The Process of Heat Exchange in A Piece Batch

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Received: 02 November 2022/ Revised: 10 November 2022/ Accepted: 17 November 2022/ Published: 30-11-2022

Abstract— *The most important phenomenon in technical practice, which affects the thermal regime of industrial aggregates, includes, among others, the heat exchange process, which is primarily characterized by the heat trans-fer coefficient. The article analyses the influence of the grain size of the batch and the flow rate of the gaseous heat-carrying medium on the heat transfer coefficient during heating of the batch to the required temperature as a function of time. The experimental measurement was carried out on shaft furnace models.*

Keywords— ***Industrial Aggregates, The Batch, Heat Transfer, Heat Transfer Coefficient.***

I. INTRODUCTION

Metallurgical furnaces are complex mechanized and automated devices. The processes that take place in them are equally complex.

A charge is placed in the working space of the furnace and then the thermal process is started. The essence of this process is heating to a temperature that leads to a change in the state of the batch or to a temperature sufficient for its further processing. To increase the temperature in industrial furnaces, it is necessary to bring heat into the working space of the furnace, or to develop heat directly in the furnace and transfer it to the batch. The thermal regime of these industrial aggregates is very complex, therefore it is necessary to pay due attention to it.

II. HEAT EXCHANGE PROCESS IN BATCH

The exchange of heat in the layer of piece batch in the form of ground granulate of non-homogenized shape of grains of different granularity formed by heat-resistant material in shaft furnaces and similar furnace aggregates is ensured by direct contact of the gaseous heat-carrying medium with the charge. The heat ex-change process itself is ensured by radiation, convection as well as heat conduction in the batch itself. The radiant component is represented to a lesser extent and in practice is mainly used at high batch temperatures. Heat exchange by conduction occurs between the individual parts of the batch and represents a negligible part compared to the heat exchange between the flowing gaseous medium and the particles of the solid substance.

The intensity of heat exchange between two substances, which are most often a gas and a solid, is repre-sented by the heat transfer coefficient. Its value depends on several factors such as grain size and tempera-ture of the batch, temperature and speed of the flowing gas medium, power of the furnace unit, etc.

III. CHARACTERISTICS AFFECTING THE HEAT EXCHANGE PROCESS IN THE BATCH

The examined batch represented an immobile cohesive layer, the particles of which were deposited close to each other, at rest with respect to each other as well as to the walls of the working environment of the furnace unit in which they were deposited. The gas, whose flow was uneven, passed through the layer deposited in this way.

For experimental purposes, crushed fireclay of different grain size was used as a feed, and heated air of a known temperature and volume was used as a gas medium. Flue gas from the process of burning natural gas with air was used to heat the gas medium.

The basic parameters that characterize the cohesive layer include:

- spacing,
- bulk density,
- specific surface,
- characteristic size and shape of solid particles.

The spacing of the layer of particles is a dimensionless quantity determined by the ratio of the volumes of free spaces and the total volume of the layer [2]:

$$\varepsilon = \frac{V_c - V_m}{V_c} \ (m^2 \cdot kg^{-1}) \quad (1)$$

where V_c is the total volume of the batch layer (m^3), V_m – the volume of the batch particles (m^3).

The spacing depends on several parameters, which can include geometric parameters given by the ratio of the determining dimensions of the layer and particles, the shape of the particles, the granulometric composition of the layer, etc. The method of creating the layer, or method of depositing particles in a layer [2].

Bulk density is also an important parameter characterizing the properties of granular material, which depends on the density of the batch and its spacing. It is defined as the ratio of the total weight of the batch to the total volume that the batch occupies:

$$\rho_S = \frac{M_m}{V} \ (kg \cdot m^{-3}) \quad (2)$$

where M_m is the total weight of the batch (kg), V – the total volume of the batch (m^3),

respectively in the case of dispersion systems, a solid particle – gas relationship applies:

$$\rho_S = \rho_m \cdot (1 - \varepsilon) \ (kg \cdot m^{-3}) \quad (3)$$

where ρ_m is batch density ($kg \cdot m^{-3}$).

