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Studying on thermal processes during the motion of combustion products in the gas chimneys of the heat power plant

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Abstract. This article discusses the new in Uzbekistan heat recovery technology is leaving the flue gas from boilers. This is achieved by condensation of water vapor therein. An analysis of the advantages and disadvantages of contact heat recovery and surface types. The analysis of the heat transfer coefficients in the condensing heat exchanger surface. The temperature regimes which provide point of the flue gas dew point. The limited stresses in the chimney of the boiler unit are calculated using condensing heat utilizers of the exhaust gas for stations of Uzbekistan.

1. Introduction

As practice shows, the placement of condensing heat recovery units behind the boilers manages to reduce the temperature of the flue gases to 45 ÷ 50^{0}C and at the same time reduce the moisture content in them from 0.115 ÷ 0.125 kg / kg dryer gas (d.g.) up to values of 0.045 ÷ 0.055 kg / kg d.g. This also leads to a decrease in the dew point temperature from 55^0 C to 40^0 C [1, 2]. The condition for the long-term operation of external gas ducts and chimneys is to ensure a thermal regime in the cold season without the appearance of condensation on the internal surfaces of the gas ducts. To do this, it is necessary to ensure that the surface temperature of the external gas duct and chimney t_{cm} rises above the dew point t_d [3-6]. First of all, at the head of the chimney, that is $t^{h.ch.}{}_{cm} > t_d$. From this point of view, a decrease in the temperature of the flue gases after the condensing heat exchanger has a negative effect due to a decrease in the wall temperature tcm, and a decrease in the moisture content in the combustion products is a positive factor due to a decrease in the dew point tp. It is important to evaluate the combined effect of these factors on the condensate fallout during the operation of the boiler unit and its gas ducts [7]. The lack of scientific research in this area can make it difficult to choose a technical solution in the development of condensing heat recovery units for a specific boiler unit, providing an increase in the efficiency and heat generating installations, reliable operation by personnel at a thermal power plant. It is required to determine the method of connecting the condensing heat exchanger,

To exclude condensation of water vapor in chimneys when removing the combustion products cooled in condensing heat exchangers, the following methods are currently used [8, 9]:

- passing through the bypass part of the hot gases, bypassing the condensation heat exchanger;
- mixing of cooled exhaust gases with heated air;

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- heating of cooled gases after the condensation heat exchanger.

2. Methodology

Let us express mathematically the conditions for the reliable operation of gas outlet chimneys of boiler plants equipped with condensing heat exchangers; we will analyze the heat engineering processes in the flue gas duct for the application of protection against hydrate corrosion by bypassing part of the hot gases. In the middle section of the external gas duct *y* in (Figure 1) within the increment of its length *dy* heat balance for flue gases

$$dQ_G = dQ_{out}, \quad (1)$$

here dQ_G is the differential of the heat content in the exhaust gases, in the section *dy* relative to the change in the temperature of the combustion products *dt*, ^{0}C; dQ_{out} - change in the heat flux, W, in the section *dy*, leaving through the chimney structure into the atmosphere

$$dQ_G = -G_G C_G dt \quad (2)$$

here G_G - flue gas flow rate, kg/s; C_G - their heat capacity, J / kg^{0}C. The formula for lowering the temperature of combustion products when they move in the gas duct [6]

$$dQ_{out} = \pi K_l (t_G - t_{amb}) dy \quad (3)$$

here K_l is the coefficient of heat transfer from flue gases through the cylindrical wall of the chimney to the external environment, which has a linear character W/(m·K); t_G is the temperature of the exhaust flue gases, in the section *dy*,^{0}C; t_{amb} air temperature outside, ^{0}C.

