ANNOTATION

dissertation for the PhD degree by specialty 6D071700 – Heat Power Engineering

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Development and research of a compact heat generator with a dualfuel air nozzle

Research rationale

While energy products rapidly rise in price, owners of large and small manufacturers have to think of energy-saving measures, use of alternative energy to heat production facilities and dry various substances. Using a heat generator is the best solution of this problem today.

Environmental and energy performance of the power plant are key factors to influence development prospects of heat generators. Besides, development of and research in new heat generators is of high priority not only for power industry, but also for construction business and agricultural sector. Heat generator burner is the most important component that defines both environmental and energy performance.

Development of burner devices for heat generators deals with the following problems:

- high combustion efficiency;
- flame blowoff probability decrease and extension of stable flammable limits;
- thermal protection of assembly parts;
- decrease in dimensions of combustion plants;
- reduction of polluting emissions with minimum combustion area.

The above problems can be solved with micro flame combustion principle where fuel is split into a large number of small jets. Application of micro flame combustion method allows reduction of harmful emissions and dimensions, thereby making the heat generator compact and ensuring high combustion efficiency.

Research purpose is to develop and study a low-toxic dual-fuel air nozzle for the compact portable heat generator.

Research objectives. To achieve the above purpose, the following objectives must be met:

1. development and creation of a new design air burner for the heat generator that ensures a lower level of toxic components in combustion products;
2. mathematical simulation of processes in the front unit of the heat generator combustion liner with reference to the air nozzle design using Ansys Fluent software;
3. development of the methodology for analytical calculation of NO_x formed with reference to amount of twist and staged air input to the heat generator combustion zone;

4. experimental study of air nozzle to determine geometry and aerodynamic parameters and perform NO_x calculation models validity check;

5. filing for the patent for the compact portable heat generator with air nozzle and confirming the novelty thereof;

6. developing recommendations on use of air nozzle in the heat generator and reduction of harmful emissions of NO_x.

Research target. The target of the research is a dual-fuel air nozzle for the compact portable heat generator with enhanced technical, economic and environmental performance that seamlessly operate under a wide output flow range and considerable fluctuations of liquid and gaseous fuel.

Research methods. To meet the above objectives, we have used experimental methods to study combustion processes in the air nozzle and findings so obtained have been processed based on mathematical statistics using computer programs. Besides, to study the processes in the front unit of the heat generator combustion liner (with reference to the air nozzle design) we used the numerical approach. Mathematical simulation was performed using Ansys Fluent software.

Scientific novelty of the research is as follows: development and study of the heat generator with a new design nozzle for micro flame combustion:

- new burner designs have been granted a patent;
- optimum dimensions of the burner device have been chosen based on the numerical simulation and experimental studies;
- nitrogen oxide output dependence on geometrical and aerodynamic parameters has been determined;
- the formula to calculate nitrogen oxide emissions by reference to flow pattern in the primary zone and staged air input into the het generator combustion liner, i.e. combustion zone, has been presented.

Practical relevance of the research consists in obtaining of experimental findings and analytical formula that can be used to develop other low-toxic burner devices and new patented thermal power plants (TPPs) for heat generators to meet the industry and heat-power engineering needs for heat supply and drying of various materials.

The fundamental distinction of the research from the previous and similar works lies in use of micro flame fuel-burning arrangements and components, comprehensive approach to studying of combustion processes, toxic substances formation, and calculation procedure that takes environmental, technical and economic aspects of the proposed device into account.

Scientific credibility. Credibility of the result received is ensured by use of high-precision instruments and advanced research methods. Moreover, results of numerical simulation and experiments are consistent with the results of other authors.

Theses for approval:

- results of numerical simulation and experimental studies of combustion processes by reference to the flow swirl and staged air input when using an air nozzle;

- analytical method to calculate harmful substances formation by reference to staged air input into the combustion zone;
- design of a micro flame dual-fuel burner device with high environmental and engineering performance;
- portable heat generator with the dual-fuel air nozzle.

Personal contribution of the author in the scientific results is as follows:
- justification of the research rationale;
- analysis and integration of the literature data;
- conducting of numerical simulation;
- conducting of experimental studies and processing of the results thereof;
- development of the universal method to calculate NO_x output;
- development of new engineering solutions.

The thesis paper is the product of the author's work, materials used in the thesis are obtained independently and in collaboration with the scientific supervisors.

