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CLASSIFICATION OF LOCAL EXERGETIC LOSSES IN HEAT RECOVERY SYSTEMS OF DIFFERENT TYPES

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Abstract. *The results of classification and analysis of local exergy losses in heat recovery systems of various types are presented. The combined heat recovery system of a boiler plant, designed for heating water and blast air, as well as heat recovery systems with anti-corrosion methods for protecting gas exhaust tracts, are considered. On the examples of these systems, a classification of local exergy losses was carried out and their type and place in heat recovery systems were established. For research, a complex methodology was used, combining structural-variant methods of exergy analysis with methods for presenting exergy balances in matrix form. Structural diagrams of heat recovery systems are presented and exergy equations are obtained for calculating exergy losses in places of localization. For a combined heat recovery system, a comparative analysis of local exergy losses was carried out. It has been established that the smallest exergy losses are observed in the hot air heat exchanger and in the gas heater. The total contribution to the total exergy losses of the pumping system and the piping system is quite significant for all boiler power values. With an increase in boiler power from 30 to 70% of the installed power, there is a slight increase in exergy losses in the heat recovery system and in the hot water heat recovery unit. In this section, the main exergy losses are in the pumping system and in the pipeline system. With a further increase in the power of the boiler, the exergy losses in the heat recovery system and in the hot water heat recovery unit begin to increase more significantly. In this case, the main exergy losses fall on the hot water heat exchanger. It is concluded that the optimal mode of operation of the installation is carried out at the boiler power, which is 50 ... 60% of its installed power.*

Key words: ***heat recovery systems; local exergy losses; classification of exergy losses***

Relevance. Increasing the efficiency of various types of power plants involves reducing exergy losses in them. Appropriate research requires the use of modern methods of thermodynamic analysis along with classical methods. A promising direction, which is increasingly used in the energy sector, is the study of the efficiency and optimization of power plants based on the exergy approach. Complex techniques based on the exergy approach make it possible to determine the locations of exergy losses in a power plant, calculate their magnitude and outline ways to reduce them. Therefore, the classification and analysis of exergy losses in heat recovery systems of various types using complex methods based on the exergy approach is an urgent scientific problem.

Analysis of recent achievements and publications. Modern research methods based on the use of exergy approaches are now becoming more and more widespread in the world for assessing the thermodynamic perfection of power plants of various types. It was noted in [1] that the exergy analysis makes it possible to identify all aspects that affect the global efficiency of systems and offer the maximum number of possible improvements for them. Work [2] emphasizes that exergy analysis can be considered as a way to obtain information that allows you to identify areas where technical improvements can be made. In [3], exergy analysis is used to evaluate the efficiency of power plant elements at various ambient temperatures. In [4], exergy analysis methods are used to estimate various types of exergy losses. Transient processes in elements of heating and hot water supply systems from a Stirling engine and a condensing boiler are considered. In [5], balance methods of exergy analysis were used to conduct comparative studies of exergy losses in elements of a multifunctional structure. The interrelation of exergy losses in the elements located in the direction of coolant movement is shown. The paper [6] presents the results of exergy studies of an integrated coal gasification system designed for hydrogen production and power generation. The article [7] presents the results of studies of energy and exergy efficiency, the purpose of which was to develop modeling and improve the performance of fuel cells. Complex methods for studying power plants, based on a combination of exergy analysis methods with other modern research methods, make it possible to determine the locations of exergy losses in a power plant and calculate their magnitude [6-11]. Such studies are important and relevant, as they provide an opportunity to obtain the necessary information for designing optimal heat recovery schemes.

Purpose and objectives of research

The aim of the work is the classification and analysis of local exergy losses in heat recovery systems of various types.

To achieve the goal, you must complete the following tasks:

- present heat recovery systems of various types in the form of block diagrams with the identification of exergy flows between individual elements;
- carry out a classification and establish the place and type of local exergy losses in the considered heat recovery systems;
- to obtain exergy equations for calculating exergy losses in places of localization;
- to analyze local exergy losses in the combined heat recovery system of the boiler plant, designed to heat water and blast air.

Materials and methods of research.

Exergy losses are an indicator of the efficiency of the heat recovery system and its individual elements. An increase in exergy losses corresponds to a decrease in their efficiency.