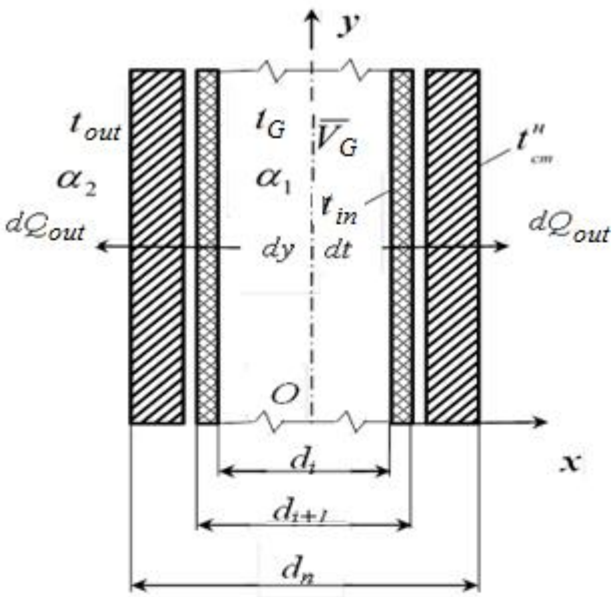

Figure 1. Scheme of heat exchange of combustion products in the chimney

The researches of the authors [10, 11] indicate a turbulent regime of gas movement in chimneys. With the parameters of the gas flow rate V_g = 1 m/s; chimney diameter d_1 = 0.5 m; kinematic viscosity υ = 21.54 · 10^{-6} m/s; Re = 23213 for calculating the convective coefficient of convective heat transfer $\alpha_{1к}$:

$$Nu = 0{,}021\mathrm{Re}^{0,8} \cdot \mathrm{Pr}^{0,44}\left(\frac{\mathrm{Pr}_\omega}{\mathrm{Pr}_c}\right)^{0,25} \cdot \varepsilon_l \quad (4)$$

here ε_l = 1 for $H_{mp}/d1 \geq 5$. In the chimneys of TPP ε_l = 1.0 ÷ 1.05.

Heat transfer coefficient on the outer surface of the chimney [12,13]

$$\alpha_2 = 6{,}3(K \cdot V_w)^{0,66} \quad (5)$$

here V_w – average wind speed, m/s; K is a correction factor that takes into account the change in wind speed along the height of the chimney. According to [12] for the values H_{ch} = 25; 50; 100 and 150 m corresponding to K = 1.2; 1.6; 2.1 and 2.3.

For chimneys with a tapered shape, the average values of the inner and outer diameters d_1 and d_2 are determined by the following formulas:

$$d_1 = \frac{2d_{1in}d_{1out}}{d_{1out}+d_{1in}};\ d_2 = \frac{2d_{2in}d_{2out}}{d_{2in}+d_{2out}}$$

here, respectively, the upper and lower diameters of the chimney are designated through the indices "*in*", "*out*".

According to the heat balance for outgoing flue gases and the law of conservation of volumetric mass for water vapor in gases, the temperature expressions and moisture content in the combustion products at the inlet to the chimney are associated with a part of the gases discharged through the bypass δ [13]:

$$\delta \cdot c_{f.g.} t'_{f.g} + (1-\delta)\cdot c''_{f.g} t''_{f.gx} = 1 \cdot c_{bas} t_G^{base} \tag{6}$$

$$\delta \cdot X'_{f.g} + (1-\delta)\cdot X''_{f.g} = 1 \cdot X_{base} \tag{7}$$

here $c'_{f.g}, c''_{f.g}, c_{base}$ - heat capacity of combustion products before and after the condensation heat exchanger, also mixed gases at the inlet to the chimney, J/(kg·K); $t'_{f.g.}$ $X'_{f.g.x}$ and $t''_{f.g}$ $X''_{f.g}$ – temperature of gases, ^{0}C, and the moisture content in them, kg / kg d.g, before and after the condensation heat exchanger; X_{base} - moisture content of mixed gases at the inlet to the chimney.

3. Results

Calculation of the temperature fields in the wall of the gas exhaust chimney is not the ultimate goal, but only provides the initial data necessary to determine the thermal stresses that generally arise in bodies when they are rigidly fixed or when an inhomogeneous temperature field appears. Due to the temperature effect on the chimney elements, radial and circumferential compressive stresses arise on a hotter surface, and tensile radial and circumferential stresses arise on a less heated surface. In this case, the thermal expansion of the structural elements of the chimney occurs under conditions of free deformation.

The parameter that determines the value of thermal stresses in the elements of the chimney is the temperature gradient, and in the case of a stationary mode of operation, the temperature difference across the thickness of the brickwork or reinforced concrete shell, i.e. chimney walls.

For lining made of acid-resistant bricks, the permissible temperature gradient is taken equal to 80 ^{0}C [14], and to ensure reliable operation of the reinforced concrete chimney, maintain the optimum temperature on its inner surface no more than 100 ^{0}C.

Thus, when operating chimneys, it is important to know the temperature differences on the borehole wall, lining and insulation at a cold ambient temperature. The reliability of the operation of both metal and conventional reinforced concrete and brick chimneys largely depends on the temperature regime.

