

ABSTRACT

to the thesis research, submitted for the PhD degree in the educational program
«8D07102 – Heat power energy»
(group of educational programs «D098 – Heat power engineering»)

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«Development and research of a burner device for a hot water boiler with low harmful emissions»

Relevance of the Dissertation Research Topic. The fuel and energy complex is a key component of a country's production infrastructure, directly influencing economic growth, national security, and the quality of life of the population. Under conditions of large-scale urbanization and the associated shortage of thermal energy in the cities of Kazakhstan, autonomous heat supply systems are developing rapidly. Today, low-capacity hot-water boiler units serve not only as a supplement but also as a full-fledged alternative to centralized heating systems.

However, the autonomous and industrial heat supply sector in the country is characterized by the predominance of environmentally unfavorable technologies. Existing boiler unit designs are marked by low efficiency, high susceptibility to corrosion, and, most critically, significant emissions of toxic components. The main problem lies in the imperfection of mixing and combustion processes in conventional diffusion burners, which leads to the formation of high-temperature zones and the intensive generation of thermal nitrogen oxides (NO_x), as well as incomplete fuel combustion accompanied by the release of carbon monoxide (CO).

Environmental performance and energy efficiency of thermal installations are decisive factors in the development of modern boiler technology. In this regard, the development and investigation of low-emission burner devices based on the principles of microflame combustion (MFC) represent a scientific and technical task of high priority for the energy sector of the Republic of Kazakhstan. The present study is aimed at providing a scientific justification and practical implementation of the microflame gas combustion method through the use of original design solutions that enable effective control of the environmental and energy characteristics of hot-water boilers.

The relevance of the research is also confirmed by participation in state-funded grant projects № AP19680488 «Investigation of efficiency and development of optimal schematic solutions for combined heat supply systems with consideration of renewable energy sources under the conditions of Kazakhstan» and

№AP26104599 «Development and investigation of new schemes and designs of combustion chambers for advanced engines-gas turbine units and the Stirling engine-to improve environmental safety and operational efficiency in Kazakhstan» in which the doctoral researcher's results were utilized in the project reports.

In this regard, the purpose of the dissertation research is formulated as follows:

The aim of this study is to investigate the characteristics of operating processes during microflame combustion of gaseous fuels and to develop a new low-emission burner device for a hot-water boiler.

Research Objectives

To achieve the stated aim, the following objectives were accomplished in this work:

- analysis of scientific literature and patents, assessment of the performance efficiency of small-capacity hot-water boilers and low-emission burner devices, as well as identification of approaches to the development of burners with reduced harmful emissions;
- assembly of an experimental test rig and execution of experimental studies on fuel ignition and combustion, as well as the formation of harmful combustion products;
- design and fabrication of a low-emission burner device for efficient combustion of gaseous fuel in a small-capacity hot-water boiler;
- mathematical modeling of the combustion process, development of the burner device geometry, and creation of a three-dimensional computational model using Ansys Fluent;
- comparison of numerical simulation results of burner performance characteristics with experimental data obtained on the test rig in order to evaluate the efficiency of the proposed microflame burner;
- description of new technical solutions aimed at the development of low-emission burner devices for hot-water boilers.

Scientific novelty of the research consists of the following:

1. A new design of a microflame burner device for gaseous fuel combustion has been investigated, experimentally tested, and proposed;
2. Results of computational studies of the microflame combustion process of gaseous fuels and the formation of thermal nitrogen oxides (NO_x) were obtained using ANSYS Fluent and ANSYS CFD software packages;
3. New experimental data have been obtained on the influence of design and operational parameters (including the air excess coefficient) on the environmental (NO_x , CO) and thermal performance of four different types of burner nozzles;

4. Relationships have been established between burner design features (in particular, the aerodynamic and temperature structure of the flame) and the mechanisms of nitrogen oxide formation;

5. The developed technical solutions are protected by patents of the Republic of Kazakhstan (№37157 and №37126).

The following main scientific results and statements are submitted for defense:

1. The development and experimental testing results of a new microflame burner design, demonstrating its environmental advantages compared to conventional swirl burners;

2. Results of numerical (CFD) modeling of operating processes in the microflame burner, validated against experimental data;

3. Experimentally established relationships connecting design parameters (type and geometry of the burner nozzle) and operational factors (air excess coefficient, fuel and air flow rates) with environmental and thermal characteristics of combustion;

4. New technically substantiated solutions aimed at reducing harmful emissions and expanding the range of stable combustion in small-capacity hot-water boilers, confirmed by patents of the Republic of Kazakhstan.

Practical significance. The practical significance of this research lies in the possibility of implementing the developed design solutions in both existing and new hot-water boiler units. This implementation can significantly reduce the emissions of harmful substances (NO_x, CO) and enhance the environmental safety of thermal power plants and boiler facilities in Kazakhstan.

