UDC 625.7.8

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RADIATIVE HEAT EXCHANGE IN HEAT GENERATORS WITH VORTEX FURNACES

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Statement of the problem. Vortex motion of smoke gases in a furnace allows one to achieve a uniform temperature distribution within a furnace. Thus processes of heat transfer grow more intense and the reliability of boiler and longevity increases. Vortex principle of burning of fuel leads to rotational speeds, which reduces the expenditure component of the vector of the absolute velocity of smoke gases in the combustion chamber of boilers. This in turn leads to a reduction in the heat losses from chemical and mechanical underburning due to keeping hot gases in a combustion chamber for longer.
Results. An attempt was made to create a vortex furnace of the boiler and the approximate method of its calculation including radiative heat transfer Established in the combustion chamber rotational speeds reduces the expenditure component of the vector of absolute velocity, which leads to an increase in the residence time of hot gases in the combustion chamber and reduce heat loss as chemical and mechanical underburning.
Conclusions. Analytical studies were performed which enabled us to obtain the equations to determine the local angular radiation coefficients of linear source on an elementary area for its different locations: on a horizontal, vertical and inclined heat transfer surface. The analytical expressions are complementary to the known data on the angular radiation coefficients and significantly enhance the radiative heat transfer calculation in the vortex boiler furnaces. The use of vortex burners will allow one to increase the intensity of heat transfer, and increase the longevity of a boiler by providing a uniform temperature distribution within the furnace and to reduce capital and operating costs.

Keywords: radiative heat transfer, angular coefficient of radiation, heat, boiler, vortex furnace, heat exchange, heat transfer.

Introduction

Decentralized and autonomous heat supply typically has relatively short main pipes or none at all, small fuel transportation costs and thus low heat losses and economic efficiency. These systems employ vapour and water-heating boilers. There have been found a few factors that influence the operation in fire chambers.

Significant thermal losses of a fire chamber call for activities to protect screen surfaces from heating excessively in particular. In practice inside a fire chamber there are local deviations of the temperature with them being as high as a few hudnred degrees. Resulting thermal unevenness are a cause of burnouts and lead to lower efficiency of a chamber. Therefore addressing this problem is currently of importance [1—15].

One of the ways to do that is to apply the whirlwind principle of fuel combustion. It means that using a relevant way of supply in a fire chamber there is a whirl flow of reacting fuel and oxidizer particles.

The twisted shape of a flow in space is reached by a tangential introduction of a fuel-air mix into a chamber. Rotation speeds reduce the consumption of an absolute speed, which results in an increase in how long hot gases stay in a fire chamber and a drop in losses in a chemical and mechanical underburning. A large speed and a high turbulization of a twisted torch cause an increase in the coefficient of gas heat transfer to heated surfaces thus improving the coefficient of efficiency of a chamber.

We have attempted to design a twisted fire chamber and its approximate calculation method as well as for radiative heat exchange. It is mainly used in fire chambers. Heat flows from a gas, fuel, powdered-coal torch contain 85—95 % from a radiative flow and 10—15 % from a convective flow.

1. Determining total integral heat flows and radiation angular coefficients. According to the method by A. N. Makarov [1], total integral heat flows consisting of radiations falling on a heated surface from a torch, wall lining, lid and convective flows. The density of an integral flow falling on the *i*-th elementary area of a heated surface is determined using the expression

$$q_{in} = q_{in.ф} + q_{in.oф} + q_{in.n} + q_{in.o.n} + q_{iкон}\,, \tag{1}$$

where $q_{in.\,t}$ is the density of an integral radiation flow falling on the *i*-th area from a torch considering the radiation absorption of a torch; $q_{in.\,oф}$ is the same for a flow generated by the reflection of radiaiton of a torch from the walls, floor and lid; $q_{in.\,n}$ is the same for a flow of radiating walls, floor, lid considering the reflection and absorption of radiation; $q_{in.\,o.\,n}$ is the same for a flow generated by the reflection of radiation from the surfaces of the walls, floor, lid; $q_{iкон}$ is the density of a convective flow per an area.

