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THE ENVIRONMENTAL RELIABILITY OF GAS-FIRED BOILER UNITS BY APPLYING MODERN HEAT-RECOVERY TECHNOLOGIES

Purpose. Improving the environmental safety of chimneys of heating boiler plants with exhaust-gas heat-recovery systems based on the use of the air method to prevent condensation in the exhaust ducts in combination with the method for drying the gases by heating them.

Methodology. In conducting computational studies, the well-known methods for thermal calculation of boiler plants and chimneys were used, as well as the results of our own experimental studies regarding heat transfer and hydrodynamics during deep cooling of the exhaust-gases of boiler plants. The studies were carried out using single thermal methods in the heat-recovery schemes of boiler plants to prevent condensation in the exhaust ducts (drying flue gases and the air method) and a complex of these methods. At the same time, various options for heat-recovery systems and chimneys were considered in the presence of air heaters in boiler houses and in their absence.

Findings. The thermal and humidity characteristics of the exhaust gases at the mouth of the chimneys were studied at used dry and heated air to reduce the humidity of these gases with a wide temperature change. Under the conditions considered, the main parameters of the chimney anti-corrosion protection systems were determined to prevent condensation in them under normative operating conditions of these chimneys. Based on the values of the obtained parameters, a comparative analysis of the effectiveness of the considered methods for protecting gas exhaust paths for various heat-recovery plants was performed. It is shown that for heating boilers, the use of the air method is most effective in complex-heat recovery systems, characterized by the use of recovered heat to heat the return heat-network water and combustion air.

Originality. For the first time, the application of the air method to prevent condensation in the gas exhaust paths of boiler plants with complex heat-recovery systems has been investigated.

Practical value. The use of the proposed complex of thermal methods will significantly increase the reliability of the chimneys of heating boiler units in municipal heat-power engineering.

Keywords: *boiler plants, deep cooling of exhaust-gases; dew point, condensation, heat-recovery*

Introduction. One of the important technological elements of gas-fired heat-installations for various purposes are chimneys. The operation of these chimneys must meet stringent environmental requirements for compliance with the regulatory dispersion of pollutants contained in the flue gases of these installations. Given this, high requirements are applied to chimneys as complex engineering structures for their reliability and durability.

The effective ways to improve the safety of operation of chimneys, including boiler plants, include the use of thermal protection systems for gas exhaust ducts from condensate formation. The formation of condensate causes corrosive destruction of these ducts and is, therefore, considered to be an inhibiting factor for the widespread introduction of heat-recovery technologies in boiler houses with the deep cooling of boiler flue-gases and the use of the heat of vaporization contained in these gases [1–3].

Literature review. To protect the exhaust-ducts of boiler plants in the conditions of use of heat-recovery technologies, thermal methods are used to prevent condensate formation on the internal surfaces of these ducts. Among these methods, the most notable are methods related to the heat and humidity treatment of the exhaust-gases of boilers after their heat-recovery [4, 5]. These are the methods of partial bypassing of hot gases after the boiler past the heat-recovery equipment, drying of the exhaust-gases cooled in this equipment in an additional heat exchanger – gas preheater, and mixing dry and heated air to the cooled gases.

The first two of these methods have become widely used in the development of heat-recovery technologies. The use of the third method, called air method, is very limited. The essence of this method is to reduce the humidity and increase the temperature of the cooled exhaust-gases of boiler plants before they enter the chimney by adding to them a part σ of heated air with relatively small absolute humidity. The limited use of this method is usually due to the lack of air heaters in boiler plants.

In modern developments of heat-recovery systems, their own air heaters – heat exchangers – are applied, in which combustion air is heated through the use of recovered heat [4, 6–9]. This circumstance may expand the scope of the air method.

The study of the effectiveness of the use of the method for mixing heated air in heat-recovery systems to protect the gas exhaust ducts of boiler plants is the main objective of this work.

Purpose: improving the environmental safety of chimneys of heating boiler plants with exhaust-gas heat-recovery systems based on the use of the air method to prevent condensation in the exhaust ducts in combination with the method for drying the gases by heating them.

