Calculation studies of the ambient temperature variation influence on the gas tube boiler efficiency

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Abstract. The ambient air temperature variation influence on the efficiency of the gas tube hot water boiler operating in the heat supply system is considered in the paper. The dependency graphs of the fuel consumption, temperature in the near-wall layer of the convective bundle on the gas side, and aerodynamic losses along the length of the fire tubes in the convection bundle on the ambient temperature were drawn. The basic calculation formulas used for the calculation, as well as the temperature chart of the heat supply system operation depending on the ambient temperature are presented.

Keywords: heat supply, hot water boiler, gas tube boiler, gaseous fuel, aerodynamic losses

1. Introduction

The heat supply system is an integrated system of the heat source, heat networks and thermal energy consumers. Three types of heat load are mainly connected to the heat supply systems: heating, ventilation and hot water. These loads have different seasonal and daily consumption schedules [1].

Thermal load of consumers varies depending on many factors. Heating and ventilation refer to the seasonal loads and depend mainly on the outside air temperature, as well as on the wind direction and velocity, solar radiation, humidity, etc. Hot water refers to the year-round load and depends on the residential and public buildings improvement, population composition and work schedule, as well as utilities working hours [2].

Temperature charts are required for regulating the heat amount supplied to the consumers. The straight and return pipelines temperature curves varying depending on the ambient temperature are presented in the chart [2].

Hot water boilers are used as a heat source in decentralized heating systems. Gas tube hot water boiler running on gaseous fuel and having the specified technical characteristics (efficiency, rated power, heat-conducting surfaces areas) was studied in this paper. Furthermore, some values impacting on the gas tube boiler efficiency (the water temperature at the boiler input, water temperature at the boiler output, burned gaseous fuel consumption) were defined by the operation mode of the heat supply system [3].

2. Problem statement

Gas tube hot water boiler with the following characteristics is used for calculations (Fig. 1):

- the rated power is 500 kW;
- the boiler efficiency is 92.6 %;

- the heat-receiving area of the combustion chamber is 5.36 m^2;
- the heat-receiving area of the fire tubes (convective bundle) is 9.68 m^2;
- the fuel consumption during rated operation is 54.2 m^3/h;
- the constant water flow through the boiler is 17.2 t/h.

