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LOCALIZATION OF EXERGY LOSSES IN THE AIR HEATER OF THE HEAT-RECOVERY SYSTEM UNDER DIFFERENT BOILER OPERATING MODES

Summary. *The results of the efficiency analysis of an air heater of a heat recovery system based on the exergy method and the thermodynamics of irreversible processes are presented. The patterns of changes in exergy losses depending on the heat output of the boiler are investigated.*

Key words: *exergy efficiency, heat conduction processes, heat recovery, boiler plants.*

When developing heat-recovery technologies, high efficiency of heat recovery and a significant increase in the utilization rate of fuel heat of the boiler plant should be ensured. This can be achieved by combining different types of heat recovery and gas heating equipment and increasing its efficiency. The effectiveness of such equipment is determined largely by the level of exergy losses in its elements. Efficiency analysis is advisable to carry out using complex techniques that combine different modern research methods. Methods of exergy analysis give a good enough result when studying the effectiveness of heat-recovery systems, because exergic characteristics are sensitive to changes in the regime and design parameters of such systems and are indicators of their thermodynamic efficiency. In works [1-3], an analysis of the exergic efficiency of an absorption refrigerator machine, a plant for the production of hydrogen from biomass and a boiler plant has been carried out. However, these works and a number of other authors studies are most often limited to the use of exergy methods only for the analysis of the exergy efficiency of plants in general. Until now, only a few works have been known from the study of the localization of exergy losses in individual elements of plants [4]. Further research in this area will make it possible to search for opportunities to reduce exergy losses in energy objects, differentiating these losses for reasons and areas of localization.

Combination of different types of heat recovery and gas-heating equipment can be implemented in various ways (Fig. 1 and 2).

Air-heating heat-recovery equipment is characterized by greater consumption of materials, and, accordingly, capital intensity compared with water-heating equipment for this purpose. Therefore, increasing the efficiency of air heaters is a very urgent task. For air heaters of heat recovery systems of boiler plants, the layout of heat transfer surfaces is carried out from packages of flat steel plates and tube bundles. Steel plate plates, plates with holes and stamped sheets are used in plate-like heating surfaces.

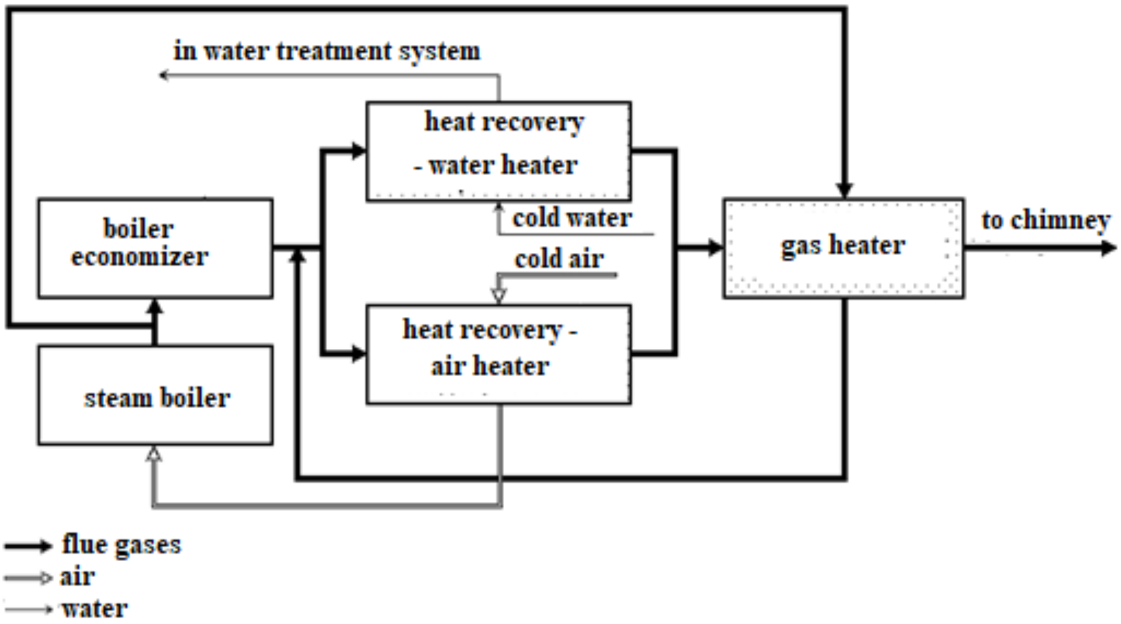

Fig. 1. Heat recovery scheme when using the utilized heat for the heating system and the boiler's own needs