The practical applicability of the obtained results is confirmed by an implementation act issued by the boiler plant LLP «Kazkotloservice».

The materials of the dissertation can also be integrated into educational programs for environmental courses as well as technical disciplines, and may be used in the preparation of undergraduate and master's theses.

Reliability of the obtained results is ensured by:

- the use of modern high-precision and certified measuring instruments, along with the evaluation of measurement errors;

- reproducibility of experimental data and their comparison with the results of similar studies conducted by foreign researchers;

- validation of numerical modeling results through comparison with data obtained from the researcher's own full-scale experiments;

- reflection of the studied problem in project reports of state-funded topics: «Investigation of Efficiency and Development of Optimal Schematic Solutions for Combined Heat Supply Systems Considering Renewable Energy Sources under the

Conditions of Kazakhstan» (№AP19680488) and «Development and Investigation of New Schemes and Designs of Combustion Chambers for Advanced Engines: Gas Turbine Units and the Stirling Engine, to Improve Environmental Safety and Operational Efficiency in Kazakhstan» (№AP26104599);

- confirmation of scientific novelty by the patents of the Republic of Kazakhstan for inventions (№37157 and №37126).

Testing and Dissemination of the Dissertation Results. The main results of the research were presented and discussed at the 12th International Scientific Conference «Chaos and Structures in Nonlinear Systems: Theory and Experiment» (Pavlodar, 2022); in two theses of the International Scientific and Practical Conference «II Jubilee Readings of F.K. Boyko» (Pavlodar, 2025); and in two theses of the XIII International Scientific and Technical Conference «Energy, Infocommunication Technologies and Higher Education» dedicated to the 50th anniversary of the university (Almaty, 2025).

Publications. The main results of the dissertation are reflected in 13 scientific publications, including: 3 articles in national journals recommended by the Committee for Quality Assurance in Science and Higher Education; 2 articles in journals indexed in the Scopus database with percentiles of 74% and 75%; 6 papers in proceedings of international scientific and technical conferences. In addition, 2 patents of the Republic of Kazakhstan for inventions have been obtained (№37157, №37126), and 2 patent applications (№371482 and №370815) are currently under examination.

Personal contribution of the author includes:

- formulation of research objectives;
- review and analysis of scientific literature and patent sources on the dissertation topic;
- conducting mathematical modeling in numerical studies of combustion processes and formation of harmful emissions;
- preparation of drawings and fabrication of a physical model of a new burner for a hot-water boiler;
- assembly of the experimental test bench and direct execution of experiments;
- development of new technical solutions for low-emission burner devices and preparation of patent applications;
- analysis and generalization of the obtained results.

Scope and Structure of the Dissertation.

The dissertation was carried out by the author in accordance with the current requirements regarding structure and content. The work consists of four main chapters, a list of abbreviations, an introduction, a conclusion, a list of references, and appendices.

In the introduction, the relevance of the research topic is substantiated, the aim and objectives of the study are formulated, the object and subject of research are defined, the scientific novelty and practical significance of the work are highlighted, and the main statements submitted for defense are formulated.

The first chapter presents a detailed analysis of the scientific literature and patent sources. Existing designs and operational issues of small hot-water boilers are examined. Modern passive and active methods for intensifying heat and mass transfer are analyzed. A critical review of existing low-emission burner devices is performed, highlighting their advantages and limitations. Based on this analysis, the research aim and objectives of the dissertation are formulated.

The second chapter presents the results of experimental studies. The first part includes experiments on the intensification of heat transfer and the determination of the optimal geometry for finned heat transfer surfaces. The second part introduces the developed and patented (Patent RK №37157) new burner design. The third part presents the results of the main combustion experiment-comparative testing of four types of burner nozzles, demonstrating the environmental advantages (reduction of NO_x and CO) of the developed «Type D» concept.

The third chapter provides the theoretical justification of the results obtained in Chapter 2 through CFD modeling. The methodology for modeling in ANSYS Fluent, creation of geometry and mesh, and validation of the numerical model against experimental data are described. A detailed analysis of calculated fields of temperature, velocity, and concentration is conducted, explaining the physical mechanisms of emission reduction in the developed burner.

The fourth chapter presents new technical solutions that constitute the scientific novelty of the dissertation. The patented «Burner Device with Stepwise Air Supply» (Patent RK №37126) and two patent applications (№371482, №370815) currently under examination are described, including a burner for the utilization of industrial gas waste.

The conclusion formulates the main scientific and practical findings of the dissertation, confirming the achievement of the research aim and the solution of the set objectives.

The appendices contain copies of the patents of the Republic of Kazakhstan for inventions, the implementation act of the dissertation results issued by LLP «Kazkotloservice», a list of scientific publications on the dissertation topic, and photographs from the experimental site.

This research is aimed at solving an important scientific and technical problem related to enhancing the environmental safety and efficiency of hot-water boiler units, which has significant potential for practical application in Kazakhstan.