DIDAR OSPANOVA

DEVELOPMENT OF ENERGY-EFFICIENT TECHNOLOGY TO INEREASE THE EFFICIENCY OF HEAT EXCHANGERS BASED ON THE STUDY OF THE EFFECT OF THE ELECTROHYDRAULIC EFFECT ON THE DYNAMICS OF HEAT AND MASS TRANSFER

ABSTRACT

of the dissertation submitted for the degree of Doctor of Philosophy (PhD)in the educational program

8D05303 – «Thermophysics and Theoretical Heat Engineering»

Relevance of the research topic. Improving energy efficiency, rational use of energy resources, and optimizing thermal and heat engineering processes are priority tasks of modern industrial and energy development. A significant portion of global energy processes involve heat exchange, and therefore, improving the efficiency of heat exchangers is considered a key area for reducing energy costs and minimizing environmental impacts.Traditional heat exchanger design solutions have certain technological limitations, necessitating the search for new physical methods for intensifying heat and mass transfer processes. Of particular interest is the use of the electrohydraulic effect to intensify various thermal engineering processes.

It is known that a high-voltage electrical discharge in a liquid medium is accompanied by the formation of pulsed pressure waves, cavitation phenomena, and turbulent flows, which can significantly increase the intensity of heat and mass transfer. These physical processes promote the destruction of solid scale on heat exchanger surfaces, increase the convective heat transfer coefficient, reduce the formation of scale deposits, and improve the reliability and durability of heat exchange equipment.Despite the existing known research results, the influence of the electrohydraulic effect on the dynamics of heat and mass transfer processes remains insufficiently studied both theoretically and experimentally, especially with regard to increasing the energy efficiency of heat exchangers.In the face of rising energy prices, stricter international requirements to reduce harmful hydrocarbon emissions, and the need to ensure the sustainability of industrial processes, the development of energy-saving technologies to improve heat transfer efficiency becomes particularly relevant.Therefore, studying the dynamics of heat and mass transfer under the influence of the electrohydraulic effect for the purpose of developing new technological solutions to improve heat exchanger efficiency is of significant scientific and practical interest.

As a result of the dissertation research, a comprehensive installation was developed using electrohydropulse technology, aimed at increasing the efficiency of heat exchangers, reducing energy costs, and enhancing the environmental safety of thermal processes. The proposed electrohydropulse technology can be used in

the power, chemical, oil and gas, and metallurgical industries, as well as in municipal heating systems.

Purpose of the Research. Improving the heat transfer efficiency of heat exchangers through the use of an optimized energy-saving electrohydropulse unit with a multi-stage LC control system.

Research Objectives:

1. Analysis of the effect of electrohydropulse treatment on the properties and dynamics of liquid flow in heat exchanger tubes and modeling of the main characteristics of heat and mass transfer under various flow heterogeneity parameters, taking into account the degree of fouling of the tube's internal surfaces.
2. Experimental study of the pulse pressure amplitude distribution during shock wave propagation in the liquid flow of a heat exchanger to develop a comprehensive technology for cleaning the internal surfaces of tubes from solid scale deposits to improve heat transfer efficiency.
3. Study of the structure and quantitative characteristics of the elemental composition of solid scale deposits on the internal surfaces of heat exchanger tubes based on X-ray diffraction analysis.
4. Development, creation, and testing of an experimental laboratory energy-saving electrohydropulse unit with a multi-stage LC control system, which allows for increased energy efficiency in heat exchanger heat transfer.

Object of the study. Heat and mass transfer processes in a heterogeneous liquid flow during electro-hydro-pulse cleaning of the internal surfaces of heat exchange pipes made of non-ferrous metals from solid scale deposits.

Research Methodology.

The elemental composition and structure of scale formed on the internal surfaces of heat exchanger tubes were studied using atomic emission spectrometry and atomic absorption spectrometry methods. The structure of solid scale deposits was analyzed by powder X-ray diffraction using a diffractometer Panalytical X’PERT PRO MRD Extended. The pressure amplitude distribution in the heat exchanger was measured using piezometric pressure sensors, followed by signal processing using a digital oscilloscope PC-500. Modeling of heat exchange process changes under shock wave impact was performed using the group argument accounting method (GAAM). The technical documentation for the experimental laboratory complex of the electro-hydropulse installation and the creation of a technological complex ensuring precise energy-efficient regulation of the magnitude of the pulse energy have been prepared in accordance with international standard requirements.

Scientific Noveltyofthe Research

1. It has been experimentally established that with an increase in the heterogeneity degree from 8.56% to 31.12%, the velocity of the gas-liquid coolant flow under pulsed action increases: in the diffuser - to 0.43 m/s, in the confuser - to 0.19 m/s. However,with an increase in the gas concentration from 12.3% to 18%, an inverse relationship is observed - a decrease in the coolant flow velocity to 0.10 m/s in the diffuser and 0.05 m/s in the confuser.

2. For the first time, it was established that increasing the heterogeneity degree of a co-directional gas-liquid flow from 8.5% to 34%, leads to a decrease in the pulse pressure amplitude from approximately 1.00 to 0.25–0.35.

3. It was determined that at a Reynolds number Re=(5000÷6000)in pipes with a cross-sectional parameter α>200, the heat transfer coefficient of the gas-liquid flow increases by 10–15% across the entire cross-section of the pipe.

4. It has been substantiated that the formation of calcium oxide in the composition of solid scale deposits is due to long-term continuous operation of heat exchanger equipment at temperatures above 60–70°C, while the formation of aragonite compounds is associated with the turbulent flow regime of the coolant, which contributes to the intensification of heat exchange processes.

5. X-ray diffraction analysis revealed that the structure of solid scale deposits is a heterogeneous multiphase system composed of calcium, magnesium, and iron carbonates. The scale was found to contain 33 chemical elements, including approximately 20 000 mg/kg (2%) Cu, and concentrations of Mn, Zn, P, and B exceeding 1000 mg/kg.

6. An optimized electrohydropulse system with a multi-stage LC control system has been developed and manufactured for the first time. This system provides 87–90% efficiency, energy-saving, and safe cleaning of heat exchange pipes made of brass, copper, and non-ferrous metals with an internal diameter of 5–100 mm and a contamination level of up to 95%.

7. It has been established that the use of a multi-stage LC regulation system allows for a reduction in voltage pulsation and an increase in the stability of the charging process, while the addition of a gas mixture in the amount of 5–8% to the working liquid medium helps to increase the intensity of cleaning.

Scientific and Practical Significance.

The developed electrohydropulse unit allows for increasing the efficiency of heat exchangers in thermal power and industrial heat supply systems. The proposed technology ensures rapid cleaning of the internal surfaces of heat exchange tubes made of non-ferrous metals without compromising their structural integrity, which helps restore flow geometry and significantly increase the heat transfer coefficient. Implementation of this technology helps improve the energy efficiency of heat exchange equipment, reduce energy costs, extend the equipment's service life between repairs, and reduce the likelihood of emergency shutdowns. The developed electrohydropulse system has undergone experimental testing at AirLogistic LLC; the results have been incorporated into the educational process.

Author’s Contribution. All results presented in the dissertation were obtained by the author personally. The author formulated the research problem, defined the objectives, conducted experimental studies, analyzed the results, and developed scientific conclusions and practical recommendations.

Structure and Scope of the Dissertation. The dissertation consists of an introduction, three chapters, conclusions, and appendices.The total volume of the dissertation is 137 pages, including 67 figures, 10 tables, and 99 references.