A CALCULATION PROCEDURE FOR HEAT RADIATION IN AN AREA AFFECTED BY OPEN FLAMES

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The objects of this study are flame installations intended for gas burning. A mathematical model is described for calculation of specific heat loads on the ground and ground temperatures under heat radiation of both a single flame and several tightly arranged flames. The position of the flame handle in relation to the ground surface is taken into consideration.

Processes of gas and liquid fuel production and refining include their partial burning in the air in flame installations. Operation safety in the radiation area requires a scientifically substantiated method to determine parameters and relative positions of the flame installations based on analysis of the expected thermal fluxes. For this purpose a mathematical model and programs were developed to calculate the incident heat fluxes and temperatures of the ground surface in the an affected by open gas flames.

The calculation procedure includes a mathematical model of heat and mass transfer and combustion in the flame and calculation of heat transfer on the ground surface. The initial parameters for calculation of heat and mass transfer in a flame are characteristics of a gas jet in the flame handle orifice and parameters providing for the calculation details desired.

The flame shape is assumed to be conical with height equal to the flame length L_f and with a cone angle of 12.5°. The flame length was calculated by the method [1] in which the free diffusion flame length $L^{fr}_{f.d}$ is basic. In this case the flame length under real conditions is obtained by multiplying $L^{fr}_{f.d}$ by correction factors taking into consideration the flame development conditions

$$\frac{L_f}{L^{fr}_{f.d}} = f(k_m,\ k_n,\ k_\Omega,\ k_{conf},\ k_T), \tag{1}$$

where k_m is the ratio of the momenta of the air and gas flows in a coaxial flame; k_n is an integral characteristic of the degree of pre-mixing of gas with air in the outlet section of a parallel-flow burner; k_Ω characterizes swirling in flames due to burner swirlers; k_{conf} is the parameter characterizing the existence of the confined space; k_T includes the confined space temperature. The last parameters are neglected in open flame systems. In the model, an explicit form of the function f obtained in [1] is used. Since the free diffusion flame length is a function of temperature, it is refined during calculation by iterations.

In order to determine heat fluxes in the objects located in the zone of action of flame installations with account of the real flame characteristics, apart from the flame size and shape, it is necessary to determine temperatures and radiation characteristics as a function of the length, the characteristics being dependent on the gas motion in the flame and fuel burn-out.

The fuel burn-out dynamics was determined from the curve [2] universal in fuel composition and various operation factors, and the air inflow and fuel concentration along the flame were found from G. P. Abramovich's relation [3].

Evaluation of the temperatures differentiated along the flame and radiation characteristics of gas requires solution of the radiative-convective heat transfer problem. This was solved using the mathematical apparatus of the zone calculation method [4]. The flame was partitioned into zones by equidistant parallel planes normal to the flame axis. Thus, every zone was shaped as a right truncated cone and its heat balance equation may be written as

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$$Q_{pj} + Q_{kj} + Q_{zone\,j} = 0, \quad j = \overline{1;\ N}. \tag{2}$$

Analysis and transformation of the set of equations (2) give the following set of equations:

$$\sum_{i=1}^{N} P_{ij}\Theta_i^4 + B_{j-1}\Theta_{j-1} - B_j\Theta_j + D_j = 0, \ j = \overline{1;\ N}. \tag{3}$$

The free term D_j in the equation includes heat generation in the j-th zone due to fuel burning. The burn-out dynamics is found from the exponential function [1].

Heat transfer due to the gas mass motion and optical characteristics of the medium are determined with account of the ambient air inflow and combustion kinetics.

In calculation of the mutual radiant energy transfer coefficients, the Monte Carlo method was used to develop a calculation technique for generalized angular coefficients in a conical flame system. The radiation nongrayness was taken into consideration by Hottel's model for gas fuel combustion products. Calculation of the gas medium composition and its thermal characteristics were found automatically and corrected in iterative computation. The final calculation results are the average reduced temperatures θ_i of the zone and emissivity factors ϵ_i of volume zones. These parameters were used in the second calculation stage for determination of heat fluxes onto the ground. The flame length, depending on its temperature, is refined in the iterative calculation process.

In calculation of the heat fluxes the area irradiated by the flame was presented as a rectangle within which a Cartesian coordinate grid is built with a required step along the axes. For every nodal point T the specific incident heat flux was calculated:

$$q_{\text{inc}\ T} = 5.67 \cdot 10^{-2} \sum_{i=1}^{N} \varepsilon_i F_i \frac{\varphi_{iT}}{dF_T} \Theta_i^4, \quad \text{MW/m}^2. \tag{4}$$

The value of φ_{iT}/dF_T is determined by numerical integration over the conical surface of the zone located arbitrarily relative to the area irradiated that allows the flame deflection by wind to be included:

$$\frac{\varphi_{iT}}{dF_T} \approx \frac{1}{\pi F_i} \sum_{m=1}^{N_\beta} \sum_{k=1}^{N_z} \frac{\cos\varphi \cos\varphi_T}{r_{iT}^2} \Delta F_{ikm}. \tag{5}$$

For flame systems, the total heat flux is determined as a superposition of heat fluxes from individual flame installations. Parameters of all flames in the system are to be calculated in advance. The ground surface temperature with neglected heat conduction is found from the equation

$$5.67 \cdot 10^{-8} \varepsilon_T T_T^4 + 5.6 u_w^{0,5} T_T - [\varepsilon_T (10^6 q_{\text{inc}\ T} + q_s) + 5.6 u_w^{0,5} T_w] = 0. \tag{6}$$

For horizontal flame installations numerical integration over the flame surface is inapplicable because of large errors at the points on the ground close to the flame axis.

The method was used for development of software for gas producing and processing CAD. The computation is done on a PC. For the users' convenience the computation results are presented graphically.

NOTATION

P_{ij}, radiative transfer coefficient, $kW \cdot K^{-4}$; B_{j-1}, B_j, convective transfer coefficients into and from the j-th zone, respectively, kW/K; θ_j, reduced temperature of the j-th zone, 10^{-3} K; F_j, lateral conical surface area of the flame in the j-th zone, m^2; φ_{iT}, local angular coefficient from the j-th zone to the elementary area dF_T at the point T; r_{iT}, distance between the surface elements of the i-th zone and the irradiated elementary area, m; ΔF_{ekm}, conical contact area of the i-th zone in the k-th layer of the m-th sector; φ, angle between the beam and the normal to the conical surface element, rad; φ_T, angle between the beam and the normal to the irradiated area, rad; N_β, the number of sectors; N_z, the number of layers in a zone; ϵ_T, emissivity of the ground surface; T_T, ground surface temperature at the point T, K; T_a, air temperature, K; u_w, wind velocity, m/sec; q_s, solar constant for the corresponding latitude, W/m^2.

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