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Development and research of 5.1 and 7.1 MW hot water boilers for heat supply of industrial and residential buildings

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Abstract. The article considers the development and research of hot water boilers with a capacity of 5.1 and 7.1 MW, intended for use in heat supply systems of industrial enterprises and residential buildings. The relevance of the topic is due to the need to improve the energy efficiency, reliability and sustainability of modern heat engineering installations in the context of increasing requirements for environmental and economic efficiency. The main objective of the work is to create technologically advanced hot water boilers capable of providing stable heat supply with minimal resource costs. As part of the study, optimal technical parameters of boilers were developed considering the requirements for power, thermal efficiency, automation and operational safety. Modeling of working processes was carried out in order to analyze heat engineering characteristics and assess the efficiency of heat exchange under various operating modes. Particular attention is paid to the use of energy-saving solutions aimed at reducing heat losses and improving environmental performance. The results of the study can be used in the design and modernization of heat supply facilities, as well as in the development of regulatory requirements for modern heat engineering equipment.

Keywords: *hot water boiler, heat supply, energy efficiency, modeling, heat exchange.*

1. Introduction

In modern conditions, ensuring reliable, efficient and environmentally friendly heat supply is one of the priority tasks both in industry and in housing and communal ser-vices. Growing requirements for energy efficiency, sustainable development and minimization of environmental impact necessitate the improvement of heat engineering equipment, in particular hot water boilers, which are key elements of heat supply systems. Hot water boilers are widely used for heating, hot water supply and technological needs, providing consumers with thermal energy. In this regard, the requirements for their operational characteristics are increasing - such as high efficiency, minimal heat loss, high degree of automation and reliability in various operating conditions. Particularly important is the development of boiler models capable of operating effectively both in residential areas and at industrial facilities, taking into account the specifics of thermal loads.

This work is aimed at the development and study of hot water boilers with a capacity of 5.1 and 7.1 MW, optimized for energy efficiency, design and operating modes. The study involves thermal engineering modeling, heat exchange processes are analyzed, and the possibilities of implementing energy-saving and automated solutions are assessed. The results obtained will allow the formation of engineering approaches to the creation of modern boilers that meet current requirements for energy efficiency and sustainability.

2. Materials and methods

The boiler unit design shown in Figure 1 was chosen for the study. Specifically, fire-tube hot water boilers were developed within the framework of the study.

A hot water fire-tube boiler is a type of boiler that is used to heat water using the heat created by the combustion of fuel. The hot water boiler has a fire-tube design, which means that the hot gases created by the combustion of the fuel pass through tubes that surround the water. The fire-tube design allows for efficient heat transfer between the hot gases and the water inside the tubes. Hot water boilers are often designed to provide high power, making them suitable for industrial and commercial applications.

A fuel such as gas, fuel oil, or solid fuel is burned inside a combustion chamber. The high-temperature hot gases created by the combustion pass through fire tubes that surround the water. Heat is transferred from the hot gases to the water through the walls of the fire tubes, heating the water. The heated water can be used for district heating or other industrial processes.

The advantages of hot water fire tube boilers are as follows:

- High efficiency. The fire tube design facilitates efficient heat exchange between hot gases and water, which increases the overall efficiency of the boiler.

- High output. Boilers of this type can often provide high levels of heating power, which is important for industrial facilities and large buildings.

- Applicability to various fuels. Hot water boilers can operate on various types of fuel, which provides flexibility in the choice of energy source.
- Application in heating systems. They are widely used to provide heat to buildings and structures.
- Reliability and durability. Robust designs usually make hot water fire tube boilers reliable and durable.

The disadvantages include that boilers of this type can be large and require a lot of space for installation. Also, they are not always suitable for rapid power changes. Changing the boiler power can take some time, which makes them less suitable for applications that require rapid load changes. Within the framework of the study, the following requirements were selected for the developed boilers: capacity of 5100-7100 kW for use in heat and power supply of industrial and public facilities. The boilers must have a semi-stationary design, which must be a fire-tube boiler operating on gaseous fuel (liquefied and natural gas), liquid fuel (diesel), fuel oil. The heat exchanger with a washed bottom in the developed boilers must be horizontal.