The paper classifies exergy losses in heat recovery systems of various types. The combined heat recovery system of a gas-consuming boiler plant with a heat output of 2 MW is considered. The heat recovery system is designed to heat water and blast air. In addition, for the classification of exergy losses, heat recovery systems of boiler plants are considered, in which methods of anti-corrosion protection of gas exhaust tracts are implemented. For research, a complex methodology was used, combining structural-variant methods of exergy analysis with methods for presenting exergy balances in matrix form. The accuracy of the obtained results is, on average, 0.4%..

Research results and discussion.

Representation of heat recovery systems of various types in the form of block diagrams with the identification of exergy flows between individual elements of the structure.

The combined heat recovery system designed for heating water and blast air includes a sufficient number of elements in order to classify local exergy losses. A hot heat exchanger for water heating, an heat exchanger for air heating, a gas heater, a smoke exhauster, a fan, a pumping system and a piping system connecting the main elements of the heat recovery system. The heat recovery systems of the boiler plant, in which the methods of anti-corrosion protection of gas exhaust ducts are implemented, make it possible to supplement the types and locations of exergy losses. The corresponding block diagrams of heat recovery systems are presented (Figure). In structural diagrams, input and output exergy flows between individual elements of the structure are identified.

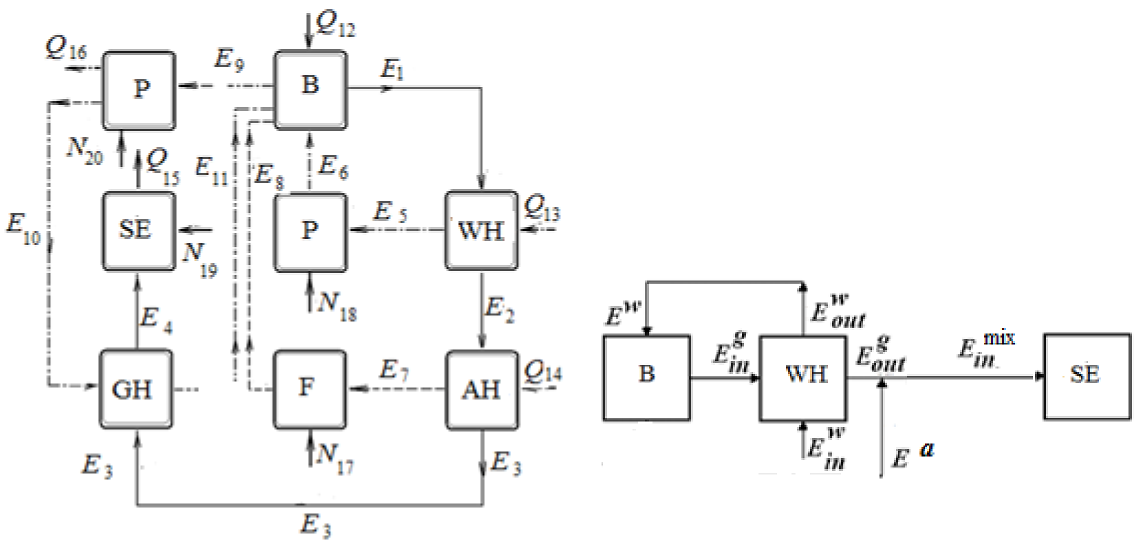
Classification of local exergy losses and determination of the location and type of losses in heat recovery systems.

A classification of local exergy losses in heat recovery systems has been carried out. Exergy losses in such systems occur due to the following factors:

- Heat transfers between coolants.
- Movement of heat carriers.
- Mixing of heat carriers.
- Exergy losses to the environment.

The first and second types of exergy losses can be observed in the main elements of the considered heat recovery systems. In hot water and hot air heat exchangers, exergy losses occur during heat transfer and movement of heat carriers, namely, cooled flue gases and heated water or heated air.

In the gas heater, the coolants are cooled water and heated gas.Exergy losses in these elements, as well as in the smoke exhauster, fan and pumps, should be calculated using the black box principle. This principle involves the calculation of exergy losses by the values of input and output thermodynamic parameters. Exergy losses in the pipeline system include losses due to the movement of coolants and exergy losses to the environment. These losses are calculated as the difference between the total exergy losses in the heat recovery system and the total exergy losses in the system elements. The total exergy losses in a heat recovery system can also be calculated using the black box principle. The third type of exergy losses is observed in the heat recovery systems of boiler plants, in which the methods of anti-corrosion protection of gas exhaust tracts are implemented: the air method and the method of bypassing part of the flue gases past the heat recovery unit. In the first case, in the flue located behind the heat exchanger, the flue gases cooled in the heat exchanger and the air heated in the boiler or in the air heater are mixed. In the second case, mixing of part of the flue gases cooled in the heat exchanger with hotter flue gases passed by the heat exchanger.



