ABSTRACT

to the thesis research, submitted for the PhD degree in the educational program «8D07102 – Heat power energy»
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«Research and improvement of the efficiency of energy use of low-calorie gases with the addition of hydrogen»

Relevance of the dissertation research. In modern conditions of the global energy transition to sustainable and low-carbon energy sources, the tasks of increasing the efficiency of using existing energy resources are of particular importance. At the same time, with the introduction of strict environmental regulations and standards, the development of new technologies is required to reduce greenhouse gas emissions and improve environmental safety.

Landfill gases formed during the decomposition of organic waste contain methane (30-50%), carbon dioxide and a number of impurities with a significant greenhouse effect. To reduce harmful emissions, it is necessary to create conditions for stable and complete combustion of low-calorie fuels.

For the complete combustion of low-calorie gas, an environmentally friendly energy carrier is required that can improve the combustion characteristics of the fuel. Gorenje A promising direction is the use of hydrogen, which will increase the energy efficiency of plants, as well as reduce greenhouse gas emissions and pollutants into the environment.

Thus, the combustion of low-calorie gases with the addition of hydrogen is a promising solution that allows to increase the completeness of combustion and reduce the formation of harmful products such as NO_x, CO and hydrocarbons. Methane and carbon dioxide are among the greenhouse gases, and the greenhouse effect of methane is 25 times higher than the greenhouse effect of carbon dioxide.

Large-scale programs for the utilization of low-calorie gases and the introduction of hydrogen technologies are being implemented in the countries of the European Union, the USA and China. In China, landfill gas utilization is being developed within the framework of the state program " *Hydrogen Energy Industry Development Plan* (*2021–2035*)". Projects on the joint use of biogas and hydrogen from renewable sources are being implemented.

In Kazakhstan, over 250 million m^3 of gas is generated annually at landfills, which is burned without being used for energy purposes. In these conditions, the task of landfill gas utilization becomes urgent. Adding hydrogen to low-calorie gases for their complete combustion is consistent with a strategy to reduce emissions and develop environmentally friendly energy.

Existing technologies for burning low-calorie gases do not always ensure the required completeness of combustion and compliance with environmental

regulations. The addition of hydrogen to the fuel mixture at low concentrations (2-10%) helps to intensify the combustion process, stabilize the flame and reduce the formation of toxic compounds. However, the combustion processes of mixtures of low-calorie gases with the addition of hydrogen and the creation of special burners for their combustion remain insufficiently studied, which determines the relevance of this study.

The relevance is also confirmed by participation in a grant project with state funding from the Ministry of Science and Higher Education of the Republic of Kazakhstan on the topic of IRN AR14872041 "*Development and research of new front-end devices for gas turbine combustion chambers to improve environmental safety and the efficiency of gas turbine units in Kazakhstan*", where the research results were used in scientific reports.

The purpose of the dissertation work is to increase the efficiency of energy use of low-calorie gases by developing a burner device for their combustion with the addition of hydrogen.

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

1. To analyze the existing technologies for the disposal of low-calorie gases.
2. Simulate the ignition and combustion processes of low-calorie gases with hydrogen.
3. To develop technical solutions for the utilization of low-calorie gas with the addition of hydrogen based on modeling the combustion process of a gas mixture in a new burner with an estimate of the NO_x output.
4. To create an experimental stand for studying the combustion process of a gas mixture under various operating modes of the proposed burner device.
5. Develop recommendations for the creation of new gas burners with an assessment of the efficiency of burning low-calorie gases.

The object of research of the dissertation work is a burner device that provides microfibre combustion of a mixture of low-calorie gases with the addition of hydrogen.

Subject of research dissertation work – the patterns of formation of a gas mixture and the formation of harmful emissions during their combustion.

The main idea and the internal unity of the work. Using the methods of system analysis, the theory of gaseous fuel combustion and the principles of greening thermal power plants, to develop technical solutions in the burner designs of the combustion chamber of the gas turbine engine and CU to reduce the formation of nitrogen oxides. In particular, for the combustion of low-calorie gases, a technical solution was used to create a gas mixture with hydrogen, which allowed for stable combustion of gas and reduced harmful emissions.

The methodological base is based on: the basic laws and patterns of heat and mass transfer, thermodynamics, mechanics of liquid and gas, as well as theoretical and experimental data in the field of studying the formation of nitrogen oxides in a combined-cycle gas installation. Scientific articles, conference materials, reference data, and data from our own experiments and numerical modeling were used as information sources.

Scientific novelty of the dissertation work is the development and research

of a new type of burner device that provides sustainable microflare combustion of a mixture of low-calorie gases with hydrogen:

- optimal structural and aerodynamic parameters of the fuel tank have been established, ensuring a reduction in NO_x emissions and an increase in combustion efficiency.

- the dependences of the concentration of harmful emissions on the structural and operating parameters of the burner device have been established.

Validity of the work. The results obtained during the experiments have the necessary degree of reliability, for the following reasons:

1) when conducting a study of a new burner device that provides micro-flame combustion of a mixture of low-calorie gases with H_2, trusted devices and proven techniques were used.