Methods. The research was carried out when applying traditional heat-recovery systems for boiler plants; the systems had single heat exchangers for heating return heat-network water, and when adding the heat-recovery exchangers for heating the combustion air to these systems. That is, when using complex with water-heating and air-heating heat exchangers for recovery of heat of the boiler exhaust-gases. At the same time, various options of the air method for use in the heat-re-

Initial data

| Parameter name | Value |
|-----------------------------------------------------------------------------------------------|-----------|
| Boiler heating capacity, MV | 2.0–1.0 |
| Excess air ratio | 1.1 |
| Environment temperatures, °C | -20 – +10 |
| Return water temperature, °C | 70–35 |
| Exhaust-gas temperature, °C | 157–95 |
| Exhaust-gas consumption, kg/sec | 0.95–0.47 |
| Water consumption, kg/sec | 19.4 |
| Air consumption, kg/sec | 0.87–0.41 |
| The moisture content of the exhaust-gases at the outlet of the boiler, kg/kg d.g. (dry gases) | 0.135 |
| Air moisture content, kg/kg d.a. (dry air) | 0.01 |

covery circuits were considered, namely: in the presence and absence of heaters in the boiler house. In the second variant, for predrying the exhaust-gases air heated by recovering the heat of the exhaust-gases of the boiler was used. Figs. 1, 2 show schematic circuits of boiler plants equipped with appropriate heat-recovery systems.

In the first of the above schemes, the air heated in the air heater of the boiler room is used to dry the exhaust-gases, and in the second scheme the corresponding thermal and humidity treatment of these gases can be carried out using one (air) or two thermal methods (Air method and gas predrying in the exhaust-gas heater). In this case, the air method is implemented by adding the air heated in the heat-recovery system itself, to the cooled exhaust-gases. The required level of mixing air and heating gases is determined by the conditions of their cooling in the exhaust ducts and chimney.

In order to determine the effectiveness of using these thermal methods to prevent the formation of condensate in the gas exhaust ducts under different boiler operation modes during the heating period for the above schemes, the flue gas dew point temperatures t_d and the surface t_s in the most vulnerable area of the duct – the mouth of the chimney, were calculated. At that, brick and metal chimneys and working conditions of the boilers were considered, in which, when their power load drops to 50 % of the nominal, the corresponding number of boilers is transferred to the nominal mode while their total number decreases. In the calculations, the operating parameters of the KSVa-2.0G (KCB-2,0Г) boiler were used, which corresponded to the heat schedule of the heating system with the calculated temperature $t_{ch} = -20$ °C and the temperature difference of the heat carrier 70–95 °C (Table 1).

To assess the effectiveness of the thermal method, the criterion γ was used, which is determined by the formula

$$\gamma = Q_m / Q_{hr} \cdot 100 \%, \quad (1)$$

where Q_m is thermal power required to implement the method; Q_{hr} is heat power of heat-recovery system.

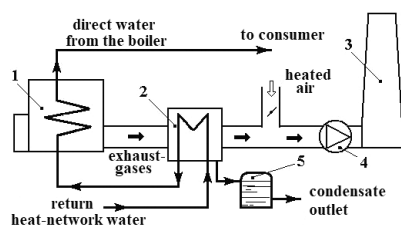


Fig. 1. Schematic circuit of a boiler plant with usage air method to prevent the formation of condensate in the exhaust duct at using a water heat-recovery exchanger:

- 1 – boiler; 2 – water heat-recovery exchanger; 3 – chimney; 4 – exhauster; 5 – condensate collector

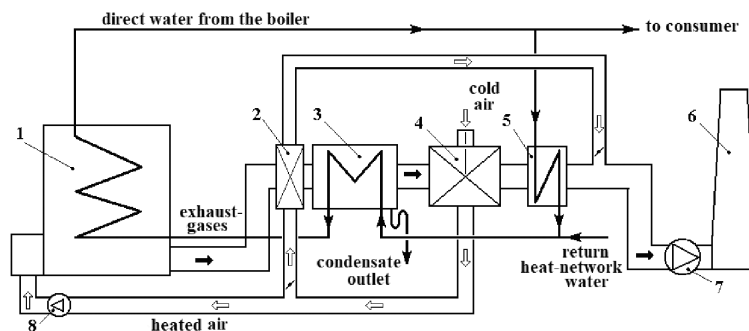


Fig. 2. Schematic circuit of a boiler plant with usage of air method to prevent the formation of condensate in the exhaust duct at using complex heat-recovery system:

- 1 – boiler; 2 – air heater for mixing; 3, 4 – water and air heaters; 5 – exhaust-gas heater; 6 – chimney; 7 – exhauster; 8 – fan

Results. Figs. 3–4 show the characteristic results of the studies carried out when using a single water heater and mixing air from air heater of a boiler room in the heat-recovery system. The temperature of the mixed air was taken in the practical range of air heating in air heater of the boiler room: $t_{ah} = 150$ °C.

