Технічні науки

UDC 621.036.7

Fialko Nataliia
Doctor of Technical Sciences, Professor,
Corresponding Member of NAS of Ukraine, Department Head
Institute of Engineering Thermophysics of NAS of Ukraine

Stepanova Alla
Candidate of Technical Sciences (PhD),
Senior Scientific Researcher, Leading Researcher
Institute of Engineering Thermophysics of NAS of Ukraine

Navrodska Raisa
Candidate of Technical Sciences (PhD),
Senior Scientific Researcher, Leading Researcher
Institute of Engineering Thermophysics of NAS of Ukraine

Shevchuk Svitlana
Candidate of Technical Sciences (PhD), Senior Researcher
Institute of Engineering Thermophysics of NAS of Ukraine

LOCALIZATION OF EXERGY LOSSES IN THE HEAT RECOVERY SYSTEMS OF BOILER PLANTS

Summary. *The results of the analysis of the localization of exergy losses in the heat recovery systems of boiler plants during the implementation of methods of anti-corrosion protection of gas exhaust tracts are presented. The methods are aimed at increasing the temperature and reducing the relative humidity of the flue gases entering the exhaust ducts. a complex methodology based on a combination of balance methods of exergy analysis and structural-variant methods was used for the study, he technique makes it possible to* *develop block diagrams for heat recovery systems in which anti-corrosion protection methods are implemented, and to establish the locations of exergy losses. Structural diagrams of the main elements of a boiler plant with heat recovery systems in the implementation of anti-corrosion protection methods are presented. On the basis of block diagrams, the main places of localization of exergy losses are determined and exergy balance equations are obtained for calculating exergy losses in places of localization.*

Key words: *heat recovery systems; localization; exergy losses; gas ducts.*

Introduction. The problems of increasing the efficiency and the service life of power plant equipment are currently becoming of great importance. The choice of methodology for the study of power plants allows us to analyze energy and exergy losses in plants that reduce its efficiency.

Statement of the problem and research method. Modern techniques for studying efficiency, based on the use of exergy methods of analysis, are now becoming more and more widespread in the world [1-4]. Complex techniques based on a combination of exergy methods of analysis with other modern research methods can significantly expand the scope of their application in the study of the efficiency of power plants [5–8]. Thus, these methods make it possible to determine the locations of exergy losses in a power plant and calculate their magnitude. In particular, this applies to heat recovery systems of boiler plants, in which anti-corrosion methods for protecting gas exhaust tracts are implemented.

The purpose of the work is to analyze the localization of exergy losses in the heat recovery systems of boiler plants when implementing methods of anticorrosion protection of gas exhaust tracts in them.

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

- on the basis of balance methods of excremental analysis and structural-variant methods, develop structural diagrams for heat recovery systems in which methods of anti-corrosion protection of gas exhaust tracts of boiler plants are implemented;

- to establish the localization locations of the main exergy losses in heat recovery systems for three cases of implementation of anti-corrosion protection methods: the bypass method, the mixing method and the drying method;
- on the basis of block diagrams and the general system of balance equations, obtain exergy equations for calculating exergy losses in places of localization.

Materials and research methods. The essence of the three methods of anti-corrosion protection of gas exhaust tracts of boiler plants is to increase the temperature and reduce the relative humidity of gases entering the exhaust tracts. In the first case, this is achieved by mixing a part of the flue gases that have passed through the heat exchanger with a part of the flue gases passing by the heat exchanger (bypass method). In the second case, by mixing part of the heated air into the flue gases after the heat exchanger (air method). In the third case, by heating the cooled flue gases leaving the heat exchanger in the gas heater (drying method).

Research results. With the help of a complex methodology based on a combination of balance methods of excretory analysis and structural-variant methods, structural diagrams for heat recovery systems have been developed in which methods for protecting gas exhaust tracts are implemented. On the basis of block diagrams, the places of localization of the main exergy losses were established (Fig. 1.2.3). Using block diagrams and a general system of balance equations for heat recovery systems, balance exergy equations were obtained for calculating exergy losses in places of localization.

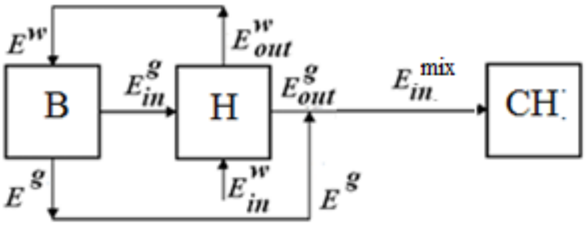

Fig. 1. Block scheme of the main elements of the heat recovery system when implementing the bypass method: B – boiler; H - heat exchanger; CH - chimney

In case of implementation of the bypass method, the main places of localization of exergy losses are the heat exchanger and the gas duct located behind the heat exchanger. Exergy losses in the heat exchanger occur due to the transfer of part of the flue gas exergy to the heated water.

