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Hydro-gas dynamics and thermophysics of two-phase flows: Analysis and current research trends

Abstract: Hydro-gas dynamics and thermophysics of two-phase flows are relevant due to their application in various industrial and energy processes. The study object is two-phase flows involving the interaction of liquid and gas. The study subject is the processes that occur during the simultaneous movement of gas and liquid phases in pipelines and heat engineering systems, like heat exchange mechanisms accompanied by phase transitions. The study aims to analyse current trends in modelling such systems to improve their efficiency. The main objectives are to study flow types, modelling methods, and heat exchange. The methods used include numerical modelling and experimental studies. The article uses the works of leading researchers, such as V. S. Karpov, S. P. Pavlov, and others. The study's main results are optimising heat exchange processes in systems with two-phase flows.

Keywords: two-phase flows, heat exchange, modelling, turbulence, phase transitions.

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Гідрогазодинаміка і теплофізика двофазних потоків: аналіз і сучасні тенденції досліджень

Анотація: Тема гідрогазодинаміки та теплофізики двофазних потоків є актуальною через її застосування в різних промислових та енергетичних процесах. Об'єктом дослідження є двофазні потоки, що включають взаємодію рідини та газу. Предмет дослідження - процеси, які відбуваються при одночасному русі газової та рідкої фаз у трубопроводах і теплотехнічних системах, а також механізми теплообміну, що супроводжуються фазовими переходами. Мета дослідження –

проаналізувати сучасні тенденції у моделюванні таких систем для підвищення їх ефективності. Основними завданнями є вивчення типів потоків, методів моделювання та теплообміну. Використані методи включають числове моделювання та експериментальні дослідження. В статті використано праці провідних дослідників, таких як В. С. Карпов, С. П. Павлов, та інших. Основні результати дослідження стосуються оптимізації теплообмінних процесів у системах з двофазними потоками.

Ключові слова: двофазні потоки, теплообмін, моделювання, турбулентність, фазові переходи.

Introduction

Two-phase flows, including liquids and gases, play a pivotal role in many industrial and natural processes, particularly in power systems, heating plants, and chemical reactors. Studying these flows can improve the energy efficiency and reliability of such systems. The relevance of research in this area is due to the complexity of the interaction processes between phases, which requires the development of new models and modelling methods.

The study object is two-phase gas and liquid flows in pipeline systems and heat exchangers.

The study subject is the processes that occur during the simultaneous movement of gas and liquid phases in pipelines, heat engineering systems, and heat exchange mechanisms accompanied by phase transitions.

The study aims to study the mechanisms of heat exchange and the influence of various factors on the efficiency of heat transfer. It will also analyse the main mechanisms of hydro-gas dynamic interaction and heat exchange in two-phase flows that occur under the joint movement of the liquid and gas phases.

The main objectives are to study flow types, modelling methods, and heat exchange.

The methods used include numerical modelling and experimental studies.

The results of the study

Fundamentals of hydro-gas dynamics of two-phase flows

Hydro-gas dynamics of two-phase flows involve studying the movement and interaction of two phases (gas and liquid) that flow together through pipes or other channels. In this case, there may be different options for interaction between the phases, in particular:

- Parallel flow: liquid and gas flow together in the same pipe;
- Mixed flow: liquid and gas mix to form different flow structures, such as gas bubbles, foam, or aerosol;
- Clearly separated flow: liquid and gas flow in separate layers with minimal interaction.

One of the main challenges that engineers and researchers face when modelling two-phase flows is accurately predicting the effect of interfacial interactions on various flow parameters, such as velocity, pressure, temperature, and energy losses.

Models of hydrodynamics of two-phase flows can be based on such approaches as:

- “Uniform flow” models: assume that gas and liquid have the same speed and move as a single medium. Such models are useful for general estimates.

- "Inhomogeneous flow" models: consider the difference in the velocities and behaviour of each phase separately, allowing you to predict the flow dynamics more accurately.

