# ABSTRACT

to the thesis research, submitted for the PhD degree in the
educational program 8D07101 – Renewable Energy
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by
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**«Development of a system for mixing and stabilizing of microflares for small hot water boilers when burning natural gas»**

**Relevance of the research.** Heat supply has always been one of the most important needs of mankind, especially those who live in regions with harsh climatic conditions. Residential buildings characterized by high energy consumption have an impact on the environmental situation. In this regard, it is important to strive to reduce costs and adhere to the principle of environmental performance in heat supply.

The renewable energy market is developing year after year. In our country, capacities based on solar and wind power plants are being reintroduced, which indicates the use of «clean» energy, in addition, the share of biogas in the generation of electric and thermal energy is gradually increasing. Despite this, such industries as energy, oil refining and metallurgy are currently dominated by technologies for burning gaseous fuels.

Currently, an urgent task is to develop innovative technical solutions aimed at improving the efficiency and environmental friendliness of fuel combustion processes in power plants. This includes, in particular, the improvement of small hot water boilers designed to burn natural gas (including propane-butane mixture), fuel mixtures based on landfill gases, and thermal decomposition products of industrial and municipal waste. At the same time, a significant number of small boiler houses are in urgent need of modernization, replacement of outdated equipment or repair. However, the execution of these works is difficult for a number of reasons. In Kazakhstan, thermal power plants remain the main sources of energy production, and in recent years there has been a tendency to increase the role of decentralized small and medium-sized boiler houses, which are both publicly and privately owned.

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These boilers vary in capacity and type, and their applications are very diverse. In a number of regions, such as Akmola, Karaganda and North Kazakhstan regions, a significant proportion of the equipment is represented by obsolete small boiler units operating on solid and liquid fuels. A special place is occupied by typical

small district boiler houses, which underlines the relevance of research in the field of creating modern burner devices for small gas-fired boilers.:

- KVTs from 0.1 to 0.4 - IP Stolyarenko, LLP «STEM-4» (S. Zerenda).
- KVU from 0.1 to 3.5 - Titan LLP (Kostanay).
- CDG from 220 kW to 525 kW - AZIYAKOTLOMASH LLP (Shchuchinsk).
- CO from 60 kW to 525 kW - Teplomechanik LLP (Karaganda).
- KSVr from 0.1 to 0.3 - AZIYAKOTLOMASH LLP (Shchuchinsk).
- TENTEK boilers – domestic boilers from 12 to 100 kW – Karaganda Boiler Plant LLP (Karaganda).
- Also homemade (low-power) furnace-type boilers, which have a number of disadvantages, are further noted in the text of the work.

The combination of such problematic issues generates great scientific interest in the need for modernization, ensuring the efficiency of old boiler houses and compliance with stricter requirements of environmental legislation.

A striking example studied in this work is the modernization and development of microfoam mixing and stabilization systems for small hot water boilers using natural gas. The introduction of the Sary-Arka main gas pipeline, passing through the Kyzylorda, Karaganda, Akmola and North Kazakhstan regions, creates prerequisites for the transfer of village boilers from solid fuels to natural gas.

Research in this area is aimed at ensuring the efficient transition of boiler houses to natural gas in compliance with strict requirements for efficiency and environmental friendliness. This is possible due to the use of microfibre combustion technology, in which the fuel burns in the form of many small torches with an excess air coefficient close to the stoichiometric. This solution ensures high completeness of fuel combustion, stability of combustion process and minimization of emissions of harmful substances.

**The object of the study** is a micromodular gas burner with a sudden expansion at the outlet.

**Subject of research:** systems of mixing and stabilization of microflares for natural gas combustion.

**The purpose of the study:** to develop a mixing system and stabilization of microflares for low-power boilers when burning natural gas (propane-butane mixture).

To achieve this goal, the following research objectives were set:

- Based on the analysis of the microfakel burner designs and patent searches, to develop a new efficient low-toxic biogas burner;
- To study the theory of describing processes in swirling flows on ANSYS fluent to reduce experiments, calculate effective sizes and their ratio;
- to identify the degree of twist of the flow, the formation of toxic substances, the characteristics of the burner at different degrees of twist;
- To develop drawings of the burner parts and organize its manufacture;
- To conduct a comprehensive experimental study of the burner on the stand;
- To compare the experimental and calculated characteristics of the burner and develop recommendations for their operation.

To achieve this goal, **the following tasks** are being solved:

- To conduct a literature and patent analysis to identify the causes of the formation of harmful substances in small hot water boilers and the main directions for improving technical and environmental performance in gas burners;

- To develop an experimental stand and organize its production;

- To develop a new micromodular gas burner (MMGB) and comprehensively investigate the characteristics of the model;

- Using numerical simulations in the COMSOL Multiphysics software package to study the aerodynamics of the air flow in the burner device;

- To investigate the physical model of a burner device with combustion processes during combustion of a propane-butane mixture using the Ansys Fluent software package;

- To conduct comprehensive studies of the characteristics of the burner device (coefficient of completeness of fuel combustion, distribution of the temperature field, yield of toxic compounds) on an experimental stand created during the work on the dissertation and to identify the effective dimensions and their ratios;

- To compare the results of theoretical and experimental data;

- Give recommendations on the use of a micromodule gas burner.