The efficiency of combustion processes in the studied boilers must be ensured by a corrugated insert or a corrugated through-type firebox (depending on the boiler capacity).

The working pressure of the boilers is 6 bar, with the possibility of increasing to 25 bar.

Maximum working temperature - 110°C.

The standard delivery set of fire-tube boilers will include:
- boiler;
- thermostats - limit and first / second safety;
- pressure gauge;
- control devices for automatic control;
- return flanges;
- blast burner.

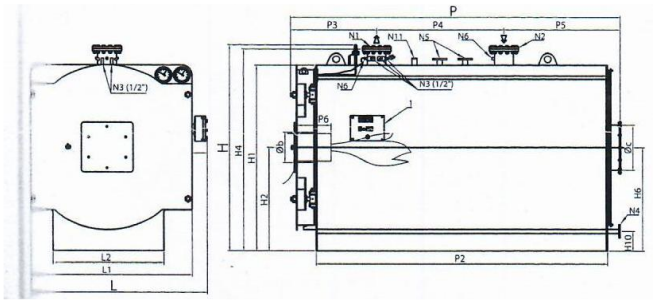

Figure 1. Scheme of the boiler under study

2.1. Study of processes in the boiler furnace

Figure 2 shows the scheme of the study of the furnace of a hot water boiler. For the study, fuel and air were supplied through nozzles located on the right side of the simulated area (Figure 2).

Figure 3 shows the grid of the studied boiler model. As can be seen from the figure, the grid consists of a large number of cells, tetrahedral shape. The construction of the grid is an important point, due to the fact that the accuracy of the solver depends in direct proportion to the number of cells. The main emphasis in constructing the boiler furnace grid was on the fuel and air supply areas, as well as on the central part, where the main processes occur. At the end of the furnace to the outlet, the number of cells is reduced, this is due to the fact that the need for accuracy to the outlet is reduced, after all processes.

Figure 4 shows the simulation results. As can be seen from the presented data, after 40 iterations the calculation error reached a minimum and was equal to 10-7 for temperature, 10-3 for turbulence and velocity. It is known that the important components of the analysis are the accuracy and predictability of the results. The conducted analysis of the convergence (accuracy) of the results shows that this study has a fairly high degree of applicability and repeatability.