For a lamellar air heater of a heat-utilization system of a boiler plant, the determination of exergy losses associated with hydrodynamic resistance during the movement of coolants, with irreversible processes during heat transfer between the coolants and with heat conductivity processes was carried out using a complex technique that includes methods of exergic analysis and thermodynamics of irreversible processes. The methodology used the following basic equations:

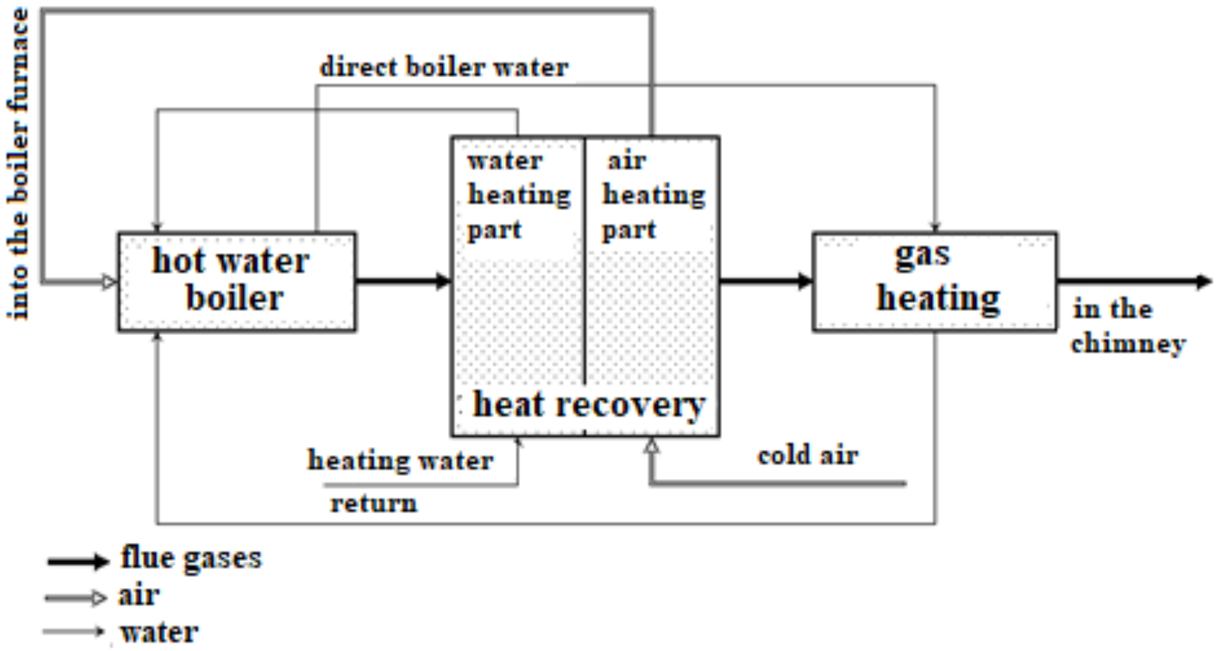

Fig. 2. Heat recovery scheme when using the utilized heat of the plant's own needs

$$\rho \frac{de}{dt} = -div(\tau q) + P_{ij}\frac{\partial u_i}{\partial x_j} - T_0 q \cdot grad\frac{1}{T} + \frac{T_0}{T}P_{ij}\frac{\partial u_i}{\partial x_j} + \frac{dp}{dt}.$$

$$E_{\text{loss}}^{q} = -T_0\int_V q_y \frac{d}{dy}(\frac{1}{T})dV = -T_0 F\langle q\rangle \int_{y_1}^{y_2}\frac{d}{dy}(\frac{1}{T})dy$$

$$E_{\text{loss}}^{G} = \frac{T_0}{T}\int_V P_{ij}\frac{\partial u_i}{\partial x_j}dV = \frac{T_0}{T}\int_V [\frac{\eta}{2}(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}divu)^2 + \zeta(divu)^2]dV.$$

$$q_y = \alpha_{\text{fg}}\left(T_{\text{fg}} - T_{\text{w1}}\right); q_y = -\lambda_{\text{w}}\left(T_{\text{w1}} - T_{\text{w2}}\right); q_y = \alpha_{\text{air}}\left(T_{\text{w2}} - T_{\text{air}}\right);$$

$$T_0\Delta S = T_0 V\Delta p/T_{\text{en}}\,; \Delta p = \xi\rho u^2/2.$$

$$E_{\text{loss}}^{\alpha_{\text{fg}}} = T_0 Q^2/\alpha_{\text{fg}} F T_{\text{fg}} T_{\text{w1}};$$

$$E_{\text{loss}}^{\lambda} = T_0 Q^2 \delta_{\text{w}}/\lambda_{\text{w}} F T_{\text{w1}} T_{\text{w2}};$$

$$E_{\text{loss}}^{\alpha_{\text{air}}} = T_0 Q^2/\alpha_{\text{air}} F T_{\text{air}} T_{\text{w2}};$$