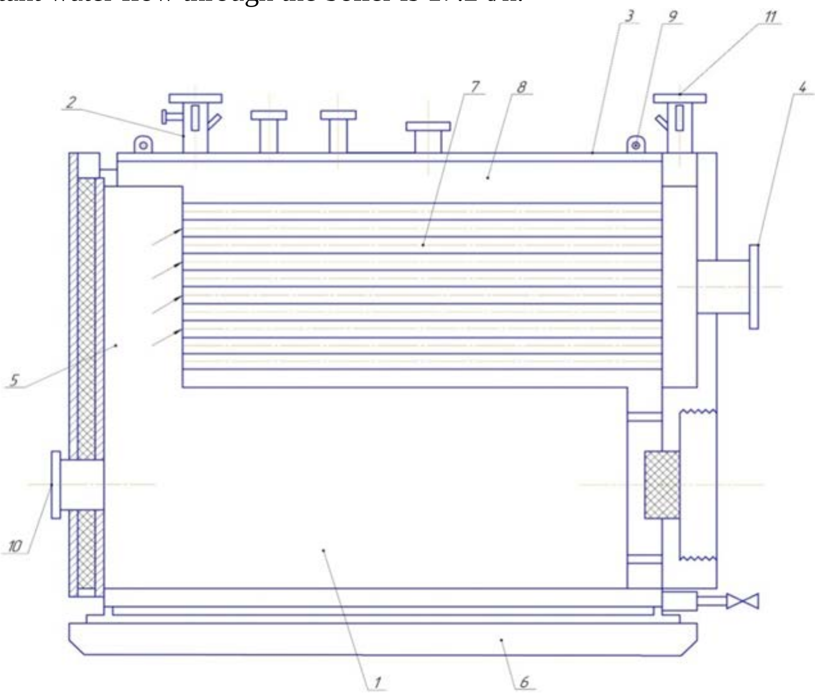

Figure 1. The gas tube boiler schematic diagram: 1 is the combustion chamber (flame tube); 2 is the feed water inlet pipe connection; 3 is the boiler lining; 4 is the stack; 5 is the reversing chamber; 6 is the support; 7 is the smoke tubes; 8 is water; 9 is the mounting; 10 is the technological hole; 11 is the waste water outlet pipe connection.

The research objective is to determine the gas tube hot water boiler efficiency when changing the heat supply system operating mode.

3. Theory

The calculation basis is the normative method of the boiler thermal calculation.

The heating surfaces heat absorption is generally defined by the flame tube heat exchange equation obtained on the basis of the Stefan - Boltzmann law and presented in the following form:

$$Q`_R = a_F \cdot c_0 \cdot \psi_e \cdot F_w \cdot (\bar{T}^4 - \bar{T}_w^4) \cdot 10^{-3} \quad (1)$$

where Q_R is the heating surfaces heat absorption, kW; α_F is the integral coefficient of the flame tube thermal radiation; c_o is the black body radiation coefficient equal to 5.67·10-8 W/(m^2·K4); ψ_e is the heating surfaces thermal efficiency coefficient; F_w is the surface area of the walls limiting the flame tube; T is the average temperature of the flame tube combustion products; T_{av} is the average temperature of the heating surface [4].

The actual temperature at the flame tube outlet is calculated using the formula:

$$\vartheta''_F = \frac{T_a}{M\left(\dfrac{5.67\psi_{av} F_w a_F T_a^3}{10^{11}\phi \cdot B_c V c_{av}}\right)^{0,6} + 1} - 273 \quad (2)$$

Heat transfer and heat balance equations are the main ones in calculating the convective heating surfaces [4].

Heat transfer equation is

$$Q_{h.t.} = K \cdot H \cdot \Delta t / B_c \tag{3}$$

Heat balance equation is

$$Q_b = \varphi \cdot (I` - I``) \tag{4}$$

Where K is the heat transfer coefficient of the heated surface; Δt is the temperature pressure; B_c is the calculated fuel consumption; H is the calculated heated surface area; φ is the heat storage coefficient; I', $I''$are the combustion products enthalpies at the fire tubes bundle inlet and outlet [5].

The hot water boiler gross efficiency can be determined by the direct balance equation:

$$\eta_{gr.} = \frac{G_w \cdot (i_{h.w.} - i_{c.w.})}{Q_o^a B_{h.b.}} \cdot 100 \tag{5}$$

where G_w the water flow through the boiler; $B_{h.b.}$ the fuel consumption of the hot water boiler; Q_o^a is the available heat; $i_{h.w.}$, $i_{c.w.}$ are the enthalpies of the hot and cold water [5].

For calculating the rough pipes frictional resistance under the heat exchange conditions, the following formula is used:

$$\Delta p_{fr.} = \lambda \frac{l}{d_э} \frac{\omega^2 \cdot \rho}{2} \left(\frac{2}{\sqrt{\frac{T_w}{T}}} + 1 \right)^2 \tag{6}$$

where λ is the frictional resistance coefficient depending on the channel walls relative roughness and number of Re; l, d_e is the length and equivalent diameter of the channel, ω is the flow velocity, ρ is the gas density; T_w and T are the average temperatures of the wall and fluid medium over the gas duct section [6].

4. Experimental results

The heat supply system operating mode is set by the water temperatures in the straight and return pipelines. These temperatures depend on the ambient temperature (Fig. 2).