The specific surface area of the particles affects the amount of thermal energy that the batch is able to receive from the heat-carrying medium, and it can be related to the weight of the considered amount of particles or their volume.

The mass specific surface is given by the ratio of the surface of the particles in the batch to the weight of the particles of the batch:

$$a_m = \frac{S}{M_m} \ (m^2 \cdot kg^{-1}) \quad (4)$$

where S is the surface of the particles in the batch (m^2), M_m – weight of the particles (kg),

respectively the specific surface area related to the volume is given by the relation:

$$a_V = \frac{S}{V} \ (m^2 \cdot m^{-3}) \quad (5)$$

The efficiency of industrial furnaces is also linked to the conditions of the gas medium flow. Many factors depend on the nature of the flow, which can include the intensity of heat exchange in the working space, the distribution of temperature and pressure along the layer of the batch, as well as resistance to flow and spacing [4].

The gas flow through the cohesive layer is non-uniform and can be considered as the movement of the medium in the channels that are formed between the particles of the solid charge and between the particles and the wall of the working space of the furnace. As the compaction of the batch increases, the channels for the flow of the heat-carrying substance in the volume of the material become smaller, which leads to an increase in pressure losses and redirection of the gas flow to areas with less compaction, or to the walls of the aggregate. Compacting the batch will improve the contact of the individual grains but will reduce the efficiency of the entire heating process.

IV. DESCRIPTION OF THE EXPERIMENT

The experimental measurement required to determine the heat transfer coefficient was carried out on a reduced model of the shaft furnace (fig. 1), the basic parameters of which are listed in tab. 1. At the bottom of the furnace model there was a stepped grate on which the batch was stored. During the experiment, the particle size of the batch changed as well as the air flow. There was a pipe under the grate, with the help of which heated air was blown into the working space of the furnace. Before the measurement itself, it was necessary to stabilize the temperature of the batch, which was achieved by blowing in air of ambient temperature. During the experiment, the temperature of the batch material and the temperature of the flowing air were measured.

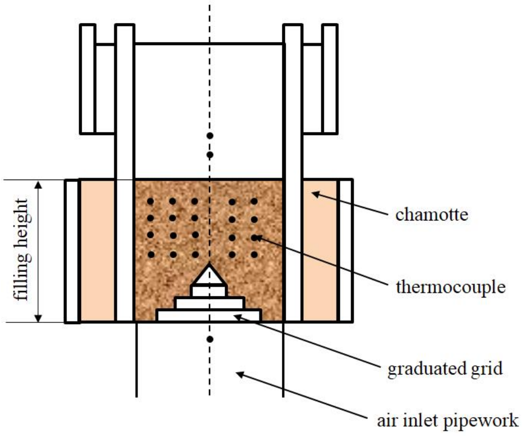

FIGURE 1: Furnace model with the distribution of thermocouples

Air flow was measured using a gas meter and its pressure using U-tube pressure gauges. The temperature of the charge and air was measured by touch thermocouples type K (NiCr-Ni).

TABLE 1
BASIC PARAMETERS OF THE FURNACE MODEL

height of the furnace model (mm)	856		
Inner pipe diameter (mm)	110		
Height of batch (mm)	488		
gas medium	air		
Batch	crushed fireclay		
Batch density ($kg \cdot m^{-3}$)	1900		
the volume of the furnace at the height of the batch (m^3)	0.046		
batch granularity (mm)	8-Apr	10-Aug	12-Oct
Spacing of batch (1)	0.55	0.61	0.623
Air flow ($m^3 \cdot h^{-1}$)	56.3	78	

