Development of low power water boilers operating on conventional and alternative fuels

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Abstract

This article substantiates the need for widespread use of non-conventional energy resources for heat supply. Designs of low-power boilers that can burn natural gas, biogas and wood are presented. The analysis of information on the determination of the dew point temperature of resins during wood combustion has been carried out. A mathematical model has been developed for a low-power hot-water boiler, which allows one to take into account the intensification of heat transfer in the fire-tube bundle, the mode of condensation of resins and water vapor. Numerical studies have been carried out and the main indicators of the boiler operation on different fuels have been determined.

Keywords: renewable energy sources; small power boiler; natural gas; biogas; wood; dew point; intensification

1. Introduction

Today Ukraine is provided with its own fuel only by 50 % [1], and the prices for imported fuel are constantly growing. An increase in energy consumption in the face of a decrease in fuel reserves can lead to an energy crisis. For the period until 2020, a significant expansion of the use of renewable energy sources is envisaged, among which the most significant contribution should be provided by the use of biomass as a fuel. The list of these sources is inexhaustible: firewood and wood waste, straw and stalks of agricultural crops, solid domestic waste, biogas. Biogas, obtained in the process of anaerobic digestion of pus and other suitable organic waste, is not only a renewable energy source, but also an environmentally friendly method of processing and utilizing this waste and converting it into organic fertilizer. During the combustion of biomass, more carbon dioxide is not produced than was absorbed by the plant during life, that is, the use of biomass for energy production does not increase the concentration of carbon dioxide in the atmosphere. The amount of harmful emissions into the environment. In our opinion, one of the most promising ways of using biogas and wood is combustion in hot water boilers in order to obtain thermal energy. As shown in [2-4], solid fuel heat-generating equipment has become widespread in small-scale heat power engineering, especially for autonomous heating. With the exception of work [5], we have not identified information on the study of the performance of low-power boilers on biogas. There is also no information in the domestic literature on the serial production of biogas boilers. Therefore, the purpose of this work is to develop low-power hot water boilers that can operate on traditional and alternative fuels, which will achieve high reliability, energy and environmental efficiency of heat production.

2. Design Development and Numerical Experiments

Based on the systematization of the literature on solid fuel boilers [2], standards [6], own developments [7] and works of A.N.Dovgal, two designs of a hot water boiler on combined energy

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carriers are proposed (see Figure 1). The main advantage of such boilers is that they can operate on different types of fuel, and in the absence of one fuel, the boiler will operate on another.

Boiler designs were accepted for consideration, allowing to burn wood, natural gas and biogas.

The convective parts of the boilers are equipped with heat exchange intensifiers in the form of a twisted plate. Wood combustion is carried out in a two-stage way with the previous gasification. First, combustible wood gas is formed in the loading chamber with an increase in temperature and a deficiency of oxygen, at the next stage, in the afterburner, this gas burns out with an excess of air.

During the calculations, we used our proposed mathematical model, mainly based on the dependencies of the Normative Method of Thermal Calculation of Boiler Units [8], with additions regarding the calculation of intensified heat transfer [9] and some simplifications. Its feature is to take into account the following design and operating characteristics of low-power boilers:

- the presence of ceramic inserts in the boiler furnace shown in Figure 1a is taken into account by the pollution factor adopted in [8] for the case of walls covered with fireclay bricks $\xi = 0.1$;
- laminar flow of flue gases;
- to calculate the intensity of heat transfer in a fire-tube bundle with intensifiers in the form of twisted plates, the dependences given in [9] were used.

Numerical experiments were carried out for both boilers with the following initial data:

- thermal power of the boiler is 32 kW;
- boiler water temperature 80/60 °C;
- elemental composition of wood, %:

$C^w = 30.6$
$H^w = 3.66$
$N^w = 0.36$
$O^w = 25.38$
$W^w = 40$

- elemental composition of natural gas, %:

$CH_4^w = 98.5$
$C_2H_6^w = 0.2$
$C_3H_8^w = 0.1$
$N_2^w = 1$
$CO_2^w = 0.2$

- elemental composition of biogas, %:

$CH_4^w = 62$
$H_2S^w = 0.8$
$N_2^w = 0.2$
$CO_2^w = 37$

- excess air ratio during:
- wood combustion $\alpha = 1.5$;
- biogas and natural gas – $\alpha = 1.4$;
- diameter of pipes in a bundle for a boiler in Figure 1a – 56/50 mm, and in Figure 1b – 48/42 mm;

Twisted plates 1.5 mm thick with a relative bending step $s/d = 4.2$ are installed as an intensifier of heat transfer in the flame tube bundle.