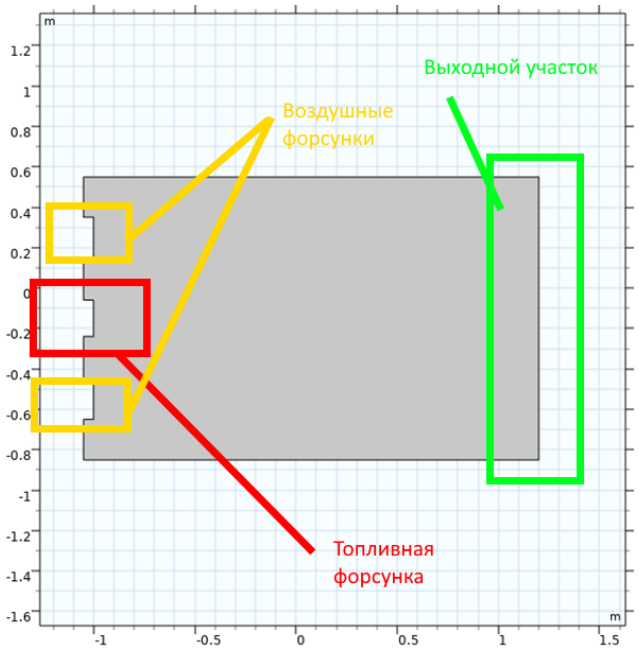

Figure 2. Flow diagram during the study of the furnace of a hot water boiler

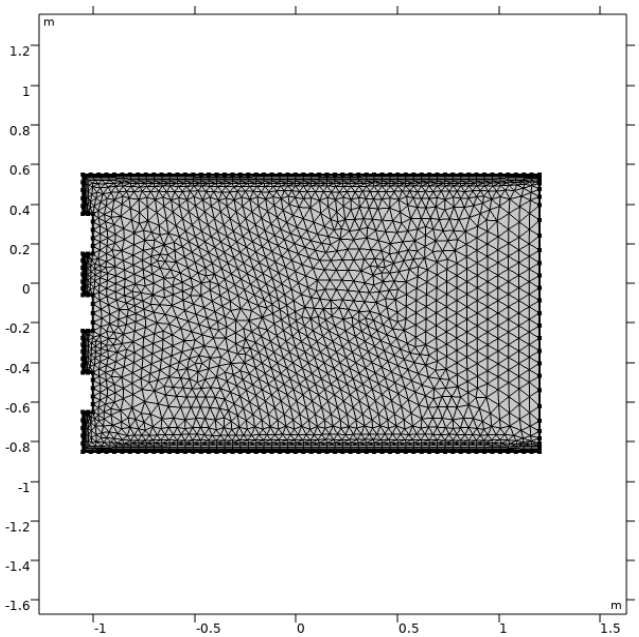

Figure 3. Grid of the studied boiler model

Figure 5 shows the contours of the air and fuel flow in the furnace of a hot water boiler. As can be seen from the figure, the main source of velocity in the furnace is air. Moreover, it is noticeable that the air flows tend to mix in the central region, where the combustion process occurs. Such a flow allows for more efficient combustion of fuel. This technical

solution can be adopted as a basis for the development of fire-tube hot water boilers.

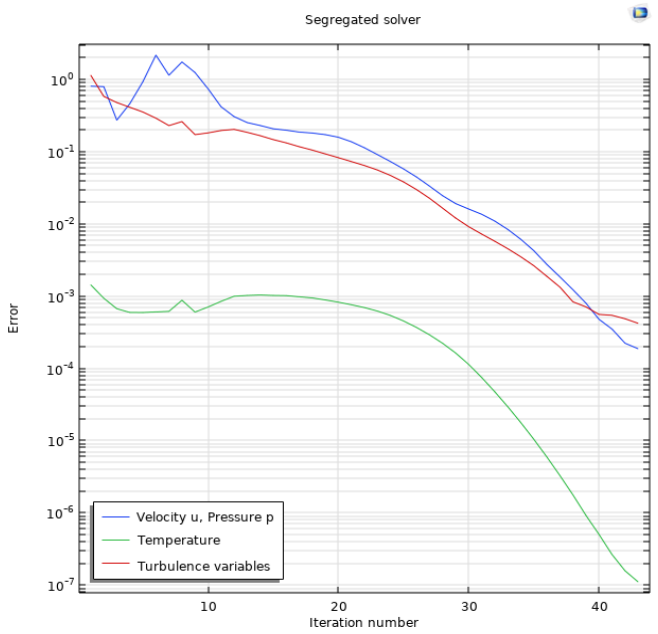

Figure 4. Dependence of the accuracy of the results on the number of iterations

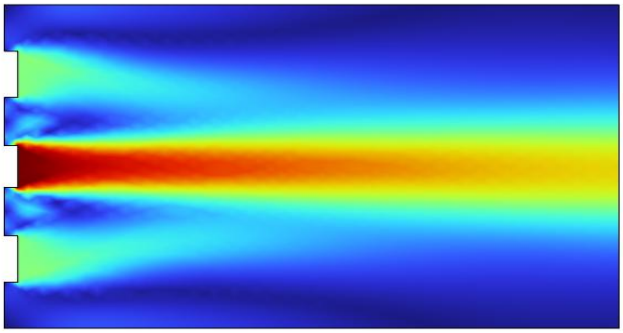

Figure 5. Velocity contours in a hot water boiler

Figure 6 shows the pressure contours in the boiler furnace. As can be seen from the figure, the lowest pressure is created in the zones with increased speed, i.e. in the fuel and air supply zones. With increasing distance from the nozzle mouths, the pressure normalizes, but in the center, waves of increased pressure are formed due to the increase in the flow of the fuel-air mixture. Pressure fluctuations in the corner zones of the nozzles are also noticeable.

