ABSTRACT

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Development and research of high-efficiency boilers of small power

In Kazakhstan, along with the development of large thermal power plants, there is a steady trend towards an increase in the number of small and medium-sized boiler plants [5]. Today, more than 5,000 small hot water boilers operating on liquid and gaseous fuel operate in decentralized heat supply systems. One of the key objectives of the state policy in the field of infrastructure development is the expansion of the gas distribution network in order to provide gas supply to such regions as Astana, Akmola and Karaganda regions by 2030. Currently, ATKE LLP manages 85 district boiler houses operating on gas and liquid fuel [5,6]. However, when connecting old districts or new territories to city heating networks, as is observed, for example, in the city of Almaty, the presence of morally and technically obsolete low-power boiler units using solid (coal) and liquid (diesel) fuel is revealed [6,7].

These installations are characterized by low efficiency, increased emissions and significant operating costs. Against the backdrop of these challenges, the modern power engineering market is rapidly developing, offering a wide range of equipment aimed at increasing energy efficiency and reducing the impact on the environment. Given the sharply continental climate of Kazakhstan, reliable and economically sound provision of the thermal load of heating and hot water supply systems, which constitutes up to 40% of the total consumption of primary energy resources [1-4], is a critical task for the sustainable development of the country's thermal energy complex. Currently, low-power boiler equipment is represented on the Kazakh market by two main types of boilers: water-tube and heat-tube.

In the Kazakhstan market, low-capacity boilers are represented by the main types of boilers: water-tube and heat-tube.

For a certain time, water-tube boiler units were mainly produced in the post-Soviet countries. Water-tube boilers were used both at large energy facilities and for the needs of small-scale energy. The main advantage of such boilers is the organization of the movement of the coolant in the water circuits, which ensures the necessary temperature regime of the water and reduces contamination of the heat exchange surfaces. However, for reliable operation of the entire pipe system of water-tube boilers, it is necessary to strictly observe the hydrodynamic regime in all operating modes with partial or even minimal power, which causes a sufficiently high hydraulic resistance of water-tube boilers [8].

For about ten years, heat-tube boilers have been widely used in the CIS countries.

Most European (ICI Caldaie [12], Buderus [13], Viessmann [14], Bosch [15], Siemens, etc.) and Russian (LLC REMEX-Energo Company, JSC Dorogobuzhkotlomash [16], CJSC Biiskenergomash [17], CJSC UralkotlomashJSC Belgorod Power Engineering Plant, CJSC Joint Venture ZIOSAB[18]) manufacturers of boiler equipment are focused on the production of heat-tube boilers [9].

Long-term experience in the operation of fire-tube boilers has shown [2, 3] the presence of the already achieved maximum possibilities of convective and radiative heat exchange during the longitudinal flow of gases with different types of inserts and different pipe designs. However, the reliability of operation has not improved, leading to an increase in repair and maintenance costs. For a long time, no attempts have been made in Kazakhstan to change the design of the boiler and improve thermal efficiency. Hot water boilers of well-known foreign manufacturers, the cost of which is significantly higher than domestic ones, do not reach the design indicators. The combination of such problematic issues creates a large open discussion about the need for modernization, ensuring the efficiency of old boilers and compliance with the stricter requirements of environmental legislation.

An analysis of the state of thermal power equipment in the market of Kazakhstan, current trends in decarbonization in the thermal power industry, environmental stability and energy efficiency improvement shows that the most acceptable solution is to replace outdated hot water boilers with modern boilers as soon as possible or modernize the design of low-power boilers with increased efficiency. There is a certain potential for the modernization of low-power hot water boilers, the service life of which has not expired, and the number of operating hours is still far from critical. This is the most realistic and attractive option from an economic and environmental point of view. This will improve the technical level of new boilers, reduce emissions and save budget funds for the construction of new boilers in the future.

