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APPLICATION OF COMPLEX APPROACHES TO STUDY THE EFFICIENCY OF THE AIR HEATER FOR THE HEAT-RECOVERY SYSTEM

The development of high-quality heat-recovery equipment for power plants of various types involves the use of integrated methods for studying the effectiveness and optimization of heat recovery systems based on modern approaches to solving this problem. Methods of exergic analysis can be used to analyze the efficiency of power plants of different types [1; 2]. However, the lack of an appropriate formal procedure [3] significantly limits the breadth of application of these methods. In the present work, methods of exergic analysis are used within the framework of a complex methodology, which also includes methods of thermodynamics of irreversible processes. The method allows to establish the causes of the exergy losses and the areas of their localization in the air heater of the heat recovery system of the boiler plant, as well as to determine the values of parameters within which the minimum level of exergic losses is ensured.

Exergetic losses are one of the reasons for the decrease in the efficiency of heat recovery systems and their individual elements. Such losses are associated with hydrodynamic resistance during the motion of heat transfer agents, with irreversible processes during heat transfer of the coolants, with processes of heat conductivity. Using a complex technique based on the methods of exergy analysis and thermodynamics of irreversible processes, the loss of exergy power in the air heater of the heat-recovery system of a boiler installation for the VK-21-M2 boiler has been investigated. Seven operation modes of the boiler were considered, while the load of the boiler changed from maximum to minimum in accordance with its change during the heating period.

Losses of exergetic power associated with irreversible processes during heat exchange between heat transfer agents, with heat conduction processes and with hydrodynamic resistance during the motion of heat transfer fluids, were characterized by the corresponding exergy dissipators:

$$R_{\alpha_{fg}} = \frac{T_0 Q^2}{\alpha_{fg} F T_w T_{w1}}, R_{\alpha_{air}} = \frac{T_0 Q^2}{\alpha_{air} F T_{air} T_{w2}}, R_\lambda = \frac{T_0 Q^2 \delta_w}{\lambda_w F T_{w1} T_{w2}},$$

$$R_{Gfg} = \frac{(G_{fg})^3 \xi_{fg} T_0}{2T_{fg}(\rho_{fg})^2 (F_{fg})^2}, R_{Gair} = \frac{(G_{air})^3 \xi_{air} T_0}{2T_{air}(\rho_{air})^2 (F_{air})^2}.$$

Here G is the mass flow rate of the coolant, kg/s; Q - thermal power, kW; T - temperature, K; T_{w1} (T_{w2}) - wall temperature on the flue gas (air) side, K; α_{fg} - heat transfer coefficient from flue gases to the wall, kW/m^2 K; α_{air} - heat transfer coefficient from the wall to the air, kW/m^2 K; δ - wall thickness, m; λ - thermal conductivity coefficient, kW/mK; ξ - hydraulic resistance coefficient; ρ - density. Lower indices: *fg*-flue gases; *w* - wall.

The results of calculations of exergy dissipators, total exergy dissipators and total exergy power losses in the air heater are shown in Table 1.

As can be seen from the table, the greatest exergy power losses in the air heater and, accordingly, the largest relative contribution K to the total losses R^{sum}, are due to heat transfer from the wall to the air, the smallest losses and contribution are due to hydrodynamic losses during air movement. These characteristics remain approximately constant when the heat productivity Q varies. The losses of exergic power in the air heater, characterized by the extraction dissipators $R\alpha_{fg}$ and $R\alpha_{air}$, are greater 5-25 times than the losses characterized by the dissipators R_λ, R_{Gfg}, R_{Gair} for all modes of boiler operation. With a decrease in the boiler heat productivity, the exergy losses, determined by heat transfer from the wall to the air and heat transfer from the flue gases to the wall, are significantly reduced (by 3-5 kW), while the losses associated with the heat conductivity and the movement of heat carriers are insignificant. A comparative analysis of the total exergy losses associated with heat transfer processes and hydrodynamic losses, and the total losses in the air heater E^{tot} allowed us to identify the exergy power losses which are inherent to the system of connecting pipelines. These losses ranged from 4% to 10%. Thus, the most effective for the overall reduction of exergy power losses in the air heater is to reduce the losses associated with heat transfer from the wall to the air. The laws of the effect on the exergy dissipators of the heat transfer coefficient from the wall to the air were studied (Fig.1,2).

