Construction and variants of the modernization of the condensing hot water boiler

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Abstract. In this article are considered the main problems facing mankind, which are related with production, transformation and use of energy and fuel resources. For purposes of fuel saving and improve environmental safety of the heat supply systems of various consumers the use of decentralized heat supply systems with the installation of a condensing hot water boilers in heat source, is proposed. The substantiation of application of these heat supply systems is made. There are considered appointment, relevance of use, design features and principle of action of the fuel-saving condensing hot water boiler, developed by the employees of the Belgorod State Technological University named after V.G. Shukhov, proposed for installation as a heat generator in the heat sources of autonomous heating systems. There are considered the variants of construction of various units of the proposed boiler and the conditions of use of a particular design variant. Also, the advantages and disadvantages of various versions of the boiler design and its main components were critically evaluated, the comparison was made and the advantages of these or other design variants in front of others for different conditions were indicated.
Keywords.
Decentralized heat supply systems, condensing hot water boiler, radiation part, contact-recuperative part.

1. Introduction

Nowadays, among the main problems facing mankind, the following can be singled out: the gradual depletion of hydrocarbon fuel in the bowels of the planet (this is especially true for those deposits from which fuel is relatively inexpensive) [1], environmental pollution (thermal, toxic compounds, greenhouse gases) and climate change associated with the latter [2–4]. In this regard, in the energy and industry there are tendencies to reduce the consumption of traditional hydrocarbon fuels for energy generation and production work due to the use of unconventional and alternative sources and methods of transformation energy [5–7], secondary energy resources [8, 9], as well as improving energy efficiency and environmental friendliness of units with hydrocarbon fuels and systems in which such units are used [10–13].

The most important life support systems are heat supply systems. In Russian Federation, the production of heat energy for these systems consumes about 1/3 of all used fuel and energy resources [14]. The purpose of this work is fuel saving and improve environmental safety of heat supply systems.

To achieve this purpose, the following tasks are set:

- the justification of higher efficiency of decentralized heat supply systems in comparison with centralized systems;
- the justification of advantages of installation of condensing hot-water boilers and water heaters in a heat source of the decentralized heat supply system in comparison with boilers and water heaters, in which there is no condensation of the water vapor, which is a component of organic fuel's combustion products;
- comprehensive consideration of the design of the condensing hot water boiler, which is proposed for installation in heat sources of decentralized heat supply systems;
- consideration and comparison of various design options of the proposed condensing hot water boiler and its main elements, their advantages and disadvantages, in relation to the different working conditions.

2. Materials and Methods

As one of the ways to reduce the consumption of hydrocarbon fuels and improve environmental safety in such an important area of human activity as heat supply for various consumers, the use of decentralized heat supply systems with the installation of a fuel-saving condensing water boiler, designed by employees of Belgorod State Technological University named after V.G. Shukhov can be proposed [15].

High energy and environmental performance of such systems are due to the following features. In decentralized systems, there are no large-scale heat networks, in which very significant heat losses occur, reaching 20% of the output, resulting both from the losses to the environment, through the walls of heat pipes and thermal insulation, and losses with coolant leakage. In addition, load control in decentralized heating systems is much simpler than regulation in centralized systems. Thus, the heat supply by the heat source of decentralized systems most closely corresponds to its consumption by subscribers [16], which also reduces heat losses by an amount reaching 15%. In addition, heat networks require maintenance and repair, which increases operating costs [17, 18].

It should be noted, that this article discusses the advantages of decentralized heat supply systems over centralized systems, the heat source in which is a large or medium-capacity boiler plant [19]. The centralized systems, in which heat supply of consumers is carried out from the thermal power plants, working on a heating cycle, when the generated thermal energy is an additional product in the production of electrical energy, is not considered in this article.