Balance exergy equations for calculating exergy losses in a heat exchanger:

$$E_{los}=(1-B)G^g c_p^g (T_{inh}^g - T_{outh}^g) - T_{en}(1-B)G^g c_p^g \ln(T_{ihh}^g / Tg) -$$
$$-T_{en}(1-B)G^g R/\mu^g \ln(p_{inh}^g / p_{outh}^g) - G^w (h_{inh}^w - T_{en} s_{inh}^w) + G^w (h_{outh}^w - T_{en} s_{outh}^w).$$

In the flue located behind the heat exchanger, exergy losses occur due to the mixing of flue gases cooled after the heat exchanger and flue gases with a higher temperature, passed by the heat exchanger.

Balance exergy equations for calculating exergy losses in a heat exchanger:

$$E_{los}=BG^g c_p^g T_{in}^g - G^{mix} c_p^{mix} T_{in3}^{mix} - T_{en} BG^g c_p^g \ln T_{in}^g + G^{mix} c_p^{mix} \ln T_{in3}^{mix} -$$
$$-T_{en} BG^g R/\mu^g \ln p_{in}^g + T_{en} G^{mix} R/\mu^{mix} \ln p_{in3}^{mix} - G^{mix} c_p^{mix} T_{inch}^{mix} + (1-B)G^g c_p^g T_{outh}^g +$$
$$+T_{en} G^{mix} c_p^{mix} \ln T_{inch}^{mix} - T_{en}(1-B)G^g c_p^g \ln T_{outh}^g + T_{en} G^{mix} R/\mu^{mix} \ln p_{inch}^{mix} -$$
$$-T_{en}(1-B)G^g R/\mu^g \ln p_{outh}^g.$$

In the case of implementing the mixing method, the main places of localization of exergy losses, as in the first case, are the heat exchanger and the gas duct located behind the heat exchanger.

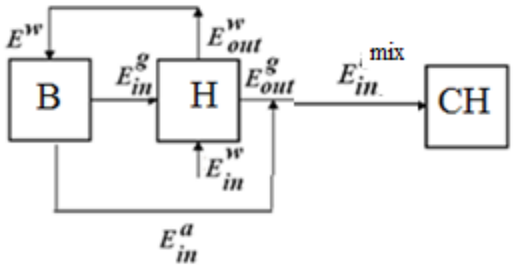

Fig. 2. Structural scheme of the main elements of heat recovery systems when heated air is mixed into the flue gases:

B – boiler; H - heat exchanger; G – gas heater; CH – chimney

In this case, an increase in temperature and a decrease in the relative humidity of gases after the heat exchanger are achieved by mixing in the gas duct part of the cooled flue gases that have passed through the heat exchanger with part of the heated air. The air comes either from the boiler air preheater or is preheated outside the boiler. Exergy losses in the gas duct occur due to the transfer of part of the exergy of heated air to the flue gases cooled after the heat exchanger.

Balance exergy balance equations for calculating exergy losses in a heat exchanger:

$$E_{los} = G^g c_p^g (T_{inh}^g - T_{outh}^g) - T_{en} G^g c_p^g \ln(T_{ihh}^g / Tg) - T_{en} G^g R / \mu^g \ln(p_{inh}^g / p_{outh}^g) -$$
$$- G^w (h_{inh}^w - T_{en} s_{inh}^w) + G^w (h_{outh}^w - T_{en} s_{outh}^w)$$

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

$$E_{los} = G^g c_p^g T_{in}^g - G^{mix} c_p^{mix} T_{in3}^{mix} - T_{en} G^g c_p^g \ln T_{in}^g + G^{mix} c_p^{mix} \ln T_{in3}^{mix} -$$
$$- T_{en} G^g R / \mu^g \ln p_{in}^g + T_{en} G^{mix} R / \mu^{mix} \ln p_{in3}^{mix} - G^{mix} c_p^{mix} T_{inch}^{mix} + G^a c_p^a T_{outh}^a +$$
$$+ T_{en} G^{mix} c_p^{mix} \ln T_{inch}^{mix} - T_{en} G^a c_p^a \ln T_{outh}^a + T_{en} G^{mix} R / \mu^{mix} \ln p_{inch}^{mix} -$$
$$- T_{en} G^a R / \mu^a \ln p_{outh}^a$$

In case of implementation of the drying method, the main places of localization of exergy losses are the heat exchanger and the gas heater located behind the heat exchanger. Exergy losses in the heat exchanger occur due to the transfer of part of the flue gas exergy to heated water, and in the gas heater - due to the transfer of part of the cooled water exergy to flue gases.