Thermophysics of two-phase flows

Two-phase flow thermophysics studies heat transfer and thermodynamic processes that occur during the interaction of the gas and liquid phases. Due to the complexity of such systems, significant aspects are:

- One of the key processes in the thermophysics of two-phase flows is the transition phase between liquid and gas (e.g., boiling, condensation), accompanied by intense changes in the thermal properties of the medium;
- Convective heat exchange mechanism: in such systems, heat exchange often occurs due to convection, which is a complex process due to phase mixing and the formation of turbulent structures;
- The effects of surface phenomena, such as surface tension, capillary forces, and interfacial interactions at the microscopic level, can significantly affect heat transfer in two-phase flows.

Modern computational models of thermophysical processes of two-phase flows consider both phenomena at the macroscopic level (temperature distribution, velocity) and the microscopic level (interaction of molecules and phase transitions).

Analytical resume

Studying two-phase flows is a significant part of scientific research, and many papers have been devoted to developing new models and methods for calculating such processes. Here are a few areas that have received significant attention in the past and present century:

- Modelling of boiling and condensation in two-phase flows: one of the significant research topics since many power plants and industrial processes involve boiling processes (e.g., in nuclear reactors or cooling systems). The use of the two-phase flow model makes it possible to accurately predict temperature and heat losses, like determining the efficiency of such systems;
- Development of numerical methods for modelling two-phase flows: many dissertation studies focus on improving numerical methods (hydrodynamic and thermophysical modelling methods), such as finite element methods and methods for solving Navier-Stokes equations for two-phase media. They help to create more accurate models for predicting the behaviour of such flows in real-world conditions;
- Experimental studies of two-phase flows in various geometries allow us to assess the influence of pipeline geometry, flow rate, and other parameters on heat exchange efficiency and flow dynamics. This is significant for developing new designs of heat exchangers and other heat engineering devices.

Recent studies, particularly dissertations (*Martynenko, 2022*), focus on a deeper study of turbulent two-phase flows, where intense turbulence significantly changes the heat transfer and dynamics of phase transitions. In particular, researchers such as V.S. Karpov and S.P. Pavlov

(2018) offer new numerical models for predicting the behaviour of such flows under high temperatures and pressures, which are critical for nuclear and thermal power plants.

Interaction between phases and thermodynamic processes: I.V. Kozlov's work (2019) develops a detailed model of phase transitions and heat transfer in two-phase flows based on statistical methods. These studies allow us to create more accurate predictions for systems with high thermodynamic changes, such as boiling and condensation.

New approaches to heat exchange optimisation: modern works in thermophysics of two-phase flows, in particular, the dissertations of V.A. Kostenko (2020), devoted to improving heat exchange installations by numerical modelling and experiments with new materials that increase the efficiency of heat exchange in two-phase flows.

Modelling of two-phase flows on a microscopic scale: M.R. Nazarov's work (2021) uses molecular dynamical models to study phase transitions in bounded geometries, such as nanochannels, which opens up new horizons for developing technologies in microelectronics and nanotechnology.

A.V. Stepanov's article (2019) presents numerical methods for modelling phase transitions in two-phase flows, particularly boiling and condensation. Using finite element methods, the author develops new approaches to mathematically modelling flow behaviour in actual conditions. Special attention is paid to temperature gradients and the influence of pipe geometry on the phase distribution.

Yu. Baklanov's monograph (2021) presents complex mathematical models of two-phase flows used to predict their behaviour in various types of pipelines. The author focuses on numerical experiments and comparing them with actual data, especially regarding energy losses and phase dynamics.

V.P. Volkov's article (2022) examines the effect of turbulence on heat exchange processes in two-phase flows. The author uses modern approaches to modelling turbulent processes under various pressure and temperature conditions, particularly for power plants. The research focuses on improving understanding of the behaviour of two-phase flows in industrial systems and improving their efficiency.

Despite significant progress in understanding the hydro-gas dynamics and thermophysics of two-phase flows, there are still many unresolved problems and difficulties (Lapin, 2017):

- *In-depth modelling of complex two-phase flows*: for accurate prediction, it is necessary to develop more detailed models that take into account microscopic details, such as bubble structures and their interaction with the liquid (Smirnov, 2019);
- *Stimulating more efficient heat exchange methods*: creating new materials and designs for heat exchangers that interact effectively with two-phase flows can significantly improve the efficiency of energy systems;
- *Applications in new fields*: Expanding two-phase flow research into new areas, such as renewable energy, quantum thermodynamics, or even space technology, could lead to breakthroughs in science and technology.