The actual state of affairs in the industry shows the urgency of measures to modernize thermal power equipment with small boilers, and the continuation of new developments with reliable, economical systems with a sharp reduction in greenhouse gas emissions. I.e., the creation of alternative and affordable renewable sources of heat supply in combination with hot water boilers. The proposed approach, considered in this paper, confirms the relevance of the ongoing research on the development of highly efficient designs of hot water boilers with the possibility of using the presented solutions as a new product, or their modernization with the improvement of all technical, economic and environmental indicators.

The presented dissertation work was carried out on the basis of a complex of scientific research analytical and experimental works, with the performance of field experiments at the production base of Kazkotloservice LLP, with the analysis and

evaluation of the effectiveness of a technical solution using reversible furnaces of small hot water boilers and spiral inserts into convective pipes to increase reliability and efficiency. In the dissertation work, mathematical modeling tools using modern computer technologies were used to improve the quality of the engineering decision, namely, to change the design of the burner nozzle.

In connection with the questions posed, the purpose of the dissertation research is formulated as follows:

A study of the thermal efficiency of using a reversible furnace on an operating BB-400 hot water boiler with an efficiency assessment using spiral wire inserts into convective pipes of hot water boilers. Investigation of the efficiency of extending the burner nozzle for uniform distribution of the torch over the furnace volume in a reversible furnace. Apply the technical solutions studied in the work for existing and new boilers.

The scientific novelty of the work performed is as follows:

1 On the basis of a complex of analytical and experimental studies of hot water boilers with reversible cylindrical furnaces, the expediency of their effective use with the use of retractable adjustable nozzles (tubes) has been proved and quantitative estimates with optimal solutions for maximizing the thermal efficiency of the wall of a reversible furnace along its entire length are presented.

2 The results of the analytical solution of the differential equation of thermal conductivity for determining the temperature field by the thickness of a cylindrical reversible furnace are obtained. The results of the approximate analytical solution make it possible to determine and evaluate the level and field of temperatures along the thickness of the furnace wall, depending on the thermal radiation flow to the inner wall of the furnace. The determination of the integral cross-section temperatures of the furnace wall (temperature field) allows you to evaluate the stress field, and knowledge of the limit values of the temperature of the inner wall of the reversible furnace, determine the beginning of scale formation on the inner wall of the furnace.

3 The design of a heat-tube hot-water boiler with a cylindrical reversible furnace is presented and investigated. Based on the results of experimental data, recommendations have been developed for BB-400 hot water boilers with reverse movement of the torch and convective pipes with spiral wire inserts and twisted ribbon inserts.

4 Data were obtained on computer modeling of the dependence of the temperature in the wall area of the furnace on the extension of the nozzle (tube) of a combined gas-liquid burner. Varying the length of the retractable nozzle of the combined burner in the reversible furnace allows you to significantly increase the length of the torch with a more uniform distribution of temperature and luminosity of the torch along the axis along the entire length of the reversible furnace.

5 Based on the results of theoretical and experimental data, the technical documentation of the steam boiler KPAzh-6.5 has been developed.

6 The results of the dissertation work are confirmed by the received security documents.

The obtained results of the dissertation work have scientific and practical value, represented by the following points:

- Based on the results of complex experimental studies, confirmed by the analytical solution of the thermal conductivity equation for a reversible furnace, temperature fields along the thickness of the furnace wall have been obtained, according to which the thermal efficiency of using reversible furnaces can be estimated. The calculated values of heat perception for the convective and radiation parts of the BB-400 hot water boiler have been confirmed, which can be useful in practical use when expanding the thermal performance of this type of boilers with a reversible furnace and topics for research.

- According to the results of complex experimental studies, analytical dependences have been obtained for evaluating the thermal efficiency of using spiral wire inserts in convective tubes. Analytical dependences of aerodynamic drag and heat transfer coefficient in convective tubes with spiral wire inserts make it possible to perform a full range of thermal calculations on the thermal perception of convective pipes and determine the total resistance of the boiler, which will expand the scope of the study.

- Based on the results of the work, options for modifying the designs of hot water and steam boilers with reversible furnaces are presented, which can be used for standard boiler models, or used as working documentation when designing new boiler houses, carrying out work to improve the thermal and environmental efficiency of boiler equipment.