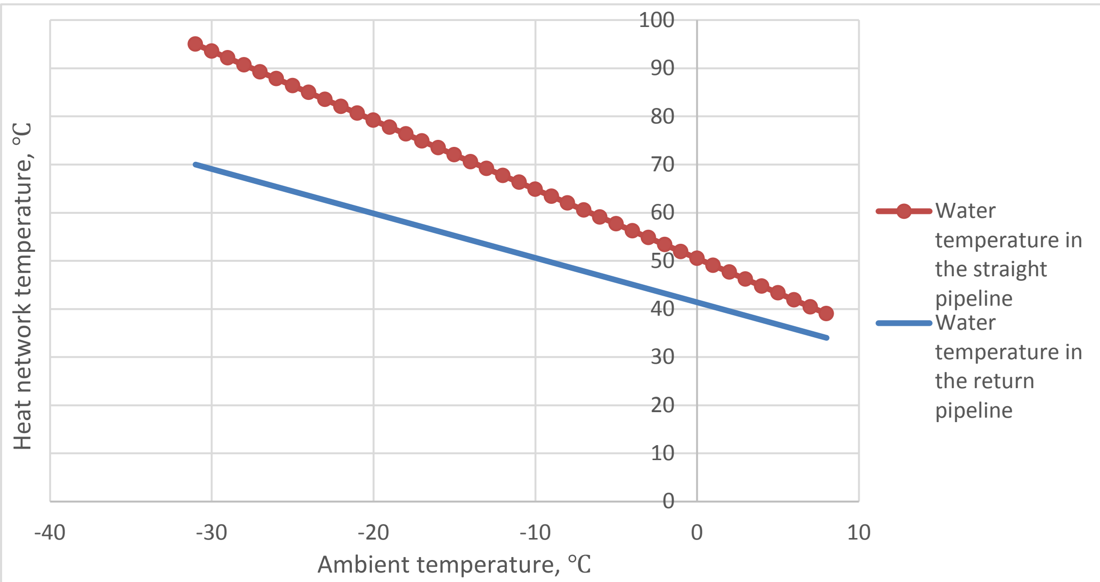

Figure 2. Temperature chart 95/70.

In the heat supply system, water is heated by the boiler as a result of the natural gas combustion. The fuel consumption needs to be changed for maintaining the water temperature in the straight and return pipelines according to the temperature chart (Fig. 3).

The ambient temperature increase results in the fuel consumption decrease due to reducing the temperature difference between water in the straight and return pipelines. As a consequence, the required boiler capacity for heating water is reduced.