The most difficult issue with applying this method is determining the angular coefficients. In practice analytical expressions are necessary to identify the angular coefficients of radiation for a cylindrical source (e.g., a torch) and an elementary area in parallel and perpendicular planes.

The properties of constant radiation of coaxial cylinders suggest that radiaiton of coaxial gas volumes can be substituted by an equivalent radiation of a cylindrical gas volume of a small diameter provided that it radiates power equal to the sum of those of radiation of coaxial cylindrical volumes. A radiating cylinder of a small diameter in thermal physics is traditionally called a linear source of radiation, which will be done further in our calculations.

Let us determine a local angular coefficient of radiation of a cylindrical source of radiation on a surface of an elementary area *K* positioned between the normals *N*3 and *N*4 passing through the centre of the upper and lower circles of the base of a linear source of radiation (Fig. 1).

2. Geometric design for determining local angular coefficients of radiation for an elementary area on a plane *F*. An elementary area lies in a plane *F* parallel to an axis of a cylindrical source of radiation with the height $l_л$. Let us point out an element $dl_л$ on the cylindrical source. As a cylindrical linear source of radiation is a cylinder of an infinitely small diameter, an element $dl_л$ is an elementary cylinder, i.e. a cylinder of an infinitely small diameter and an infinitely small height $dl_л$.

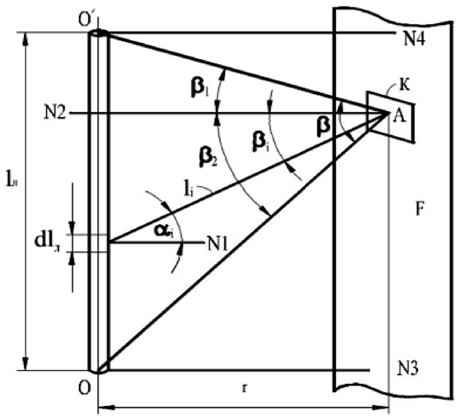

Fig. 1. Geometric designs for determining local angular coefficients of radiation of a linear source on an elementary area for its position in mutually parallel planes

An elementary angular coefficient of radiation $d\varphi_{ik}$ from a surface of an elementary area is given by the expression

$$d\phi_{ik} = \frac{\cos\alpha_i \cos\beta_i F_k dl_л}{\pi^2 l_i^2 l_л}, \tag{2}$$

where α_i is an angle between a normal *N*1 to an axis of an elementary cylinder and a direction of radiation, degrees; β_i is the angle between the normal *N*2 to the centre of an elementary area and a direction of radiation, degrees; F_k is an area of an elementary area, m^2; l_i is a distance from an elementary cylinder to an elementary area, m.

Let us designate the centre of an elementary area with *A*, a minimum distance from a point *A* to an axis of a cylinder with *r*. Let us draw rays *AO* and *AO′* into the centre of a linear source of radiation at a point *A*. Let us designate an angle between a straight line *AN*2 and a ray *AO′* through β_1, an angle between *AN*2 and a ray *AO* through β_2. As seen from the designs, a linear source radiates into a point *A* within the angle β with $\beta = \beta_1 + \beta_2$.

A local angular coefficient of radiaiton of a linear source on a surface of an elementary area is given by integrating the expression (2) on the height of a source of radiation:

$$\phi_{ik} = \int_{l_л} \frac{\cos\alpha_i \cos\beta_i F_k}{\pi^2 l_i^2 l_л} dl_л. \quad (3)$$

