

ABSTRACT

Nowadays, there is a rather developed classification of options for heat supply systems presented in the world. As for Kazakhstan, which is located in a climate area with seasonal differences of conditions, it is noted that significant part of generated energy is used as heat energy to satisfy the demand and needs of heat supply systems and Hot-Water Supply (HWS) systems.

The majority of large heat supply sources within Kazakhstani structure of heat sources are Heat Power Plants (HPP), however, along with HPPs there is a developing decentralized network of small and medium size boiler houses under private or state ownership. But, the diversity range in terms of type, produced power, and initial fuel, is quite broad. Among others, special significance is given to large district boiler houses and peak boiler houses of HPPs on the one hand, and small boiler houses represented by fire-tube water heating boilers on another.

It is necessary to mentioned and already well-known and discussed fact of problem that is present in Kazakhstan and concerns moral and physical wear of major portion of heat power equipment, and water heating boilers in first place. Actual use efficiency of such boiler houses may vary from 55% to 92%, moreover, one should consider that not every boiler house (especially private ones) has possibility to provide fully professional maintenance of high technical and economical level. Also, there is a huge amount of small size boiler houses, which desperately require a substitution of outdated equipment, or, at least a repair or commissioning, which are not being performed for various reasons.

Combination of such issues creates a big open topic for discussion about the necessity of modernization, efficiency increase of old boilers operation, and meeting gradually rising requirements of eco legislation.

Considering the latest development of market relationships, opening of new great import opportunities for foreign technologies, solution to the abovementioned issue was partially found in substitution of outdated water heating boilers with foreign alternative systems. In this regard, one of the first choices is Russian federation with their boiler manufacturing factories, however, quite a large part of demand for updated equipment is conveniently satisfied by well-known global brands from China, Western Europe and USA. Latter are equipped with reverse-direction combustion chambers and three-way longitudinal gas passages, automated torches and micro-processors to regulate boiler's operation. Nevertheless, considering operational specifics and fuel quality (in reference to liquid and solid types of fuel) there are still some concerns about maintenance and repairs costs, and necessity of special operational commissioning and service by manufacturer.

The most unsophisticated and "adapted" to harsh operational conditions appear to be water heating boilers from Russia (JSC "Dorogobuzhkotlomash". JSC "Biysk boiler factory), which satisfy such requirements as simplicity of structure and use, operational efficiency, and adequacy in terms of technical maintenance, repair and availability of spare parts. Similarly and almost with 100% reference to again Russian

manufacturers, one may observe a situation with operation and spread on medium-power boilers (up to 200 MW).

Analyzing the current condition of heat and power equipment bank, as well as trends towards decarbonizing, better ecological stability and increase of energy efficiency, the most applicable should be considered the option of substitution of outdated water heating boilers with much modern and efficient boilers. However, there is still rather big potential in modernization of those boiler units, which have not yet reached the end of their operational period and their operating hours are far from critical value. Such alternative comes out to be more palatable, first of all from economical point view, and provide improvement of boiler's technological excellence while not "blowing" the budget of boiler houses for new construction works in the near future.

Thus, brilliant example is an opportunity of modernization of wide spread tower-type water heating boilers of medium heating power such as PTVM type boilers, which after years and years of operational experience have shown a number of structural and operational weaknesses.

Mentioned palatability and, which is important, cost-effectiveness of modernization solutions for heat and power equipment on the one side and growing demand for reliable, efficient and "cheap" sources of heat supply based on water heating boilers from another side, verify the **applicability and significance of conducted research** on development of highly efficient alternative structures of water heating boilers with ability to use given solutions as the new product or as a basis for modification of the existing units.

This thesis paper was performed on the basis of scientific and research complex of analytical and experimental works along with running live experiments on the production base of JSC "Kazkotloservice", and further analysis and evaluation of technical solution that suggests use of bi-radiated screens inside chambers of water heating boilers as one of the options for increase of heating efficiency of boiling units, improvement of their reliability and operational efficiency.

Mentioned factors form the **aim of thesis research**, which may be put as follows:

Research of heating efficiency of coaxial bi-radiated screens for currently operating water heating boilers and evaluation of possibility to use bi-radiated screens in wide range of water heating boiler models.