The installation of a decentralized heat supply system for condensing-type heat generators in a heat source also contributes to significant fuel savings [20, 21]. As is known, the products of combustion of hydrocarbon fuels contain a significant amount of water vapor. For example, the share of water vapor in the composition of natural gas combustion products is 10...12%. In condensing boilers, the combustion products are cooled to temperatures that are below the dew point for gases of this composition. As a result, the water vapor contained in the flue gases is partially condensed, and their heat of condensation can be useful. Thus, in condensation-type heat generators, heat losses with flue gases can be significantly reduced (for example, when natural gas is burned, by up to 15%) by lowering the temperature of gases and due to the beneficial use of the latent heat of condensation of water vapor contained in them [22].

Improving the environmental performance of decentralized heating systems with a condensing hot water boiler, developed by employees of Belgorod State Technological University named after V.G. Shukhov is achieved thanks to the following merits. First, in such systems, the specific consumption of combustible fuel is two times lower than in centralized systems, because of their higher energy efficiency. Secondly, the condensation part of the specified heat generator is an effective particulate trap [23]. Thirdly, in the case of organizing the injection of water into the furnace of such a boiler, the formation of thermal nitrogen oxides is significantly reduced, and the heat losses with flue gases do not increase [24].

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3. Results
The design of the condensing hot water boiler under consideration can be adapted to the specific conditions of its operation, the requirements for the layout of equipment in the boiler room, as well as the characteristics and parameters of working environments.

The main units of the condensing hot water boiler are the radiation and contact-recuperative parts, as well as the adiabatic part connecting them, which includes a condensate tank [25]. In the radiation section, which is carried out mainly in the same way as the traditional designs of modern gas-tube boilers, fuel is burned and the water for heating is heated. In the adiabatic part, the combustion products are moistened, passing through the condensate plumes, and adiabatically cooled. In the contact-recuperative part, there is a deep cooling of the combustion products (to a temperature of about 35° C), the condensation of most of the water vapor contained in them, as well as the heating of water supplied to meet the needs of hot water.

4. Discussion
For technological reasons the contact-recuperative part is always positioned vertically, while the radiation part can be placed either horizontally or vertically (figure 1).

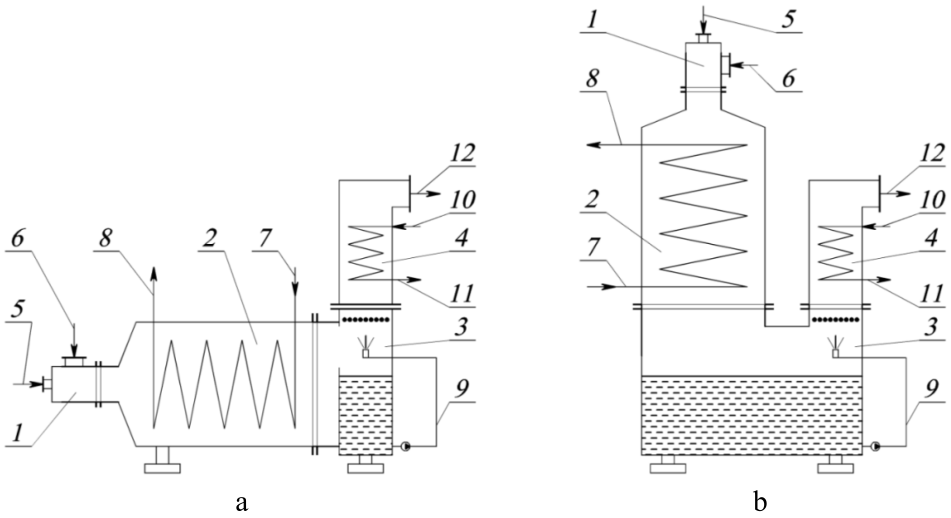

Figure 1. Options for the location of the radiation part: a – horizontal; b – vertical; 1 – burner; 2 – radiation part; 3 – adiabatic part; 4 – contact-recuperative part; 5 – natural gas; 6 – air 7 – back water heating system; 8 – direct water heating system; 9 – condensate; 10 – cold water; 11 – heated water to hot water needs; 12 – flue gases

