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COMPLEX OPTIMIZATION OF PROCESSES OF HEAT EXCHANGE IN GAS-FIRING INSTALLATIONS WITH UTILIZATION OF HEAT

É. M. Malaya and M. E. Yakovlev

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Results of complex experimental investigations of the processes of combustion and combined heat exchange with separation of radiative and convective components of boilers with utilization of secondary energy resources are presented. The complex optimization is conducted by solving a system of partial differential equations on EC, CM, and IBM computers. For the purpose of controlling the combustion and heat-exchange processes automatically, the calculated dependences are given and charts of regimes are composed.

A comprehensive evaluation of the operating efficiency of gas-firing installations in the construction industry and development of a method for decreasing harmful ejections of combustion products and contaminants in the manufacture of structural materials make it possible to create a technique for estimating the power-to-weight ratio of enterprises of the construction industry and to conduct complex energy inspections (energy audits).

The optimization of heat exchange with simultaneous investigation of the processes of combustion and the ejections of combustion products from gas-firing installations was carried out extensively using the radiation-field theory. This allows one to determine the reduced heat liberation in a radiating volume in different fuel-burning devices (Table 1).

Under the optimum operating conditions, in different cross sections of the units we measured the values of the difference in the radiation fluxes $(I' - I'')$ along the x, y, and z axes by means of a device for measuring the flow of a gas during its burning [1]. The reduced heat liberation in the radiating furnace volume was determined in conformity with the expression of [2] from the formula

$$q_{\text{red}} = (I' - I'')_x / dx + (I' - I'')_y / dy + (I' - I'')_z / dz \,. \tag{1}$$

The tendency toward an increase in the considered combination of waste gases and ejected harmful substances and a certain attendant decrease in the percentage of captured and decontaminated harmful substances must stimulate works on construction of highly efficient gas- and dust-catching devices at the sites (sources) of ejection of harmful substances into the atmosphere. The assumed increase in waste substances and harmful substances ejected into the atmosphere will not result in contamination of work places due to the monitoring of ejections.

A more complete account for the amount of waste and ejected harmful substances, especially that with application of a computer, will help to provide a greater degree of substantiation in determination of the damage caused here and to develop measures for decreasing the ejection of the harmful substances into the atmosphere; these measures are calculated from the formula

Saratov State Technical University, Saratov, Russia; email: rec@renet.ru. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 4, pp. 81–83, July–August, 2001. Original article submitted September 11, 2000.

TABLE 1. Some Operating Parameters of Radiating Burners

Type of burner	Capacity, m^3/h	Concentration			Temperature, K	
		CO, %	NO_x, mg/m^3	benzopyrene $\mu g/(kg \cdot m^3)$	on surface	in tunnel
Burners of infrared radiation (GIIs)						
GII 01	0.8	0.045	29–30		1300	
GII Bl	0.78	0.02	29–30		1200	
KG 27U	0.75	0.01	29–30		1173	
Radiative burners of plane-flame design of the Institute of Gas, Academy of Sciences of Ukraine						
RG-1	5.7	Traces	65	–		
RG-2	10.4	»	160	1.198		
RG-3	16	»	160	3.55		
GPP_{low}-4	57	0.028	90	0.971		
GPP_h-4	58	0.056	120	0.620		
GPP_{low}-5	80	Traces	100	0.192		
GPP_h-5	80	»	100	0.799		
Cup-shaped burners designed at the All-Union Scientific-Research Institute of Industrial Gas						
GVICh-4A	12.0	Traces	260	–		
GVICh-6	47.0	»	120	0.215		
Panel flameless burners						
GBP-250	20	0.12	75		1273	1473
GBP-280	33	0.108	80		1373	1573
High-temperature radiative burners						
VGI-2Shch	5.0	0.004	52		1273	1583
VGI-6Shch	15.0	0.0068	95		1570	1778

$$T = \sum_{j=1}^{n} T_j = C_1/\mathrm{MPC}_1 + C_2/\mathrm{MPC}_2 + ... + C_n/\mathrm{MPC}_n \le 1 \,. \quad (2)$$

Because of this, the basic problem consists of developing a technology for efficient burning of hydrocarbon fuels in boilers of low and moderate capacity and in burners with a reduced yield of nitrogen oxides and other harmful substances, decreasing dust and gas ejections of enterprises of the construction industry, and producing devices for realization of these measures.

