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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  $45 \div 50^{\circ}\text{C}$  and at the same time reduce the moisture content in them from  $0.115 \div 0.125 \text{ kg / kg dry gas (d.g.)}$  up to values of  $0.045 \div 0.055 \text{ kg / kg d.g.}$  This also leads to a decrease in the dew point temperature from  $55^{\circ}\text{C}$  to  $40^{\circ}\text{C}$  [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  $t_{cm}^{h.ch.} > t_d$ . 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  $t_{cm}$ , and a decrease in the moisture content in the combustion products is a positive factor due to a decrease in the dew point  $t_p$ . 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;



- 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

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

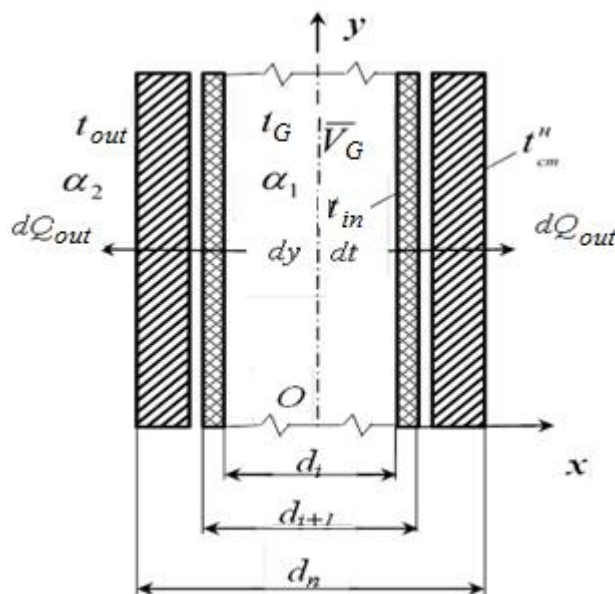
here  $dQ_G$  is the differential of the heat content in the exhaust gases, in the section  $dy$  relative to the change in the temperature of the combustion products  $dt$ ,  $^{\circ}\text{C}$ ;  $dQ_{out}$  - change in the heat flux,  $\text{W}$ , in the section  $dy$ , leaving through the chimney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

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

here  $G_G$  - flue gas flow rate,  $\text{kg/s}$ ;  $C_G$  - their heat capacity,  $\text{J} / \text{kg}^{\circ}\text{C}$ . 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  $\text{W}/(\text{m} \cdot \text{K})$ ;  $t_G$  is the temperature of the exhaust flue gases, in the section  $dy$ ,  $^{\circ}\text{C}$ ;  $t_{amb}$  air temperature outside,  $^{\circ}\text{C}$ .



**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  $d_l = 0.5$  m; kinematic viscosity  $\nu = 21.54 \cdot 10^{-6}$  m<sup>2</sup>/s;  $\text{Re} = 23213$  for calculating the convective coefficient of convective heat transfer  $\alpha_{1k}$ :

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

here  $\varepsilon_l = 1$  for  $H_{mp} / d_l \geq 5$ . In the chimneys of TPP  $\varepsilon_l = 1.0 \div 1.05$ .

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:

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

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  $\delta$  [13]:

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

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

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);  $t'_{f.g}, X'_{f.g}$  and  $t''_{f.g}, X''_{f.g}$  - temperature of gases, °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  $80$  °C [14], and to ensure reliable operation of the reinforced concrete chimney, maintain the optimum temperature on its inner surface no more than  $100$  °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].

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

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.

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

here  $\alpha_{\text{mas.p}}$  - linear temperature coefficient of wall expansion,  $1 / ^\circ\text{C}$  (within  $t = 20 \div 200^\circ\text{C}$ ,  $\alpha_{\text{mas.p}} = 5 \cdot 10^{-6} 1 / ^\circ\text{C}$ ) [18];  $\Delta t$  - temperature gradient along the chimney barrel wall thickness,

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

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

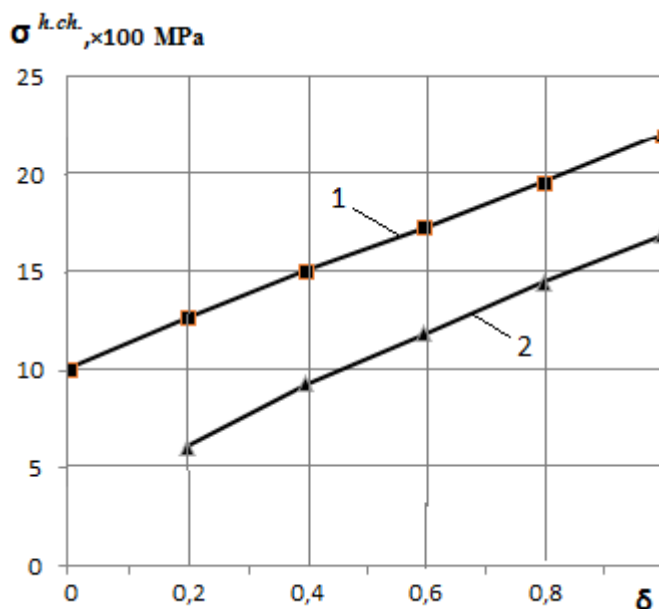
The composition of dry gaseous fuel in percent by volume, its density  $\rho_{\text{g.f.}}^{\text{dry}}$ ,  $\text{kg}/\text{m}^3$ , and the lowest calorific value  $Q_i^b$ ,  $\text{kJ}/\text{m}^3$ , under normal conditions can be determined on the basis of data obtained by the operating at the Syrdarya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

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

Name	CO <sub>2</sub> , %	N <sub>2</sub> , %	CH <sub>4</sub> , %	C <sub>2</sub> H <sub>6</sub> , %	C <sub>3</sub> H <sub>8</sub> , %	C <sub>4</sub> H <sub>10</sub> , %	C <sub>5</sub> H <sub>12</sub> , %	$\rho_{r.mn}^c$ , $\text{kg}/\text{m}^3$	$Q_H^c$ , $\text{kJ}/\text{m}^3$
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  $G_i$ ,  $\text{kg}/\text{s}$  and the temperature at the inlet to the heat recovery unit  $t'_i$ ,  $^\circ\text{C}$ . For chimneys made of reinforced concrete 2000 MPa ( $E_0 = 0.02 \cdot 10^6 \text{ kgf}/\text{cm}^2$ ) [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  $\sigma_i^{h.ch} \cdot 10^2 \text{ MPa}$ , from the proportion of bypass gases  $\delta$  for a brick chimney;  $H_{ch} = 320 \text{ m}$ ;  $V_0 = 10 \text{ m/s}$ , up to  $t'_{f.g.} = 150^\circ\text{C}$  and after  $t''_{f.g.} = 60^\circ\text{C}$  of the condensing heat exchanger at the outside air temperature: 1 -  $t_{\text{amb}} = -15^\circ\text{C}$ ; 2 -  $t_{\text{amb}} = 0^\circ\text{C}$

#### 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  $20 \div 70\%$ , 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  $7 \div 10$  m/s, the cooling of gases in winter time in external gas ducts is  $7 \div 5$  °C when boilers are operating under normal conditions and  $4.5 \div 3$  °C when installing condensation heat exchangers, and in brick chimney with a height of 320 m, respectively,  $3 \div 2$  °C and  $2 \div 1.5$  °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  $2 \div 2.5$  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.

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