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Improving the efficiency of the contact heat exchanger with the use of a built-in surface cooler

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ABSTRACT: Recently, the problems of environmental protection have become increasingly important due to the increase in the negative impact on humans. The deterioration of the ecological situation leads to man-made disasters of various scales. The main directions of research in the field of energy in the modern world are energy saving and continuous improvement of energy technologies, as well as saving fuel and other natural resources. Increasing the efficiency of natural gas use is one of the urgent tasks today. Proceeding from this, in the presented work, the results of a study of increasing the efficiency of natural gas in boiler plants of housing and communal structures and many industrial enterprises are considered. The author proposes the use of exhaust gas heat for the purpose of deep cooling, for which a contact-type heat exchanger is used, where the combustion products are cooled below the "dew point". The design of a condensing heat exchanger with cooling of gases below the "dew point" is presented, the dependence of CO_2 concentration in water heated to 40 ^{0}C on the coefficient of excess air in gases is studied.

KEY WORDS: contact heat exchanger, boiler unit, energy efficiency, natural gas, deep cooling, dew points, water vapor condensation, combustion products, heat transfer coefficient, excess air coefficient, heat transfer coefficient.

I. INTRODUCTION

Currently, a huge number of boiler houses (industrial and heating) consuming fossil fuels are operated in the Republic of Uzbekistan. The vast majority of these boilers use natural gas as fuel.

Many boiler houses still operate steam and hot water boilers, flue gas temperature, beyond which 150 - 160 ^{0}C (with surface-type economizers) and up to 350-370 ^{0}C for steam boilers without tail surfaces (example E-1/9)

Since during the operation of boilers on natural gas, heat losses from mechanical underburning are completely absent, and losses from chemical underburning are usually close to zero, the efficiency of natural gas boilers depends mainly on the flue gas temperature, which determines the amount of loss heat with exhaust gases (q_2), while heat loss to the environment (q_5) with modern means of thermal insulation and calculation of q_5 individual for each boiler according to the thermal conductivity of the insulation and the surface of the enclosing structures does not exceed 0.6 - 0.7 % for powerful industrial (75 - 100 t/h, 58 - 78 MWt) and 1,3 – 1,5 % for low-power (1,0 - 20 t/h, 0,7 - 13 MWt) boilers and the determining effect on the efficiency is not render [1 - 4].

Thus, the efficiency of gas boilers with tail surfaces is 90-92% and 84-86% without tail surfaces, when calculating the net calorific value.

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II. EXPERIMENTAL TECHNIQUE

One of the methods for increasing the efficiency of natural gas use in boiler plants of housing and communal structures and many industrial enterprises is the deep cooling of flue gases below the “dew point”, which makes it possible to use the heat of condensation of a part of the water vapor contained in the combustion products of natural gas for preheating make-up water heating networks or feed water of steam boilers.

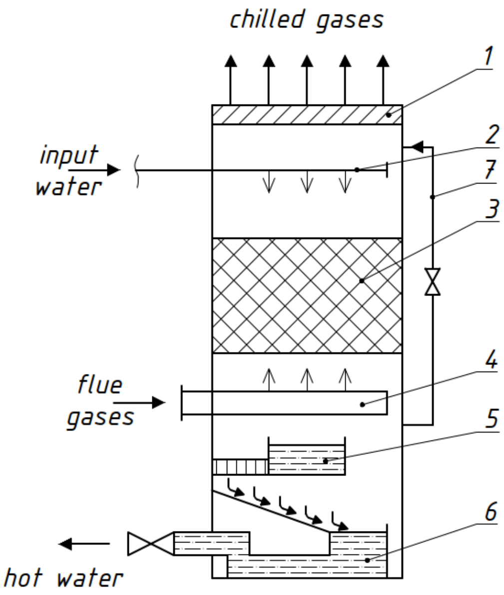

Fig. 1 Design of a condensing heat exchanger with gas cooling below the "dew point".

In the vast majority of boiler houses burning natural gas, the flue gas temperature is 120 - 130 ^{0}C (in the best boiler houses) and up to 270 - 280 ^{0}C (in boiler houses with E-1/g boilers).

In boiler houses with steam boilers, as a rule, surface economizers are used to reduce the temperature of the flue gases, which ensure the efficiency of the boiler plant in terms of lower calorific value $\eta_{\text{ка}} = 90 - 92\ \%$ [1, 5, 6].

The design of the most common type of condensing heat exchanger is shown in Fig. 1.

1. drip catcher
2. distributive collector of source water
3. pin nozzle
4. perforated pipe for flue gas supply
5. water decarbonization device
6. hydraulic seal for the removal of heated water
7. removal of gases CO_2, O_2, removed and water.