It should be particularly noted that, in order to decrease the ejection of oxides, it is required that boiler-furnace temperature be decreased, which, however, leads to a drop in the efficiency. This means that the environmental and energy-saving requirements are in clear contradiction. Therefore, in order to rationally solve the technical problems associated with the decrease in harmful ejections in the combustion products, it is necessary to formulate and solve a number of optimization problems in installing contact heat exchangers for utilization of waste gases.

At the present time, the process of burning of a fuel in the furnaces of existing boilers cannot be considered satisfactory, since control of the composition of flue gases and regulation of the proportion of the fuel-air mixture are exerted only periodically, no more than once a year, and between regulations burner devices operate under nonoptimum conditions. At the same time, because of the change in the load, growth in single powers of the units, and continuous deterioration of the quality of the fuel, situations can appear where the chemical underburning and volumes of ejections of toxic substances increase in an uncontrolled manner. This can be prevented by the automatic maintenance of the optimum regime of combustion and heat ex-

TABLE 2. Results of Measurement of Combined Heat Exchange

Gas flow rate per boiler	Type of boiler	Calculated heat flux, kW		Measured heat flux, kW						α
		furnace	pass	furnace			pass			
				q_c	q_r	Σq	q_c	q_r	Σq	
632 m^3/h	DKVR-10/13	52.8	9.2	10.8	33.6	44.4	5.06	4.09	9.15	1
310 tons/h	BKZ-320-140	345	–	58	277.5					1.09
210 tons/h	BKZ-210	210	69	69	123.9	192				1.12
78 tons/h	TGM-84 at 6.75 m	73.92	14	14	60	74				1.16

TABLE 3. Analysis of the Flue Gases under the Conditions of Optimum Operation of Boiler Units

BKZ-320-140										
Σq, kW	q_r, kW	RO_2	RO_2	RO_2	O_2	RO_2	O_2	NO_x	α	
		I	II	I	II	I	II	mg/m^3	I	II
345	277.2	12.6	14.2	15	16	2.4	1.8	203	1.12	1.09
TGM-84										
Σq	q_r	RO_2		$RO_2 + O_2$		O_2	NO_x		*A*	
73.92	60	13.6		16.8		3.2	132		1.16	
DKVR-10/13										
Σq	q_r	O_2		CO		CO_2	CO_2		NO_x	*A*
52.8	33.62	17.8		0.0015		10.6	10.72		118	1.09

Note: I, left side of the furnace; II, right side of the furnace

TABLE 4. Specific Ejections of Contaminants (kg/kg of products) in Ceramics Production

Products	SO_4	NO_2	CO
Covering plates	0.72 (9.3)	2.0 (26.0)	1.98)26.0)
Plates for floors	0.28 (8.6)	1.05 (32.5)	1.20 (37.9)
Facade plates	0.18 (5.0)	1.85 (40.0)	1.40 (38.0)
Sanitary engineering goods	2.95	3.92	4.23
Sewer pipes	1.90	0.45	0.86
Acid resistances	2.00	0.42	1.05

Note. The amount of ejections in g/m^2 of products is given in parentheses.

change during the complex experimental investigation and by the subsequent optimization of the processes of combustion and combined heat exchange with separation of radiative and convective components. Experimental investigations are performed for the furnaces and combustion chambers of a complicated configuration using a device for complex measurements of the flow characteristics in combustion of the fuel [2] (see Tables 2 and 3).

To solve the problems of optimizing the regime or design parameters, a criterion is required by means of which it is possible to evaluate the efficiency of the heating unit with account for its environmental characteristics and energy-saving parameters simultaneously.

