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THE MEASUREMENT OF RADIANT HEAT FLUX IN COMBUSTION CHAMBERS OF LARGE STEAM BOILERS

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ABSTRACT

The design of a modern boiler furnace requires the computation of furnace wall metal temperatures for proper selection of the tube material and thickness. These temperatures are functions of the heat fluxes and the internal heat transfer coefficients. The heat flux distribution is required also for the sizing of the boiler's combustion chamber and fouling monitor [1,2]. The flux-tube is illustrated in Figs. 1 and 2. The tubular type instrument developed here is an improved version of the instrument described in references [1]. The meter is constructed from a short length of eccentric tube containing four thermocouples on the fire side below the inner and outer surfaces of the tube. The fifth thermocouple is located at the rear of the tube (on the casing side of the water-wall tube).

In this study, two unknown parameters: the heat flux q_m and heat transfer coefficient h_{in} on the inner flux-tube surface are estimated such that the calculated temperatures agree with measured temperatures at five interior locations (Fig. 1). The temperature distribution is governed by the non-linear partial differential equation

$$\nabla\cdot[k(T)\ \nabla T] = 0, \tag{1}$$

where ∇ is the vector operator, which is called nabla, and in Cartesian coordinates is defined by $\nabla \equiv \mathbf{i}\partial/\partial x + \mathbf{j}\partial/\partial y + \mathbf{k}\partial/\partial z$. The unknown boundary conditions may be expressed as:

$$\left[k(T)\frac{\partial T}{\partial n} \right]\Bigg|_s = q(s), \tag{2}$$

where $q(s)$ is the radiation heat flux absorbed by the exposed flux-tube and membrane wall surface. The local heat flux $q(s)$ is a function of the view factor $F(s)$: $q(s) = q_m \cdot F(s)$, where q_m is measured heat flux (thermal loading of heating surface). The view factor $F(s)$ from the infinite flame plane to the differential element on the membrane wall surface can be determined graphically or numerically. In this paper, $F(s)$ was evaluated numerically using the finite element program ANSYS. The convective heat transfer from the inside tube surfaces to the water-steam mixture is described by Newton`s law of cooling

$$-\left[k(T)\frac{\partial T}{\partial n} \right]\Bigg|_{s_{in}} = h_{in}\left(T\big|_{s_{in}} - T_f \right), \tag{3}$$

where $\partial T/\partial n$ is the derivative in the normal direction, h_{in} is the heat transfer coefficient and T_f denotes the temperature of the water-steam mixture. The rear side of the membrane water-wall is thermally insulated. In addition to the unknown boundary conditions, the internal temperature measurements f_i are included in the analysis:

$$T_e\left(\mathbf{r_i}\right) \equiv f_i, \quad i = 1,...,m, \tag{4}$$

where m = 5 denotes the number of thermocouples (Fig. 2). The unknown parameters: $x_1 = q_m$, and $x_2 = h_{in}$ were determined using the least-squares method:

$$S = \sum_{i=1}^{m}\left[f_i - T\left(\mathbf{x},\mathbf{r_i}\right)\right]^2, \quad m = 5, \tag{5}$$

The object is to choose $\mathbf{x} = (x_1, \ldots, x_n)^T$ for n = 2 such that computed temperatures $T(\mathbf{x},\mathbf{r}_i)$ agree with certain limits with the experimentally measured temperatures f_i. The fluid (water/steam or water) temperature T_f can be estimated indirectly from the metal temperature measurement at the rear of the tube. The heat flux $x_1 = q_m$ and the heat transfer coefficient $x_2 = h_{in}$ were determined using the Marquardt-Levenberg method.

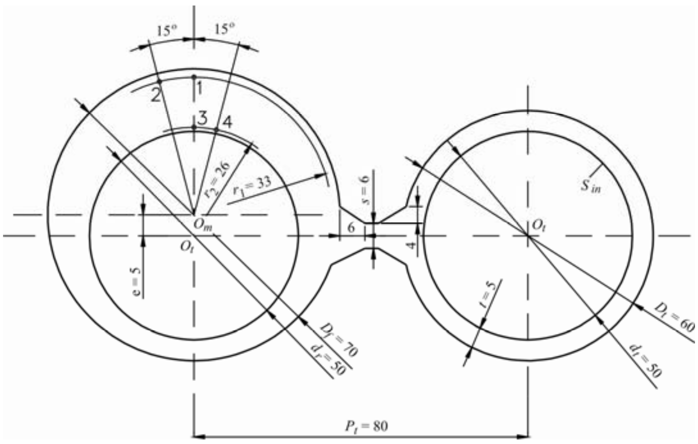

Fig. 1. Flux-tube with adjacent water-wall tube; 1÷5 – locations of thermocouples;

Fig. 2. Tubular type instrument (flux-tube) for heat flux measurement

The temperatures $T(\mathbf{x}, \mathbf{r}_i)$, i = 1, …, m were calculated at every iteration step using the program ANSYS. Several flux meters with the design shown in Fig. 1 were installed at a 50 MW coal fired steam boiler. The results of measurements and numerical calculations are presented in the paper.

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