V. DETERMINATION OF THE HEAT TRANSFER COEFFICIENT

When determining the heat transfer coefficient, balance equations were used, by comparing which a relationship was obtained for the expression of the heat transfer coefficient related to the volume of the furnace model:

$$\alpha_V = \frac{m_m \cdot c_m \cdot (t''_m - t'_m)}{V_C \cdot \Delta t_{LS} \cdot \tau} \ (W \cdot m^{-3} \cdot K^{-1}) \qquad (6)$$

where m_m is the batch weight (kg), c_m - average specific heat capacity of the batch($J \cdot kg^{-1} \cdot K^{-1}$), t_m' - temperature of the batch at the inlet (°C), t_m'' - temperature of the batch at the outlet (°C), V_C - volume of the shaft furnace model (m^3), τ - time (s), Δt_{LS}- mean logarithmic temperature difference (K), for which the relation applies:

$$\Delta t_{LS} = \frac{\Delta t' - \Delta t''}{\ln \frac{\Delta t'}{\Delta t''}} \ (K) \qquad (7)$$

where $t'_{vz} - t''_m = \Delta t'$ is the temperature difference between the air and the batch at the inlet to the model and $t''_{vz} - t'_m = \Delta t''$ temperature difference of the air and the charge at the outlet of the model.

In fig. 2, 3 shows the course of the heat transfer coefficient as a function of time at three different particle sizes for air flows of 56.3 $m^3 \cdot h^{-1}$ and 78 $m^3 \cdot h^{-1}$.

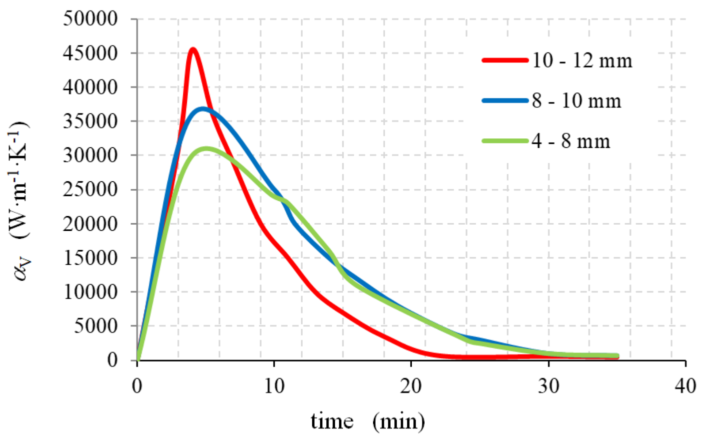

FIGURE 2: The course of the heat transfer coefficient as a function of time at three different grain sizes in the air flow 56.3 $m^3 \cdot h^{-1}$

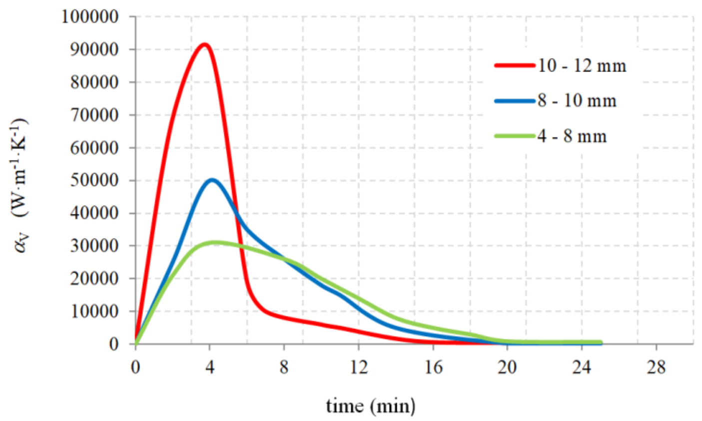

FIGURE 3: The course of the heat transfer coefficient as a function of time at three different grain sizes in the air flow 78 $m^3 \cdot h^{-1}$

From the graphical dependencies shown in fig. 2 and 3 clearly shows that the smaller the particle size of the batch, the lower the heat transfer coefficient between the batch and the heated air. Since the heat transfer coefficient depends on the heat exchange surface of the batch, it can be observed from the dependence that the batch with a larger heat exchange surface is able to receive more heat than the batch with smaller grain size in the same period of time, which means that the batch heated up to the required temperature earlier than in the case of small grain size.

In fig. 4, 5 show the courses of the heat transfer coefficient as a function of time at two different flow rates for batch grain sizes 10 – 12 mm and 4 – 8 mm.

