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STUDY OF FEATURES OF STAGE REGIME OF HEATING FLAMING THERMAL FURNACES OF CHAMBER TYPE

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There is educed necessary degree of the incomplete burning of fuel on the first stage of its stage burning in the flaming thermal furnaces of chamber type. There is set growth of temperature of burning products on the second stage of burning at homogenization of the field of temperature. There are certain conditions of realization for management the stage regime of heating in the furnaces of this type.

Keywords: thermal furnace of chamber type, burning of fuel, stage regime, its features

Actuality of problem. At the conditions of continuous increase of cost of energy carriers the task of economy of natural gas actual becomes in a metallurgical production, where its basic consumers the flaming thermal furnaces of chamber type serves. In this connection new decision on heating of foregoing furnaces and improvement of management their thermal work, allowing to optimize an external heat exchange [1], both from position of increase of evenness for heating of metal and economies of power resources are needed.

Analysis of publications. In the middle XX century in heating of boiler plants began successfully to apply the method of stage burning of fuel [2], which provide artificial distribution of burning process in space by the distributed admission of air and successive burning of fuel parts in structurally or the gas-dynamically divided zones.

In future stage burning of fuel found application in the heater furnaces of metallurgical and machine-building industry for the receipt of low- or non-oxidation atmosphere. However decline of oxidization for metal the less expected size and presence of additional contamination of atmosphere by the carbon monoxide limits application of this method.

The problems of afterburning of combustible components in the working chamber of industrial furnaces at stage burning are considered in works [3,4]. It is set that for maintenance of calorimetric temperature of fuel most rational is the use as an oxidant of oxygen for order to prevent the losses of heat on heating of cold nitrogen of air. There is executed the coverage of the existent systems of afterburning and there are educed prospects of its use in industrial furnaces.

Problem formulation. The task of work is an estimation of necessary degree of the incomplete burning of fuel on the first stage of its burning, increase for temperature of burning products on the second stage of burning at supply homogenization for the field of temperature, and also determination of conditions of realization of content the stage regime of heating in the thermal furnaces of chamber type.

Basic part of researches. Stage burning of fuel in the furnaces of this type will be realized by organization of gaseous fuel burning at the coefficient of expense of primary air $\alpha_1 < 1.0$ with the receipt of air-gas mixture, consisting of products of the incomplete burning and her subsequent afterburning directly in a gas stream. Process of burning in a stream at permanent pressure, in obedience to a classic theory [6,7], carried out by advance of secondary air to the air-gas mixture at their moving in space. Thus the transmission of heat from a layer to the layer of mixture is executed by heat conductivity (by diffusion). Moving of front of fire is executed in the direction of transmission of heat, that corresponds to the burning process of free flame with external interfusion originally in the zone of burning, and then and in the zone of the diffusive burning.

Considering burning products, got on the first stage of burning of fuel, as combustible components, and process of afterburning - as a process of mixing of these components with secondary air directly in the working chamber of furnace of chamber type and subsequent burning of air-gas mixture, in according to Semikin classification [8], the stage regime can be examined as a process of fire burning with complete external interfusion. At this case most length of flame is arrived, that provides packing of longitudinal space of working chamber of furnaces of this type by products of burning.

The directed moving of front of distribution of fire along the streams of burning products is carried out at presence of gradient temperature with a temperature at the beginning of stream, sufficient for lighting mixture of combustible components and air. Thus firing is carried out in the zone of mixing of air-gas mixture and air at a contact with fire of flame.

In connection with that the afterburning of burning products is executed at normal distribution of fire for the stable burning it is necessary to provide the concentration of combustible components in the range of her self-ignition. For mixture natural and blast gases basic combustible components are methane (CH_4) and carbon monoxide (CO). Their content in burning products is determined by both the coefficient of expense α_1 for primary air, given in gas-rings and coefficient of expense α_2 of secondary air, applied into for the afterburning of primary burning products. A range of self-ignition for methane is 5.6-14.5 %, for the carbon monoxide is 16.3-.71.2 %. For mixture of fuel and air with considerable content of noncombustible components the range of self-ignition of mixture is taped. At stoichiometrical correlation of fuel and air this mixture at a contact with fire of flame always inflames independently on its initial temperature.

The temperature of mixture of combustible components of fuel and air after the first stage of burning of fuel must be below than temperature of self-ignition that allows avoiding firing of mixture in all volume of chamber and, the same, to provide the regime of burning. At the increase of initial temperature of mixture the range of it self-ignition develops. So, from data of work [6], increase of temperature of mixture to 700 °C accompanied by expansion of limits of self-ignition to 3.25-18.75 %.

