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REFRACTORY MATERIAL MOISTURE METERING WHEN HEATING HIGH-TEMPERATURE UNITS

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The specifics of the drying process of the lining of high-temperature units are described, in particular, the average drying rate is analyzed. The adequacy of the proposed mathematical dependencies is confirmed by comparing the results obtained by calculation, and experimental data obtained at the laboratory bench. The research results can be used to develop a schedule for heating high-temperature units after major repairs to remove moisture.

Keywords: refractory materials, drying, high-temperature units (HTU), lining, moisture limit coefficient.

INTRODUCTION

Drying of high-temperature units (HTU) is the removal of moisture (free and chemically bound) from the materials of the lining, which gets into it during the manufacture of materials or during their storage and installation. When the lining is heated, water vapor appears, which is initially contained in the lining materials. This is due to the fact that sudden heating leads to rapid vaporization and steam passing through the gaps in refractory products and softening the seams between them. When drying refractory concrete and ramming masses at high speed, explosive cracks may occur. Moreover, with a quick heating of the lining, a situation is possible in which steam from heated sections will condense in the lower temperature areas of the lining.

Of great interest is the removal of free moisture (at a temperature of about 100°C), since it is at this stage that there is a significant increase in pressure inside the refractory material due to vaporization, which can cause cracking, or even explosive cleavage [1]. Studies show [2, 3] that during the drying process additional loads arise due to steam pressure, the values of which can reach 2 MPa, which is enough to destroy a monolithic concrete lining.

Standards determining the rate of rise of the temperature of the lining during the drying process have not yet been developed. The complexity lies in the variety of refractory materials used, the various thicknesses and the number of layers of the lining, as well as in the many ways of heating, etc. Thus, in article [4], data are given on the drying of refractory concrete applied using a shotcrete machine and in bulk lining. The diffusion coefficients of these two methods differ by about a factor of 10, while the estimated drying time of the working layer of the lining differs about 5 – 7 times. For this reason, when heating the HTU lining, heating schedules developed by the manufacturer for a particular unit are used, or the rules obtained based on operating experience.

HTU drying examples are presented in [5, 6], which describe the drying and heating of HTU according to the schedules provided by the refractory materials manufacturer, and the task of the maintenance personnel was only to adjust the thermal power of the energy source based on the readings of temperature sensors. In both examples, the change in thermal power is automatic; for this, two controllers connected to thermocouples are used with the ability to set upper and lower temperature limits. When the upper limit is reached, a signal is sent to turn off the burner; when the lower limit is reached, the signal turns on the burner [6].

However, even the schedules provided by the manufacturer are not optimal. The main task of the manufacturer is the maximum continuous operation of refractory materials in the HTU. The drying and heating schedules given in this case should avoid the maximum drying speeds. The goal of enterprises operating the HTU, on the contrary, is to reduce the

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time as much as possible, sometimes even exceeding the standardized indicators for refractory materials. As such, in [7], an example of reducing the drying and heating time of a HTU lining from the recommended 43 to 22 hrs is given, completely excluding the isothermal phase at a temperature of about 100°C. This led to the need for continuous monitoring of the temperature of the lining due to its accelerated destruction as a result of non-compliance with the drying schedule.

Studies show that a reduction in drying time is possible with a decrease in the density of refractories used. High porosity allows the steam formed during drying to pass through the refractory with less obstructions and helps to reduce the vapor pressure even at high heating rates. For the manufacture of lining of high porosity (and lower density), special additives are used that are introduced into the refractory material at the stage of its manufacture. Thus, the authors of [8] investigated the effect of additives of active compounds that increase the permeability of samples and prevent their destruction during heating. But the change in the properties of the refractory material to increase the drying speed, as noted in [8], in addition to the positive effect leads to a decrease in strength, a change in fluidity and an increase in the setting time. Given the fact that the strength of refractories is a determining parameter when choosing the heating rate after drying, and the rate of temperature increase is proportional to the strength of the refractory, the method of increasing the drying speed by introducing additives in the form of active compounds is not generally applicable and can be used only for certain conditions.