A new characteristic, i.e., ultimately permissible ejections (UPEs), is used as a basis for the sanitary standards of the MPC. For a single source or a group of closely spaced single sources of ejection of a heated gas-air mixture, the value of the UPEs is determined as

$$\text{UPEs} = \frac{(\text{MPC} - C_{\text{bg}})\, H^2 \sqrt[3]{V_1 \Delta T}}{AFnm\chi}\,. \qquad (3)$$

At ceramics-firing enterprises, we verified the calculation of the UPEs performed by means of formula (3) and using a chemical analysis that showed a good convergence in determining the specific ejections of the contaminants (Table 4).

Analysis of the possibilities of using well-known methods and means for control of the purification of a gaseous medium has shown that at the present time the dust content of a gaseous medium is investigated mainly by a sampling method. Since this method has received the widest application, there is no need to dwell on its essence and devices for its implementation. We should only note some drawbacks that considerably restrict the capabilities of this method. The main drawback is the determination of the averaged value of the dust content for a long time interval, which does not allow one to control the process of purification promptly.

Using, as an example, the operation of a KS-450 furnace, we established that the absence of knowledge of the amount of dust in a gas flue at any instant of time makes it impossible to affect the course of the process. We will dwell on this factor in detail.

From the experience of operation of KS-450 furnaces, it can be concluded that with change in the quality of the raw material, its moisture, dispersivity, etc., the firing process is disrupted and the parameters by which the control is exerted vary. At the Ust'-Kamenogorsk lead-zinc integrated plant, during the firing of a zinc concentrate in KS-450 fluidized-bed furnaces, it is the dust content of a gas flow that is a very sensitive parameter characterizing stable operation of the furnace with change in the firing process. As the dust content changes 5–6 times, a threat of sintering various fractions and creating an emergency situation appears.

The method suggested was experimentally tested at enterprises for firing of various products (Table 4).

The results of optimization showed the extreme dependence of the relative intensity of ultraviolet radiation from the unit surface of the flame and the relative density of the radiation flux in the furnace on the excess-air coefficient of ultraviolet radiation α at all the investigated units with utilization of the heat of waste gases in contact heat exchangers (CHAAs). The optimum (from the viewpoint of completeness of combustion of the gas) excess-air coefficient corresponds to the maximum values of the total and radiative components of the heat exchange and the intensity of ultraviolet radiation in the working ranges of the loads of boiler units and gas-firing installations.

When the CHAA was installed behind the boiler unit, the combustion process improved and the radiative component of the heat exchange in the furnace amounted to 85% of the total component. The content of CO, H_2, CH_4, and NO_x under the revealed optimum conditions for the investigated units is within the limits of the MPC. To control the process of combustion and heat exchange in the investigated units with CHAAs, we composed the corresponding regime charts and presented techniques for calculating the radiative and convective components of heat exchange with their dependence on the aerodynamic structure of the flow in [2].

NOTATION

I, radiation flux; *x*, *y*, *z*, Cartesian coordinates, m; C_1, C_2, ..., C_n, concentration of harmful substances in the atmosphere at one and the same point of the area, mg/m^3; MPC_1, MPC_2, ..., MPC_n, maximum permissible concentrations of harmful substances in the atmosphere, mg/m^3; C_{bg}, background concentration of the impurity under consideration in the atmospheric air around the source, mg/m^3; *H*, height of the ejection source above the ground, m; V_1, volume of the gas-air mixture, m^3/sec; ΔT, temperature difference of the ejected gas-air mixture and the ambient air, $^{\circ}$C; *A*, coefficient depending on the conditions under which the horizontal and vertical scattering of the impurities occurs (for the central region of Russia, A = 120); m, n, and χ, dimensionless coefficients by means of which account is taken of the conditions for the escape of the gas-air mixture from the ejection source and the influence of the relief of the terrain on the scattering of the impurity; F, coefficient which takes into account the velocity of settling of the harmful substances, CHAA, contact heat exchanger with an active attachment; q, heat-flux density, W/m^2; CO and NO_x, concentrations of carbon monoxide and nitric oxide, respectively; α, excess-air coefficient; T_j and T, local and total ejections of the harmful substances into the atmosphere, respectively. Subscripts: low, low pressure; h, high pressure; r, radiation; c, convection.

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