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CALCULATIONS OF THE RADIATION HEAT CONDUCTION COEFFICIENT IN THE BED OF RODS

Very often in many metallurgical processes porous metallic charge is being heated. Such charge can be coils of wire, bundles of bars, pipes or any sections, and many other fine elements heating on a mass scale. The determination of optimal conditions of heating such a kind of charge requires knowledge about its thermal properties. This paper presents a calculating procedure of the thermal properties of porous charge on the base of an appropriate heat exchange mathematical model.

Во многих металлургических процессах происходит нагрев пористой металлической шихты. Этой шихтой могут быть катушки проводов, металлические стержни, трубы, разнообразные куски металла и прочие мелкие элементы, нагреваемые все одновременно. Определение оптимальных условий нагрева такого рода шихты требует знания ее термических параметров. Представлена процедура расчета термических параметров пористой шихты, основанная на соответствующей математической модели теплообмена.

Introduction

In the theory of heating charge, two principal types of charge are distinguished, i.e. the thin charge and the thick charge. The criterion upon which this division is made is the Biot number. However, another, completely different type of charge can still be distinguished, which has not been mentioned so far in relevant literature, namely the porous charge. The examples of this charge type are: wire rod coils, wire wound on spools, bundles of rods, tubes or other shapes, and many other minor items heated in mass, such as bolts, nuts or balls fig.1 [1, 2].

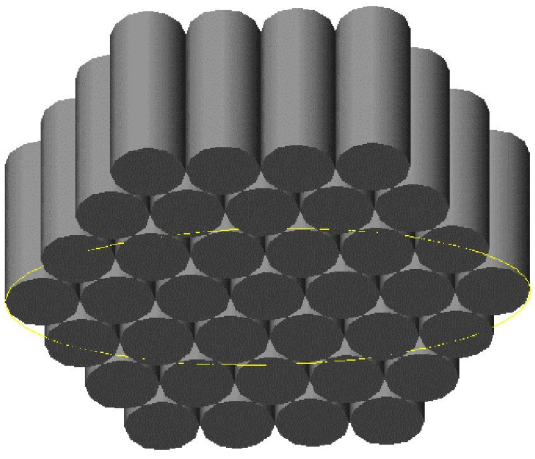


Fig.1. Typical example of the porous charge: rods bundle

In a general case, in the bundle rods all types of heat exchange can occur at the same time. In the cross-sections and in the locations of contacts between individual rods, and in the gas that occupies the pores, heat conduction occurs. In the pores, heat transfer by radiation and convection also takes place. Therefore, the heat flow in this type of charge is quantitatively expressed with the coefficient λ of a value chosen so that the amount of heat exchanged in complex heat conduction, convection and radiation processes corresponds to the amount of heat conducted in the solid material with the identical temperature field. The above-mentioned coefficient is referred to as the effective thermal conductivity or the effective heat conduction coefficient λ_e. It should be emphasized at the same time that the concept of effective thermal conductivity can be applicable to a medium area, whose dimensions exceed by at least an order of magnitudes the dimensions related to its inhomogeneity.

However, not all of the above-mentioned mechanisms have the same contribution to the heat conduction process. As the sizes of pores

do not exceed 10mm, the convection can be excluded from consideration [3, 4]. The heat conduction in the gas can be also neglected because of its low heat conduction coefficient ($\lambda_g \cong 0{,}02$ W/(m·K)). The highest heat flow resistance exists at the surfaces separating successive charge layers. The total heat flux flowing in this location is the sum of the radiation heat flux $\dot{Q}_r$ and the contact heat flux $\dot{Q}_k$. The radiation heat flux flows through the pores, between the surfaces of particular charge elements, whereas the contact heat flux flows in the location of contact between these elements. Hence, it can be assumed that the effective heat conduction coefficient of the porous charge is the sum of the radiation heat conduction coefficient λ_r and the contact heat conduction coefficient λ_k:

$$\lambda_e = \lambda_r + \lambda_k . \qquad (1)$$

The value of the radiation heat conduction coefficient λ_r, which expresses quantitatively the heat flux $\dot{Q}_r$, can be determined by solving the problem of heat exchange in the charge cross-section by radiation, using e.g. the method of surface brightness balances [5, 6]. The value of this coefficient will depend to the greatest extent on temperature, since the intensity of radiation is proportional to the fourth power of absolute temperature, and then on the charge porosity, the diameter of charge elements and the charge surface emissivity. In turn, the contact heat conduction coefficient λ_k expresses quantitatively the contact heat flux $\dot{Q}_k$. Assuming that no temperature drop occurs at the contact between particular charge elements, the value of this coefficient will depend on the thermal conductivity of the material and on the contact ratio.

Calculation results of the radiation heat conduction coefficient in the bed of rods

Below, calculation results are given for different rod diameters and rod surface emissivities. The following values of the above-mentioned parameters were taken:

- rod diameter – d_p [mm]: 10, 16, 18, 20, 22, 24, 26, 28, 30, 35, 40, 45, 50;
- rod surface emissivity, ε: 0.4, 0.5, 0.6, 0.65, 0.7, 0.8, 0.9;
- number of rod layers, $n = 5$.

For each bed of rods of specified values of the parameters d_p and ε, a series of calculations were made for different values of boundary conditions. These conditions were set on two surfaces that limited the considered heat exchange system. On one of the surfaces, temperature – the boundary condition of the first kind, and on the other, the heat flux – the boundary condition of the second kind, were set.

Figure 2 presents the results of calculations of the radiation heat conduction coefficient as the graph of the function $\lambda_r = f(t)$, for the above-mentioned rod diameters and an emissivity of $\varepsilon = 0.7$.