Speeds of normal distribution of fire for methane and carbon monoxide have approximately an equal size and depend both on composition of mixture before a afterburning and from the coefficient of expense for secondary air α_2. Its maximal value for the carbon monoxide is arrived at $\alpha_2 < 0.60$, and for methane at $\alpha_2 = 0.97$. Thus, a control is possible by speed of distribution of fire flame, and, consequently, and distributions of temperature along the stream of burning products of fuel by the change of coefficients of expense for primary α_1 and secondary α_2 air.

Intensity of diffusive burning of fuel is determined by quality of mixture formation. So, at the afterburning of stoichiometrical mixture of fuel and air in the laminar regime of flow speed of burning depends both on character of interfusion and speeds of gas stream. At the turbulent regimes of flow of the designated mixture interfusion takes place more intensively. Distribution of burning is carried out both by heat conductivity and turbulent pulsations and, in the total, determined by hydrodynamics of gas stream. Thus, than below heat of burning and concentration of combustible components, the slower there is distribution of flame. At the turbulent regimes of flow the process of interfusion is so accelerated, that burning can be completed directly in the zone of afterburning for fuel.

The regime of flow of gas stream at other conditions depends on the expense of mixture of fuel and air, determined by the thermal loading of furnace, variable during all cycle of heat treatment, that is accompanied by the change of distribution of components of burning in a working chamber, and, consequently, and the field of temperature in it. Moving of zone of afterburning along a gas stream is arrived at by shift of place of input of secondary air. However as far as distance of place of its input in relation to the zone of complete burning in a furnace the temperature of air-gas mixture can appear considerably below than temperature of self-ignition. In this case application of the forced lighting with the use of the special devices is needed. At the same time local input of cold secondary air to the zone of afterburning is tracked by a cooling effect, reducing potential of temperature for afterburning mixture at $\alpha_2 >> 1.0$. In this connection in the process of management it is necessary to execute control and optimization of coefficient of expense for secondary α_2 air.

Analysis of temperature conditions of primary burning of gaseous fuel, and also secondary afterburning of its combustible components executed on the basis of making of instantaneous thermal balances for every stage of the regime of heating. Thus next assumptions are accepted:

- combustible components, participating in burning, have a permanent heat capacity;
- burning of fuel takes place in adiabatic conditions;
- cold air, which offset from an atmosphere, does not have influence on the temperature of primary burning of fuel in a flame, and participates only in the process of afterburning of burning products.

Equation of thermal balance for the first stage of burning of fuel looks like:

$$\left[Q_l^w\right]_{\alpha_1} = C_{pb} \cdot V_{\alpha_1}^{\mathrm{I}} \cdot T_{pb}^{\mathrm{I}} , \qquad (1)$$

where $\left[Q_l^w\right]_{\alpha_1}$ is a heat of fuel burning at the coefficient of expense for air α_1; C_{pb}, $V_{\alpha_1}^{\mathrm{I}}$, T_{pb}^{I} - accordingly heat capacity, volume expense and temperature of burning products; an index «I» is the first stage of fuel burning at the stage regime of its burning.

The decline of temperature of burning products $\Delta T_{pb}^{\mathrm{I}}$ at the incomplete burning of fuel on the first stage of its burning is determined as

$$\Delta T_{pb}^{\mathrm{I}} = T_{pb}^{0} - T_{pb}^{\mathrm{I}} = \frac{\left[Q_l^w\right]_{\alpha_1=1}}{C_{pb}\cdot V_0} - \frac{\left[Q_l^w\right]_{\alpha_1}}{C_{pb}\cdot V_{\alpha_1}}\ , \qquad (2)$$

where index «0» is a condition of complete of burning for fuel.

Realization of the second stage of burning for fuel in the thermal furnaces of chamber type - afterburning of products of its incomplete burning - possible both by the organized serve of secondary air through the special devices directly in the zone of afterburning and leaking of cold air through the specially provide channels in the protection of the working volume of furnace.