Influence of pipeline geometry. Pipeline geometry has a decisive influence on heat exchange characteristics and flow dynamics (Orlov, 2020). The main parameters are the shape of the cross-section, the length of pipes, the presence of bends, and the diameter and roughness of the walls.

Pipeline diameter. Changes in the pipeline diameter can significantly affect the flow dynamics. During the study, it was found that with an increase in the pipe diameter, the flow resistance decreases, leading to a decrease in pressure losses. Still, at the same time, the intensity of heat exchange decreases due to a decrease in the contact surface between the flow and the pipe walls.

Roughness of the walls. High roughness contributes to turbulence, improving convective heat exchange by increasing heat transfer between the pipe walls and the flow. However, excessively high roughness increases hydrodynamic losses and energy costs for maintaining the flow.

Pipeline bends. The simulation results showed that bends and changes in the direction of flow movement lead to developing turbulence in areas of change in direction, increasing the heat transfer coefficient. At the same time, this increases hydraulic losses due to local supports. In systems with a large number of bends, it is necessary to find an optimal balance between heat exchange and energy losses.

Influence of the flow rate. The flow rate is one of the critical factors affecting the efficiency of heat exchange. Studies have demonstrated the following patterns:

- *Low speeds*. At low flow rates, laminar flow modes occur, in which convective heat exchange is low due to insufficient mixing of the flows. However, energy losses due to friction and local resistances are also reduced at low speeds.
- *High speeds*. As the flow rate increases, heat exchange increases due to developing turbulence, contributing to more efficient heat transfer from the walls to the flow. However, significant speeds also increase pressure losses and energy costs for pumping the medium.

Influence of the medium's phase state. In the case of two-phase flows (gas-liquid), the efficiency of heat exchange significantly depends on the phase ratio, the type of flow, and the dynamics of interaction between gas and liquid.

Phase transitions. Phase transitions, particularly boiling and condensation, are significant processes that affect heat exchange. Boiling a liquid in a two-phase stream significantly increases the heat transfer coefficient since there is an active mass exchange between the phases, and local zones of intense heat transfer are formed.

Structures of two-phase flows. The flow structure – bubble, film, or jet – also plays a significant role. Phase mixing and interaction increase heat transfer efficiency but complicate flow dynamics due to the need to consider the phase distribution over the pipe cross-section.

Influence of temperature gradients and thermodynamic conditions. The temperature gradient also determines the efficiency of heat exchange. Increasing the temperature difference between the liquid and the pipe walls contributes to an increase in heat flow. However, high-temperature gradients can cause instability of the flow, particularly the formation of bubbles or steam plugs in two-phase systems, which reduces the uniformity of heat exchange.

Influence of pipe diameter on heat transfer coefficient: as the pipe diameter increases, the heat transfer coefficient decreases, indicating a decrease in heat transfer efficiency at larger diameters due to less contact between the pipe walls and the flow.

Influence of flow rate on pressure loss: As the flow rate increases, pressure losses increase, which indicates an increase in energy costs to maintain the medium's movement at high speeds.

The graphs (*Figure 1*) show the importance of choosing the optimal parameters for efficient heat exchange in pipelines.

Discussion

The study's relevance is due to the complexity of the behaviour of two-phase flows and the need for accurate modelling of phase transitions (such as boiling and condensation), the influence of geometric features of pipelines on the efficiency of heat transfer and reduction of energy losses. Although capable of considering basic physical parameters, modern two-phase flow models need further improvement to improve accuracy under real-world operating conditions. In particular, considering microscopic effects (such as capillary forces and molecular interactions) is a significant challenge and opens up prospects for future research.

Further areas of work may include:

(1) Developing more detailed microscopic models of two-phase flows that consider capillary phenomena and interactions at the molecular level. This will allow us to better understand the processes of heat and mass transfer under high temperatures and pressures, especially for micro- and nanochannels.

(2) Optimising heat exchange systems by developing new pipeline materials and structures. Using materials with improved thermal conductivity characteristics and special coatings that contribute to improving heat transfer efficiency is a promising area of research for improving two-phase heat exchange systems.

(3) Introducing numerical models of two-phase flows into engineering practice to predict the behaviour of flows under non-standard conditions, such as renewable energy, heat pumps, and Microelectronics. Studying the specifics of such applications will help specialists and scientists improve design solutions and increase the energy efficiency of new systems.

