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RADIATIVE HEAT TRANSFER IN THE FURNACE SPACE WITH VARIABLE VOLUME

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РАДИАЦИОННЫЙ ТЕПЛОВОЙ ПЕРЕНОС В ПЕЧНОМ ПРОСТРАНСТВЕ С ПЕРЕМЕННЫМ ОБЪЕМОМ

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Abstract. The combustion chamber and flues boiler radiant heat exchange occur between the gas (combustion products) and limiting gas surfaces of the combustion chamber and flues. In this case, part of the energy-emitted gas is absorbed by the surfaces, and part of it is reflected into the gas. The resulting heat flow between the gas and the surface defined by the difference between the amount of energy emitted by the gas on the surface, and the amount of energy absorbed by the gas from the radiation surfaces. The article presents the basic formulas for boilers on solid fuel with movable grate. Calculations show that the change in volume of the furnace leads to a change in radiant heat transfer.

Аннотация. Камера сгорания и дымовая радиация теплового дыма проходят между газом (продуктами сгорания) и предельными газовыми поверхностями камеры сгорания и дымоходов. В этом случае часть излучаемого энергией газа поглощается поверхностями, а часть его отражается в газе. Конечный поток тепла между газом и поверхностью, определяется разностью между количеством энергии, выделяемой газом на поверхности, и количеством энергии, поглощаемой газом от поверхностей излучения. В статье представлены основные формулы для котлов на твердом топливе с подвижной решеткой. Расчеты показывают, что изменение объема печи приводит к изменению лучистого теплообмена.

Keywords: boiler, solid fuel fireplace, grate, the products of combustion.

Ключевые слова: котел, твёрдый топливный камин, решетка, продукты сгорания.

Hot water boilers for solid fuels include furnace grate, heat perceiving flues and a number of supporting elements [1, 2]. In some cases, for the combustion of various fuels and the need to control the temperature of the combustion products, used boilers with moving grate.

In furnaces with a movable grate, heat treatment varies depending on the position of the grate (Figure 1). Geometrical characteristics of the furnace are shown in Table. 1.

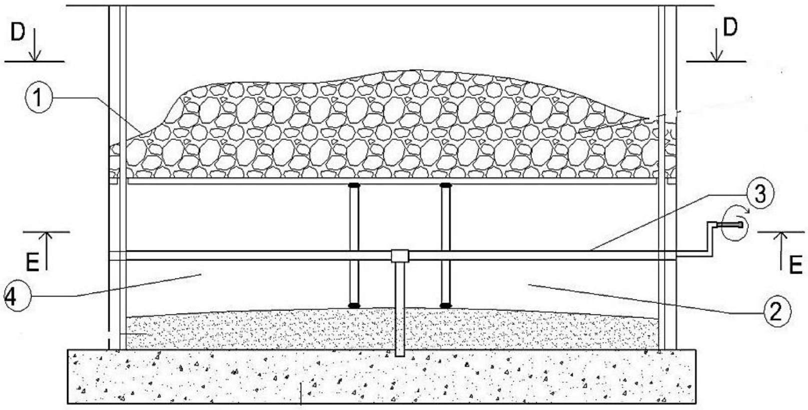

Figure 1. Sema furnace with moving grate

Table 1

GEOMETRIC CHARACTERISTICS OF THE FURNACE

The surface of the walls		*The volume of the combustion chamber*	
Name	*Value*	*Name*	*Result*
The surface of the hearth furnace, m^2	0,2826	The volume of the furnace	$1{,}1304\cdot 10^{-1}$
The lateral surface of the furnace, m^2	0,7536		
The ceiling of the furnace, m^2	0,27033		
The inner surface of the penny-General flue pipe, m^2	0,314	The volume of the central flue pipe	$9{,}8125\cdot 10^{-3}$
The surface of the ceiling flue pipe , m^2	$1{,}2265\cdot 10^{-2}$		
Total	$H_{ст} = 1{,}632795$ м^2	Total	$V_т = 1{,}228525 \cdot 10^{-1}$м^3