Scientific novelty of the performed work lays in the following:

1. Based on the complex of experimental researches of water heating boilers, was proved the practicability of use of coaxial bi-radiated screen; quantitative evaluation was given; and suggested optimal solutions for maximum use of heating efficiency of heating surfaces of boiler unit.

2. Were suggested structures of fire-tube and water-tube water heating boilers with bi-radiated screens. There was also developed a set of operational technical documentation for KV-GM 125-150 water heating boiler with bi-radiated screen, and optimized structure of sets of convective tubes as modernization option for PTVM-100 type boilers.

3. Experimentally reliable quantitative data were obtained on possibility to decrease the size of water heating boiler, which would allow to increase nominal power of boiler by adding bi-radiated screens in current structure of boiler (location of boiler).

4. Research results are verified by obtained documents with title of protection, including patents of the Republic of Kazakhstan for inventions and Eurasian patents.

Results obtained during this thesis paper have **scientific and practical value** represented by following terms:

1. According to the results of complex experimental researches, supported by engineering calculations, there were obtained analytical dependencies on evaluation of heating efficiency during the use of bi-radiated screens, calculations of heat absorption by convective and radiant parts, which may be beneficial for further researches within this topic and beyond.

2. By results of thesis paper there were suggested options of structural modifications of water heating boilers, which may be implemented in typical models of boilers or used as operational documentation during design of boiler houses, conduction of works on heat and power equipment efficiency increase, modernization and reconstruction of currently existing units of heat energy sources.

3. Obtained and shown analytical dependencies and calculations for determination of adjustment factors for geometry of belt-type inserts in fire tubes (coefficient of resistance ξ and coefficient of thermal output α (Nu) in dependence of swirl angle φ of belt insert) in order to define operational efficiency of belt-type turbolizer.

4. Presented sets of operational documentation designed for water heating boiler of KVGM-125-150 type, which may be used as product in case of commercialization.

Validity of obtained results may be verified by the following:

1. Researches were conducted on live water heating boilers with the use of accepted measuring devices included in register of State System of Ensuring Measurement System of the Republic of Kazakhstan.

2. Experiments were performed in complex and backed up with calculations for imitation model using program system Boiler Designer, which showed great similarity of live test results and calculations.

3. Practical usability of obtained results is verified by acts of implementation, which in it's turn were received from boiler factories JSC “Kazkotloservice” and JSC “Temirkran” to support dissertation paper.

As part of dissertation paper, in order to achieve the set goal, the following **research tasks** were performed:

1. To conduct review of literature that is related to the topic of method of operational efficiency increase for water heating boilers, particularly on existing solutions of use of bi-radiated screens.

2. To research the possibility of effective use of bi-radiated screen within combustion chamber of typical water heating boiler models.

3. To conduct experimental research on efficiency of use of coaxial bi-radiated screen as structural part of KVa series fire-tube water heating boilers on specialized stand, featuring boilers with power range from 0,1 up to 3,14 MW.

4. To evaluate key parameter of relation between radiation surface and convective surface and total heated surface, to obtain parameter value for water heating boiler of various power band supported by thermal tests.

5. To calculate typical structures of water heating boilers using automated software complex of all-mode simulation Boiler Designer in order to evaluate optimal use of bi-radiated screen and to define necessity and alternatives for optimization of convective surfaces.

6. Based on the results of conducted research, to design and present the structure of water heating boiler with implemented coaxial bi-radiated screens and to participate in immediate design of full package of operational documentation for updated and improved KVGM-125-150 water heating boiler with bi-radiated screen and altered structure of convective packs.

According to results of completed theses and conducted researches, **the following terms are suggested to defense:**

1. Optimal relation between radiant and convective heating surfaces of KVa series water heating boilers with 0,4 to 3,15 MW power range and coaxial bi-radiated screens.

2. Results of researches on thermal tests for the chosen optimized relations between radiant and convective heating surfaces of KVa series water heating boilers with coaxial bi-radiated screens.

3. Results of calculations for structural values and key parameters on the basis of software complex BOILER DESIGNER for KVa and KV-GM-125 and KV-GM-145 series boilers with implemented coaxial bi-radiated screens.