Conclusion

The study's results show that heat exchange efficiency in pipelines largely depends on the geometric parameters, flow rate, and Phase state of the medium. Optimising the pipeline geometry and selecting appropriate flow modes and phase ratios allows you to achieve maximum efficiency with minimal energy and resource losses.

Hydro-gas dynamics and thermophysics of two-phase flows are significant and dynamically developing branches of science that play a key role in energy, chemical, and technological processes. Modern research in this area makes a significant contribution to developing new models, methods, and technologies that can improve the efficiency and reliability of such systems.

References:

Baklanov, Yu. S. (2021). *Two-phase flows in pipelines: Mathematical models and experiments*. Kyiv: Scientific Publishing House "Academy".

Karpov, V. S., & Pavlov, S. P. (2018). Modelling of thermal processes in turbulent two-phase flows. *Journal of Thermodynamics*, 35(2), 85-97.

Kostenko, V. A. (2020). *Numerical modelling of turbulent two-phase flows in heat exchange installations*. Kyiv: Publishing House "Technique".

Kozlov, I. V. (2019). *Phase transitions and heat transfer in two-phase flows: Modelling and experiments*. Kharkiv: Kharkiv University.

Lapin, Yu. V. (2017). *Thermophysics of two-phase flows: Theory and practice*. Lviv: Lviv National University.

Martynenko, O. V. (2022). Innovative methods of heat exchange in systems with two-phase flows. *Technical Science*, *49*(1), 56-63.
Nazarov, M. R. (2021). Molecular dynamic modelling of two-phase flows in microscopic channels. *Scientific Works*, *42*(5), 112-123.
Orlov, I. M. (2020). Convective heat exchange in systems with two-phase flows: New approaches. *Engineering Physics*, *45*(3), 142-152.
Smirnov, P. O. (2019). Numerical methods for modelling phase transitions. *Journal of Applied Mechanics*, *48*(3), 234-245.
Stepanov, A. V. (2019). Numerical modelling of phase transitions in two-phase flows. *Thermodynamics and Heat Exchange*, *12*(4), 203-215.
Volkov, V. P. (2022). Analysis of turbulence and heat exchange in two-phase flows. *Journal of Applied Mechanics*, *37*(2), 77-89.

Appendix

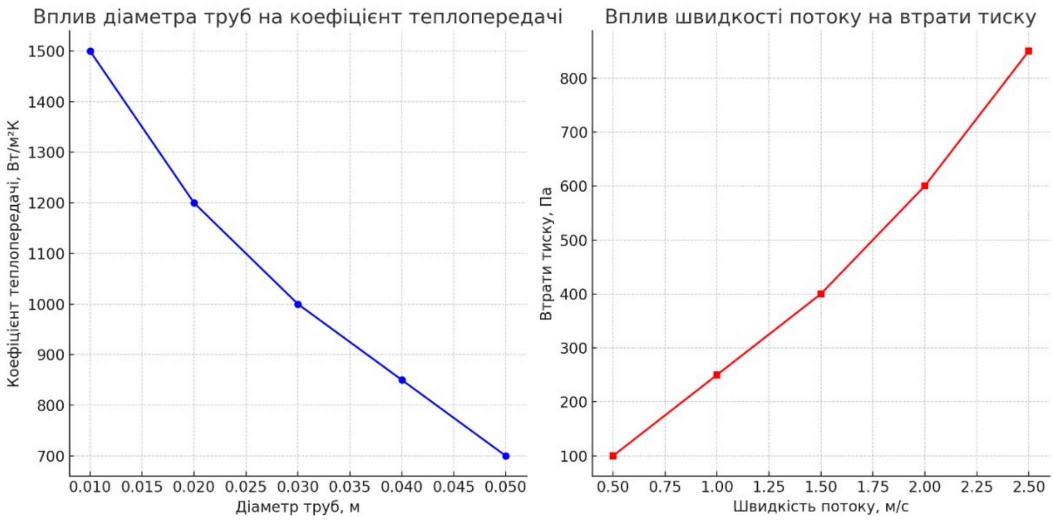

Figure 1. Graphs of optimal parameters