Water-heating boilers, on natural gas, have an efficiency of boilers of 92 - 93%, depending on the temperature schedule for heat supply (95 - 70, 110 - 70 ... 150 - 70 ^{0}C).

In any heat supply scheme (classical) above, the heat contained in the water vapor of the exhaust gases is not used. Theoretically, the heat of fully condensed water vapor will increase the thermal efficiency of the unit to ~ 111 % when calculated using the lower (classical) calorific value.

To use the heat of exhaust gases for the purpose of deep cooling, contact-type heat exchangers of various designs are used with cooling of combustion products below the dew point [2, 4, 6].

The dew point of natural gas combustion products of most fields in Uzbekistan at α=1,0 is $t_p = 53 - 58$ ^{0}C.

The initial (raw or softened) water is supplied through the distribution manifold 2 to the contact chamber 3, made of ceramic or plastic elements (Raschig rings, Intalox saddles, etc.), where, in contact with flue gases, it cools them to the dew point temperature and below, providing partial condensation of water vapor contained in the combustion products of natural gas [3, 6].

III. SOLUTION METHODS

Upon contact with flue gases, the temperature of the water rises, depending on the initial parameters of the combustion products (temperature, excess air ratio, moisture content, dew point ...), the temperature of the source water. Theoretically, the limiting value of contact heating of water, equal to the temperature of the "wet" thermometer $\tau_{\text{м}}, a,$ in reality is:

$$t_{\text{в}}^{max} \approx \tau_{\text{м}} - (3 - 6\ ^\circ\text{C})$$

The temperature of the "wet" thermometer, in turn, also depends on the temperature ($t_{\text{г}}$), moisture content ($d_{\text{г}}$) and the coefficient of excess air of gases ($\alpha_{\text{г}}$) - fig. 2 and 3.

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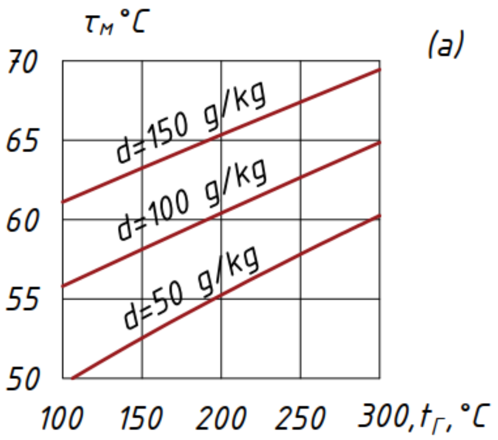

Fig.2. Dependence $\tau_м = f(t_г)$ at different $d_г$

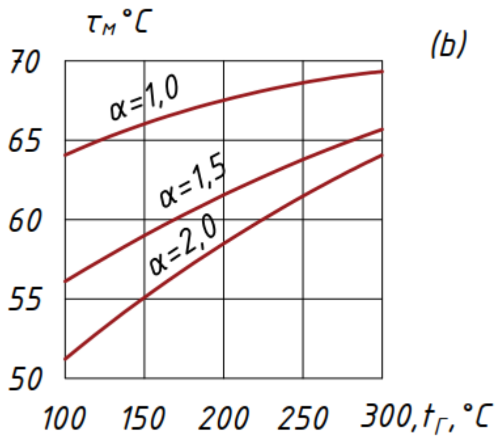

Fig.3. Dependence $\tau_м = f(t_г)$ at different $\alpha_г$

The products of burning natural gas contain carbon dioxide CO_2, oxygen O_2, nitrogen N_2, nitrogen oxides NO_x, benz (o) pyrene $C_{20}H_{12}$, which, upon contact with water, partially pass into its composition. Of practical interest for the use of condensing heat exchangers in heat supply systems are carbon dioxide CO_2 and oxygen O_2, since heating boiler houses of small capacity, as a rule, do not have deaerators, and these gases (CO_2, O_2) have significant corrosive activity to the metal of pipelines and equipment [7 - 11].

The dependence of CO_2 concentration in water heated to 40°C on the coefficient of excess air in gases is shown in Table 1.

Table 1. Dependence of CO_2 concentration (mg/l) in water heated up to 40 ^{0}C by contact method on excess air coefficient α_2 in flue gases.

α_2	1,2	1,4	1,6	1,8	2,0	2,2
CO_2	86	75	62	53	48	45

It should be noted that at a CO_2 concentration of 60-70 in water heated by the contact method, the pH of the water decreases:

- when fed with raw (hard) water up to pH ≈ 6,7 - 7,2
- when fed with softened water up to pH ≈ 4,5 - 5,0

Thus, with contact heating of hard water, the medium remains practically neutral, not representing a corrosion hazard for the metal, and with softened water, the medium acquires a pronounced acidic character with pH = 4.5≪7.0 [12-14]

To prevent a significant decrease in pH, a decarbonization device 5 is designed, which reduces the concentration of CO_2 in the heated water to acceptable limits by blowing air through the system 7 (figure 1).

