ABSTRACT

to the thesis research, submitted for the PhD degree in the educational program
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«DEVELOPMENT AND RESEARCH OF TECHNICAL SOLUTIONS FOR NEW HOT WATER BOILER UNIT WITH IMPROVED CHARACTERISTICS»

Kazakhstan's ongoing urbanization and the projected large-scale construction of residential and social infrastructure are expected to significantly increase heat consumption, leading to a projected heat deficit. In recent years, several regions of the country have already experienced insufficient heat supply. While thermal power plants and district heating boilers remain primary heat generators in Kazakhstan, a decentralized network of medium and low-power boiler houses is actively developing. According to the Ministry of Energy of the Republic of Kazakhstan, the average wear and tear of main equipment at thermal power plants across the country is approximately 66%. Furthermore, the average age of all combined heat and power (CHP) plants exceeds 60 years, with about 76% of them having been in operation for over half a century.

The country predominantly utilizes outdated and environmentally unfavorable technologies, alongside inefficient autonomous, individual, and industrial heating systems. Heat transportation is often hindered by the complete or partial absence of thermal insulation, unsatisfactory hydraulic conditions in heating networks, and irregular hydraulic and temperature tests, as well as leak checks. There is a lack of developed schemes for the expansion of heating networks and supply systems, and the level of automation in heat production, transmission, and distribution remains low.

Considering the current state of thermal power equipment and modern trends in decarbonization, environmental sustainability, and energy efficiency, the most rational solution is the gradual replacement of obsolete hot water boilers with modern, more efficient, and environmentally friendly alternatives.

The high attractiveness and, more importantly, the economic efficiency of modernizing thermal power equipment, coupled with the continuous growth in demand for reliable, economical, and accessible heat supply sources based on hot water boilers, underscore the relevance of this research. This study aims to develop highly efficient structural solutions for hot water boilers that can be applied both as new products and for the modernization of existing facilities.

In light of these issues, the objective of this dissertation research is formulated as follows: To develop and investigate technical solutions for a new hot water boiler unit with improved characteristics, and to apply the technical solutions investigated in this work to both existing and new boilers.

To achieve this goal, the following research tasks have been set:

- To conduct a literature review and patent search focused on improving the characteristics of hot water boilers.
- To explore the possibility of creating a new hot water boiler design using two-pass corrugated screens as heating surfaces above a cylindrical furnace, and to justify its effectiveness.
- To conduct experimental studies to evaluate the efficiency of heat exchange and hydraulic resistance in corrugated tubes and in elements of a plate recuperative air preheater.
- To perform mathematical modeling of natural gas combustion in a cylindrical furnace with varying numbers of micro-flame burners compared to a furnace with a hearth burner.
- To conduct a verification calculation of the new hot water boiler to obtain its main technical parameters.

The scientific novelty of the conducted work lies in the following:

1. Experimental data were obtained, based on which adjustments to the calculation dependence for determining the hydraulic resistance coefficient and Nusselt number in a two-pass corrugated channel were justified and implemented.
2. Experimental data on the intensification of heat exchange in the elements of a plate recuperative air preheater were obtained.
3. Based on experimental studies, the feasibility of using a two-pass corrugated screen and variations of its application for improving hot water boiler characteristics were demonstrated.
4. Based on the analysis of using two-pass corrugated screens and experimental studies of heat and mass transfer, technical solutions for improving the operation of hot water boilers by increasing heat exchange intensity were presented.
5. Based on theoretical studies, the optimal design of a hot water boiler furnace was determined from the perspective of reducing the concentration of harmful substances in the exhaust gases.

The scientific novelty is supported by the developed technical solutions, for which patents for inventions in the Republic of Kazakhstan have been obtained: two patents for a hot water boiler; a patent for the design of a combustion chamber; and a patent for the design of a hot water boiler air preheater.

Based on the completed work and conducted research, the following provisions are submitted for defense:

1. Results of experimental studies for increasing the intensity of heat exchange in heating surfaces through the use of two-pass corrugated screens.
2. Results of experimental studies on the intensification of heat exchange in the elements of a plate recuperative air preheater.
3. Results of numerical studies on increasing efficiency and reducing nitrogen oxide formation during natural gas combustion in a boiler furnace under various fuel supply options.
4. Technical solutions based on the conducted research for improving hot water boiler characteristics:
    - Cylindrical furnace with micro-flame combustion (MFC).

- Two-pass heating surfaces with corrugated tubes.
- Recuperative air preheater with corrugated plates.