Table 1

The results of calculations of exergy dissipators with different modes of operation of the boiler

Parameter	Boiler operation modes						
	1	2	3	4	5	6	7
Q, kW	71,5	59,1	46,3	35,4	52,9	39,5	23,8
$R\alpha_{fg}$, kW	4,96	3,80	2,69	1,86	2,85	1,88	0,91
R_λ, kW	0,88	0,61	0,38	0,23	0,49	0,28	0,11
$R\alpha_{air}$, kW	7,66	5,61	4,05	2,70	4,17	2,66	1,26
R_{Gfg}, kW	0,52	0,37	0,24	0,15	0,49	0,31	0,13
R_{Gair}, kW	0,28	0,20	0,14	0,09	0,30	0,20	0,08
$K_{R\alpha fg}$, %	34,6	35,8	35,8	36,9	34,3	35,25	36,7
$K_{R\lambda}$, %	6,1	5,8	5,1	4,5	5,9	5,3	4,3
$K_{R\alpha air}$, %	53,5	53,0	54,0	53,7	50,2	49,9	50,4
K_{RGfg}, %	3,6	3,5	3,2	3,0	5,9	5,8	5,2
K_{RGair}, %	2,0	1,9	1,9	1,8	3,6	3,7	3,3
R^{tot}, kW	14,3	10,6	7,5	5,0	8,3	5,3	2,5
E^{com}, kW	16,0	11,9	9,0	5,6	9,0	5,7	2,6

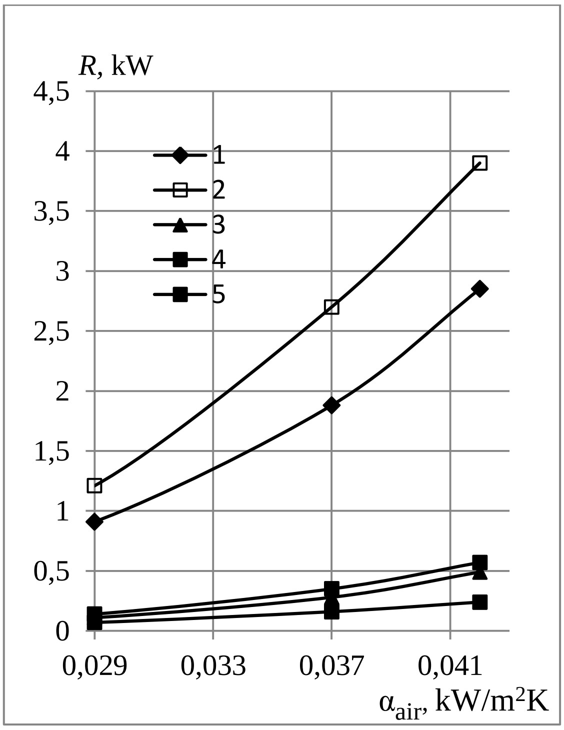

Fig. 1. The dependence of exergy dissipators *R* on the heat transfer coefficient on the air side α_{air} for modes 1-4; 1 - $R\alpha_{fg}$; 2 - $R\alpha_{air}$; 3 - R_λ; 4 - R_{Gfg}; 5 – R_{Gair}

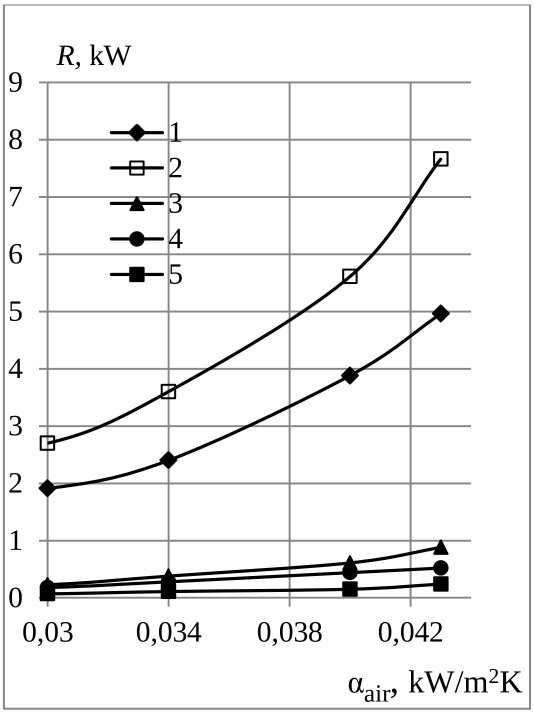

Fig. 2. The dependence of exergy dissipators *R* on the heat transfer coefficient on the air side α_{air} for modes 5-7; 1 - $R\alpha_{fg}$; 2 - $R\alpha_{air}$; 3 - R_{λ}; 4 - R_{Gfg}; 5 – R_{Gair}

An increase in the heat transfer coefficient from the wall to the air leads to an increase in exergy losses. For heat transfer coefficient values 0.04-0.06 kW/m^{2}K this growth is insignificant, a further increase in heat transfer coefficient leads to a more significant rise in losses. The area of change of the heat transfer coefficient from the wall to the air was determined, within which the minimum level of exergy power loss is ensured. The optimal area of change of the heat transfer coefficient from the wall to the air is 0.04-0.06 kW/m^{2}K.

Conclusions

1. The causes of the exergy losses and the areas of their localization in the air heater of the heat recovery system of the boiler plant have been established.

2. The contribution of each of the exergy dissipators and the system of connecting pipelines to the exergy losses is determined.

3. The laws of influence on the exergy dissipators of the heat transfer coefficient from the wall to the air were studied and the area of its change, with the minimum level of exergy losses was determined.

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