The combustion chamber and flues boiler radiant heat exchange occurs between the gas (combustion products) and limiting gas surfaces of the combustion chamber and flues. In this case, part of the energy-emitted gas is absorbed by the surfaces, and part of it is reflected into the gas. The resulting heat flow between the gas and the surface defined by the difference between the amount of energy emitted by the gas on the surface, and the amount of energy absorbed by the gas from the radiation surfaces. Calculated equation for determining the heat flux $q_{г.с}$ transmitted from the surface of the gas, that limiting the gas

$$q_{г.с} = C_0 \frac{\varepsilon_с + 1}{2}\left[\varepsilon_г \left(\frac{T_г}{100}\right)^4 - A_г \left(\frac{T_с}{100}\right)^4\right] \quad (1)$$

Where: $T_г -$ the gas temperature; $T_с -$ surface temperature; $\varepsilon_с -$ the emissivity of the surface; $\varepsilon_г -$ the emissivity of the gas; $A_г -$absorbance of gas at the surface temperature.

The degree of blackness of flue gases is defined by the formula

$$\varepsilon_г = \varepsilon_{CO_2} + \varepsilon_{H_2O} \quad (2)$$

Where: ε_{CO_2}и ε_{H_2O} $-$ the emissivity of carbon dioxide and water vapor.

For determination of the law of variation of the degree of the emissivity of gases in the combustion chamber with a variable volume, combustion chamber will specify distribution of degree of gas blackness by second-degree polynomial

$$\bar{\varepsilon_г} = a + b\bar{t} + c\bar{t}^2 \qquad (3)$$

Where: $\bar{t}$ –the relative temperature in the combustion chamber, $\bar{t} = t/t_т$; $\bar{\varepsilon_г}$ –the relative degree of blackness of gas; $\bar{\varepsilon_г} = \varepsilon_{г,t}/\varepsilon_{г,t_0}$— degree of gas blackness at temperature *t*; $\varepsilon_{г,t_0}$ – emissivity of gas at gas outlet flue of the boiler; *a,b and c* polynomial coefficients are determined from the known boundary conditions

$$\left.\begin{array}{lll} \text{при } \bar{t} = 0; & \dfrac{d\varepsilon_г}{d\bar{t}} = 0; & b = 0 \\ \text{при } \bar{t} = 0; & \bar{\varepsilon_г} = 1 & a = 1 \\ \text{при } \bar{t} = 1 & \bar{\varepsilon_г} = 0{,}45 & c = 0{,}55 \end{array}\right\} \qquad (4)$$

In view of the found coefficients (3) polynomials of degree distribution of gases in the furnace blacks will have the form

$$\bar{\varepsilon_г} = 1 - 0{,}55\bar{t}^2 \qquad (5)$$

Graph of the changes of the degree of gas blackness that built on the obtained dependence is shown on Figure 2. A comparison of Figure 2 with the calculated data given in the technical literature shows a good match. The graph on Figure 3 shows the values $\bar{\varepsilon_г}$ for various values of the position of the grate.