**The practical significance** of this research is to develop and obtain:

- the principle of using sudden expansion in a micromodular gas burner, which ensures high stabilization of the flare and low emissions of toxic substances, protected by an author's certificate of invention;

- results with implementation in production and educational process. The results of the work are recorded by the acts of implementation from the production enterprises of «KazKotloService» LLP and «SMN Trade» LLP. Types of microflares combustion and stabilization have been introduced into the educational process at the NJSC «Kazakh Agrotechnical University named after S. Seifullin» from the academic year 2022-2023.

The experimental data obtained on microflare devices make it possible to create a new design of gas burners with high environmental, technical and economic indicators.

**The scientific novelty** of the work is reflected in new patents on methods of flame mixing and stabilization, as well as in experimental and theoretical research results, in particular:

- A new design scheme of a micromodule burner based on microflare fuel burners has been developed, ensuring low emissions of toxic substances;

- The principle of microflare combustion in MMGB with a sudden expansion at the outlet is investigated;

- The effective ratios of nozzle diameters for MMGB and emissions of toxic NOx and CO have been determined;

- 2 Patents for inventions were obtained as part of the dissertation work.

Experimental research in this dissertation work was carried out on the basis of a complex of scientific research and experimental work, in which field experiments were carried out at the production base of «KazKotloService» LLP.

**Scientific statements** submitted for protection:

- efficient mixing of the fuel-air mixture in a micromodular gas burner with sudden expansion at the outlet, designed for small hot water boilers;

- results of mathematical modeling of the distribution of velocities and turbulence levels of isothermal flows in a micromodular gaseous medium;

- the results of mathematical modeling of combustion conditions and concentrations of harmful substances, including nitrogen oxides (NOx) and carbon monoxide (CO), in a micromodule gas;

- experimental data on the study of the average velocity and intensity of turbulence of isothermal flows inside a micromodule gas burner;

- rational design of a micromodular gas burner with sudden expansion at the outlet.

**Publications.** The main provisions are reflected in scientific publications: 15 scientific articles, ISTC reports, proceedings, including: 2 scientific articles indexed in the Scopus database, 1 in the Eastern-European Journal of Enterprise Technologies with a percentile of 37% at the time of publication, 2 in the journal Energies citescore 6.2 (Q1) impact factor 3.0; 3 scientific articles in domestic publications from the list recommended by the SHEQAC of the Ministry of Internal Affairs of the Republic of Kazakhstan; 7 scientific reports in collections at international scientific and technical conferences, including a face-to-face presentation at a foreign scientific conference; As an author and co-author, the results of research activities were recorded in 2 Patents of the Republic of Kazakhstan for inventions on the subject of microflare combustion and 1 textbook was published.

**The author's personal contribution** includes performing a literary and patent review on the topic of the dissertation, conducting mathematical modeling using the Ansys Fluent software package, developing strategies for conducting experimental research, organizing and performing experiments, assembling an experimental stand, processing experimental data, preparing a textbook, publishing articles in international scientific journals, filing patents for inventions, and also the approbation of the obtained results. The idea of the research and the direction of the scientific work were determined with the participation of a scientific and foreign consultant.

**The reliability of the results** is confirmed by comparing the calculations with experimental data, as well as their comparison with the results of similar studies. The average discrepancy between the results does not exceed 12.5%. During the experiments, trusted equipment with a high accuracy class was used, the standard deviation of the measurements was within the permissible error of the equipment.

**Volume and structure**. The dissertation contains an introduction, 4 sections, a conclusion, a list of references, and appendices. The dissertation is presented on 103 pages of a computer set, including 44 figures and 9 tables, and a list of 106 references.

**The introduction** substantiates the relevance of scientific research and specifies the problem under consideration. The main idea of the work, its scientific novelty and reliability are described, the personal contribution of the author is reflected, and information about the approbation of the results and publications is presented.

**The first section** of the dissertation is devoted to the analysis of key areas of development of small and medium-capacity boiler equipment, the role of small hot

water boilers in the energy systems of the world and Kazakhstan. The main approaches to improving environmental performance are considered, and a review of burner devices for small boiler furnaces implementing microflare combustion (MFC) technology is conducted. The principles and characteristics of the MFC are described, as well as the results of theoretical and experimental research in this field. The purpose and objectives of the study are also formulated, and the development and study of a micromodular gas burner with a sudden expansion at the outlet, designed for small hot water boilers, is proposed.

**The second section** of the dissertation presents the results of mathematical modeling of a micromodular gas burner with a sudden expansion at the outlet, the study of flow aerodynamics, and the process of microfacel combustion of a confusor-diffuser channel with a sudden expansion at the outlet. Combustion modeling results are presented for determining the temperature distribution zones, as well as the flow structure at the outlet of the simulated area from the type of microfoam elements used.

**The third section** describes the experimental setup and the physical models used, describes in detail the methodology for conducting experiments and measuring key parameters, and evaluates measurement errors.

**The fourth section** includes the results of an experimental study of a micromodule gas burner. The data of measurements of temperatures and concentrations of nitrogen oxides at the outlet of MMGB, as well as the results of their analysis, are presented. Based on the experiments, the dependences of nitrogen oxide concentrations, the coefficient of completeness of fuel combustion and temperature irregularities on the type of microfactory elements used were revealed and a comparative analysis of data based on the results of theoretical and experimental studies is presented.

**In conclusion,** the results of the work are summarized, the main results and conclusions formulated during the study are reflected.