In the expression (3) we have three variables. Using insertion, we will remove two out of three and in addition, integration on the height lл will be replaced by integration on an angle. According to Fig. 1, we have:

$$\angle\alpha_i = \angle\beta_i,\ \cos\alpha_i = \cos\beta_i, \quad (4)$$

$$\cos\alpha_i = r / l_i,\ l_i = r / \cos\alpha_i, \quad (5)$$

$$dl_i \cos\beta_i = l_i d\beta. \quad (6)$$

Inserting (4)—(6) into (3) and integrating on an angle, we get an expression for determining a local angular coefficient of radiation of a linear source of radiation on an elementary area:

$$\phi_{lk} = \frac{F_k}{2\pi^2 r l_л}\left[\beta + \sin\beta\cos(\beta_1 - \beta_2)\right], \quad (7)$$

where β is an angle at which a linear source radiates on an elementary area, degrees. If an elementary area is positioned in a way that a normal *N*3 (or *N*4) passes through a point *A*, the expression (7) takes the following form:

$$\phi_{lk} = \frac{F_k}{2\pi^2 r l_л}\left[\beta + \sin\beta\cos\beta\right] = \frac{F_k}{2\pi^2 r l_л}\left(\beta + \frac{1}{2}\sin 2\beta\right). \quad (8)$$

3. Geometric designs for determining local angular coefficients of radiation for an elementary area outside a plane *F*. In case if an elementary area is positioned outside a projection of a linear source of radiation on a plane *F* (Fig. 2), the calculation runs as follows.

Let the centre of an elementary area *A* be positioned at a distance *h* from a plane that passes through the base of a linear source of radiation with $h > l_л$. An angle at which a linear source radiates on an elementary area is formed with rays *AO* and *AO′* and is β. Let us designate an angle between a normal *N*2 at a point *A* and a ray *AO* through β_1, an angle between *N*2 and a ray *AO′* through β_2.

Fig. 2 suggests that according to the expression (4)—(6), these are appropriate for an elementary area and a linear source of radiation. For determining a local coefficient of radiaiton of a linear source on an elementary area let us insert (4)—(6) into (2) and integrate the resulting expression within an angle β:

$$\phi_{lk} = \frac{F_k}{2\pi^2 r l_л}\left[\beta + \sin\beta\cos(\beta_1 + \beta_2)\right]. \quad (9)$$

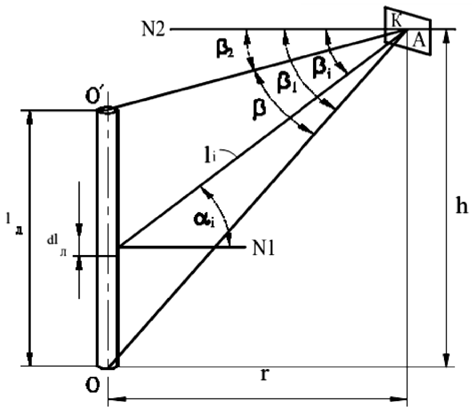

Fig. 2. Geometric designs for determining local angular coefficients of radiation for an elementary area on a vertical plane at a random height

4. Geometric design for determining local angular coefficients of radiation of linear source on an elementary area for their position in mutually perpendicular planes. Let us examine a mutually perpendicular position of planes where there are linear sources of radiation and an elementary area. Let a plane where an elementary area is passes through the base of a linear source of radiation (Fig. 3). Let a shortest distance from a linear source to a point *A* — *r*, a normal to the centre of an elementary area be *N*2, an angle at which a linear source radiates on a point *A* — $\angle OAO' = \beta$. An elementary angular coefficient of radiation *dlл* on an elementary area is given by the expression (2). A local angular coefficient of radiation of a linear source on an area is identified using integration of the expression (2) on the height of a linear source or after corresponding insertions on an angle β.