a) *b)*

Fig. Block diagrams of heat recovery systems:
a) combined heat recovery system for heating water and blast air;
b) heat recovery system with air method of anti-corrosion protection of gas exhaust ducts: B - boiler; WH – heat exchanger for water heating; AH – heat exchanger for air heating; GH - gas heater; SE - smoke exhauster; F - fan; P - pump; —→– flue gases; - - → – air; -·-→ – water;; E_1 - E_{11} - exergy flows; Q_{12} - Q_{16} - heat fluxes; N_{17} - N_{20} - energy flows

Obtaining exergy equations for calculating exergy losses in places of localization.

The calculation of exergy losses in individual elements of the heat recovery system and for the system as a whole is carried out according to the black box principle using input and output thermodynamic parameters.

Exergy equations for calculating exergy losses in a heat exchanger for water heating:

$$E_{los}^{WH} = G^g c_p^g (T_{inWH}^g - T_{outWH}^g) - T_{en} G^g \left[c_p^g \ln(T_{inWH}^g / T_{outWH}^g) - R/\mu^g \ln(p_{inWH}^g / p_{outWH}^g) \right] -$$
$$- G^{w1} \left[(h_{inWH}^{w1} - T_{en} s_{inWH}^{w1}) - (h_{outWH}^{w1} - T_{en} s_{outhWH}^{w1}) \right]$$

Exergy equations for calculating exergy losses in a heat exchanger for air heating:

$$E_{los}^{AH} = G^g c_p^g (T_{inAH}^g - T_{outAH}^g) - T_{en} G^g \left[c_p^g \ln(T_{inAH}^g / T_{outAH}^g) - R/\mu^g \ln(p_{inAH}^g / p_{outAH}^g)\right] - $$
$$- G^a c_p^g (T_{inAH}^a - T_{outAH}^a) + T_{en} G^a \left[c_p^a \ln(T_{inAH}^a / T_{outAH}^a) - R/\mu^a \ln(p_{inAH}^a / p_{outAH}^a)\right].$$

Exergy equations for calculating exergy losses in a gas heater:

$$E_{los}^{GH} = G^{w2}(h_{inGH}^{w2} - T_{en} s_{inGH}^{w2}) - G^{w2}(h_{outGH}^{w2} - T_{en} s_{outGH}^{w2}) - G^g c_p^g (T_{inGH}^g - T_{outGH}^g) +$$
$$+ T_{en} G^g c_p^g \ln(T_{inGH}^g / T_{outGH}^g) + T_{en} G^g R/\mu^g \ln(p_{inGH}^g / p_{outGH}^g).$$

Exergy equations for calculating exergy losses in the flue when mixing flue gases and air:

$$E_{los}^{GP} = G^a c_p^a (T_{inGP}^a - T_{outGP}^{mix}) - T_{en} G^a \left[c_p^a \ln(T_{inGP}^a / T_{outGP}^{mix}) - R/\mu^a \ln(p_{inGP}^a / p_{outGP}^a)\right] - $$
$$- G^g c_p^g (T_{inGP}^g - T_{outGP}^{mix}) + T_{en} G^g \left[c_p^g \ln(T_{inGP}^g / T_{outGP}^{mix}) - R/\mu^g \ln(p_{inGP}^g / p_{outGP}^{mix})\right].$$

Analysis of local exergy losses in the combined heat recovery system of a boiler plant designed to heat water and blast air.

On the example of a combined heat recovery system, a comparative analysis of exergy losses in the places of their localization was carried out (Table 1).

As can be seen from the table, the exergy losses for all elements of the combined heat recovery system increase with increasing boiler power. At the same time, the smallest exergy losses are observed in the hot air heat exchanger and in the gas heater. The total contribution to the total exergy losses of the pumping system and the piping system connecting the main elements of the heat recovery system is quite significant for all boiler power values. The exergy losses in the pumping system and the piping system significantly exceed the exergy losses in the heat recovery units and the gas heater for the boiler capacity of 30 to 70% of the installed capacity. With an increase in the boiler power from 30 to 70% of the installed power, there is a slight increase in the total exergy losses in the heat recovery system and exergy losses in the hot water heat exchanger.