On the second stage of burning for fuel at organization of serve of secondary air through the special channels, equation of thermal balance looks like:

$$\left[Q_l^w\right]_{\alpha_1} + C_{pb}\cdot V_{\alpha_1}^{\mathrm{I}}\cdot T^{\mathrm{I}} = V_{\alpha_2}^{\mathrm{II}}\cdot C_{pb}\cdot\left(T^{\mathrm{I}} + \Delta T_{pb}^{\mathrm{II}}\right)\ , \qquad (3)$$

where $\left[Q_l^w\right]_{\alpha_1}$ is a heat of combustion for fuel on the second stage of its burning at the coefficient of expense for primary air $\alpha_1 < 1{,}0$, $V_{\alpha_2}^{\mathrm{II}}$, $\Delta T_{pb}^{\mathrm{II}}$ - accordingly volume expense and increase of temperature of burning products at the afterburning of combustible components; an index «II» is the second stage of burning of fuel.

Deciding equation (3) relative $\Delta T_{pb}^{\mathrm{II}}$, get

$$\Delta T_{pb}^{\mathrm{II}} = \frac{\left[Q_l^w\right]_{\alpha_1} + \left(C_{pb}\cdot V_{\alpha_1} - C_{pb}\cdot V_{\alpha_2}^{\mathrm{II}}\right)\cdot T^{\mathrm{I}}}{C_{pb}\cdot V_{\alpha_2}^{\mathrm{II}}}\ . \qquad (4)$$

In the case of leaking of cold air in the zone of the primary burning of furnace and as far as passing through a working chamber its heating is carried out to the temperature, near to the temperature of burning products. In this case equation of thermal balance can be written down as

$$C_{pb}\cdot V_{\alpha_1}\cdot T^{\mathrm{I}} + C_a\cdot L_0^{\mathrm{II}}\cdot\alpha_2\cdot T^{\mathrm{I}} + \left[Q_l^w\right]_{\alpha_1} = C_{pb}\cdot V_{\alpha_2}^{\mathrm{II}}\cdot\left(T^{\mathrm{I}} + \Delta T^{\mathrm{II}}\right)\ , \qquad (5)$$

where L_0^{II} is theory necessary volume of air for the complete afterburning of burning products; C_a is a volume heat capacity of air.

From where

$$\Delta T_{pb}^{\mathrm{II}} = \frac{\left[Q_l^w\right]_{\alpha_1} + T^{\mathrm{I}}\cdot\left(C_{pb}\cdot V_{\alpha_1} + C_a\cdot L_0^{\mathrm{II}}\cdot\alpha_2 - C_{pb}\cdot V_{\alpha_2}^{\mathrm{II}}\right)}{C_{pb}\cdot V_{\alpha_2}^{\mathrm{II}}}\ . \qquad (6)$$

The calculations of content of combustible components in burning products, acting’s on the second stage of burning for fuel, execute with the use of correlation:

$$[CC]^{II}_{\alpha_2} = \frac{[CC]^{I}_{\alpha_1} \cdot V_{\alpha_1}}{0{,}01V^{I}_{\alpha_1} \cdot \left([CC]^{I}_{\alpha_1} + \sum [NCC]^{I}_{\alpha_1}\right) + \alpha_2 \cdot (1-\alpha_1)}, \quad (8)$$

where $[CC]^{II}_{\alpha_2}$ is content of combustible components in burning products, acting's on the second stage of afterburning of fuel at the coefficient of expense for air α_2; $[CC]^{I}_{\alpha_1}$, $[NCC]^{I}_{\alpha_1}$ are content of combustible and noncombustible components in burning products after the first stage of burning accordingly.

Expressions (4) and (6) got in a general kind allow in number to estimate the size of change of temperature of burning products of fuel at various conditions its burnings for the thermal furnaces of chamber type and, the same, to define the features of flowing of the stage regime at their heating.

The case of heating of foregoing furnaces mixture natural and blast gases with the heat of combustion 10472.5 kJuo/m^3 and composition, presented in a table. 1, are examined.

Table 1 - Composition of dry components of mixture of gases

Type of gas	Components, %							
	CH_4	C_2H_2	C_3H_8	C_4H_{10}	CO_2	CO	H_2	N_2
Natural	98,8	0,4	0,2	0,1	0,1	-	-	0,4
Blast	0,1	-	-	-	10,7	28,5	2,5	58,2

For natural gas the experienced results on composition of products of the incomplete burning depending on the coefficient of expense for air (1, driven to the table. 2 are used [9]. The calculation of blast gas was executed as for one component combustible gas (table .2).