Here: e – specific exergy, kJ/kg; E_{loss} – exergy losses, kW; F – side surface area, m^2; G – the mass flow rate of the coolant, kg/s; P_{ij} – viscous stress tensor, kPa; p – pressure, kPa; Q – heat power, kW; q – heat flow, kW; T – temperature, K,; T_{w1} (T_{w2}) – wall temperature on the flue gas (air) side, K; t – time, s; u – velocity, m/s; α – heat transfer coefficient, kW/m^2 K; δ – wall thickness, m; λ – heat conductivity coefficient, kW/mK; ξ – hydraulic resistance coefficient; ρ – density, kg/m^3; τ – thermodynamic temperature. Lower indices: fg – flue gases; air – air; en – the environment; loss – losses.

The dependences of exergy losses on the boiler heat output are obtained (Fig. 3).

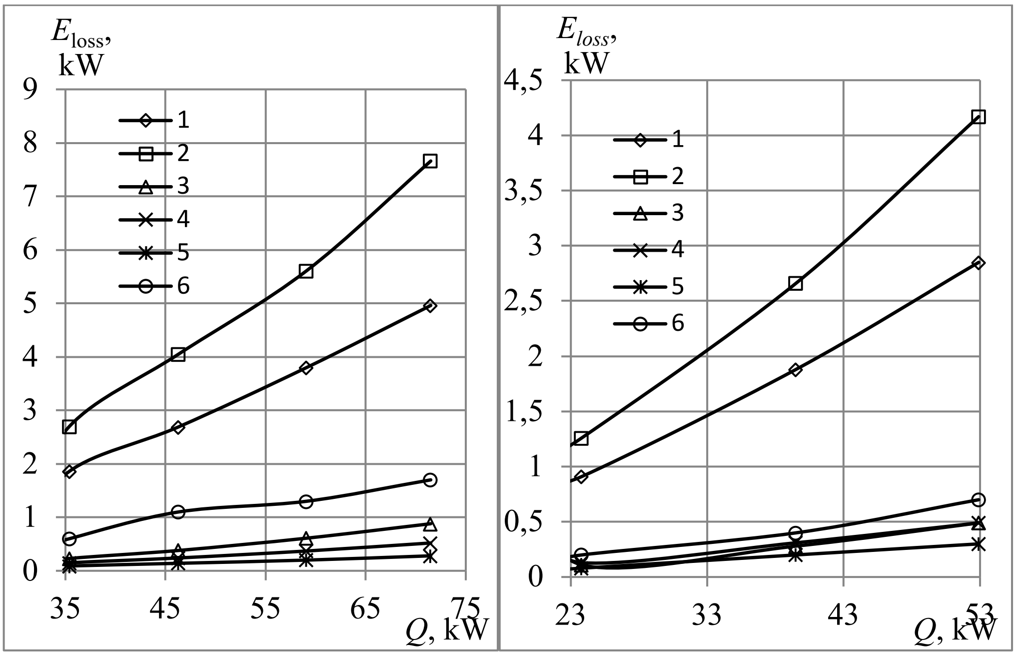

Fig. 3 The dependence of exergy losses on the boiler heat output:

a) - modes 1-4; b) - modes 5-7

$$1 - E_{loss}^{\alpha_{fg}};\ 2 - E_{loss}^{\alpha_{air}};\ 3 - E_{loss}^{\lambda};\ 4 - E_{loss}^{Gfg};\ 5 - E_{loss}^{Gair};\ 6 - E_{loss}^{pipe}.$$

As can be seen from Figure 1, for all values of boiler heat output, the exergy losses and the growth of these losses for cases of heat transfer from the wall to the air and from the flue gases to the wall significantly exceed the corresponding values for the losses of exergy associated with heat conduction, the movement of heat carriers and losses in the connecting pipelines. Thus, the reduction of exergy losses associated with heat transfer from the wall to the air is most effective for the overall reduction of losses in the air heater.

Conclusions

1. The analytical substantiation of the developed complex method for analyzing the efficiency of the air heater of the heat utilization system,

including the methods of exergy analysis and thermodynamics of irreversible processes, is given.

2. The laws governing changes in exergy losses associated with irreversible processes during heat exchange between heat transfer fluids, with heat conduction processes and with hydrodynamic resistance during heat transfer motion, as the heat output of the boiler changes.

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