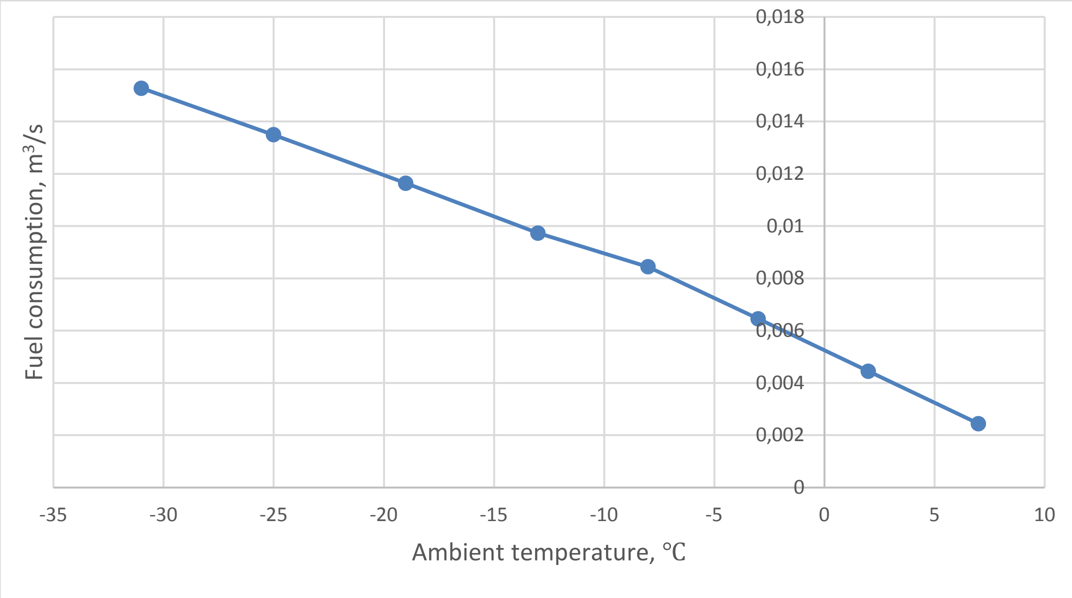

Figure 3. The graph of the fuel consumption dependency on the ambient temperature.

Changing the gas tube boiler operation mode leads to the wall temperature variation (Fig. 4).

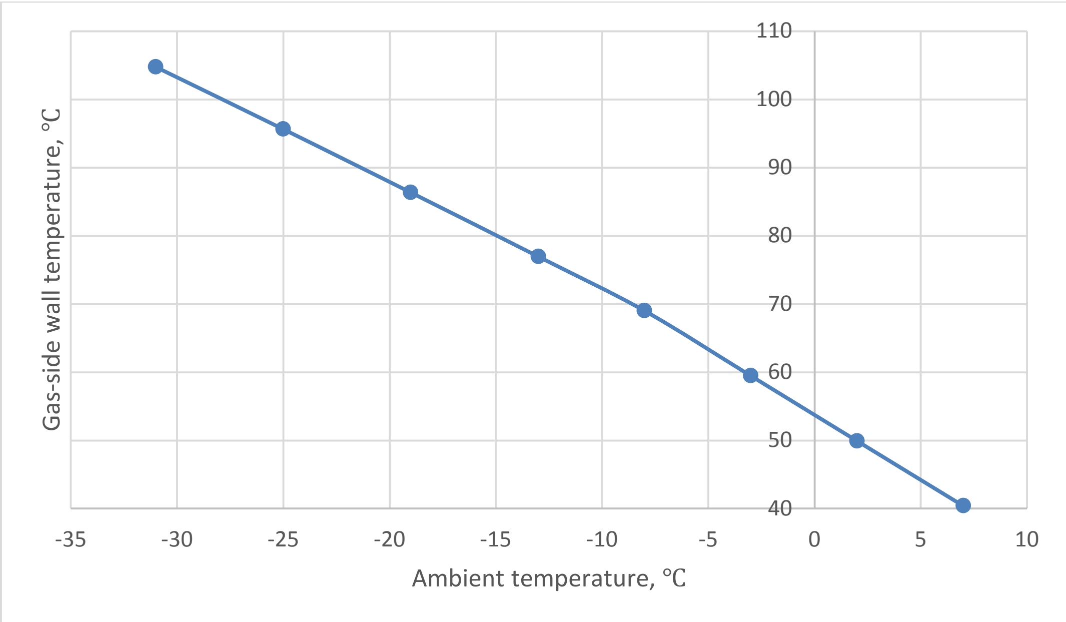

Figure 4. The graph of the gas-side convective bundle wall temperature dependency on the ambient temperature.

The convective bundle wall pipe temperature variation results in changing the aerodynamic losses along the pipes length (Fig. 5).