The design dimensions of the fire-tube bundle were determined from the results of the calculation of a wood-fired boiler, since the temperature of the exhaust gases on this fuel is limited by the possibility of condensation of tar from the flue gases. We are not aware of the Ukrainian standards for the concentration of harmful emissions for low-power gas-generating boilers. In addition, no information has been found in the literature on the permissible concentration of resins in the flue gases of such boilers. Observations of the operation of a gas-generating boiler have shown that when wood is burned, a certain amount of tar can be deposited in the boiler (in the chimney, in the heat exchanger). It is known [10] that in installations for gasification of solid fuel, depending on the design, the concentration of resins in the gas can be different: 10 ÷ 100 g/m^3 – for the direct process, for the reverse process – 50 ÷ 500 mg/m^3 (gas movement down through a roasted dense layer of coke residue). According to [11], during gasification (downward movement of gases) of wood chips ($\rho = 166$ kg/m^3, $W^w = 11$ %), a gas with a resin concentration of about 6 g/m3 is released, during gasification of firewood ($\rho = 256$ kg/m^3, $W^w = 6$ %) – 3.24 g/m^3, heads of cabbage and corn stalks ($W^w = 11$ %) – 7.24 g/m^3.The site of the Dutch company ECN [12, 13] contains a resin classification system.

It is based on the solubility of the resin in water and its condensation temperature. According to foreign studies [13], resins are divided into five

classes according to their physical properties. Depending on the class of resin and its concentration in the combustion products, the dew point temperature of the resin will vary. Focusing on the possible concentrations of resin in the combustion products [10, 11] and on the description of resins [13], we have identified the possible ranges of the dew point temperature of the resin in the boiler. In the range from 1000 to 10000 mg/nm^3, the temperature of the dew point of the resin will be 100 ÷ 135 °C. This condensation occurs in the volume of flue gases. The designs of gasifiers in the boilers shown in Figure 1 have a descending flow of generator gas, therefore, it can be assumed that the dew point temperature of the resins will not exceed the above range. Thus, the temperature of flue gases during wood combustion for both boiler designs in Figure 1 is assumed equal 160 °C.

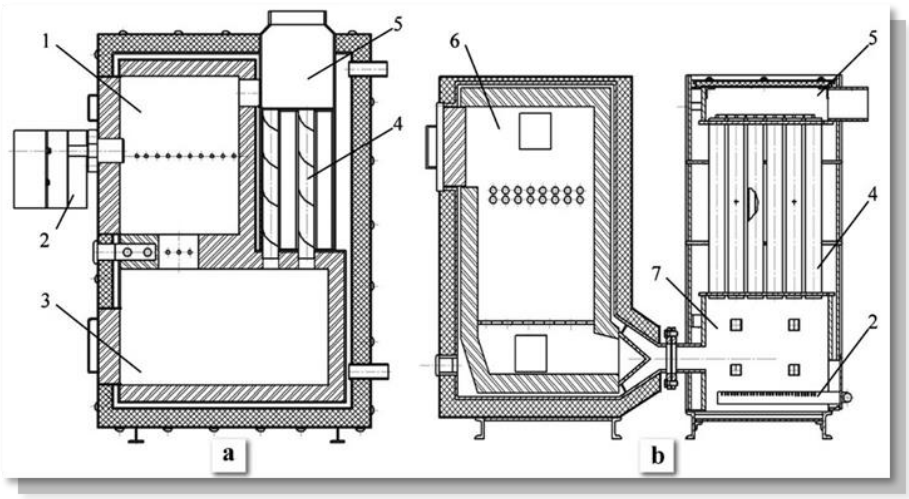

Figure 1. Designs of hot water boilers on traditional and alternative fuels: 1 – loading chamber; 2 – gas fuel burner; 3 – afterburner chamber; 4 – fire tube bundle with intensifiers; 5 – chimney; 6 – gas generator; 7 – firebox

The calculation results are shown in Figure 2. The adiabatic temperature for combustion of wood under the conditions of the above coefficients of excess air is 1254 °C, biogas – 1490 °C, natural gas – 1576 °C.

As can be seen in Figure 2, the highest boiler efficiency can be obtained when firing natural gas, since at low excess air ratios, the lowest flue gas temperatures are achieved. The flue gas temperatures for natural gas and biogas are in the range of 125 ÷ 146 °C, which meets the standards for natural gas boilers [6] and allows achieving high efficiency and reliability of operation. The fundamentally different ratio of temperatures at the exit from the furnace of boilers using different fuels is explained, in our opinion, by the different quality of cooling of the furnace wall.

3. Conclusions

In the context of a shortage of exhaustible energy resources, it is necessary to partially or completely switch to the use of unconventional fuels. In literary and other sources of information, we have not identified information on the development and study of the operation of boilers on traditional and alternative energy sources.