Evaluation of the thesis results. Key results have been presented and discussed at the International Research-to-Practice, Science and Technology Conferences:

1. II International Science-to-Practice Conference – Global Science and Innovations 2018: Central Asia (Kazakhstan, Astana, 2018);
2. XXIV Scientific Conference with International Participation (Sozopol, Bulgaria 2019);
3. International Science and Technology Conference – Anniversary readings of F.K. Boyko devoted to 100-year anniversary of F.K. Boyko. (Kazakhstan, Povladar, 2020);
4. VIII International Science-to-Practice Conference – Current Problems of Transport and Power Industry: Ways for Innovative Solution (Kazakhstan, Nur-Sultan, 2020).

Validity and credibility of scientific findings, conclusions and recommendations is ensured by use of high-precision instruments and advanced research methods. Moreover, results of numerical simulation and experiments are consistent with the results of other authors.

Publications. 20 research articles have been published on the research topic including 5 publications in the editions recommended by the Committee for Control in the Sphere of Education and Science of the Republic of Kazakhstan Ministry of Education and Science, 1 research article in Thermal Science, International Scientific Journal, included in the Thomson Reuters database, 4 publications in foreign journals, 4 publications at the international conferences, 3 patents for utility models, in 2 monographies and 1 study aid.

Volume and structure of the thesis: thesis paper contains introduction, four sections, conclusions, list of literature references and appendices.

Introduction deals with the research rationale and the problem under study. It formulates the main idea, scientific novelty, key points of the thesis, personal contribution of the author, evaluation of the results and publications.

The first section of the thesis paper includes the analysis and review of key ways to enhance heat generators. Section one also contains the analysis of burner units for micro flame heat generators and main advantages thereof. Micro flame burner units are fuel supply and stabilizing components of combustion chambers in fuel-burning plants at a time. Besides section one outlines main directions of micro flame unit development, core principles of micro flame combustion with preliminary preparation of fuel-air mixture.

The second section presents the results of the numerical simulation of the processes of preparation and combustion of fuel-air mixture in the heat generator front unit with due account for the flow swirl and formation of toxic substances, in particular, nitrogen oxides. To study advantages of micro flame air nozzle with prepared fuel-air mixture, which is an effective way to decrease generation of toxic substances, we use the schemes and certain major parts of the nozzle wherefor the applicant has obtained the certificates of authorship (utility model patent 4377 PK). As is evidenced by the analysis performed, in the course of simulation we have studied the effect of the spin of blade swirlers installed at the outlet of the burner device. The results show that an angle of 30º is optimum in the context of nitrogen oxide formation. To study influence of the secondary air at the outlet of the burner device, three modes have been tested, mode one – maximum air input, mode two – a half less, and mode three – no air input. It was in studies revealing that increase of air flow at the initial stages results in decrease of nitrogen oxide concentration, however a fully opened position results in increased concentration.

Zeldovich mechanism of NO formation has been taken as the basis of the analysis. To determine the nitrogen oxides concentration, the end formula has been presented that includes the coefficient correcting for the quality of mixture in the primary zone of combustion chamber (determined by the design of the burner unit through the spin parameter which depends on the swirler type and the angle of blades) and the micro flame coefficient of the burner unit that enables measurement of air input to the combustion zone.

Section three describes the test bench and physical models used to study a micro flame air nozzle, method of procedure, details and parameters of measurement instrumentation, basic equation to determine key parameters, and estimate of accuracy.

Section four presents the results of experimental studies of the processes and efficiency of liquid and gaseous fuel combustion behind the air nozzle. The research has been conducted with two types of fuel, in various modes. Experimental findings and estimate indicators have been analyzed and compared at various values of the staged air input which ensures burnout of small and burning of vaporizing medium and large droplets. The section contains the engineering solutions wherefor the applicant has obtained the certificates of authorship and the comparison of engineering solutions developed by the applicant with the prototypes thereof.

The thesis describes the developed dual-fuel burner device with the improved design against the prototype thus ensuring high stabilization characteristics. The second engineering solution is the air nozzle, which enables

adjustment of the blades installation angle. Besides, this nozzle has a lower nitrogen oxide formation and a possibility to burn two types of fuel. When working with the downgrade liquid fuel, there is a possibility to adjust gas recirculation. We have developed the heat generator which enables highly turbulent flow with intensive fuel mixing and burning processes that materially reduce emissions of nitrogen oxides. Such portable heat generator is very compact, enables burning of two fuel types and has removable heat-exchange unit.

Key findings and conclusions of the thesis paper are formulated **in the Conclusion**.