2) the results of experiments and numerical modeling were consistent with the results of foreign authors;

3) the results have the necessary degree of reliability, since they are confirmed by the convergence of calculated and experimental data.

The practical significance of the dissertation is determined by the possibility of efficient use of low-calorie gases as a renewable energy source for generating heat, electricity or combined energy production.

The proposed burner devices, the novelty of which is confirmed by the Patent of the Republic of Kazakhstan, can be used for the utilization of low-calorie gases. Its use contributes to the reduction of greenhouse gas emissions, energy dependence and environmental pollution, as well as contributes to the development of innovative waste disposal technologies.

The textbooks can be used in the educational process at universities to train specialists in the field of thermal power engineering.

Provisions submitted for defense:

- results of modeling and experimental studies of combustion processes of a mixture of gases, low-calorie gases with the addition of H_2;

- new technology for the utilization of low-calorie gases with the addition of hydrogen;

- design solutions for gas burner devices for burning low-calorie gases with the addition of hydrogen, characterized by high technical and environmental performance, have been developed.

The personal contribution of the dissertation candidate consists of:

- in literary analysis and patent search on the current state of the issue and, together with a scientific consultant, in setting research objectives;

- in the development of a model of the combustion process of low-calorie gases with the addition of H_2;

- in the preparation and execution of applications for prospective patents of the Republic of Kazakhstan;

- in the preparation of drawings and production of a physical model of the burner device;

- in conducting and processing experimental research.

Approbation of the results of the dissertation work. The main results of the work were presented and discussed at international scientific, technical and scientific conferences.:

- XI Scientific and Technical International Conference "Energy, Information and Communication Technologies and Higher Education" October 16-18, 2020 (Almaty, 2020);

- International Scientific and Technical Conference "Energy, Information and Communication Technologies and Higher Education" (Almaty, Kazan, October 20-21, 2022);

- International Conference on Electronics, Engineering Physics and Earth Sciences (EEPES 2024), Kavala, Greece, June 19-21, 2024 (SCOPUS);

- Proceedings of the 6th International Scientific and Practical Conference "Scientific Community: Interdisciplinary Research". - Hamburg, Germany, № 96, 26-28.01.2022. - Pp. 831-841.

Publications. 16 publications have been published on the topic of the dissertation, including 3 in publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; 4 in the materials of international scientific, technical and scientific-practical conferences; 3 patents of the Republic of Kazakhstan for an invention and 1 patent for a utility model; 2 articles in the journal "Energies" (Q1-75%) and 1 article "Engineering Proceedings" (Q3-26%), included in the Scopus and WoS database; 2 textbooks "Otyn zhane zhan protesteri. Tomen sorty otyndy jagudyn yerekshelikteri" and "Zhylu energetikalyk zhuyeler men energiyany koldanu".

Scope and structure of the dissertation: The content of the thesis: normative references, designations and abbreviations, introduction, sections of 4 chapters, 13 subsections, conclusion, references and appendices. The volume of the dissertation is 157 pages of a computer set, including 80 figures, 30 tables and a list of references in 153 titles.

The introduction contains the identified problems on the subject of the study and the relevance of the chosen topic. The statement of the purpose and objectives of the research, the scientific novelty of the work, reliability, personal contribution of the author, articles and approbation of the research results are presented.

The first chapter provides an in–depth analysis of the current state of the issue and provides a detailed description of low-calorie gases of various origins - landfill gas, biogas and MSW gasification gases. Their energy and environmental features are noted, as well as the difficulties of their direct application in gas turbines and boilers due to their low calorific value and instability of the combustion process. The author justifies the need to enrich low-calorie gases with hydrogen and methane in order to increase their energy characteristics and flame stability.

The second chapter presents theoretical studies of the combustion processes of biogas mixtures with the addition of hydrogen, performed using modern numerical modeling methods in the ANSYS Fluent software package. The author has studied in detail the patterns of change in the rate of combustion, temperature, composition of combustion products and concentrations of toxic substances at

different proportions of hydrogen and excess air coefficients. The obtained results made it possible to establish optimal ranges of parameters to ensure maximum combustion completeness with minimal emissions of nitrogen oxides.

The third chapter is devoted to the development of technical solutions and the creation of an experimental stand. Of particular note is the constructive solution of the new burner, adapted to the combustion of mixtures of low-calorie gases with the addition of hydrogen. The author has developed a physical model of the device that ensures stable combustion with varying composition and temperature of the gas mixture. Significant work has been done on the design, assembly and testing of the stand, as well as on the development of measurement methods and error estimation. This section demonstrates the high level of engineering training and practical competence of the researcher.

In the fourth chapter, experimental data are compared with the results of theoretical modeling, the effectiveness of the proposed burner device is analyzed, and recommendations for its further implementation are developed. It has been established that the use of a biogas mixture with the addition of up to 20% hydrogen ensures stable combustion, an increase in flare temperature and a decrease in concentrations of incomplete combustion products. The results of the work have a practical orientation and can be used in the design and operation of hot water boilers and gas turbine installations powered by waste or alternative gases.

In conclusion, it is indicated that all the research goals of the dissertation have been achieved, the task has been completed, and the main results and recommendations of theoretical and experimental research are presented.