4. Design documentation represented by operational technical documentation for KV-GM-125-150 water heating boiler with implemented bi-radiated screen and improved convective heating surfaces.

Practical use of results obtained after scientific research was performed during the conduct of scientific and research work performed by author of this thesis as a member of the team on project by government financing on topic No. AP05133388: “Research and design of wide range of perspective water heating boilers with power band from 0,63 MW to 145 MW operating on natural gas, liquid and solid fuel, designated for domestic industrial production within Kazakhstan” in accordance with Agreement No. 247 dated March 27, 2018 signed with Science Committee of Ministry of Science of the Republic of Kazakhstan. Results of this work were verified by acts of implementation received from manufacturers JSC “Kazkotloservice” and JSC “Temirkran”.

Main terms and topics were discussed in **academic articles**: 15 scientific articles and international scientific-research conference reports, including: 4 scientific articles printed by publishing houses chosen from the list of recommended by Committee on Provision of Education Quality (CPEQ); 9 scientific reports added to volumes of international scientific and research conferences, including in-person speech at international scientific conference; 3 scientific articles added to Scopus database, including 1 article published in International Energy Journal, where it was ranked with 35% within “General energetics” topic. As a co-author, results of scientific and research activity were presented in the following: 8 Patents of the Republic of Kazakhstan for inventions concerning structures of water heating boilers; 4 Eurasian patents that were included into Derwent Innovation Clarivate Analytics database.

Personal contribution of author in solving the researched topic is defined as follows:

1. Justification, drafting and choosing the methodology of research with the use of samples of KVa series water heating boilers with low thermal output from 0,4 to 3,15 MW.

2. Establishment and realization of mathematical model using BOILER DESIGNER software complex for calculation of the behavior of KVa series water heating boilers with coaxial bi-radiated screens and medium size KV-GM-125-150 water heating boilers with bi-radiated screens.

3. Administration on all stages of design and immediate research (participation in thermal measurements and processing of data) of sample and live three-way low power water heating boilers: KVa-0,4, KVa-0,6, KVa-1,16, KSGn-1,16, KVa-2,0, KVa-3,15 (JSC “Kazkotloservice”) and medium power water heating boilers KV-GM-100 and PTVM-100 (JSC “AIES”, Almaty city).

4. Coordination and immediate participation in compiling all sections of project’s Technical Specifications and technical materials (boiler’s passport project, operational technical documentation) for KV-GM-125-150 boiler.

Dissertation paper was performed by author in accordance with existing requirements for layout, structure and content of a document. Paper consists of 4 main sections: list of symbols, introduction, conclusion, bibliography and enclosures.

First section overviews issues of thermal efficiency of water heating boilers and existing weaknesses of their structures. There also given a review of literature about existing technologies and description of bi-radiated screen structure. It also has theoretical verification of effective use of bi-radiated screen.

Second section describes special stand or testing environment for semi-industrial thermal tests of low power output fire-tube water heating boilers with coaxial bi-radiated screens. There also given some terms from method of carrying out tests, obtaining results, evaluation of their validity and further analysis.

Third section contains analysis results from experimental research of thermal efficiency of coaxial bi-radiated screens and possibility of use of these results for implementation on boilers with higher power output rate. There also given the results

of data on definition of relation rate between radiant and convective surfaces, including results of calculations using Boiler Designer software. It also contains solutions and suggestions on use of bi-radiated screens for PTVM and KVGM type boilers, as well as calculations results represented by analytical dependencies used for definition of adjustment coefficients for geometry of belt-type inserts put into fire tubes (resistance coefficient ξ and heat exchange coefficient α (Nu) in dependency from swirl angle φ of belt insert).

Fourth section shows results of research in form of designed operational documentation and description of structures of the new solution on implementation of bi-radiated screens within the volume of combustion chamber of fire-tube water heating boiler and PTVM-100 boiler with improvement in nominal thermal output equal to KVGM-125.

Conclusion summarizes obtained research results and contains main conclusions on dissertation paper.

Enclosure section contains general report materials of calculations of water heating boilers, including those from Boiler Designer software, copies of acts of solution implementation at production facilities, copies of main patents.