As an advantage of the horizontal arrangement of the radiation part can highlight the possibility of using such structures in any industrial gas burners. In the embodiment of the vertical furnace with a burner cannot be used as it does not allow the working position "burner on the torch" [26]. A significant drawback of the horizontal layout of the radiation part is the uneven heating of the flame tube over its cross section [27], since there is an elevation of the torch as it is removed from the mouth of the burner. The result of this phenomenon will be an uneven temperature lengthening of the forming flame tube and an increase in temperature stresses in it, which can lead to serious accidents. Another advantage of boilers with a vertical layout of the radiation part is their smaller dimensions in the plan compared to boilers equipped with a horizontal firebox. At the same time, the height of the room must ensure compliance with the requirements of regulatory documents for boiler rooms, and, in addition, ensure the possibility of mounting and dismounting the burner and the radiation unit.

For technological reasons, it is necessary to provide a three-way scheme for the movement of combustion products in the radiation part of the boiler. There are two most obvious ways to organize such a gas flow pattern (figure 2).

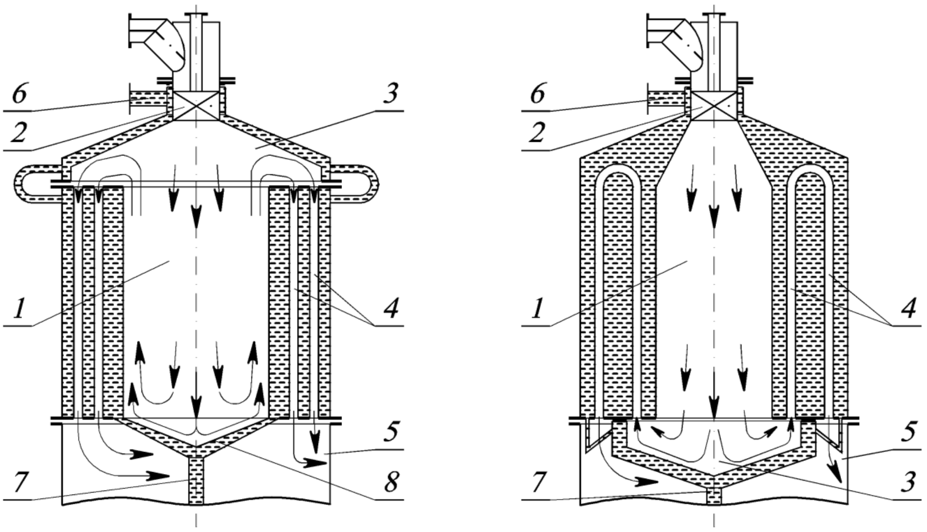

Figure 2. Diagrams of the radiation part: a – with a reversive fire chamber; b – with U-shaped smoke tubes; 1 – flame tube; 2 – burner; 3 – rotary chamber; 4 – smoke tubes; 5 – adiabatic part; 6 – branch pipe of direct heating water outlet; 7 – pipe for supplying the return water to the heating system; 8 – bottom of the flame tube

In the first method, the flame tube is a reversible furnace (figure 2, a), its part opposite to the burner is plugged with the help of a water-cooled bottom. Combustion products moving in the central part of the firebox, having reached the bottom of the flame tube, turn 180 ° and move along the periphery of the firebox towards the burner. Coming out of the flame tube, the flue gases in the rotary chamber are turned 180 ° and sent to the smoke tubes, which pass into the adiabatic part of the boiler. In the second method, the combustion products pass the flame tube in one direction (figure 2, b). A rotary chamber is located at the exit of the flame tube. In this rotary chamber, the flue gases are rotated 180 ° and then flow into the smoke tubes. Smoke tubes are U-shaped, so the products of combustion in them make two moves.