The process of drying the lining can be divided into two stages: external diffusion, in which moisture from the surface of the lining evaporates into the environment, and internal diffusion, in which moisture moves inside the lining from its inner layers to the outer surface. The process of moving moisture continues throughout the drying period. The evaporation of moisture from the lining surface is influenced by the following factors: initial lining moisture; temperature at which drying is carried out; the speed of movement of the drying gases, etc. In this case, the drying speed is not constant throughout the entire drying process. When the moisture content decreases to a certain value, the drying speed decreases. The rate at which this transition occurs, under normal drying conditions, is approximately constant for each refractory material. This transition is called the moisture limit coefficient. The drying period after the critical value takes place with a decreasing moisture limit coefficient [9]. The drying period at a constant moisture limit coefficient is associated with the ratio of the volume of the lining and the outer surface from which moisture evaporates. Therefore, different HTUs with the same capacity and lining of the same materials may have different drying speeds due to different surface areas.

In regards to the amount of moisture, HTU lining includes the moisture content of packed refractory masses (5 – 9%), traditional dense refractory concrete with 25 – 30% cement during installation (10 – 12%), and low-cement concrete (5 – 7%) [10]. It is obvious that monolithic linings have a greater initial amount of moisture than linings of piece refractories. This explains the significant number of publications devoted to bulk linings. But brickwork, in addition to moisture absorbed by refractories from the atmosphere, contains a rather large amount of water introduced with the solution used for it. Therefore, a drying calculation is important for any lining.

It should be noted that modeling drying processes both mathematically and physically is a rather difficult task. The difficulty lies in the large number of factors that affect the drying process. Physical modeling involves the use of fuel burners, which, as a rule, perform the heating. This causes a number of technical problems when creating laboratory benches. Therefore, physical models are limited to studying the drying of an individual element of the lining when it is heated in an electric furnace [2, 4].

Thus, it is of interest to study problems related to both the mathematical description of the drying process of the lining, and the physical modeling, which includes heating the lining with a gas burner and studying the drying of the HTU lining elements.

KEY RESEARCH RESULTS

The following is a mathematical description of the drying process used to determine its average speed for the purpose of practical application and adaptation in real conditions. To determine the average drying rate, we make a number of assumptions. We assume that during the drying period the temperature of the lining material is unchanged and all the heat transferred to the lining is used to evaporate moisture. Based on this, we can write the following equality:

$$q_{\text{in}} = j_{\text{c}} r; \tag{1}$$

where q_{in} is the heat flux density of the heat input, W/m^2; j_{c} is drying intensity, kg/sec; r is the latent heat of vaporization, kJ/kg.

The drying rate is denoted by N:

$$N = \frac{dW}{d\tau} \qquad (2),$$

where dW is the amount of moisture removed from the material, %; $d\tau$ is the drying time period, s.

Thus, the formula (1) can be written in the form [9]:

$$q_{\text{in}} = \rho R N r; \tag{3}$$

where ρ is the density of the dry lining material, kg/m^3; R is the volume to surface ratio, m.

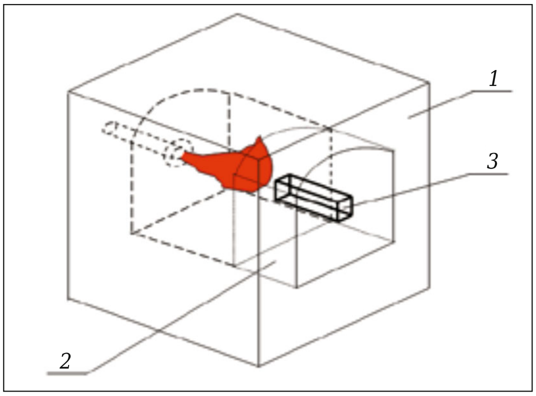

Fig. 1. Stand for determining the moisture content of the refractory sample.