Approximate flow rate of purge air through the built-in decarbonized of 15-20 m3 per 1 ton of water ensures that the concentration of CO_2 at the outlet of heated water is not more than 25 mg/l, which corresponds to a neutral or weakly acid reaction [15, 16].

An extensive analysis of literature data and operational data on condensing heat exchangers leads to the conclusion that it is permissible to consider the average parameters characterizing their performance indicators [17]:

- temperature of gases after the contact chamber – 40-43 ^{0}C
- relative humidity of gases after the droplet eliminator – 98-100 %
- moisture content at the outlet of the heat exchanger – 45-50 g/kg d.g.

- the degree of gas drying after the contact chamber – 0,45-0,55

The degree (coefficient) of drying (Kos) depending on the temperature of the gases at the outlet of the contact chamber with an average of $\alpha_2 \approx 1{,}4$ is shown in Fig. 4.

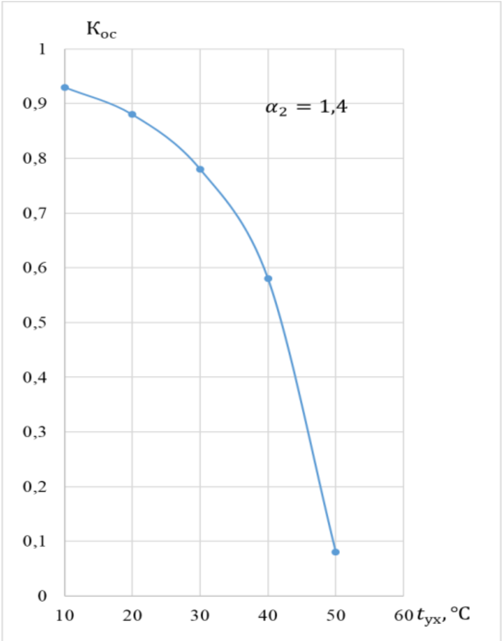

Fig. 4 Gas drying coefficient after the contact chamber $К_{oc} = f(t_{yx}), \alpha_2 = 1{,}4$

At a relative humidity of gases φ ≈ 100 %, cooling in the gas ducts and the chimney will occur with intensive condensation of residual (d_2 ≈ 45 - 50 g/kg d.g.) water vapor with the formation of carbonic acid H_2CO_3 and corrosive wear of the metal of the gas ducts and the chimney. This process will be especially intensive in winter at low temperatures, which will require emergency measures to prevent or at least slow down the metal [6,7, 17, 18, 19].

In order to prevent acid corrosion of gas ducts and a chimney when heating water in contact heat exchangers, it is necessary to achieve the maximum possible degree of gas drying within the condensing heat exchanger to obtain exhaust gases with a minimum moisture content.

This result can be achieved by using a surface-type gas cooler located within the condensing heat exchanger behind the water distribution manifold.

The authors of this work obtained a patent for a utility model of a contact heat exchanger (patent No. FAP 02070 dated August 22, 2022), on which they studied a surface cooler built into a contact heat exchanger [9, 20 – 23].

Due to the limited size of the article, a detailed description of the design is not given here. Of main interest is the comparison of the indicators obtained at the outlet of the contact chamber and after the surface cooler (table 2).

Table 2. Of main interest is the comparison of the indicators obtained at the outlet of the contact chamber and after the surface cooler

№	Name		Dimension	Contact chamber	Surface cooler	Total value
1	Gas temperature:	at the entrance	°C	120	43	120
		at the exit	°C	43	27	27
2	Moisture content of gases:	at the entrance	g/kg d.g	94,5	48,2	94,5
		at the exit	g/kg d.g	48,2	15,5	15,5
3	Drying ratio		-	0,489	0,678	0,836
4	Thermal power		kW	4,21	4,37	8,58
5	Inlet water temperature		°C	17,0	9,0	-

IV. CONCLUSION

1. The use of a built-in surface cooler increases the gas drying coefficient by 1.71 times, reduces the moisture content of gases by 3.11 times, and increases the heat output by 2.04 times compared to a purely contact chamber;
2. The main conditions for the use of a surface cooler should be considered to be made of alloyed pipes and the presence of cold water in the contact for supply to the cooler with a temperature of 8 - 10 ^{0}C lower than at the inlet to the contact chamber.

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