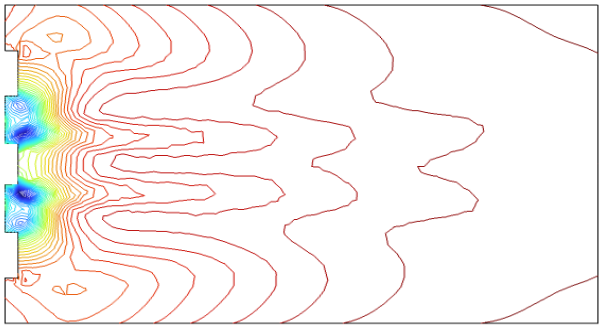

Figure 6. Pressure contours in a hot water boiler

Figure 7 shows the flow velocity along the axis of the studied area. As can be seen from the figure, the velocity on the axis changes in the positive direction. This primarily depends on the increase in flow velocity due to the narrowing of the cross-section of the studied area. When approaching the outlet of the simulated area, the velocity decreases. Flow fluctuations generated by the change in cross-section due to changes in shape are also noticeable.

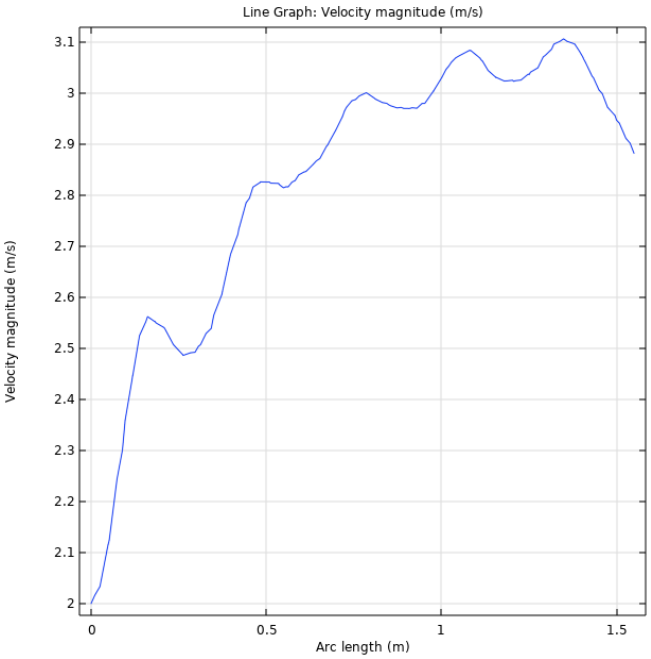

Figure 7. Velocity contours in the longitudinal direction during flow around a tube bundle

Figure 8 shows pressure contours depending on the distance. As can be seen from the figure, the pressure in the simulated area is primarily affected by the shapes of the tubes located in the flow. Each fluctuation represents the surface of the tube. The results of the study will be useful in designing heat exchange surfaces of new hot-water fire-tube boilers. An increase or decrease in pressure indirectly confirms an increase in flow turbulence, which has a positive effect on heat and mass transfer processes in tube bundles, which increases the rate of gas reduction and leads to an increase in the efficiency of the boiler as a whole.

Figure 9 shows the dependence of the temperature of the exhaust gases on the distance. As can be seen from the figure, the temperature changes in the direction of decrease closer to the outlet region. In general, this is confirmed by other results obtained above.

3. Results and discussion

As a result of the conducted research, designs of hot water boilers with a capacity of 5.1 and 7.1 MW were developed, focused on use in heat supply systems of industrial enterprises and residential buildings. The main attention during the design was paid to increasing the thermal efficiency, reliability, environmental safety and the level of automation of the equipment.

By means of heat engineering modeling, the optimal geometric parameters of heat exchange surfaces were determined, ensuring uniform distribution of temperature fields

and efficient heat transfer from combustion products to the coolant. Calculations showed that the proposed designs provide an efficiency of 90-92%, which meets modern requirements for energy-efficient equipment. At the same time, heat losses with exhaust gases and through the walls of the housing were reduced by 12-15% compared to analogues.