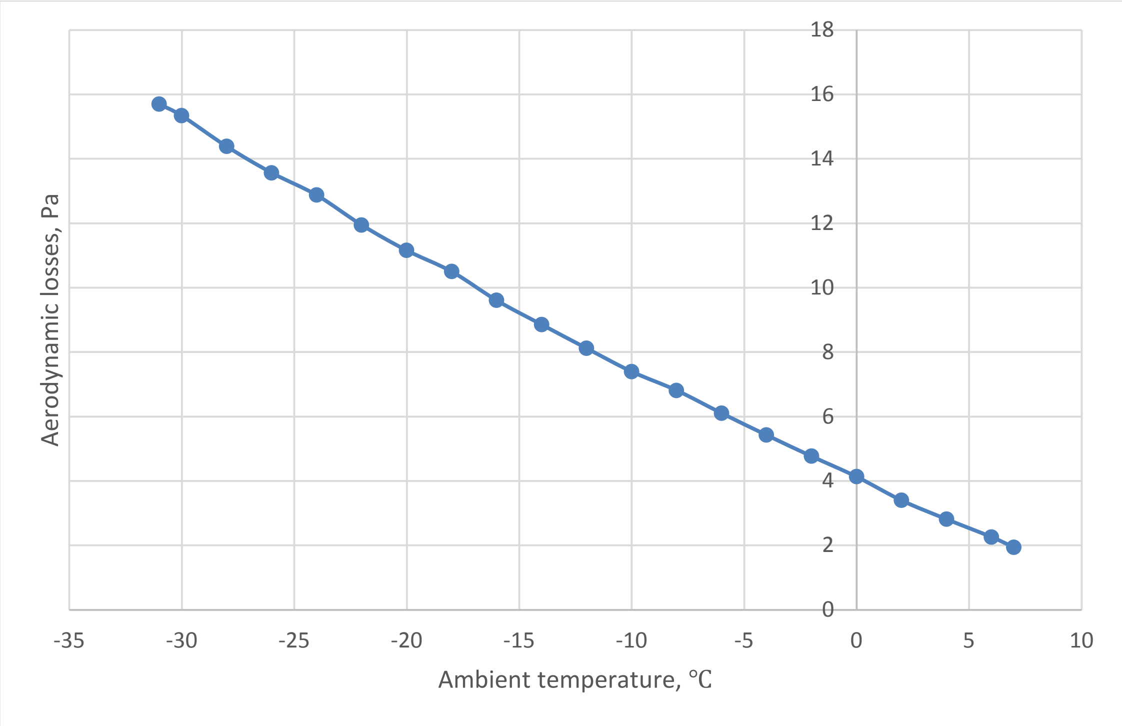

Figure 5. The graph of the aerodynamic losses dependency on the gas-side wall temperature.

5. Results discussion

As the ambient temperature increases, the temperature difference between water in the straight and return pipelines decreases (Fig. 2). Water flow through the boiler remains constant due to the use of the proper control method of the heat amount supplied to the consumers. It can therefore be concluded that when the ambient temperature increases, the required power to supply the consumers decreases. For maintaining the thermal balance between the heat amount released during the fuel burning and taken by the heated water, it is necessary to reduce the fuel consumption. The fuel consumption variation depending on the heat supply system operating mode is shown in Fig. 3.

Figure 4 is characterized by the fact that when the ambient temperature increases, the fuel consumption decreases in accordance with the temperature chart. Due to the constant water flow through the boiler and its inlet temperature decrease, the temperature pressure between the boiler inlet water and combustion products increases, changing the amount of heat transferred. Therefore, the exhaust gases temperature becomes lower as compared to the exhaust gases temperature when the boiler is operating in the lower ambient temperature mode. The exhaust gases and water temperature decrease at the boiler outlet results in the wall temperature reduction.

Changing the aerodynamic losses in the gas-tube boiler convective bundle is calculated according to the formula (6) (Fig. 5). The main value affecting the aerodynamic losses is the squared gas velocity. Gas velocity in turn depends on the fuel consumption determined by the heat supply system operating mode depending on the ambient temperature.

6. Conclusions

The boiler efficiency depends on the heat supply system operating mode, as proved by the calculation studies.

- If the ambient temperature decreases by 1 degree, the fuel consumption should be increased by 3 %.
- When the ambient temperature decreases by 1 degree, the convective bundle pipe wall temperature increases within 1.7 degree.

- When the ambient temperature decreases by 1 degree, the aerodynamic losses along the convective bundle pipes length increase within 0.4 Pa.

7. References

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