As can be seen from the above data, the surface temperature at the mouth of the chimney depends significantly on the type of chimney, the mode of operation of the boiler plant during the heating period and the volume of mixed heated air. So for a brick chimney, characterized by relatively high thermal insulation properties of the body, preventing the formation of condensate at the mouth of the chimney during the heating period is provided by mixing heated air with a fraction of σ , which varies from 0 to 12 % depending on the environment temperature t_{env} . At this, the coefficient of heat consumption for drying the cooled exhaust-gases γ_d does not exceed 23 %.

As for the metal chimney, as shown by the data obtained, the prevention of condensate formation with mixing fractions σ up to 20 % is realized only in the operating modes of the boilers close to the nominal, which correspond to low environment temperatures ($t_{env} < -10$ °C). In other modes of operation of the boilers, corrosion protection of chimneys requires significant additional heat consumption ($\gamma_d > 40$ %). When operating metal chimneys in conditions of using heat-recovery technologies in boiler practice, it is effective to enhance the insulating properties of the chimney body by coating it with low thermal conductivity materials [10].

The data presented in Fig. 3 also show that the most dangerous mode of operation of chimneys in terms of condensate

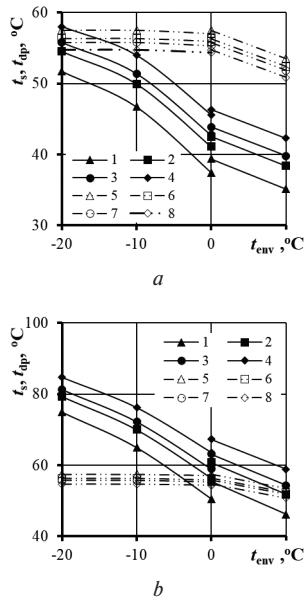


Fig. 3. The dependence of the temperature of the inner surface t_s at the mouth of the chimney (1–4) and the dew point t_{dp} (5–8) on the ambient temperature at $t_{ah} = 150\text{ }^\circ\text{C}$, $t_{gn} = 160\text{ }^\circ\text{C}$ (exhaust-gas temperature in nominal mode of boiler) for the hot water boiler when using the air method for different values of the mixing air σ :

1, 5 – $\sigma = 0\%$; 2, 6 – 8% ; 3, 7 – 12% ; 4, 8 – 20% ; a – metal chimney; b – brick chimney

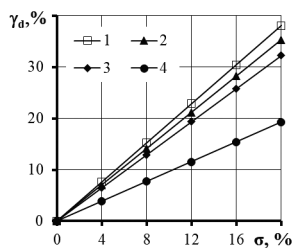


Fig. 4. The dependence of the ratio of the relative consumption of heat γ_d for the implementation of the air thermal method on the proportion of mixed air σ at $t_{ah} = 150\text{ }^\circ\text{C}$, $t_{gn} = 160\text{ }^\circ\text{C}$:
1 – at $t_{env} = -20\text{ }^\circ\text{C}$; 2 – $-10\text{ }^\circ\text{C}$; 3 – $0\text{ }^\circ\text{C}$; 4 – $10\text{ }^\circ\text{C}$

formation in them is the mode corresponding to the temperature range t_{env} of the heating period from minus 5 to $+10\text{ }^\circ\text{C}$.

Under these conditions, due to a decrease in the heat load of the boilers and the temperature of their exhaust-gases, these gases are deeply cooled in the heat exchange equipment, which requires enhanced measures for their further drainage.

When $t_{env} < -5\text{ }^\circ\text{C}$, brick and metal chimneys with heat insulation can be reliably operated without the addition of heated air.