Based on Fig. 3, we have:

$$\cos\beta_i = \cos\alpha_i, \quad (10)$$

$$l_i = r / \cos\alpha_i, \quad (11)$$

$$dl_i \cos\alpha_i = l_i d\alpha. \quad (12)$$

Inserting (10)—(12) into (2) and integrating the resulting expression within an angle α, we get an analytical expression for calculating a local angular coefficient of radiaiton of a linear source on an elementary area positioned in a perpendicular plane:

$$\phi_{lk} = \frac{F_k}{2\pi^2 r l_л}\sin^2\beta. \quad (13)$$

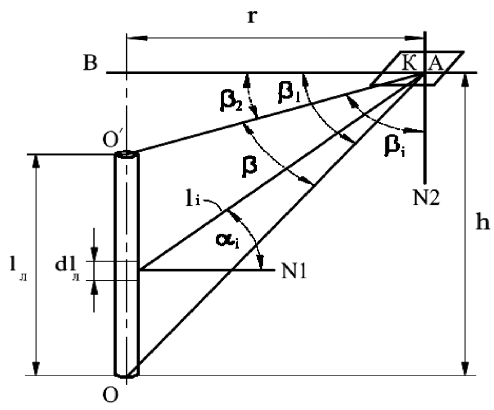

Fig. 3. Geometric designs for determining local angular coefficients of radiaiton of a linear source on an elementary area for their position in mutually perpendicular planes

5. Geometric designs for determining local angular coefficients of radiation for an elementary area on a horizontal plane at a random height. For a position of an elementary area at any random height h from the lower (or upper) base of a linear source we have the following geometric designs (Fig. 4). The shortest distance from point A to a linear source is r. Let us designate $\angle OAO' = \beta$, $\angle OAB = \beta_1$, $\angle O'AB = \beta_2$, $\beta_1 - \beta_2 = \beta$.

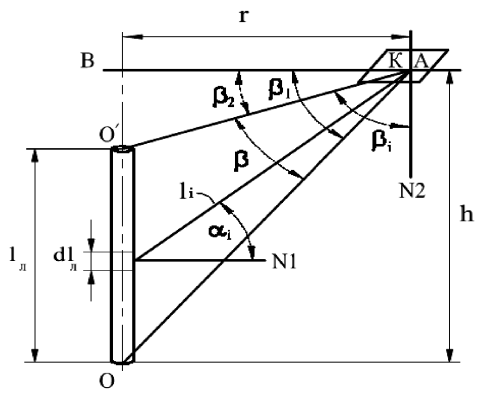

Fig. 4. Geometric designs for determining local angular coefficients of radiaiton for an elementary area on a horizontal plane ata random height

Fig. 4 suggests that for the equation (10)—(12) mutual positions of a linear source and an elementary area are appropriate. For determining a local angular coefficient of radiation of a linear source on an elementary area it is necessary to insert (10)—(12) into (2) and integrate within changes of an angle αi, i.e from β_2 to β_1:

$$\phi_{lk} = \frac{F_k}{2\pi^2 r l_л}\left(\sin^2\beta_1 + \sin^2\beta_2\right). \tag{14}$$

Average angular coefficients of radiation of a linear source on a flat surface F (see Fig. 1) ϕ_{lF} are determined as a sum of local angular coefficients of radiation of a linear source on elementary areas on a surface F:

$$\phi_{lF} = \sum_1^n \phi_{lk}, \tag{15}$$

where n is the number of elementary areas on a F.

The expressions for determining a local angular coefficient of radiation of a linear source on a surface of an elementary area positioned on random planes are obtained identically.
Energy setups with twisted fire chambers used for heat supply of buildings and structures allow an even temperature distribution in fire chambers and thus improving their life cycle.

Conclusions

1. Rotation speeds in a fire chamber decrease the consumption of a vector of absolute speed resulting in hot gases staying longer in a fire chamber and smaller heat losses for a chemical and mechanical underburning.
2. The use of twisted fire chambers intensifies heat transfer as well as increases the durability of a fire chamber by means of even temperature distribution within a fire chamber and reduces maintenance costs.
3. Based on the analytical studies, equations for determining local angular coefficients of radiation of a linear source on an elementary area for its position on horizontal, vertical, slope surfaces of heat transfer. The obtained analytical expressions supplement the available data on angular coefficients and enable new methods of calculating radiation heat transfer in twisted fire chambers.

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