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N.X Bobomurodov
Department of "Automation of production processes" Tashkent State Technical University, Uzbekistan, Address: Prospect Uzbekistanskya-2, 100095, Tashkent city, Republic of Uzbekistan

U.U Holmanov
Department of "Automation of production processes" Tashkent State Technical University, Uzbekistan, Address: Prospect Uzbekistanskya-2, 100095, Tashkent city, Republic of Uzbekistan

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Since 2005

MATHEMATICAL MODELING OF A GAS BURNER OF COMBUSTION OF NATURAL GAS IN GLASS FURNACES

N.X.Bobomurodov[1], U.U.Holmanov[2]

[1,2]Department of "Automation of production processes" Tashkent State Technical University, Uzbekistan
Address: Prospect Uzbekistanskya-2, 100095, Tashkent city, Republic of Uzbekistan

The mathematical modeling of processes, flowing gas burners of glass melting furnaces, is performed. Models are proposed in the form of equations for the material and heat balance with the physical variables of natural gas and air entering the burner. Calculations of the calorific value of gas fuel are performed, the equations of combustion of simple gases, the consumption of the oxidizer and the amount of products of complete combustion are given in theoretical conditions.

Keywords: *Mathematical modeling, gas-burner, gas-burning furnaces, material and heat balance, combustion products, natural gas, calorific value.*

So far, the theory of combustion processes has not been fully developed, which accounts for the lack of accurate calculation methods. As a result, there is a need for long-term experimental adjustment to the industrial operation of almost all furnaces and units in which the combustion process takes place [1]. The reasons for the current situation are, firstly, that the fuel is a complex of natural organic substances of complex chemical structure; secondly, in the combustion process, the following steps are required: the creation of molecular contact between fuel and oxidant (physical stage) and the interaction of molecules with the formation of reaction products (chemical stage). The combustion process is characterized as unsteady problems of turbulent mass and heat conduction in the presence of dynamic sources of matter and heat.

The organization of the process of combustion of fuel in the furnace is achieved by using aerodynamic techniques that determine the form of interaction between the fuel and the oxidizer, as well as determine the type of combustion process. The latter can be divided into flare and layer. During flare combustion, the fuel is introduced by the gas-air stream and burns on the fly, almost without falling out of the stream. In a layered process, most of the fuel lies almost motionless on a lattice, and air and gas flows penetrate the layer through the existing pores and channels.

The paper discusses the main issues of the movement of gases and fuel in the combustion chambers. This draws attention to the following:

- movement and interaction of air-gas jets, depending on the configuration of the combustion space;
- ensuring the ignition of fresh fuel due to the supply to it of hot gases from the zones of active combustion;
- ensuring the residence time of the fuel in the combustion chamber to achieve the desired degree of burnout.

The furnace burning process at "Onyx-Tashkent" and the movement of the jet in the combustion chamber were studied. When calculating the burnout of fuel particles, the movement of particles relative to the gas flow was taken into account, since this phenomenon enhances the heat exchange between the particle and the medium and has a significant impact on the entire burnout process. The relative velocity of a particle depends on the physical characteristics of the flow itself, on the size and configuration of the particle, as well as on the temperature difference between the particle and the flow, that is, on the non-isothermality of the motion conditions.

When creating a mathematical model of the burner, in which natural gas is burned, it was taken into account that it comes under pressure of 5 MPa [2]. Air is supplied to the burner by an electrically driven compressor fan. As a result of the combustion of fuel, high temperature combustion products are formed in the burner. The desired mathematical model of the burner must link the parameters of the combustion products with the variables of the gas and air entering the burner.

To derive a mathematical model, we write the equations of material and heat balance, provided that there are no gas leaks and heat loss to the environment.

The material balance equation has the form:

$$g_{печ} = g_т + g_в, \quad (1)$$

where $g_т$ and $g_в$ - the amount of fuel and air entering the burner per unit of time; $g_{печ}$ - the number of generated products of combustion.