As can be seen, the value of the radiation heat conduction coefficient of the bed of rods is a strongly increasing function of temperature. This is quite obvious in view of the fact that the intensity of thermal radiation, on which the value of the coefficient λ_r is dependent, is proportional to the fourth power of absolute temperature. Also the increase in the rod diameter causes an increase in the value of this coefficient (fig.3). This can be explained by comparing a layer of rods in the bed to a screen. The smaller rod diameter, the more layers – screens present on the bed diameter. As the coefficient λ_r relates to the section, in which heat exchange takes place, increasing the number of screens in this section, i.e. making them more dense, causes the radiation heat exchange to weaken. As a consequence, the value of the coefficient λ_r decreases. As can be further noticed, the function $\lambda_r = f(d_p)$ is linear, and the slope of particular curves is the greater, the higher the average bed temperature is.

Summary

In this article was presented the influence of difference parameters i.e.: temperature of bundle, rods diameter and surface emmisivity, on the change range of the radiation heat conduction coefficient in the bed of rods.

It was specified the renge in which changes the radiation heat conduction coefficient in dependence from above-mentioned parameters choice. In the range of temperature to 300 °C about, the values of this coefficient are relatively not large maximum to 1,5 W/(m·K).

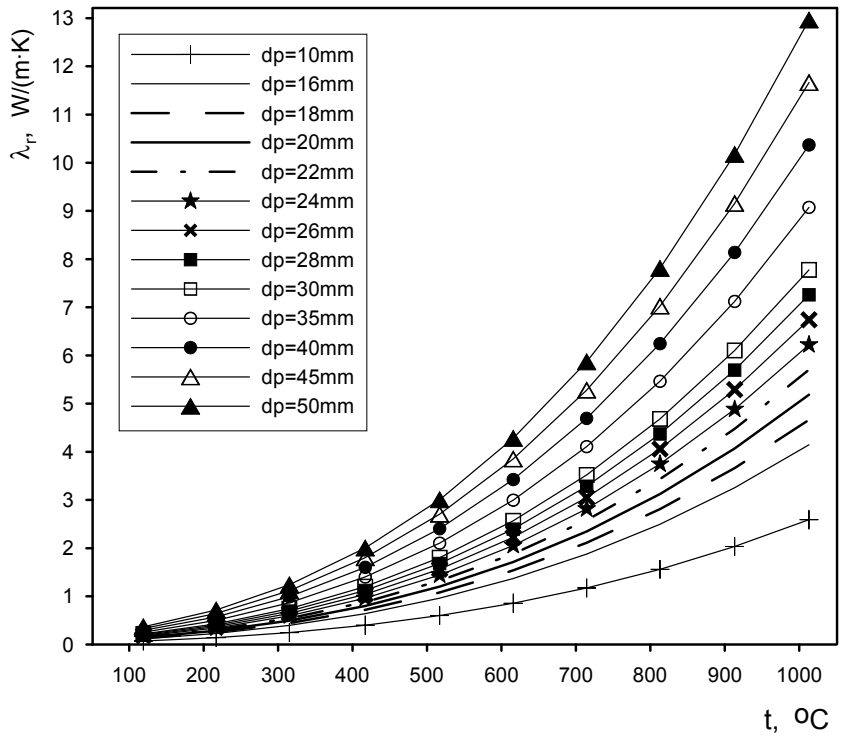


Fig.2. Radiation heat conduction coefficient of the bed of rods as dependent on the average temperature of the bed of rods, for selected rod diameters and an emissivity of 0,7

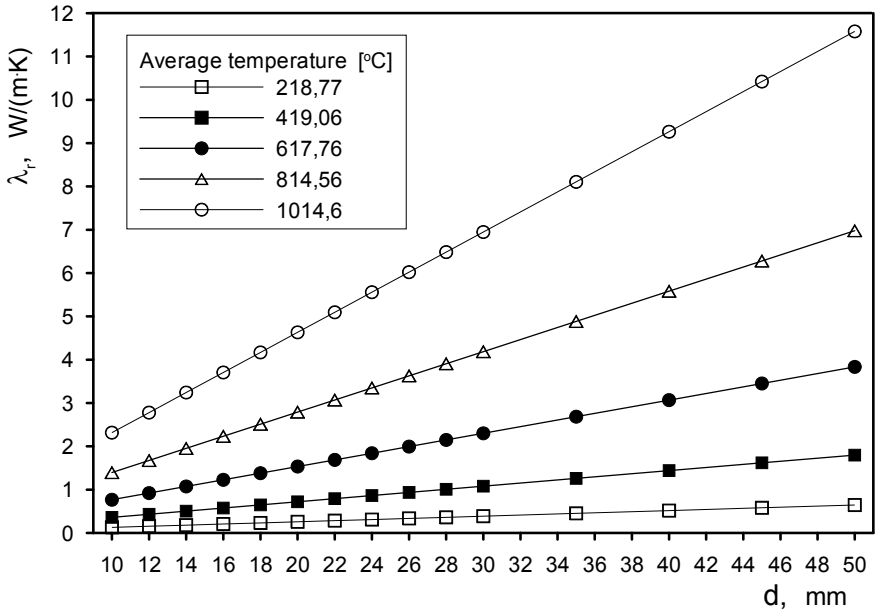


Fig.3. Radiation heat conduction coefficient of the bed of rods of an emissivity of 0.7, as dependent on the rod diameter for selected temperatures

Just above temperature 300 °C the values of this coefficient grove and in the 1000 °C cross the value 10 W/(m·K) in the rods bundle on diameter above 40 mm.

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