Table 2 - Composition for products of the incomplete burning natural (numerator) and blast (denominator) gases, %

Components	Contents of components at the coefficient of expense for air α_1				
	0.65	0.70	0.80	0,90.	1.0
CO_2	5,0 / 22,0	5,6 / 22,1	7,3 / 20,2	8,6 / 19,3	9,0 / 18,9
O_2	– / –	– / –	– / –	0,3 / –	2,0 / –
CO	10,2 / 8,5	8,4 / 6,3	5,2 / 4,4	2,9 / 1,7	1,0 / –
H_2	10,0 / –	8,2 / –	5,2 / –	2,6 / –	0,9 / –
CH_4	1,4 / –	1,0 / –	0,6 / –	0,2 / –	– / –
N_2	– / 2,9	– / 2,7	– / 2,4	– / 2,1	– / 1,9
H_2O	73,4 / 66,7	76,9 / 69,8	82,0 / 73,2	85,5 / 76,9	87,0 / 79,0

With use of formula (2) the decline of temperature of burning products on the first stage of burning for fuel $\Delta T_{pb}^{\mathrm{I}}$ (table 3) are calculated.

Table 3 - Decline of temperature of burning products on the first stage of burning fuels, $\Delta T_{pb}^{\mathrm{I}}$

Decline of temperatures for burning products, $\Delta T_{pb}^{\mathrm{I}}$, °C	Coefficient of expense for air, α_1				
	0.65	0.70	0.80	0.90	1.0
	497.3	482.6	340.3	182,8	-

As follows from the analysis of calculation data, on the first stage of burning of fuel at diminishing of coefficient of expense for air α_1 to 0.65 there is a decline of temperature of burning on 23.3 %.

With the use of formulas (4) and (6) the calculation of increase of temperature for burning products $\Delta T_{pb}^{\mathrm{II}}$ on the second stage of burning of fuel at the different ways of admission of secondary air depending on values α_1 and $\Delta T_{pb}^{\mathrm{I}}$ (table 4) is executed.

Table 4 is temperature of products of burning on the second stage of burning $\Delta T_{pb}^{\mathrm{II}}$ depending on a temperature $\Delta T_{pb}^{\mathrm{I}}$ and values of coefficients α_1 and α_2

Temperature burning products $\Delta T_{pb}^{\mathrm{I}}$, °C	Increase of temperature for burning products, $\Delta T_{pb}^{\mathrm{II}}$, °C, at a coefficient α_1:			
	0.65	0.70	0.80	0.90
400^{I}	971,6 / 1086,1	839,1 / 759,,1	608,7 / 676,6	308,6 / 340,5
1000	803,8 / 1090,2	719,0 / 786,3	533,4 / 703,8	284,1 / 363,6
400^{II}	770,0 / 918,1	505,7 / 655,4	460,2 / 528,0	206,2 / 236,8
1000	542,4 / 912,2	320,6 / 570,2	310,4 / 480,2	100,6 / 176,7

Note: results of calculations of fuel burning in a numerator and denominator at the cart of secondary air on the special channels and at leaking atmospheric air are brought
I, II is a afterburning of products of burning at α_2 = 1.0 and α_2 = 1.2 accordingly

On the second stage of burning the most substantial increase of temperature for burning products $\Delta T_{pb}^{\mathrm{II}}$ was looked at their afterburning with leaking of atmospheric air, because in this case air at interfusion with warming combustible components to the moment of afterburning acquires a near to them temperature. On the size of parameter $\Delta T_{pb}^{\mathrm{II}}$ qualificatory influence accords the degree of incompleteness of burning for fuel: at α_1 = 0.65 a size $\Delta T_{pb}^{\mathrm{II}}$ arrives at a value 1090 °C, while at α_1 = 0.90 does not exceed - 360 °C.

At the serve of cold air directly in the zone of afterburning with the use of the special channels, because of its cooling act, takes place the less increase of parameter $\Delta T_{pb}^{\mathrm{II}}$, the size of which depends both on a coefficient α_1 and from a temperature $\Delta T_{pb}^{\mathrm{I}}$.

In spite of decision of task in the simplified formulation it is possible to select general conformities to law of management the regime of stage burning of fuel in the thermal furnaces of chamber type: the afterburning of burning products with the use of leaking of cold atmospheric air allows to change the temperature of products of burning in more wide range; management by the size of drop of temperature on the height of the working volume of furnaces of this type possibly by the change of coefficient of expense for primary air α_1; the coefficient of expense for secondary air α_2 must be chosen from the condition of complete burning of burning products, and control of its size (2 to execute on results a gas.

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