Since the thermal expansion of structural elements of chimneys occurs under conditions of free temperature deformation, only thermal stresses arise in the vertical sections of a homogeneous chimney barrel, caused by uneven heating of the barrel wall along the thickness. In this case, tensile stresses arise on the outer surface of the chimney wall in winter.

Temperature stress in the laying of the gas outlet chimney [15].

$$\sigma_{mas.1} = 0{,}165 \cdot i_{mas.1} \cdot E_0 \tag{8}$$

here $i_{mas.1}$ –temperature deformation of the masonry of the annular section of the chimney barrel; E_0 - the initial modulus of elasticity of the masonry, MPa.

$$i_{mas} = \alpha_{mas.p} \Delta t \frac{d_1}{d_2} \tag{9}$$

here $\alpha_{masi.p}$ - linear temperature coefficient of wall expansion, 1 / ^{0}C (within t = 20 ÷ 200^{0}C, $\alpha_{кmas.p}$ = 5 10-6 1 / ^{0}C) [18]; Δt - temperature gradient along the chimney barrel wall thickness,

$$\Delta t = t_{cm.in} - t_{cm.out}$$

here $t_{cm.in}; t_{cm.out}$–temperature of the inner and outer surfaces of the chimney barrel walls.

The composition of dry gaseous fuel in percent by volume, its density $\rho_{g.f.}^{dry}$, kg/m^3, and the lowest calorific value Q_l^b, kJ / m^3, under normal conditions can be determined on the basis of data obtained by the operating at the Syrdarya HPP (Table 1.)

Table 1. Characteristics of natural gas for the TGMP-114S boiler at the Syrdarya TPP

Name	CO_2,%	N_2, %	CH_4, %	C_2H_6, %	C_3H_8, %	C_4H_{10}, %	C_5H_{12}, %	$\rho_{r.mn}^c$, kg / m^3	Q_H^c, kJ / m^3
Value	0.8	7.8	84.5	3.8	1.90	0.9	0.3	0.837	36000

Raw, chemically treated water and water for hot water supply can be used as a heated heat carrier. From the point of view of cooling the gases, it is necessary, at least in the last stage of the heat exchanger along the course of the gases, to supply water with the lowest possible temperature and heat it below the dew point of the flue gases. The characteristic of each water flow is its flow rate G_i, kg / s and the temperature at the inlet to the heat recovery unit t'_i, ^{0}C. For chimneys made of reinforced concrete 2000 MPa (E_0 = 0.02 · 10^6 kgf / cm^2) [16].

The presented analytical dependencies were used to calculate the temperature fields, thermal stresses and other parameters of the operation of brick gas outlet chimneys with a height: reinforced brick 320 m at Syrdarya HPP. A number of results on the determination of temperature stresses on internal surfaces in the heads of chimneys are presented in Figure 2

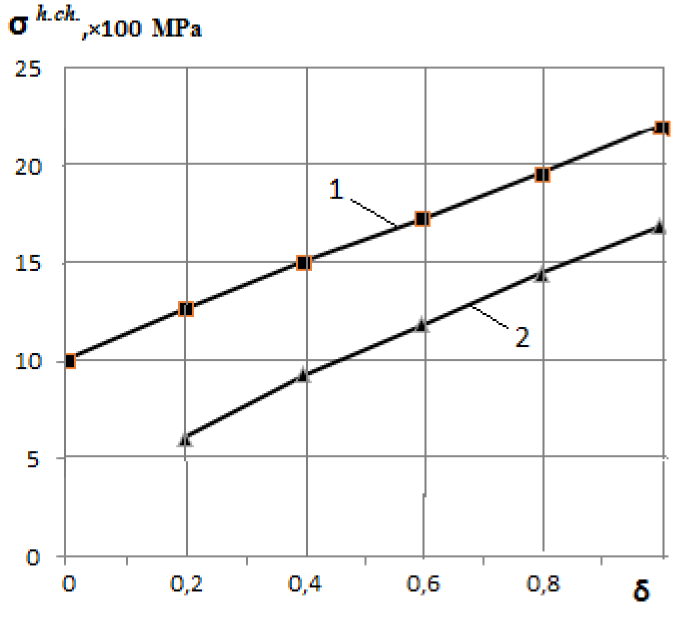

Figure 2. Thermal stress dependence $\sigma_i^{h.ch}$ · 102 MPa, from the proportion of bypass gases δ for a brick chimney; H_{ch} = 320 m; V_0 = 10 m/s, up to $t'_{f.g.}$ = 150^{0}C and after $t''_{f.g.}$ = 60^{0}C of the condensing heat exchanger at the outside air temperature: 1- t_{amn} = -15^{0}C; 2 – t_{amb} = 0^{0}C