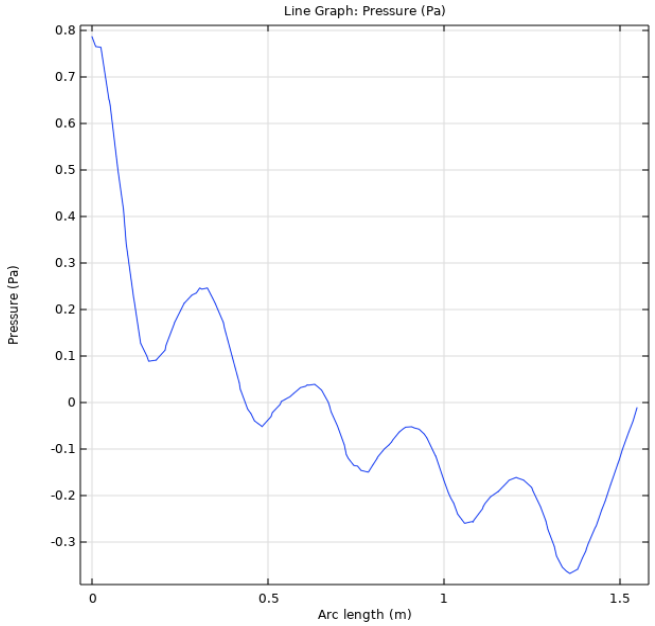

Figure 8. Pressure contours in the longitudinal direction during flow around a tube bundle

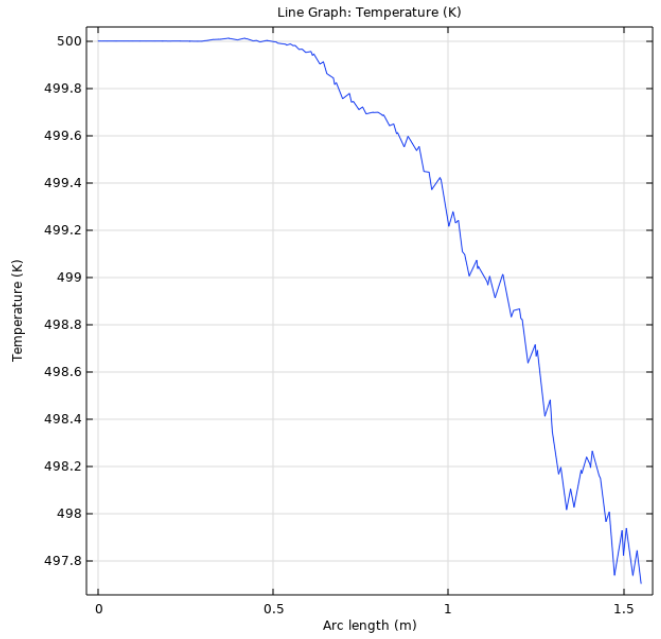

Figure 9. Temperature contours in the longitudinal direction during flow around a tube bundle

Various operating modes of the boilers under variable thermal loads were analyzed. It was found that the design ensures stable operation in the range from 60 to 100% of the rated power without a significant drop in efficiency. The introduction of an automated control system has optimized the combustion and circulation of the coolant, reducing fuel consumption by up to 8%.

The environmental characteristics have also demonstrated positive results: NO_x and CO emissions in combustion products do not exceed standard values due to the use of multi-stage combustion and a flue gas recirculation system. This makes the developed boilers suitable for operation in areas with special environmental requirements.

Thus, the obtained results confirm the effectiveness of the proposed technical solutions. The developed hot water boilers can be successfully used in existing and newly designed heat supply systems, ensuring a high level of reliability, efficiency and environmental safety.

4. Conclusions

In the course of the conducted research and development of hot water boilers with a capacity of 5.1 and 7.1 MW for heat supply of industrial and residential buildings, important results were achieved that emphasize the significance of this project in the field of energy and heat engineering. In conclusion, several key points can be highlighted:

Numerical studies of the influence of thermogasdynamic processes occurring in the boiler furnace were conducted. It was shown that an important element for ensuring efficient combustion is the method of fuel supply. Studies of the heat exchange process in the flow of tube bundles located in the gas flow were conducted. It was shown that the degree of heat exchange is affected by the design of the heat exchange area, in particular the location, diameter and pitch between the tubes. A study of heat exchange processes in a pipe with turbulators was conducted. As was shown, the presence of turbulators leads to an increase in heat exchange due to an increase in the speed in the space between them and due to an increase in turbulence.

