ABSTRACT

of the thesis, which is presented for the defense of the PhD degree under the educational program 8D07102 - Thermal Power Engineering

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Development and research of micro modular air atomizers for the annular combustion chamber of gas turbine engine

Relevance of the dissertation research. Demand for electricity and transport has led to a new wave of research in power sector due to rapid population growth. Large amounts of fuel must be burned for generation and transportation of energy. Gas turbine engines (GTE) have been making a significant contribution to energy production for several decades. The development of such engines has helped to reduce fuel consumption as well as reduce the amount of pollutants of exhaust gases. The exhaust gases from GTE are divided into major and minor. Emission standards for GTE have become stricter since the Kyoto Protocol in 1997 due to their impact on the environment and human health.

Key parameters for quantifying emissions are turbine engine design and fuel composition. Today, gas turbine equipment manufacturers are developing new designs to handle a wide range of loads and fuels. At the same time, they comply with emission standards and also increase fuel consumption efficiency. These devices are based on the following concepts for the design of the combustion chamber (CCh) in the development of cooling methods. The size of the combustion chamber can be reduced with increasing engine productivity. It helps to reduce both moisture content and CO emissions. In addition, greenhouse gas emissions can be reduced by improving fuel quality and increasing combustion efficiency. Therefore, we can control the emissions through the workload of the GTE. But NOx is the main contributor to total emissions under all conditions. Thus, NOx emission standards are strictly regulated around the world. Significant changes in the design of the front of the annular chambers and the introduction of micromodular nozzles with low NOx <ppm emissions will be required to meet the currently imposed very stringent requirements and restrictions on harmful emissions of gas turbine engines.

Three main methods exist to obtain high environmental performance of CCh and the entire gas turbine plant (GTP):

- application of wet CCh of conventional design with a diffusion flame and water (steam) injection;
- additional use of catalytic cleaning exhaust gases from GTP;
- application of dry micro-flare multistage combustion of a lean fuel mixture in dry CCh.

The research purpose. Development and research of micromodular air atomizer for the annular combustion chambers of gas turbine engines with reduced NOx emissions.

The research objectives:

- to make literature and patent studies of the causes of the appearance of harmful gas emissions in fuel-burning devices and the main directions for improving the technical and environmental performance of annular CCh GTE
- to develop a design of a new micro-modular air nozzle that will efficiently burn a fuel-air mixture with low NOx emissions;
- to make theoretical studies using the Ansys fluent software package to select the effective swirl angles of the flow at the inlet and outlet from the module and their impact on NOx emission;
- to carry out an isothermal study of the intensity of turbulence of the inlet air flow for the quality of mixing of the air-fuel mixture;
- to carry out a fire test of the physical model of the micro-modular air nozzle, in order to determine the influence of the geometric parameters of blade swirlers on the emissions of toxic nitrogen oxides and CO;
- to get analytical equations for calculating the turbulence intensity factor and NOx emissions using regression analysis;
- to carry out a comparative analysis of the numerical and experimental values of NOx;
- to formulate design recommendations for the possible mass creation of structures and to assess the economic efficiency of the proposed solutions; to patent the results obtained by filing an application for an invention.

The research object. Fuel-air flows inside and outside the micro-modular air nozzle.

The research methods. The methodology is based on: the basic laws and regularities of thermodynamics, heat and mass transfer and liquid and gas mechanics, as well as experimental and theoretical data in the field of studying the intensity of turbulence in annular chambers. The main sources of information are materials of scientific articles, international conferences, monographs, reference data, as well as data from own numerical modeling and experiments.

Scientific novelty:

1) The investigated chamber was modeled on the basis of the Ansys Fluent platform using the CFD (computation fluid dynamics) code. A number of geometric characteristics have been optimized. The characteristics contribute to the intensive formation of the fuel-air mixture by increasing the degree of turbulence in the flow. Simulation was carried out with and without the combustion process.

2) An isothermal experiment was carried out. The change in turbulence was measured, namely, the scale and intensity of the air flow inside micromodular air nozzles with different diameters of micromodules and different angles of the inlet swirler blades. Optimal geometrical parameters of micromodules have been determined. The rational angles of swirling of the input and output streams are revealed.

3) Fire tests were carried out. They proved the value of the proposed design and the adequacy of the previously carried out numerical simulation. New experimental results were obtained, such as temperature fields, flame length, concentration of harmful emissions, etc.

4) The multifactorial regression dependence of the turbulence intensity on the

geometric characteristics was obtained from the data available in the present work. The dependence allows us to recreate the turbulence field inside the micromodule. Also, mathematical dependences were obtained for temperature, combustion efficiency and CO and NOx emissions on such indicators as the intensity of turbulence inside the micromodule and the angles of rotation of the blades of the inlet and outlet swirlers. The influence of the degree of turbulence on the formation of NOx was established and corrections were made to the method for calculating NOx.