- The calculated dependences on the geometry of spiral inserts and twisted ribbon inserts in convective pipes (resistance coefficient ξ and heat transfer coefficient α (Nu)) are presented to determine the effectiveness of using inserts.

Based on the results of modeling the retractable burner nozzle in a reversible furnace, the expediency of using an adjustable nozzle in a reversible furnace of hot water and steam heat-tube boilers is described.

- Recommendations are presented for boilers of the BB-400 series to increase efficiency.

- New hot water boilers are described according to the patents obtained.

- Working documentation has been prepared for heat-tube steam boilers with convective pipes and spiral inserts with a steam capacity of up to 6.5 tons/hour.

The reliability of the results obtained is confirmed by the following:

1 The research was carried out on existing hot water boilers BB-400 and KVa-400 using certified measuring instruments included in the register of the State Registration Service of the Republic of Kazakhstan.

2 Experimental work was carried out in accordance with current requirements, and the results were compared with thermal calculations according to the Standard Methodology.

3 The practical value of the experimental and calculated results obtained is confirmed by their applicability to existing heat-tube boilers, confirmed by the act of implementing the results of the dissertation work from the boiler plant of Kazkotloservice LLP.

In the process of completing the dissertation work, the following research tasks were performed to achieve the set goal:

- To conduct a literary review on the topic of methods for improving the efficiency of hot-water cylindrical boilers with reversible furnaces and existing design solutions of furnaces.

- To perform an analytical solution of the differential equation of thermal conductivity for the symmetrical region of a cylindrical reversible furnace in order to determine the temperature field by the thickness of the furnace wall and compare it with the experimental results of thermal engineering tests.

- To investigate the thermal efficiency of the use of reversible furnaces and spiral inserts in convective pipes of hot water boilers.

- To conduct an experimental study and comparison of the thermal efficiency of the BB-400 boiler with a reversible furnace and spiral inserts in convective pipes with the efficiency of the KVa-400, KVa-500 boiler using a cylindrical double-light screen and twisted ribbon inserts in heat-tube convective pipes on a specialized stand.

- Perform calculations to determine the resistance and heat transfer in convective pipes when using spiral wire inserts of a certain design in convective heat pipes;

- Based on the results of the performed research and the results of thermal engineering tests, to propose recommendations for increasing the efficiency of the BB-400 boiler. To take a direct part in thermal engineering tests and correction of the working documentation of the BB-400 hot water boiler and the KPAzh steam boiler series with an effective geometry of convective spiral wire inserts in relative pitch.

According to the results of the completed work and research, the following provisions are submitted for protection:

1 Results of the analytical solution of the differential equation of thermal conductivity in relation to the cylindrical reversible furnace of a hot water boiler with a thermal capacity of 0.4 MW with a retractable nozzle (tubes) of a combined burner.

2 Results of studies of hydrodynamics (aerodynamics) and heat transfer in the convective part with spiral inserts according to thermal engineering tests of the BB-400 boiler and comparison with similar results for the KVa-400 and KVa-500 hot water boilers with ribbon inserts.

3 Adjustment of the design documentation for a hot water boiler with a reversible BB-400 furnace using spiral wire inserts in convective heat pipes.

4 Working documentation for heat-tube steam boilers with convective pipes and spiral inserts with a steam capacity of up to 6.5 tons/hour.
The results of the work were recorded by the acts of implementation from the production enterprise Kazkotloservice LLP.

The main results of the dissertation work are reflected in 15 scientific publications and reports of the ISTC, including: 4 scientific articles in domestic publications from the list recommended by CQASHE; 4 scientific reports in collections at international scientific and technical conferences, including a face-to-face presentation at a foreign scientific conference; 1 article in the journal Polityka Energetyczna – Energy Policy Journal indexed in the Scopus database with a percentile of publication of 55% in the section "General Energy". As a co-author, the results of research activities were recorded in: 4 Patents of the Republic of Kazakhstan for an invention on the subject of designs of hot water boilers.