4. Conclusions

i) When using condensing heat recovery units in boiler units, the required increase in the temperature of flue gases at the entrance to external gas ducts, which ensures the protection of chimneys from hydrate corrosion, is primarily determined by the thermal insulation properties of the enclosing structures of chimneys and the speed of movement of combustion products in them. The amount of exhaust gases going into the chimney through the bypass varies within a significant range of 20 ÷ 70%, which cannot but affect the heat output of the condensing heat exchanger.
ii) it was found that in brick chimneys with a height of 50 m for a flow rate of exhaust combustion products of 7÷10 m/s, the cooling of gases in winter time in external gas ducts is 7 ÷ 5 ^{0}C when boilers are operating under normal conditions and 4.5 ÷ 3 ^{0}C when installing condensation heat exchangers, and in brick chimney with a height of 320 m, respectively, 3÷2 ^{0}C and 2÷1.5^{0}C. Thus, the connection of a condensing heat exchanger at the Syrdarya HPP with gas bypass will provide permissible voltages during the cold season.
iii) Installation of a condensing heat recovery unit in the gas ducts of the boiler unit reduces the temperature difference with the surrounding air, and as a result, the temperature deformation and thermal stresses in the structural elements of gas ducts and chimneys by 2÷2.5 times. Moreover, regulation with an increase in the bypass fraction of gases leads to an increase in overstresses in cold weather by more than 2 times.

References

[1] Baskakov AP, Munts VA, Filippovsky NF 2009 Analysis of the possibilities of deep cooling of combustion products of boiler plants *Industrial Energy* **10** 14-16.
[2] Bespalov VV 2015 Technologies for deep utilization of flue gas heat *Energy of Tatarstan* **38** 32-36.
[3] Garyaev AB 2011 Improvement of methods for calculating devices and installations for deep utilization of the heat of moist gases and the development of measures to increase the efficiency of its use, Doctor of Science Dissertation, Moscow.
[4] Ionkin IL et al. 2015 Influence of the condensation heat exchanger on the operation of steam and hot-water gas boilers *Thermal Power Engineering* **5** 44-49.
[5] Kudinov AA 1999 Heat and mass transfer in surface-type condensation heat utilizers *Energosberezhenie* **2** 54-57.
[6] Kudinov AA, Ziganshina SK 2011 Energy saving in heat power engineering and heat technologies Mashinostroenie, Moscow.
[7] Kuzma-Kichta YuA, Bukhonov DYu, Borisov YuV 2007 Intensification of heat exchange during condensation of water vapor from outgoing flue gases *Heat Power Engineering* **3** 39-42.
[8] Pavlov DA 2014 Features of the use of natural gas combustion products *Modern High Technologies* **5-1** 181.
[9] Shadek EG 2016 Evaluation of the efficiency of deep utilization of heat from combustion products of boilers of power plants *Energosberezhenie* **2** 62-80.
[10] Jeong K, Kessen M, Bilirgen H, Levy E 2010 Analytical modeling of water condensation in condensing heat exchanger *International Journal of Heat and Mass Transfer* **53** 2361-2368.
[11] Shi X, Che D, Agnew B, Gao J 2011 An investigation of the performance of compact heat exchanger for latent heat recovery from exhaust flue gases *International Journal of Heat and Mass Transfer* **54** 606-615.
[12] Normuminov J, Anarbaev A 2020 Utilizers of the condensing heat in the boiler's unit at heat power station of Uzbekistan *E3S Web of Conferences* **216** 01123.
[13] De Antonellis S, Joppolo CM, Liberati P, Milani S, Romano F 2017 Modeling and experimental study of an indirect evaporative cooler *Energy and Buildings* **142** 147-157.
[14] Gosling SN, Bryce EK, Dixon PG, Gabriel KMA, Gosling EY, Hanes JM et al. 2013 A glossary for biometeorology *International Journal of Biometeorology* **1** 32.

[15] Hessel EF, Zurhake C, Van den Weghe HF 2011 Heating and cooling performance of earth-tube heat exchanger in a mechanical ventilated farrowing house *Journal of Agricultural Science and Technology A* **1** 187-193.
[16] St-Pierre NR, Cobanov B, Schnitkey G 2003 Economic losses from heat stress by US livestock industries *Journal of Dairy Science* **86** E52-E77.