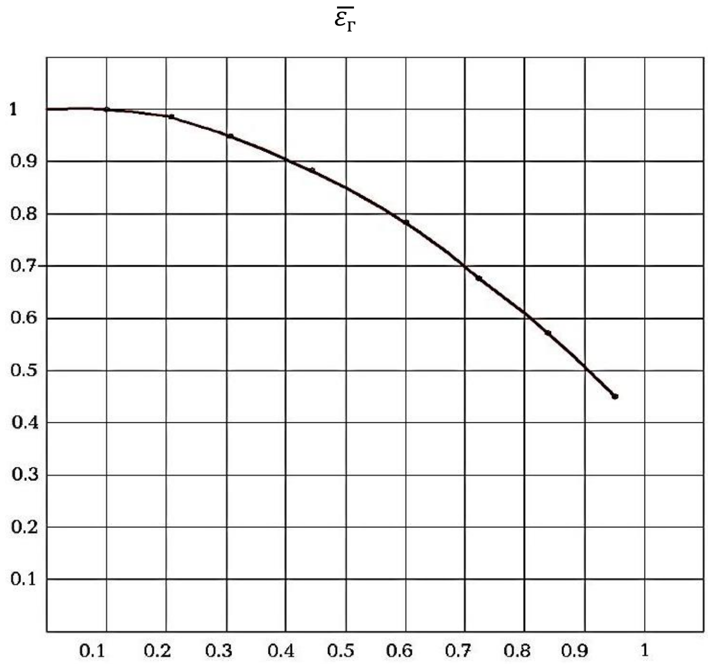

Figure 2. The degree of blackness of the combustion products

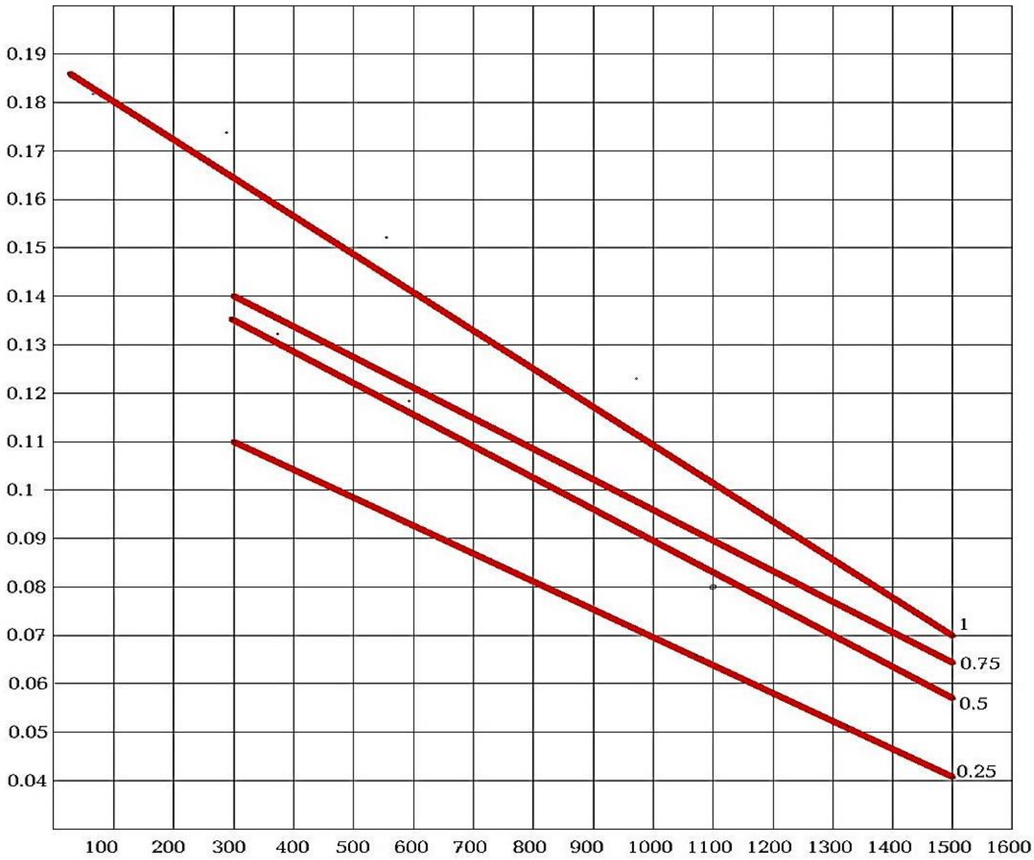

Figure 3. hanging the degree of blackness of the combustion products in the furnace according the temperature and the relative position of the grate

The absorption capacity of gases at a wall temperature is determined

$$A_г = \varepsilon_{CO_2} \left(\frac{T_г}{T_с}\right)^{0,65} + \beta \varepsilon_{H_2O} \quad (6)$$

Degree of gas blackness at an average temperature of the gases is defined by

$$\varepsilon_Г = \varepsilon_{co_2} + \beta \varepsilon_{H_2o} \quad (7)$$

Thermal load of surface of the pipe due to radiation

$$q_л = \frac{1}{2}(\varepsilon_с + 1)C_o \left[\varepsilon_г \left(\frac{T_г}{100}\right)^4 + A_г \left(\frac{T_c}{100}\right)^4\right] \quad (8)$$

The coefficient of heat transfer by radiation

$$q_л = \frac{q_л}{t_г - t_с} \quad (9)$$

Calculation of the results of emissivity of carbon dioxide ε_{CO_2} and water vapor and gases at various temperatures is given in Table 2, 3 and 4.