The personal contribution of the author in solving the problems of the work under study is determined by:

-In the formulation and formulation of the research task and the choice of research methodology using the head sample of a hot water boiler with a reversible furnace with a thermal capacity of BB-400 MW;

-In the formulation and analytical solution of the Laplace differential equation of thermal conductivity in relation to a reversible cylindrical furnace to determine the temperature field by the thickness of the metal of the furnace wall;

-In the formulation and conduct of a theoretical analysis of the dependence of the thermal resistance of pollution and the coefficient of thermal efficiency for the tube screens of the furnace of a hot water boiler.

-Direct participation at all stages of thermal engineering tests and direct research (participation in thermal measurements and data processing) at a stand with operating hot water boilers: BB-400, kVA-400 and kVA-500 at the production base of Kazkotloservice LLP in Almaty).

- Correction of design documentation for a hot water boiler with a reversible BB-400 furnace using spiral wire inserts in convective heat pipes.

- Participation in thermal engineering tests and correction of the working documentation of the BB-400 hot water boiler and the KPAzh steam boiler series with an effective geometry of convective spiral wire inserts in relative pitch.

The dissertation work was performed by the author in accordance with the current requirements of design, structure and content. The work consists of 5 main sections, a list of symbols and abbreviations, an introduction, a conclusion, a list of references and an appendix.

The first section provides an overview of the issues of thermal efficiency of cylindrical heat-tube and water-tube hot water boilers, as well as the advantages and existing disadvantages of their designs. The current state of intensification of heat transfer in convective pipes with protrusions and spiral inserts for use with reversible furnaces is presented.

The second section describes the analytical solution of the differential equation of thermal conductivity with boundary conditions applied to a reversible furnace in order to determine the temperature field by wall thickness. The section presents temperature profiles based on the results of the analytical solution of the differential equation in polar coordinates and compares them with experimental temperature measurements from the furnace side and from the reverse side of the reversible furnace with cooled water.

The third section describes a comprehensive specialized stand for industrial thermal engineering tests of the BB-400 heat-tube hot water boiler with a reversible furnace and KVa-400, KVa-500 with double-light screens, where different types of inserts in the convective pipes of the boiler were studied. The methodology of conducting thermal engineering tests, processing the results, evaluating their reliability with a full analysis of the experimental data is given.

The fourth section contains an analysis of the results of thermal engineering tests of the thermal efficiency of a reversible furnace with spiral wire inserts in convective pipes. The data obtained for the BB-400 boiler with a reversible furnace are compared with similar results for cylindrical hot water boilers of the KVa-400 series according to the main technical and economic indicators.

The results of calculations and experimental data are presented in the form of analytical dependencies on the geometry of spiral inserts and twisted ribbon inserts in convective pipes (resistance coefficient ξ and heat transfer coefficient α (Nu) depending on the angle φ of the ribbon twist and the spiral pitch).

A description of a cylindrical isothermal furnace model with a reversible furnace for measuring the temperature field and velocities depending on the length of the nozzle extension of a combined burner is given.

The section presents the results of computer simulation of a reversible furnace with a standard burner and a retractable burner nozzle.

The direct and indirect errors of the experimental data are calculated.

The fifth section provides recommendations for improving the efficiency of heat-tube boilers with reversible furnaces using the example of the BB-400 boiler and a description of the boiler design with recommendations for retractable nozzles (tubes) of the burner. And also, taking into account these modifications, proposals are presented for the effective operation of the KPAj steam heat-tube boiler with a reversible furnace. The working technical documentation for serial steam boilers KPAJ is presented.

In conclusion, the work summarizes the results of thermal engineering tests of the BB-400 hot water boiler with a reversible furnace and an experimental study of the convective part with spiral inserts in convective pipes with the main conclusions on the topic of the dissertation.

The appendices contain the main accounting materials for calculations of the BB-400 hot water boiler according to a standard methodology, a copy of the

implementation act from the production enterprise Kazkotloservice LLP, copies of the main patents of the Republic of Kazakhstan.