Heat balance equations for an infinitely small time interval:

$$dQ_{выд} = dQ_{погл}, \quad (2)$$

where $dQ_{выд}$ - the amount of heat released during combustion $g_т dt$ fuel over time dt; $dQ_{погл}$ - the amount of heat absorbed by the combustion products during dt.

The amount of heat released can be determined by the formula:

$$dQ_{выд} = \lambda_т g_т dt, \quad (3)$$

where $\lambda_т$ - calorific value of fuel, cal/kg.

The heat absorbed by the combustion products is determined as follows.:

$$\begin{aligned} dQ_{погл} &= C_т g_т dt(\theta_{погл} + \theta_т) + \\ &+ M_{пог} C_{пог} d\theta + C_n g_n dt(\theta_{пог} - \theta_{атм}) \end{aligned}, \quad (4)$$

where $C_т$ and $\theta_т$ - heat capacity and temperature of fuel entering the burner; C_n and $\theta_{àòì}$ - heat capacity and air temperature; $C_{пог}$ и $\theta_{пог}$ - heat capacity and temperature of combustion products in the flare; $M_{пог}$ - the amount of combustion products contained in the torch torch.

When writing equation (4), it was assumed that the temperature is evenly distributed throughout the volume due to intensive mixing. This assumption is accepted in order to obtain a simpler mathematical model of the burner.

After the transformations we get

$$\begin{aligned} \lambda_т g_т dt &= C_т g_т dt(\theta_{погл} + \theta_т) + \\ &+ M_{пог} C_{пог} d\theta + C_n g_n dt(\theta_{пог} - \theta_{атм}) \end{aligned}. \quad (5)$$

Relationship (5) is a burner model written in physical variables. To convert it to the form adopted in control theory, we divide into both dt sides of equation (5) and give similar terms. As a result, we get:

$$\begin{aligned} M_{пог} C_{пог} \frac{d\theta_{пог}}{dt} + (C_т g_т + C_в g_в)\theta_{пог} &= \\ = C_т g_т \theta_т + C_в g_в \theta_{атм} + g_т + \lambda_т \end{aligned}. \quad (6)$$

We introduce the following notation:

$$T_{гор} = \frac{M_{пог} C_{пог}}{C_т g_т^0 + C_в g_в^0}; \quad K_{\theta,T} = \frac{g_т^0 C_т}{C_т g_т^0 + C_в g_в^0};$$

$$K_{g,T} = \frac{g_т^0 \lambda_т}{C_т g_т^0 + C_в g_в^0}; \quad K_{\theta,атм} = \frac{g_в^0 C_в}{C_т g_т^0 + C_в g_в^0},$$

where $T_{гор}$ – time constant; $K_{\theta,T}; K_{g,T}; K_{\theta,атм}$ - burner transfer ratios; $g_т^0; g_в^0$ – nominal fuel and air flow rates.

Taking into account the introduced notation, equation (6) takes the form:

$$T_{гор} \frac{d\theta_{пог}}{dt} + \theta_{пог} = K_{g,T} g_т + K_{\theta,T} \theta_т + K_{\theta,атм} \theta_{атм}. \quad (7)$$

With the entered notation, the input-control input is the fuel consumption $g_т$, entering the burner. Changing its value, you can change the temperature of the combustion products, which allows you to control the combustion process. Equation (7) is the desired burner model in the form of "input-output".

The purpose of optimal energy-saving automatic control of the process of burning fuel is to determine and maintain such an air flow at which the burning of current fuel consumption is carried out with the highest possible thermal effect. Compliance with this condition ensures the implementation of the main process with minimal fuel consumption. To solve this complex problem, you must use the additional output parameter of the main TP – $Z(\tau)$, the achievement of the extremum of which corresponds to the maintenance of the main TP with maximum fuel efficiency.