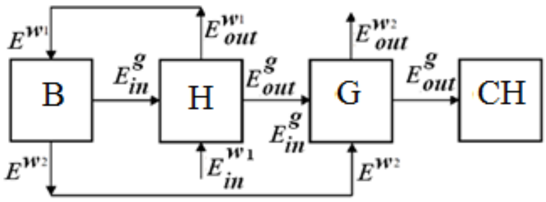

Fig. 3. Structural scheme of the main elements of heat recovery systems when drying flue gases in a gas heater:

B – boiler; H - heat recovery; G – gas heater; CH - chimney

Exergy balance equations for calculating exergy losses in a heat exchanger:

$$E_{los} = G^g c_p^g (T_{inh}^g - T_{outh}^g) - T_{en} G^g c_p^g \ln(T_{ihh}^g / T_{outh}^g) - T_{en} G^g R / \mu^g \ln(p_{inh}^g / p_{outh}^g) -$$
$$- G^{w1}(h_{inh}^{w1} - T_{en} s_{inh}^{w1}) + G^{w1}(h_{outh}^{w1} - T_{en} s_{outh}^{w1}).$$

Exergy balance equations for calculating exergy losses in the gas heater:

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

The results obtained can be used to determine the locations of exergy losses in heat recovery systems and to calculate them when developing optimal heat recovery schemes.

Conventions

B – proportion of bypassed gases; c_p is the specific heat capacity; *E* is exergy; *G* is the coolant flow rate; *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; *m* is mixture; 1– heated water, 2 - cooled water. **Lower indices:** *los* – losses; *in, out* - input, output; *en* is the environment; *h* - heat exchanger; *ch* - chimney.

Conclusions

1. On the basis of balance methods of excretory analysis and structural-variant methods, structural diagrams for heat recovery systems have been developed, in which methods of anti-corrosion protection of gas exhaust tracts of boiler plants are implemented.
2. The main places of localization of exergy losses in three cases of implementation of anti-corrosion protection methods are established: the bypass method, the mixing method and the drying method.
3. Exergy balance equations have been obtained for calculating exergy losses in the places of their localization.

References

1. Cziesla F., Tsatsaronis G., Gao Z. Avoidable thermodynamic inefficiencies and costs in an externally fired combined cycle power plant // Energy. 2006. V. 31, Issues 10–11. P. 1472-1489. doi: https://doi.org/10.1016/j.energy.2005.08.001
2. Yuan Yuan Jian, Shao Xiang Zhou. Exergy Analysis of Boiler Based on the Temperature Gradient. Asia-Pacific Power and Energy Engineering Conference. 2010. P. # 11258018. P. 4. doi: https://doi.org/10.1109/APPEEC.2010.5449523
3. Zare V., Moalemian A. Parabolic trough solar collectors integrated with a Kalina cycle for high temperature applications. Energy, exergy and

economic analyses. Energy Conversion and Management. 2017. 151. P. 681-692. doi: 10.1016/j.enconman.2017.09.028.

4. Ameri M., Ahmadi P., Hamidi A. Energy, exergy and exergoeconomic analysis of a steam power plant: A case study. International Journal of Energy Research. 2008. V. 33. Issue 5. P. 499-512. doi: https://doi.org/10.1002/er.1495.
5. Fialko N., Stepanova A., Navrodska R., Meranova N., Sherenkovskii J. Efficiency of the air heater in a heat recovery system at different thermophysical parameters and operational modes of the boiler. Eastern-European Journal of Enterprise Technologies. 2018. 6/8(96). P. 43-48. doi: 10.15587/1729-4061.2018.147526.
6. Fialko N., Stepanova A., Navrodska R., Gnedash G., Shevchuk S. Complex metods for analysis of efficiency and optimization of heat-recovery system. Scientific and innovation. 2021. 17(4). P. 11-18. doi: https://doi.org/10.15407/scine17.04.011 ISSN 1815-2066.
7. Fialko N., Stepanova A., Navrodska R., Shevchuk S. Comparative analysis of exergetic efficiency of methods of protection of gas exhaust tracks of boiler installations Eastern-European Journal of Enterprise Technologies. 2021. 3/8(111). P. 42-49. doi: https://doi.org/1015587/1729.4061.2021/234026; ISSN 1729-3774 4061.2021/234026.
8. Stepanova A. Analiz rabotosposobnosti ustanovki s kombinirovannoy teploutilizatsionnoy sistemoy dlia podogreva vody i dutevogo vozdukha kotloagregata [Analysis of the application combined heat recovery systems for water heating and blast air of the boiler unit]. Industrial Heat Engineering. 2016. 38(4). P. 38-46. doi: https://doi.org/10.31472/ihe.4.2016.06.