Using the existing regulatory framework and our own developments, two designs of low-power hot-water boilers have been developed, which can operate on both traditional and alternative fuels.

Numerical studies of the operation of such boilers for wood, biogas and natural gas have been carried out using the developed mathematical model. Analysis of the dew point temperature of resins during wood combustion made it possible to identify the rational temperature of exhaust gases during wood combustion and the design characteristics of the boiler.

For both designs, the flue gas temperature

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during combustion of natural gas and biogas at the same boiler output turned out to be lower than during combustion of wood and, accordingly, higher boiler efficiency. On the other hand, the obtained flue gas temperatures meet the standard values.

The use of low-power hot water boilers using traditional and alternative fuels will allow achieving high economic and energy efficiency while ensuring reliability during operation.

All these factors make it possible to more widely use unconventional energy sources, reduce the use of exhaustible resources and reduce harmful emissions into the environment.

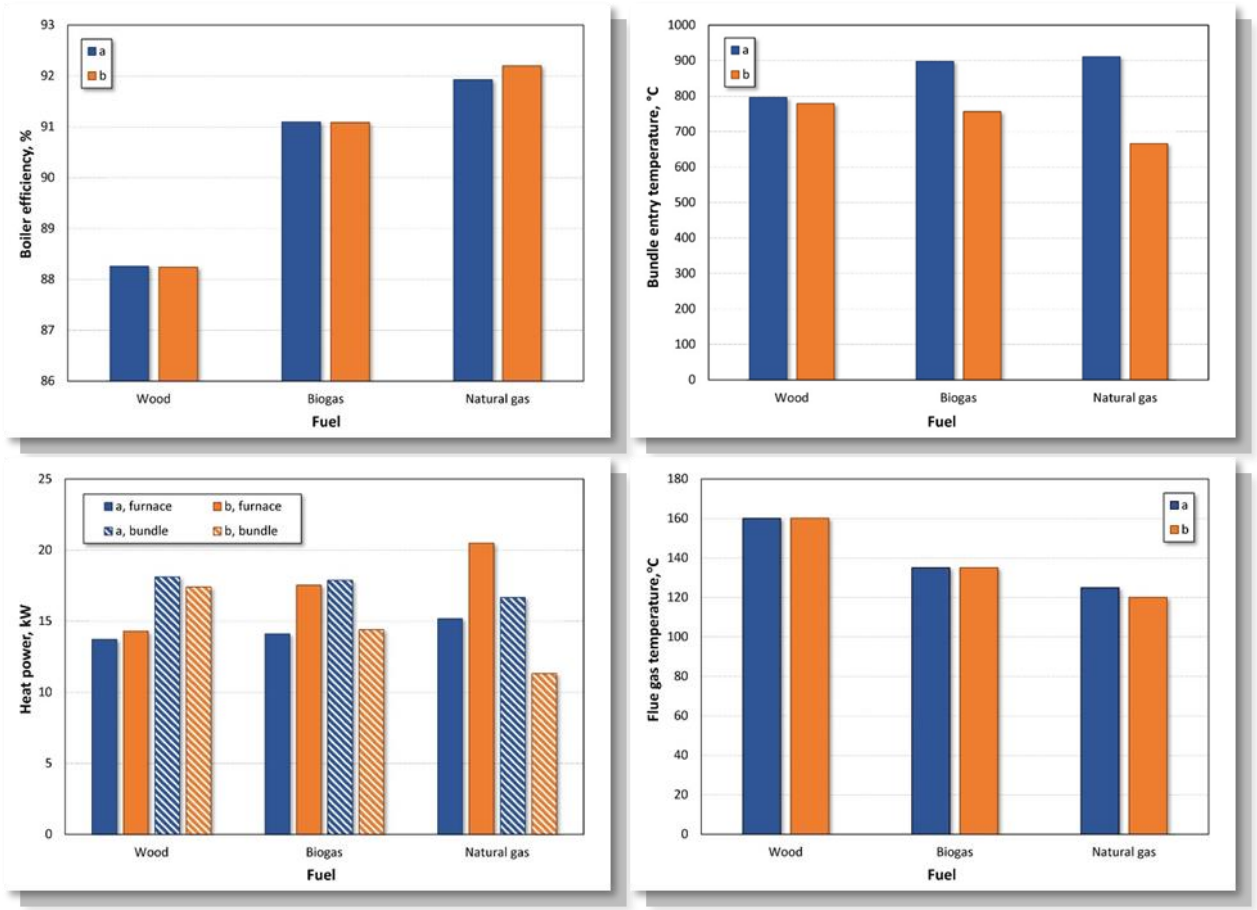

Figure 2. The results of numerical experiments on the operation of the boilers (design **a**, design **b** – Figure 1), when burning Wood, Biogas and Natural gas

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