A significant drawback of the design of the radiation part with reversing furnace is the need to use compensating devices in order to avoid the destruction of elements of this part due to stresses arising due to the uneven thermal lengthening of the flame tube and fire tubes, as well as the body. One option to compensate for temperature lengthening in this design is the use of a corrugated flame tube. In the design of the radiation section with U-shaped pipes, the fire tubes can freely lengthen in the longitudinal direction, and the probability of occurrence of metal damage or welded joints caused by thermal stresses is significantly reduced [28]. However, in this design of the radiation part, access to the welds in the attachment points of the flame tube and U-shaped tubes to the tube plate is very difficult.

In order to provide access to the specified welds without destroying the details of the radiating part of the boiler, it can be offered as shown in figure 3 variant of the design of the considered node, when the rotary chamber is made in the form of a water-cooled truncated cone, and the diameter of the smaller base of the cone provides access to the welds at the attachment points of the flame tube and fire tubes to the tube plate [29].

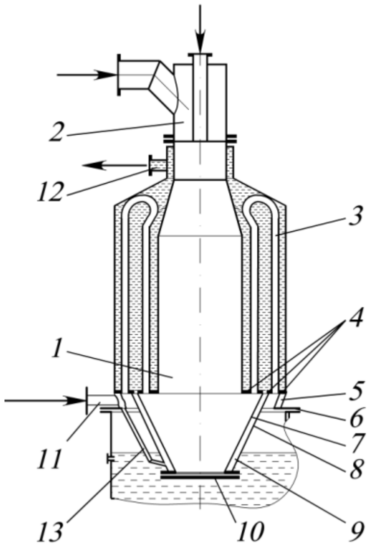

Figure 3. Diagram of the radiation part with increased maintainability: 1 – flame tube; 2 – burner; 3 – smoke tubes; 4 – tube sheet; 5 – ring water jacket; 6 – mounting flange of the radiation part; 7 – inner bottom of the flame tube; 8 – the outer bottom of the flame tube; 9 – water jacket; 10 – a cover; 11 – pipe for supplying return water to the heating system; 12 – branch pipe of direct heating water outlet

After leaving the radiation part, the combustion products of the fuel pass through the adiabatic part, the main elements of which are the condensate tank, nozzles and the reference-distribution grid. The nozzles spray condensate from the tank into the flue gas stream, the temperature of which exceeds 250 °C. In this case, the condensate partially evaporates, and the gases are respectively moistened and adiabatically cooled to a temperature approaching the temperature of the wet thermometer. With the passage of the resulting two-phase gas-liquid flow through the reference distribution grid, phase inversion occurs. Thus, above the grate - in the contact-recuperative part of the boiler - a foamy two-phase flow is formed, which is characterized by high intensity of heat and mass transfer between the phases. In the contact-recuperative part, a tube bundle is installed, into which cold water of drinking quality is supplied. Water, heated in a tube bundle, to temperatures reaching 50...60 °C is supplied to the needs of hot water supply. The gas-liquid stream, passing through the inter-tubular space of the tube bundle, is cooled. When this occurs, the condensation of the majority (up to 80%) of water vapor contained in the gas. Above the tube bundle, the velocity of the gas-liquid flow drops sharply and gravitational separation of condensate droplets from the gas flow occurs. Condensate is discharged to the walls of the casing and discharged into the condensate tank. For a better separation of gas and liquid, an inertial droplet separator should be installed in front of the flue gas pipe.

The heat exchange surface of the tube bundle is formed by straight tubes. The use of round tubes in the contact-recuperative part of the condensing hot water boiler under consideration is not recommended, since in this case the increase in hydraulic resistance is much higher than the increase in heat transfer efficiency. In addition, in this case, the dimensions of the contact-recuperative part and the whole boiler increase. To increase the intensity of heat transfer, and both the compactness of the contact-recuperative part, the use of staggered flat-oval tubes arranged in a checkerboard pattern, which can be made by squeezing standard round tubes, seems most appropriate. It should be noted, that the pipes must be oriented with a larger axis along the flow in the inter-tubular space of the contact-recuperative part.

