ANNOTATION

thesis for the degree of Doctor of Philosophy (PhD)
in the specialty 6D072300 – «Technical Physics»

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The experimental study and modeling of heat transfer processes in components of water heating boilers

The dissertation work presents the results of: studies of heat exchange processes in the flues of a boiler unit; pyrometric examination of the furnace space and thermographic survey of the surface of the downflow flue; computer modeling of the heat exchange process in the air heater of a hot water boiler and practical recommendations for improving the efficiency of boiler installations depending on the state of convective heating surfaces.

Relevance of the research subject.

The quality of the boiler unit depends on how efficiently the heat exchange processes take place inside it. Heat exchange processes occurring sequentially in all elements of the boiler unit are interconnected. Gorenje process in the furnace space is affected by the temperature of the air supplied from the tail heating surfaces. The high temperature of the air entering the furnace space improves the process of ignition and gorenje fuel. Complete combustion of fuel in the furnace space reduces heat losses with mechanical and chemical underburning, prevents the removal of unburned fuel particles into the flues of the boiler, increases the efficiency of the installation. The temperature of the air entering the furnace, in turn, depends on the intensity of heat exchange in the air heater, where it is warmed up by the heat of the outgoing flue gases. Special attention is paid to the study of heat exchange processes in order to increase the efficiency of boiler units. Basically, thermophysical processes in combustion devices are considered, and the laws of heat exchange processes in the tail heating surfaces, such as economizers and air heaters, have been studied to a lesser extent, namely, these processes greatly affect the efficiency of fuel combustion. It is by considering the heat exchange processes in the furnace space and in the air heater that it is possible to fully assess the operation of the equipment and, if necessary, make adjustments to the operating parameters.

The efficiency of heat exchange processes in an air heater is described by the heat transfer coefficient, which depends on the heat transfer coefficients, the thermal conductivity coefficients of the wall material and impurities, as well as the design features of the heat transfer surface.

The development and improvement of operating mode maps of power equipment, created on the basis of the study of heat transfer processes, allows to significantly optimize the process of boiler equipment operation, reduce the degree of its technogenic impact. However, the study of thermophysical processes occurring in the furnace space and tail heating surfaces is complicated by many features of the objects of study. The complex nature of heat exchange processes in all elements of

boiler units makes it necessary to conduct a comprehensive theoretical and experimental study of the processes occurring in them.

The aim of the research is to increase the efficiency of the boiler unit based on the establishment of the influence of contamination of low-temperature heating surfaces on the intensity of convective heat exchange during the combustion of non-project fuel using experimental studies and computer modeling.

To achieve this goal, the following **tasks** were solved:

– Draw the isothermal surfaces of the boiler furnace.

– Determine the degree of blackness and conduct a thermographic study of the air heater.

– To develop a meaningful statement of the modeling problem and to establish boundary conditions for the heat exchange processes of low-temperature tail heating surfaces.

– To determine the nature of changes in the dependences of the temperatures of heat carriers and the intensity of heat transfer on the degree of contamination in low-temperature convective heating surfaces.

– To establish the criterion of the frequency of cleaning the air heater and the influence of the gas-dynamic nature of the flow of the medium on the efficiency of the boiler when changing the temperature-time effect.

The object of the study is a convective pipe bundle of the boiler air heater, taking into account the changes in the flow sections at different degrees of contamination of the pipes with deposits from flue gases.

The subject of the study is the processes of heat transfer in high-temperature and low-temperature heating surfaces of the KV-T-116,3-150 boiler unit.

Research methods.

To study the processes of heat transfer in the elements of the boiler unit, the following research methods were used: pyrometric study of the furnace space of the boiler unit at different heat output; thermographic study of the heating surface of the downfall flue; modeling of thermophysical processes using the ANSYS software package based on the finite element method.

The scientific novelty of research is that for the first time it presents as follows:

- a new method for calculating the thermophysical parameters of the heat transfer process has been developed on the basis of the ANSYS software package, which allows us to obtain a complete description of the complex heat transfer processes in the air heater of the boiler unit. In the developed computational three-dimensional thermophysical model of a recuperative tubular air heater, there is no tube wall, the created thermal resistance of the wall is taken into account by introducing the coefficient of effective thermal conductivity of the flue gas flow λ_{ef}. The results of computer simulation are in good agreement with the available actual data, the relative error of calculations does not exceed 3 %. The developed computer model is protected by a certificate of entering information into the State Register of Rights to Objects Protected by Copyright No. 14347 of 11.01.2021;

- the thermophysical characteristics of the heat transfer process in a recuperative tubular air heater are determined, taking into account the state of the tail convective heating surfaces when the boiler is running on non-project fuel;
- the dependences of the heat transfer and heat transfer coefficients in the air heater on the degree of contamination of the low-temperature convective heating surfaces during the operation of the boiler on non-project fuel are established;
- the influence of the gas-dynamic nature of the flow of the medium on the efficiency of the boiler when changing the temperature-time effect is determined.
- a complete spatial picture of the heat exchange process in the recuperative air heater of the boiler unit is obtained, and various scenarios of the heat exchanger operation are implemented, depending on the contamination of the heat exchange surface.

Key points for defense:

1 Features of the nature of the distribution of temperature fields along the height of the furnace of a hot water boiler when deviating from the rated power.

2 Results of computer simulation of heat transfer intensity in low-temperature convective heating surfaces depending on the degree of contamination.

3 Regularities of the influence of the gas dynamics of the flow of heat carriers on the efficiency of convective heat transfer in the tail surfaces of the boiler.