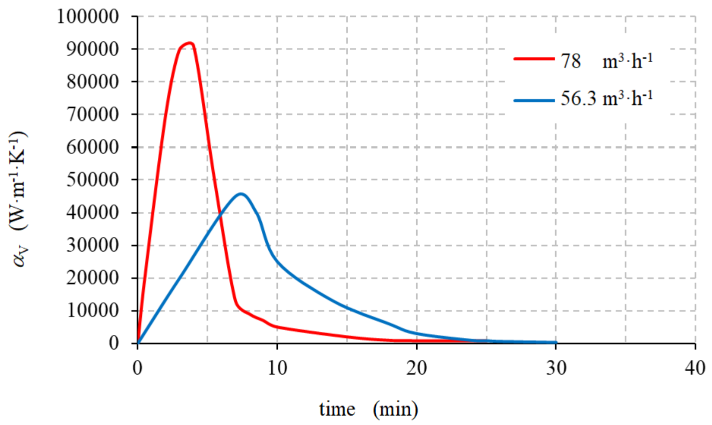

FIGURE 4: The course of the heat transfer coefficient as a function of time at a particle size of 10-12 mm at air flows 56.3 and 78 $m^3 \cdot h^{-1}$

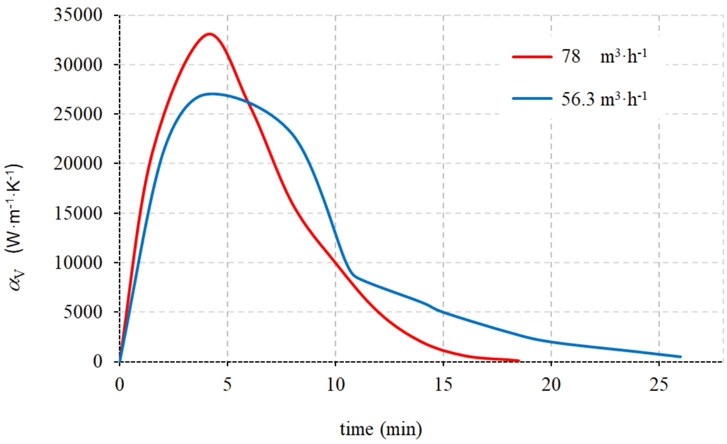

FIGURE 5: The course of the heat transfer coefficient as a function of time at batch granularity of 4 – 8 mm at air flows of 56.3 a 78 $m^3 \cdot h^{-1}$

The speed of the air flow depends on the flow rate. When comparing the dependence curves of the heat transfer coefficient in fig. 4, 5, which describe the development of the heat transfer coefficient at two different air flows, it clearly follows that the higher the air flow, the higher the heat transfer coefficient and the time required for heating the batch is shortened. At a higher flow rate, a larger amount of heated air enters the furnace, which transfers a larger amount of heat to the batch, and thus shortens the time required for its heating.

VI. CONCLUSION

The The value of the heat transfer coefficient from the flowing air to the batch depends on several factors. The grain size of the batch, the uniformity of the distribution of the batch, the inlet temperature of the flowing air as well as the amount of the heat-carrying medium flowing through the batch play a role.

As the particle size of the batch increased, the air flow through the batch also increased, which caused a faster and more homogeneous overheating of the material. In order to achieve more optimal heat transfer at lower grain sizes, it is necessary to ensure a higher air flow in order to achieve comparable heat transfer results between the air and the batch.

In order to increase the overall efficiency of industrial aggregates and reduce the costs associated with the operation of such devices, it is necessary to ensure optimal conditions for the transfer of heat from the heat-carrying medium to the material of the batch, which will also reduce the energy demand of the process and the time required for melting or heating the material to the required technological temperatures.

ACKNOWLEDGEMENTS

This paper was written with the financial support from the VEGA granting agency within the project solutions No. 1/0626/20 and No. 1/0532/22 from the KEGA granting agency within the project solutions No. 012TUKE-4/2022 and with financial support from the granting agency APVV within the Project Solution No. APVV-15-0202, APVV-21-0274 and APVV-20-0205.

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