Practical Significance

The results of the research on the adopted technical solutions in the new hot water boiler unit will contribute to their implementation and realization. The obtained results enable efficient combustion of various fuel types in similar cylindrical boiler furnaces, addressing current challenges in thermal power engineering and ecology.

The developed new technical solutions, including coaxial two-pass heating surfaces with corrugated tubes, a cylindrical furnace with MFC of natural gas, and a new design of recuperative air preheater (RWP), can be utilized in other boiler units, thereby improving their technical characteristics.

The reliability of the obtained results is confirmed by the following:

1. During the research, proven methodologies and verified measuring instruments included in the State System of Instruments of the Republic of Kazakhstan were used.
2. The results of experiments and numerical modeling were checked and compared with results presented in the works of foreign authors.
3. The results possess the necessary degree of reliability, as they are confirmed by comparing calculated and experimental data.

The approbation of the obtained scientific research results was carried out during the author's participation in scientific research projects within a scientific team under projects AR14872041 "Development and Research of New Front-End Devices for Gas Turbine Combustion Chambers to Improve Environmental Safety and Efficiency of Gas Turbine Installations in Kazakhstan" and №AP19680488 "Study of Efficiency and Development of Optimal Scheme Solutions for Combined Heat Supply Systems with the Use of Renewable Energy Sources in Kazakhstan." The results of the work are documented by an implementation act from the production enterprise "Kazkotloservice" LLP.

The main results of the dissertation work are reflected in 14 scientific publications and reports at international scientific and technical conferences, including: 3 scientific articles in domestic publications from the list recommended by the Science and Higher Education Quality Assurance Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan and 1 scientific article included in the Russian Science Citation Index (RINC) database; 5 scientific reports in proceedings of international scientific and technical conferences, including an in-person presentation at a foreign scientific conference; 3 articles in journals indexed in the Scopus database with a percentile of 35% or higher at the time of publication. As a co-author, the results of research activities were documented in 11 RK Patents for inventions related to hot water boiler designs.

The author's personal contribution includes:

- Setting and formulating research tasks, conducting a literature review, and searching patent databases related to technical solutions for hot water boiler units.

- Performing calculations using the ANSYS Fluent software package for micro-flame combustion processes and Comsol Multiphysics for investigating the influence of the number and position of burner devices on the aerodynamics in the boiler furnace.
- Conducting experiments in collaboration with staff from the "Thermal Power Engineering" Department of NAO "AUES named after G. Daukeev."
- Processing experimental data and analyzing experimental results.
- Writing the dissertation work.

The dissertation work was completed by the author in accordance with current requirements for formatting, structure, and content. The work consists of 4 main sections, a list of abbreviations, an introduction, a conclusion, a list of references, and appendices.

The first section provides an overview of the general state of efficiency of medium and low-power hot water boilers. It examines the designs of hot water boilers considering environmental and technical indicators, and analyzes promising technical and design solutions aimed at improving hot water boiler characteristics. As a result, it was found that systems based on the integration of two-pass heating surfaces with corrugated tubes and cylindrical furnaces with micro-flame combustion, as well as the use of recuperative air preheaters with corrugated plates, demonstrate the greatest potential for increasing equipment efficiency and operational reliability.

The second section presents experimental studies of heat exchange and hydraulic resistance of boiler heat exchange surfaces. It describes the experimental setup and methodology for studying heat exchange and hydraulic resistance in corrugated tubes, and presents the results of these studies. It also considers the methodology and setup for studying non-isothermal flow, as well as the results of studying working surfaces with corrugated plates.

The third section is devoted to a numerical study of a cylindrical hot water boiler furnace with the possibility of micro-flame combustion due to an increased number of burner devices. It describes the combustion chamber and boundary conditions for conducting computational experiments using the Ansys Fluent software package. The results of numerical modeling of the fuel combustion process are presented, along with a numerical study of the influence of the number of burners on aerodynamic parameters using the Comsol Multiphysics software package.

The fourth section outlines the developed technical solutions and the patents obtained for them. It examines the developed hot water boiler units and designs of hot water boiler elements, including air preheaters and the design of a cylindrical furnace with the possibility of micro-flame combustion due to an increased number of burner devices for use in boiler installations.

The conclusion summarizes the obtained research results and the main findings of the dissertation work.

The appendices include copies of the main patents, a copy of the implementation act from the manufacturing enterprise, and the main reporting materials for hot water boiler calculations.