With regard to the results of studies on the effectiveness of the protection of the gas exhaust ducts for the complex heat-recovery system (Fig. 2), two options were considered, as noted. The first concerned the use of only one air method to prevent the formation of condensate, and the second was to jointly apply this method and the method for drying cooled exhaust-gases in an exhaust-gas heater. Research data on dew point temperatures t_{dp} of gases and surface t_s in the first version showed its low efficiency. So due to the relatively low temperature ($63\text{--}96\text{ }^\circ\text{C}$) of the air heated in the heater 2, even at $\sigma = 100\%$, the necessary condition $t_s > t_{dp}$ was not fulfilled in some operating modes of the boiler. In this case, the coefficient γ_d varied within $20\text{--}40\%$. Actually, due to the low efficiency of this option, another one was proposed.

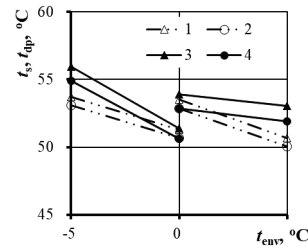


Fig. 5. The dependence of the internal surface temperature t_s at the mouth of a brick chimney (3, 4) and dew point t_{dp} (1, 2) as a function on the environment temperature t_{env} when using the air method with a fraction of mixed air $\sigma = 5\%$ (2, 4) and without it (1, 3)

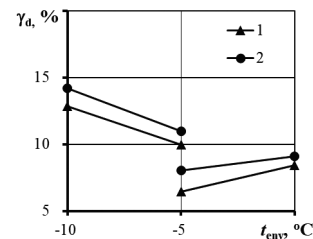


Fig. 6. The dependence of the ratio of the relative consumption of heat γ_d on the environment temperature t_{env} for the implementation of the air thermal method with the proportion of mixed air $\sigma = 5\%$ (2) and without it (1)

The results of studies on the effectiveness of preventing the formation of condensate in a brick chimney in the most vulnerable operating temperature range ($-5\text{ }^\circ\text{C} < t_{env} < +5\text{ }^\circ\text{C}$) for the second variant are shown in Figs. 5, 6.

These data indicate that the use of a complex of thermal methods in these conditions can prevent the formation of condensate in the chimney at significantly lower levels of the coefficient of consumption of heat γ_d (approximately 1.3 times). At the same time, the proportion σ of the mixed air in the considered range of environment temperatures varies from 0 to 5% . That is, for some environment temperatures during the heating period, the heat-recovery system can be used without admixture heated air.

At the same time, in the boiler plant, the flow of heated combustion air increases by the fraction σ , respectively, the effect of heat-recovery of the boiler exhaust-gases increases.

When using a metal chimney, the application of the proposed set of methods can also give a close positive result, provided that the pipe body will be insulated.

Thus, when applying the proposed protection system in heat-recovery technologies of boilers, safe operation of chimneys is realized.

In addition to observing the environmental reliability of boiler plants by anticorrosive protection of the gas exhaust ducts, the proposed heat-recovery systems are also characterized by additional environmental effects, namely:

- reduction of harmful emissions into the environment due to reduction of fuel consumption by $4.5\text{--}7.0\%$ and dissolution in the condensate of harmful substances formed during its combustion;

- the possibility of beneficial use of condensate formed in the heat-recovery system in the amount of $45\text{--}115\text{ kg/h}$ per 1 MW of boiler thermal power, to recharge heating networks. This circumstance provides a reduction in the consumption of natural water resources in heat supply systems.

Conclusions.

1. The analysis of the effectiveness of the application of air method to improve the environmental reliability of chimneys of heating boilers and preventing the formation of condensate

in them in the conditions of usage of modern heat-recovery technologies are performed.

2. The necessary conditions for the anticorrosion protection of chimneys for various heat-recovery systems and the temperature of the admixed air are determined.

3. The main environmental aspects of the application of heat-recovery technologies for boiler plants are indicated.

The work was carried out under the project R 5.6 "Extension of the resource of elements of heat-recovery plants and chimneys of gas-fired boiler units using polymer micro- and nanocomposites" of the target research program of the National Academy of Sciences of Ukraine "Reliability and Durability of Materials, Structures, Equipment and Structures" (Resource-2), approved Resolution of the Presidium of the NAS of Ukraine dated December 16, 2015 No. 293.

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Екологічна надійність газоспоживальних котелень при застосуванні сучасних теплоутилізаційних технологій

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Мета. Підвищення екологічної безпеки димових труб опалювальних котельних установок із системами теплоутилізації димових газів на основі використання повітряного методу запобігання конденсації в газівідвідних трактах у комплексі з методом підсушування газів шляхом їх підігрівання.