Scientific and practical significance.

The results of the dissertation research are aimed at solving practical problems. The use of non-project fuel in modern hot water boilers it necessary to determine ways to improve the efficiency of boiler equipment and reduce the technogenic impact of the installation on the environment.

A new three-dimensional computer model has been developed that allows you to quickly and accurately determine the thermophysical characteristics of the heat exchange intensity in the air heater, control the frequency of cleaning the heat exchanger to eliminate possible causes of a decrease in the heat exchange intensity, which contributes to improving the efficiency of the boiler plant. The proposed method for studying the processes of heat transfer in the tail surfaces of heating a hot water boiler is the most promising among the many ways to improve the efficiency of modern boiler installations. The computer model is applicable for calculations of the heat transfer process in the air heaters of other boiler units, when using non-project fuels, as well as changing the quality of the fuel composition.

Based on the results of computer simulation of the heat transfer process, the operating mode maps of the air heater in the form of nomograms and graphs are developed to determine the optimal operation of the heat exchanger. Nomograms allow you to predict the efficiency of the boiler unit depending on the heating capacity, the speed of the heated air, the temperature of the outgoing flue gases, taking into account the state of the heat exchange surface.

The criterion of the periodicity of cleaning the air heater from deposits is established, which regulates the cleaning interval, in the form of a critical value of the temperature of the outgoing flue gases.

The implementation of the results of research work in the operation of the hot water boiler KW-116.3-150 allowed to optimize the operation of the unit, increase the duration of its uninterrupted operation and the annual working time coefficient.

Connection of work with research projects. As part of the program of financing and support for talented youth, the Foundation of the First President of the Republic of Kazakhstan - Leader of the Nation sponsored a trip to participate in the 23rd annual International Scientific and Technical Conference of Students and postgraduates «Radioelectronics, Electrical Engineering and Power Engineering» in the section «Thermophysics» (Moscow Power Engineering Institute, Moscow, Russia). The results of the study are implemented in the educational process and in the workplace. The certificate of the Grant holder for the trip, the Acts on the implementation of the research results are presented in the Appendix to the dissertation.

The author's personal contribution includes: setting the purpose and objectives of the study; development of experimental methods and conducting experiments on pyrometric and thermographic studies of heat transfer processes in boiler elements; development and verification of computer and mathematical models of the air heater; analysis of the results obtained together with scientific consultants and formulation of the main conclusions; development of practical recommendations.

The degree of validity and reliability of the results obtained in the work is ensured by the use of proven standard research methods, repeated experiments, the use of modern high-precision measuring instruments and installations, the use of the Ansys Fluent 14.5 license program, the comparison of a large amount of experimental data with previously obtained research results in CIS countries and abroad.

The research results have been publicly tested: published in scientific journals, reported and presented by the author at national and international conferences. Experimental research on the topic of the dissertation work was carried out on the operating boiler unit of the CHP-1 of the city of Semey in the conditions of its real operation, computer modeling was carried out on the basis of the laboratory of "Experimental Thermophysics" of the Institute of Atomic Energy of the National Research Center of the Republic of Kazakhstan (the city of Kurchatov).

Testing of the research results.

The materials of the dissertation work were presented and discussed at the following international and national conferences: IV Rus. scientific youth school-conf. "Power engineering, electrical engineering and energy-efficient technologies through the eyes of youth", on November 1-3, 2016; V International youth forum "Smart grids", Tomsk, RF, 2017; Internat. scientific-practical conf. "Scientific achievements and discoveries of modern youth", Penza, RF, 2017; 23 Internat. scientific-technical conf. of stud. and postgraduate. "Electronics, electrical and power engineering", Moscow power engineering Institute, Moscow, RF, on 2-3 March 2017; XVI Conference-competition of scientific research and development work of young scientists and specialists of the NNC of the Republic of Kazakhstan, Kurchatov, Kazakhstan, 3-5 may 2017; Internat. scientific-practical conf. "Problems of food security of Kazakhstan in the conditions of globalization", Semey,

Kazakhstan, on 15 September 2017; Internat. scientific-practical conf. "Actual problems of food production: status and prospects", Kazakhstan, Semey, November 24, 2017; 24th Annual Internat. Scientific and Technical Conference of Stud. and Postgraduat. "Radioelectronics, Electrical Engineering and Power Engineering", MPEI, Moscow, RF, March 15-16, 2018; The 11th Internat. Scientific and Practical Conference "Chaos and Structures in Nonlinear Systems. Theory and Experiment" November 22-23, 2019 Karaganda State University named after Academician E.A. Buketov; Internat. online educational Conf. "Education-the basis of Euro-Asian cooperation", Shakarim State University of Semey, 2019. There are diplomas and certificates of participation presented in the Appendix to the dissertation.

The results of the dissertation work were discussed at scientific seminars of the Educational Department of Technical Physics and Heat Power Engineering of the non-profit joint stock company «Shakarim University of Semey» and the Department of Thermal Power Plants of the Novosibirsk State Technical University (Russian Federation).

Publications.

The main results of the dissertation work are presented in 18 printed works. 5 articles have been published in peer-reviewed scientific publications recommended by the Committee for Control in the Field of Education and Science of the Ministry of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, in journals indexed in the Scopus and Web of Science databases - 1 (quartile Q2), 1 certificate of entering information into the State Register of Rights to Copyrighted Objects has been obtained.

The structure and scope of the dissertation. The dissertation work is presented on 100 pages and consists of an introduction, four sections, a conclusion and a list of used sources from 121 titles. The dissertation work presents 40 figures and 8 tables.