In this case, the ends of the pipes can be additionally crimped in the horizontal direction (figure 4). This additional compression of the ends of the pipes allows you to meet the technological requirements for fastening pipes in tube plates.

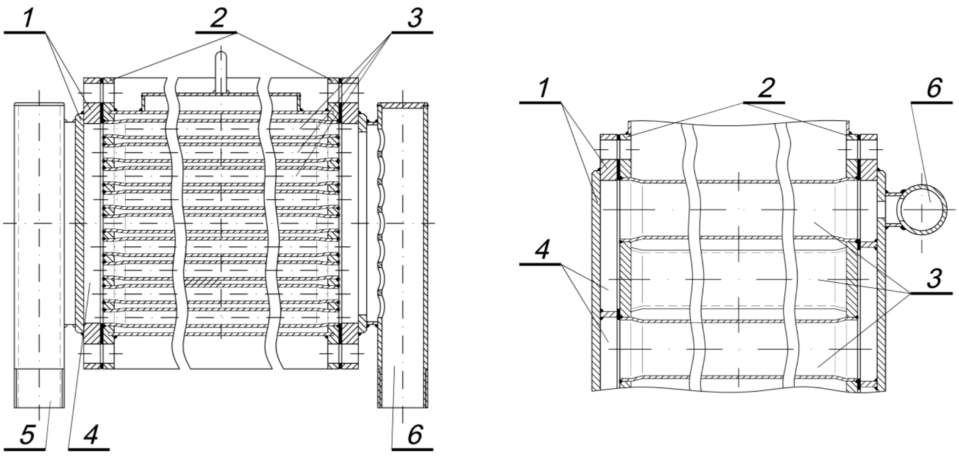

Figure 4. Pipe bundle of the contact-recuperative part: a – horizontal section; b – vertical section; 1 – tube cover; 2 – tube sheet; 3 – flat oval tube; 4 – bypass water chamber; 5 – outlet pipe for heated water; 6 – cold water inlet

The use of flat-oval tubes with an additional crimping of their ends in the tube bundle of the contact-recuperative part of the hot water boiler allows reducing horizontal gaps between the tubes. This, respectively, reduces the flow area in the inter-tubular space of the heat exchanger. In this case, the speed of the two-phase gas-liquid flow in the inter-tubular space of the contact-recuperative part of the boiler increases, and the intensity of heat transfer from the condensate to the outer surface of the heat exchange tubes increases too. In addition, the use of flat-oval tubes with additional crimping of their ends in the tubular heat exchanger of the contact-recuperative part of the condensing hot water boiler allows reducing the relative horizontal pitch of the tubes. This, in turn, allows reducing the width of the casing of the contact-recuperative part of the boiler, to reduce its mass and material consumption while maintaining the required heat exchange surface [30].

5. Conclusion

The use of decentralized systems with the installation of condensing-type hot-water boilers in their heat source allows a 2-fold reduction in the unit cost of fuel for the needs of heat supply to consumers. As such heat generators can be very effectively used condensing boiler, developed by employees of Belgorod State Technological University named after V.G. Shukhov.

When using this hot water boiler in addition to increasing the energy efficiency of the heat supply system, its negative environmental impact can be significantly reduced. This can be achieved both by reducing the specific fuel consumption for the production of a unit of thermal energy, and due to the fact that the proposed apparatus can be an effective wet particulate trap, and in addition, in the case of organizing the injection of water into the furnace chamber of the heat generator, the formation of thermal nitrogen oxides can be reduced. Since the hot water boiler is condensing, the injection of water into the combustion zone will not have a negative impact on its technical and economic indicators.

The design of this boiler allows you to adapt it to different conditions of use. It is also distinctive features of this heat generator are its compact size and low metal consumption.

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