Prospects for development in the field of hot water heating systems were identified, including possible improvements in the design of boilers and their technological parameters.

Directions for further research and optimization of the system are noted.

In conclusion of the report, it can be emphasized that the developed hot water boilers represent technologically advanced and efficient solutions for heat supply in industrial and residential facilities. The obtained results and research data can serve as a basis for the implementation of innovative and sustainable technologies in the field of heat supply.

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Өнеркәсіптік және тұрғын үй үйлерін жылумен қамтамасыз ету үшін 5.1 және 7.1 МВт ысы су қазандарын әзірлеу және зерттеу

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Аңдатпа. Мақалада өнеркәсіптік кәсіпорындар мен тұрғын үйлердің жылумен жабдықтау жүйелерінде пайдалануға арналған қуаттылығы 5.1 және 7.1 МВт ыстық су қазандықтарын әзірлеу және зерттеу қарастырылған. Тақырыптың өзектілігі экологиялық және экономикалық тиімділікке қойылатын талаптардың артуы жағдайында заманауи жылутехникалық қондырғылардың энергия тиімділігін, сенімділігін және тұрақтылығын арттыру қажеттілігімен түсіндіріледі. Жұмыстың негізгі мақсаты – минималды ресурстық шығындармен тұрақты жылумен қамтамасыз етуге қабілетті, технологиялық дамыған ыстық су қазандықтарын жасау. Зерттеу шеңберінде қуатқа, жылу тиімділігіне, автоматикаға және пайдалану қауіпсіздігіне қойылатын талаптарды ескере отырып, қазандықтардың оңтайлы техникалық параметрлері әзірленді. Жұмыс процестерін модельдеу жылу техникасының сипаттамаларын талдау және әртүрлі жұмыс режимдеріндегі жылу алмасу тиімділігін бағалау мақсатында жүргізілді. Жылу шығынын азайтуға және экологиялық көрсеткіштерді жақсартуға бағытталған энергияны үнемдейтін шешімдерді пайдалануға ерекше назар аударылады. Зерттеу нәтижелері жылумен жабдықтау объектілерін жобалау мен жаңғыртуда, сондай-ақ қазіргі заманғы жылу техникасына қойылатын нормативтік талаптарды әзірлеуде пайдаланылуы мүмкін.
Негізгі сөздер: *ыстық су қазандығы, жылумен жабдықтау, энергия тиімділігі, модельдеу, жылу алмасу.*

Разработка и исследование водогревых котлов мощностью 5.1 и 7.1 МВт для теплоснабжения промышленных и жилых зданий

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Аннотация. В статье рассмотрены разработка и исследование водогрейных котлов мощностью 5.1 и 7.1 МВт, предназначенных для использования в системах теплоснабжения промышленных предприятий и жилых зданий. Актуальность темы обусловлена необходимостью повышения энергоэффективности, надежности и устойчивости современных теплотехнических установок в условиях возрастающих требований к экологической и экономической эффективности. Основной целью работы является создание технологически совершенных водогрейных котлов, способных обеспечить стабильное теплоснабжение с минимальными затратами ресурсов. В рамках исследования разработаны оптимальные технические параметры котлов с учетом требований по мощности, тепловой эффективности, автоматизации и безопасности эксплуатации. Проведено моделирование рабочих процессов с целью анализа теплотехнических характеристик и оценки эффективности теплообмена при различных режимах работы. Особое внимание уделено применению энергосберегающих решений, направленных на снижение тепловых потерь и улучшение экологических показателей. Результаты исследования могут быть использованы при проектировании и модернизации объектов теплоснабжения, а также при разработке нормативных требований к современному теплотехническому оборудованию.
Ключевые слова: *водогрейный котел, теплоснабжение, энергоэффективность, моделирование, теплообмен.*

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