In this section, the main exergy losses are in the pumping system and in the pipeline system. With a further increase in the boiler power to 90% of the installed power, the exergy losses in the heat recovery system and in the hot water heat recovery unit begin to increase more significantly. In this case, the main exergy losses fall on the hot water heat exchanger. Taking into account the feasibility of reducing exergy losses in the heat recovery system by regulating exergy losses in the pumping system and piping system, it can be concluded that the optimal mode of operation of the plant is carried out at a boiler power of 50 ... 60% of its installed power.

1. Exergy losses in the elements of the combined heat recovery system

№	Elements of the heat recovery system	Exergy losses, *kW*			
		30% of installed boiler capacity	50% of installed boiler capacity	70% of installed boiler capacity	90% of installed boiler capacity
	Heat recovery system	5,0	8,5	17,0	33,0
1	Heat exchanger for water heating	0,8	1,0	4,5	15,0
2	Heat exchanger for air heating	0,7	1,0	1,5	2,2
3	Gas heater	0,1	0,4	0,5	0,7
4	Smoke exhauster	1,0	2,2	4,0	6,1
5	Fan	0,3	0,7	1,5	2,6
6	Pump 1	0,7	1,3	2,1	2,7
7	Pump 2	1,0	1,8	2,5	3,2
8	Piping system	0.1	0,1	0,4	0,5

Scientific novelty and practical value of the obtained results. The scientific novelty and practical value of the results obtained lies in the classification of local exergy losses in heat recovery systems of various types, the establishment of their place and type, as well as the possibility of their reduction in the development and implementation of optimal heat recovery schemes.

Conclusions

1. For a combined heat recovery system of a boiler plant designed for heating water and blast air, and a heat recovery system with an air method for protecting gas exhaust ducts, block diagrams are presented with the identification of exergy flows between individual elements.

2. On the examples of the heat recovery systems under consideration, a classification of local exergy losses was carried out and their place and type in heat recovery systems were established.

3. Exergy equations are obtained for calculating exergy losses in localization areas.

4. For the combined heat recovery system of the boiler plant, designed for heating water and blast air, a comparative analysis of local exergy losses was carried out.

Conventions

c_p is the specific heat capacity; *E* is exergy; *h* is the specific enthalpy; *p* is pressure; *R* is the universal gas constant; *s* is the specific entropy; *T* is the absolute temperature; μ is the molecular weight. **Upper indices:** *g, w, a* – flue gases, water, air; *mix* is mixture; 1– heated water, 2 – cooled water; PS – piping system. **Lower indices:** *los* – losses; *in, out* - input, output; *en* is the environment.

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КЛАСИФІКАЦІЯ ЛОКАЛЬНИХ ЕКЗЕРГЕТИЧНИХ ВТРАТ В СИСТЕМАХ РЕКУПЕРАЦІЇ ТЕПЛА РІЗНИХ ТИПІВ

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Анотація. *Наведено результати класифікації та аналізу локальних втрат ексергії в системах рекуперації тепла різних типів. Розглянуто комбіновану систему рекуперації тепла котельні, призначену для підігрівання води та дуття, а також системи рекуперації тепла з антикорозійними методами захисту газовідвідних трактів. На прикладах цих систем проведено класифікацію локальних втрат ексергії та встановлено їх вид і місце в системах рекуперації тепла. Для дослідження була використана комплексна методологія, що поєднує структурно-варіантні методи ексергетичного аналізу з методами представлення ексергетичних балансів у матричній формі. Наведено структурні схеми систем рекуперації тепла та отримано рівняння ексергії для розрахунку втрат ексергії в місцях локалізації. Для комбінованої системи рекуперації тепла проведено порівняльний аналіз локальних втрат ексергії. Встановлено, що найменші втрати ексергії спостерігаються в теплообміннику гарячого повітря і в газовому нагрівачі. Сумарний внесок у загальні втрати ексергії насосної системи та системи трубопроводів досить значний для всіх значень потужності котла. При збільшенні потужності котла від 30 до 70 % від встановленої потужності відбувається незначне збільшення втрат ексергії в системі утилізації тепла і в установці утилізації тепла ГВП. На цій ділянці основні втрати ексергії припадають на насосну систему та систему трубопроводів. При подальшому збільшенні* *потужності котла втрати ексергії в системі рекуперації тепла і в водогрійному утилізаторі починають зростати більш істотно. При цьому основні втрати ексергії припадають на водогрійний теплообмінник. Зроблено висновок, що оптимальний режим роботи установки здійснюється при потужності котла, що становить 50 ... 60 % від його встановленої потужності.*

Ключові слова: ***системи рекуперації тепла; локальні втрати ексергії; класифікація втрат ексергії***