Методика. При проведенні розрахункових досліджень використовувалися відомі методики теплового розрахунку котельних установок і димових труб, а також результати власних експериментальних досліджень стосовно теплообміну й гідродинаміки при глибокому охолодженні відхідних газів котельних установок. Дослідження виконувалися при застосуванні в теплоутилізаційних схемах котельних установок одиночних теплових методів запобігання конденсації в газівідвідних трактах (підсушування димових газів і повітряного методу) та комплексу цих методів. При цьому розглядалися різні варіанти теплоутилізаційних систем і димових труб за наявності в котельнях повітрянагрівачів та за їх відсутності.

Результати. Досліджувалися тепловологісні характеристики вихідних газів в усті димових труб при використанні для зниження вологості цих газів сухого й нагрітого повітря зі зміною його температури в широких межах. Визначалися в розглянутих умовах основні параметри систем антикорозійного захисту димових труб, що забезпечують відвернення в них конденсації при нормативних режимах експлуатації цих труб. За значеннями отриманих параметрів виконано порівняльний аналіз ефективності розглянутих методів захисту газівідвідних трактів для різних теплоутилізаційних установок. Показано, що для опалювальних котлів застосування повітряного методу є найбільш ефективним у комплексних теплоутилізаційних системах, що характеризуються використанням утилізованої теплоти для нагрівання зворотної тепломережної води та дуттьового повітря.

Наукова новизна. Уперше досліджено застосування повітряного методу запобігання конденсації в газівідвідних трактах котельних установок з комплексними системами теплоутилізації.

Практична значимість. Використання запропонованого комплексу теплових методів дозволить суттєво підвищити надійність димових труб опалювальних котелень комунальної теплоенергетики.

Ключові слова: котельні установки, глибоке охолодження відхідних газів, точка роси, конденсація, теплоутилізація

Экологическая надежность газопотребляющих котельных при применении современных теплоутилизационных технологий

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Цель. Повышение экологической безопасности дымовых труб отопительных котельных установок с системами теплоутилизации дымовых газов на основе использования воздушного метода предотвращения конденсатообразования в газоотводящих трактах в комплексе с методом подсушивания газов путём их подогрева.

Методика. При проведении расчетных исследований использовались известные методики теплового расчета котельных установок и дымовых труб, а также результаты собственных экспериментальных исследований касательно теплообмена и гидродинамики при глубоком охлаждении отходящих газов котельных установок. Исследования выполнялись при применении в теплоутилизационных схемах котельных установок одиночных тепловых методов предотвращения конденсатообразования в газоотводящих трактах (подсушивание дымовых газов и воздушного метода) и комплекса этих методов. При этом рассматривались различные варианты теплоутилизационных систем и дымовых труб при наличии в котельных воздухонагревателей и при их отсутствии.

Результаты. Исследовались тепловлажностные характеристики уходящих газов в устье дымовых труб при использовании для снижения влажности этих газов сухого и нагретого воздуха с изменением его температуры в широких пределах. Определялись в рассматриваемых условиях основные параметры систем антикоррозионной защиты дымовых труб, обеспечивающих предотвращение в них конденсатообразования при нормативных режимах эксплуатации этих труб. По значениям получен-

ных параметров выполнен сравнительный анализ эффективности рассмотренных методов защиты газоотводящих трактов для различных теплоутилизационных установок. Показано, что для отопительных котлов применение воздушного метода является наиболее эффективным в комплексных теплоутилизационных системах, характеризующихся использованием утилизированной теплоты для нагрева обратной теплосетевой воды и дутьевого воздуха.

Научная новизна. Впервые исследовано применение воздушного метода предотвращения конденсатообразования в газоотводящих трактах котельных установок с комплексными системами теплоутилизации.

Практическая значимость. Использование предлагаемого комплекса тепловых методов позволит существенно повысить надежность дымовых труб отопительных котельных коммунальной теплоэнергетики.

Ключевые слова: котельные установки, глубокое охлаждение отходящих газов, точка росы, конденсатообразование, теплоутилизация

Recommended for publication by V. G. Prokopov, Doctor of Technical Sciences. The manuscript was submitted 07.05.19.