5) Three patents of the Republic of Kazakhstan were obtained for new designs of the micromodule and CCh.

6) Concretization of the novelty lies in the creation of a new micromodule design, which contains a cylindrical bypass at the inlet with an air swirler and a fuel supply line. The angles of the swirler are revealed by a theoretical-empirical method. Two registers (swirlers) with a certain pitch on the same axis with the air swirler are installed in series inside the cylinder at the outlet. The angles of blades rotation are also analyzed numerically and experimentally.

The practical significance of the research. The design of the device ensures the organization of preliminary mixing of air and fuel, turbulization of the flame and stabilization of the combustion process.

The practical significance of this research is reflected in the use of the results in the educational process (act of implementation in the educational process) and in manufacturing (act of implementation in manufacturing). The obtained numerical values, formulas and coefficients are introduced into the educational process of L.N. Gumilyov ENU and G.Daukeev AUPET from the 2021/22 academic year.

Reasonableness and reliability of obtained results. The reliability is confirmed by the results of the comparison of numerical methods and experimental research, as well as comparison with similar studies. The average discrepancy of the results does not exceed 12.5%. Verified equipment with a high class of accuracy was used in the experiments. The standard deviation of measurements does not exceed the limit of permissible error of the measuring equipment.

Provisions for defense:

- rational conditions for the formation of a fuel-air mixture in annular chambers of micromodular air nozzles of combustion chambers of GTP or GTE;
- results of numerical simulation of the velocity field and turbulence intensity of isothermal flows in a micromodular air nozzle;
- results of numerical modeling of combustion conditions and emission of harmful emissions (NOx and CO) of streams, in a micromodular air nozzle;
- experimental data on the study of the average speed and intensity of turbulence of isothermal flows inside a micromodular air nozzle;
- - rational design of a micromodular air nozzle of the CCh of a gas turbine.

Personal contribution of the author. Literary review and patent search according to the topic of dissertation research, implementation of numerical modeling on the Ansys Fluent platform, development of a strategy for experimental research, preparation and conduct of experiments, processing of experimental results, preparation of publications in scientific journals, preparation of patents, approbation of work results. The scientific direction of the research and the idea were determined with the participation of the scientific leader and a foreign consultant.

Approbation of dissertation results. The main results were presented and discussed at the International Scientific Technical Conferences:

- International scientific conference: "Technium". - Constanta (Romania), 2019.
- Scientific-practical conference: Coal power engineering in Kazakhstan: problems, solutions and development prospects. - Nur-Sultan: Nazarbayev University, February 27-28, 2020.
- International scientific and technical conference: I Anniversary Readings of Boyko F.K., dedicated to the 100th anniversary of Boyko F.K. - Pavlodar: S. Toraigyrov PSU, 2020.
- VIII International Scientific Practical Conference: Actual problems of transport and power: ways of their innovative solutions. - Nur-Sultan: L.N. Gumilyov ENU, March 20, 2020;
- XV International Scientific Conference: " Ǵylym jáne bilim -2020". - Nur-Sultan: ENU them. L.N. Gumilyov, April 10, 2020.

Publications. The following works have been published according to the topic of the dissertation: one article in a journal included in the Web of Science database, three articles in journals recommended by National Committee for Control in Science and Education (KKSON in local transcription), and three patents for an invention of the Republic of Kazakhstan, five reports in collections of international domestic and foreign conferences.

Volume and structure of the thesis. The dissertation work contains an introduction, four sections, conclusion, references and applications.

The introduction reveals the relevance of scientific work and expounds the problem under study. The introduction describes the main idea, scientific novelty, the main provisions of the work, the personal contribution of the author and the approbation of the results and publications.

The first section of the dissertation is presented with an overview of current achievements on various topics related to the object of study, such as the causes of the formation of harmful emissions and methods of reducing them, the effect of the efficiency of mixing fuel assemblies on NOx emissions, similar experimental studies of micromodular installations, as well as methods of numerical simulation of the dynamics of turbulent combustion.

The second section theoretically reveals the effect of swirling flows on the combustion process using turbulence as a main factor, and also contains a description of the developed mathematical model of isothermal flows in a micromodule and taking into account the chemical reactions of combustion.

The third section describes the design, constraction and testing of modules in isothermal mode and real gas fuel combustion conditions to optimize design parameters, such as swirler blade angle, micromodule diameter, distance to fuel supply to the air flow, and output swirler blade angles. The chapter also describes experimental installations used for research both in isothermal mode and for hot flame streams with an assessment of the measurement accuracy. Isothermal flow results are discussed, which are derived from measurements of aerodynamics, mixing quality and emissions of both nitrogen oxides and carbon monoxide.

The fourth section provides a mathematical analysis of the data obtained in experiments with the derivation of universal equations that can be used to create similar structures. The conclusions contain the current development of a new micromodule and provide recommendations for further use.

The conclusion contains the main results and conclusions of the dissertation thesis.