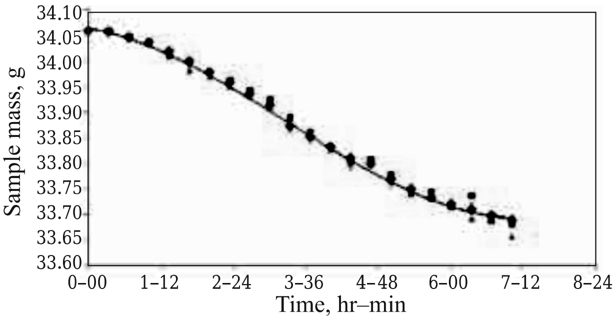

Fig. 2. Mass decrease of chamotte sample during drying.

From this, the value of drying rate N can be expressed:

$$N = \frac{q_{\text{in}}}{\rho R r} \tag{4}$$

Knowing the drying speed, it is possible to calculate the time required for drying according to equation (2).

Analysis of the above formulas shows that this does not take into account a number of factors affecting the thermal work of the lining: porosity of the dried materials, the presence of a binder, etc. For the correct application of the formulas in practice, it is necessary to verify the adequacy of the calculation method of drying time experimentally. For this, a stand was developed consisting of a muffle furnace *1* (Fig. 1). The exit window of the furnace is closed by masonry made of fireclay brick elements *2*. In the masonry *2* there is an investigated sample *3*. During experiments, the furnace is heated to a temperature of (110 ± 5)°C and the drying of the sample is examined. The main feature of drying the test sample in this way is that the masonry *2* with the test element *3* simulates the drying of the HTU lining: heating is implemented from the inside with a medium with a temperature of (110 ± 5)°C, while the outside faces the environment for moisture to escape from the lining. The sample is located in the thickness of the masonry and is surrounded on all sides by masonry elements, in which drying processes also take place.

The drying rate of chamotte refractory samples at (110 ± 5)°C was investigated. A graph of the decrease in the mass of the chamotte sample during the first 7 hrs is shown in Fig. 2. Three stages can be distinguished on the graph: the initial drying stage, the constant drying rate stage, and the decreasing rate stage. The drying rate in the constant rate stage is on average 0.0025%/hr.

The calculation of the drying rate N will be performed according to the formula (4) for the above conditions. By measuring the temperature on the outside of the masonry surface, we can estimate the density of heat flux from the masonry surface. For example, at a surface temperature of 50°C, the density of heat flux from the surface will be 250 W/m^2. Assuming a latent heat of evaporation of 2258 kJ/kg and a density of chamotte material equal to 2000 kg/m^3, we obtain an average drying rate of 0.0031%/hr under these conditions. Thus, the difference in results in practical measurements is no more than 20% less than the value obtained by calculation.

In industry, HTU drying is often carried out at significantly higher values of the heat flux. This is due to the fact that when drying with a flame from a burner or an electric arc, it is not possible to maintain a temperature level of about 100°C. Moreover, the drying process itself proceeds with a significant component of forced convection due to the operation of the fuel burner. In this regard, the need arises to conduct additional experiments with modeling the drying process in an open flame. The research bench was improved and the electric heating was replaced by heating from a gas burner by burning a propane-butane mixture (50% propane and 50% butane). At the stand using the gas burner, the drying rate was measured during the constant rate stage, the average value of which was 0.00375%/hr. The drying rate when using a gas burner was 1.5 times higher than the drying rate during electric heating. A comparison of the experimentally obtained drying rate of chamotte with the drying rate determined by formula (4) shows that the difference between these values is no more than 17.5%. Based on the study, we can conclude that it is possible to use formula (4) for calculating the drying time of the linings of existing HTUs.

Next we calculate the drying rate and time for a steel casting ladle with a capacity of 25 tons. When burning a propane-butane mixture as fuel, the heat flux through the lining will be 18 kW/m^2. Taking into account the thickness of the periclase-carbon layer (135 mm) and the density of the material (3000 kg/m^3), we obtain a drying rate of 0.07%/hr. At this rate, 5.43 hours are required to remove moisture in an amount of 0.38%. The obtained value can be used to develop a schedule for heating the HTU after major repairs to remove moisture at a temperature of 100°C.

CONCLUSION

Experimental tests show that the difference between the calculation method and the data obtained experimentally on the bench when drying chamotte by electric heating is no more than 17.5%, and when drying by burning a propane-butane mixture, no more than 20%. Thus, it is possible to use the obtained mathematical dependencies for practical application.

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