Imagine $Z(\tau)$ as a function

$$Z(\tau) = [V_G(\tau), V_A(\tau), U(\tau)] \quad (8)$$

Then the optimal energy-saving control of the main TP can be represented as a sequential implementation of the following technological operations

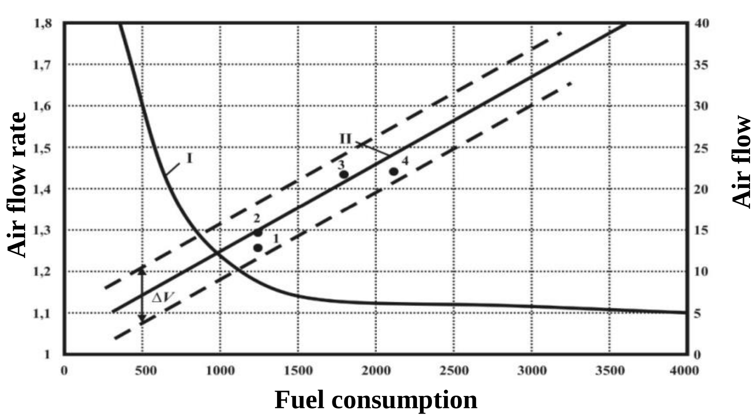
$$V_G(\tau) \to V_G^0(\tau) \text{ при } V_G(\tau) \in (V_G^{MIN}, V_G^{MAX}) \quad (9)$$

$$V_A(\tau) \to V_A^0 = Y[V_G(\tau), U(\tau)] \text{ при } V_A(\tau) \in \ (V_A^{MIN}, V_A^{MAX}) \quad (10)$$

$$Z(\tau) = E[V_G(\tau), V_A(\tau), U(\tau)] \ \to extrem \text{ при } \ U(\tau) \in U^{MIN}(\tau)\ U^{MAX}(\tau)) \quad (11)$$

Operations (9-11) can be carried out using stabilizing automatic control systems that implement typical control laws within the limits of the PID. The operation of optimal control (8) can only be carried out using an automatic control optimization system (EACS) that implements an optimizing control algorithm (OAU) by using the search method of extreme control systems [3, 4]. With this use $Z(\tau)$ as equivalent $W(\tau)$ at ОАУ should be reliably substantiated. Analytical (exact) determination of functions (9), (10) under production conditions is difficult due to the influence of a large number of random uncontrollable factors of a particular TA on the conditions of fuel combustion.

The experience of the practical use of the automatic optimization control system shows that minimizing fuel consumption during the automatic control of the main one is possible with the use of a dual-circuit scheme for controlling the process of burning fuel. The first stabilizing circuit realizes, in accordance with the OAU, rapid but rough control of the process of burning fuel in accordance with condition (9-11). The second, optimizing circuit, ensures, in accordance with OAU, the achievement of the control objective (11), but more slowly in the search process. As a concrete example of the implementation of the considered principle of operation of the SAOU by the process of fuel combustion, we consider a method for improving the management of the process of fuel combustion in methodical furnaces.
It has been established that, contrary to popular belief, the dependence of a rational (technologically sound) value of the air consumption coefficient on fuel consumption has a substantially non-linear appearance and is close to hyperbolic (see Fig. 1).



α_0	$V_A . M^3$/ч	$V_G . M^3$/ч
1.9	5700	250
1.6	8000	500
1.35	10130	700
1.24	12400	1000
1.175	14690	1250
1.14	17250	1500
1.13	19780	1750
1.125	22560	2000
1.12	25310	2250
1.12	28000	2500
1.116	30690	2750
1.113	33390	3000
1.11	3608	3250
1.109	38820	3500
1.106	41480	3750
1.102	44080	4000

Fig. 1. ***Experimental dependence of the required rational value*** $\alpha_0(\tau)$ ***fuel consumption*** $\boldsymbol{V_G(\tau)}$.

This means that the system of volumetric proportioning costs, stabilizing the set value $\alpha_0(\tau)$, able to function satisfactorily only in the range of changes in gas flow rates from 150 to 250 m ^ 3 /

h. In this range, the value of B α_B varies slightly from 8.25 to 21.

Experimentally obtained static characteristics of the process of burning fuel, representing the dependence of the radiation temperature of the torch (heating medium) at various fixed costs of natural gas from air flow. In fig. 1. presents the optimal ratio of air supply and gas in a glass melting furnace. The positions of the extremes of the static characteristics depend on the current consumption of natural gas and the actual conditions of heat exchange in the working space of the furnace.

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