Table 2

THE DEGREE OF BLACKNESS OF CARBON DIOXIDE ε_{CO_2} AND WATER VAPOR ε_{H_2O} AT VARIOUS TEMPERATURES AND VARIOUS AMOUNTS OF GAS FURNACES $\bar{h}_T$

Gas temperature, Tг	$\bar{h}_т$=1	$\bar{h}_т$ = 0,75	$\bar{h}_т$=0,5	$\bar{h}_т$=0,25
	pl = 0,003908	pl =0,0032879	pl = 0,002751	pl = 0,0018461
1773	0,05	0,047	0,041	0,031
1573	0,06	0,055	0,05	0,042
1373	0,07	0,065	0,06	0,05
1173	0,08	0,078	0,07	0,06
973	0,083	0,08	0,072	0,068
773	0,085	0,07	0,066	0,062
573	0,076	0,072	0,067	0,06

Table 3

DEGREE OF BLACKNESS OF WATER VAPOR

Gas temperature, Tг	$\bar{h}_т$=1	$\bar{h}_т$ = 0,75	$\bar{h}_т$=0,5	$\bar{h}_т$=0,25
	pl = 0,003908	pl =0,0032879	pl = 0,002751	pl = 0,0018461
1773	0,02	0,018	0,017	0,01
1573	0,025	0,022	0,02	0,013
1373	0,035	0,03	0,028	0,017
1173	0,042	0,036	0,034	0,021
973	0,05	0,048	0,036	0,028
773	0,066	0,056	0,053	0,038
573	0,078	0,068	0,064	0,05

Table 4

DEGREE OF GASES BLACKNESS $\varepsilon_Г$

Gas temperature,	$\bar{h}_т$=1	$\bar{h}_т$ = 0,75	$\bar{h}_т$=0,5	$\bar{h}_т$=0,25
	pl = 0,003908	pl =0,0032879	pl = 0,002751	pl = 0,0018461
1773	0,0704	0,06572	0,05868	0,0414
1573	0,086	0,07788	0,0708	0,0552
1373	0,1064	0,0962	0,08912	0,06768
1173	0,1236	0,11544	0,10536	0,0794
973	0,135	0,12992	0,10944	0,08712
773	0,1536	0,12824	0,12112	0,0942
573	0,1571	0,14272	0,13356	0,11

Tables 2, 3 and 4 obtained by calculation:

$$\varepsilon_{H_2O} = \varepsilon_{H_2O,1773} \cdot \left(\frac{1773}{T_г}\right)^{1,6} \bar{h}_т^{0,5} = 0,02\left(\frac{1773}{T_г}\right)^{1,6} \quad (10)$$

The dependence on the definition of the absorbance of gases after some transformations will look as

$$A_г = \bar{h}_т^{0,5} \cdot \left(\frac{1773}{T_г}\right)\left[0,05\left(\frac{T_г}{T_c}\right)^{0,65} + 0,0208\left(\frac{1773}{T_г}\right)^{0,6}\right] \quad (11)$$

Radiant heat exchange between the products of combustion and the heat-receiving wall

$$q_л = \frac{1}{2}(\varepsilon_c + 1)C_o\left[\varepsilon_г\left(\frac{T_г}{100}\right)^4 + A_г\left(\frac{T_c}{100}\right)^4\right] \quad \text{при } \bar{h}_т = 1 \quad (12)$$

Radiant heat transfer generally:

$$q_л = \frac{1}{2}(\varepsilon_c + 1)C_o\left[\varepsilon_г\left(\frac{T_г}{100}\right)^4 - A_г\left(\frac{T_c}{100}\right)^4\right] = \frac{1}{2}(\varepsilon_c + 1)C_o\bar{h}_т^{0,5}\left[\varepsilon_г\left(\frac{T_г}{100}\right)^4 - 0,19\left(\frac{T_c}{100}\right)^4\right] \quad (13)$$

Here $A_г$ for engineering calculations with an accuracy of up to 5% can be represented by the dependence:

$$A_г = \left[\varepsilon_{CO_2}\left(\frac{T_г}{T_c}\right)^{0,65} + 0,0208\left(\frac{1773}{T_г}\right)^{0,6}\right] - = 0,19 \cdot \left(\frac{1773}{T_г}\right) \quad (14)$$

Thus, the change of the furnace volume results in a change (increase or decrease) of radiant heat transfer.

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