The influences of parameters, including the pin fin numbers, the temperature in the water bath, and the CuO nanoparticles in paraffin, are discussed and analyzed. In addition, a regression model is fitted to investigate the effects of different parameters on the melting time of the phase change material (PCM). The results show that the interaction between the water bath temperature and the pin fin numbers significantly affects the melting time of the PCM in the heat storage unit. A prediction model is further established to calculate the melting time via the response surface methodology. The work can prove to be helpful in the design of thermal storage units.

The seventh article focuses on the process of steam condensation heat transfer in nuclear engineering. Li et al. from China Nuclear Power Engineering Co. Ltd. propose a comprehensive heat transfer model (considering liquid film heat transfer, steam condensation, and convective heat transfer), aiming to study the heat transfer process of steam condensation with non-condensable gas. A model is then adopted via the Integrated Program of Severe Accident Analysis (PISAA) for nuclear power plants. By comparing the calculated results from the PISAA program with those obtained using the traditional containment analysis codes of nuclear reactors, as well as the experimental data in the Wisconsin condensation tests, the model is verified and shows good performance with a stable calculation process, less iteration, and fast convergence. Moreover, sensitivity analysis of the heat transfer coefficient parameters shows that the average error is about 10% for the condensation heat transfer coefficient and that the maximum value is below 30%, which indicates that the model is suitable for thermal-hydraulic analysis in nuclear engineering.

3. Conclusions

The compilation of studies in this Special Issue is devoted to highlighting the recent progress and various applications of multiphase flow and heat transfer, ranging from conventional research and interdisciplinary research; additionally, it aims to introduce the different methodologies and interdisciplinary manners that are employed in the respective case studies.

In summary, the first paper and the seventh paper both focus on the phenomenon of steam condensation, while the numerical simulation performed in the first paper and the seventh paper establishes a calculation model to analyze the steam condensation heat transfer with non-condensable gas; then, the model is employed using the analysis code for severe accidents of nuclear reactors. Applications of machine learning technologies in multiphase flow and heat transfer are discussed and explored in the second and the fifth articles, corresponding to petroleum engineering and nuclear engineering, respectively. Based on the experimental studies conducted in the third paper, a mathematical model is established to better understand the fundamental growth mechanism of the bubble-like fingertip. The fourth paper proposes a numerical algorithm used in ocean engineering, while the sixth paper conducts an experimental study related to the field of energy storage.

In the end, I would like to emphasize that the studies compiled in this Special Issue may be seen as a starting point to inspire scientists and researchers in the field of multiphase flow and heat transfer to explore innovative studies, including the fundamentals of multiphase flow and heat transfer, interdisciplinary studies, those under extreme working conditions, etc.

Conflicts of Interest: The authors declare no conflict of interest.

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