IRSTI 44.41.35

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Research of heating the lining of high-temperature units in order to increase their residual resource

Abstract. The article contains an analysis of the initial stage of the heating process of high-temperature units. The heating modes used at the enterprises lead to various difficulties: a delay in the heating process or heating at a high speed at which mechanical stresses arise and exceed the permissible values. The proposed graphical dependencies for heating allow us to heat up at the highest possible speeds, taking into account the time spent on drying. In this case, the ultimate strength of refractory materials is not exceeded, which leads to a significant reduction in the time for the heating process.

Key words: refractory materials, drying, heating rate, lining, high-temperature unit, heating schedule.

DOI: doi.org/10.32523/2616-7263-2021-135-2-106-112

Introduction

Currently, enterprises that operate high-temperature units have an important task - to determine the residual working time of the equipment (units). This allows as avoiding emergencies situations related to the safety of the operating personnel so predicting the time and amount of resources consumed.

Technological processes in high-temperature heat-technological installations are distinguished by a great variety and are determined by the following [1]:

- intensity of heat supply to the surface of the processed material (intensity of external heat transfer) and heat transfer inside the processed material;
- the intensity of mass supply from the outside to the reacting surface of the processed material (intensity of external mass transfer) and the intensity of molecular mass transfer inside the processed material;
- intensity of mixing of phases (solid, liquid) in the zone of their heat treatment;
- the speed of the actual chemical reaction and separation of target and related products;
- a combination of two or more of the listed factors.

This classification makes it possible to consider and analyze entire classes of technological processes from a single point of view and uniform methods. The approach facilitates the borrowing of the research results of some types of technological processes for the organization of others, using physical and mathematical analogies.

Research methods

Thermal stresses in the lining are a decisive condition in assessing the residual time, since a decrease in the thickness of the lining due to the action of temperature stresses is the most common reason for the withdrawal of high-temperature units for repair.

Let's consider three methods of heating high-temperature units that use fireclay bricks as lining.

Heating up of high-temperature units should be carried out with the avoidance of thermal stresses in the lining of the unit exceeding the permissible limit. The technique developed by the authors makes it possible to select the temperatures at which this condition is met. The analysis of various heating modes was carried out for the material under study (chamotte) to a temperature of 110 °C (the temperature of the drying process beginning) using the developed program. The drying process and further heating to operating temperature were also investigated. Three heat up options were considered:

- uniform heating up to operating temperature;
- initial heating at minimum speeds and further heating at maximum speeds;
- the maximum possible rising of temperature from the initial stage.

The maximum heating rate was limited by the arising temperature stresses, and the choice of the optimal heating method was determined by its minimum time. Let's consider different ways of heating the unit intensity.

The way No 1. The intensity of heating should be as follows: The first four steps have a speed of 10 °C/min (the time step was 10 minutes), then nine minutes with 1 °C/min, then - 2 °C/min until the temperature of 110 ° C is reached. Exposure at this temperature is 37 minutes.

The way No 2 has a heating rate of 2 °C/min until the temperature of 110 °C is reached. Temperature holding in this case takes 44 minutes and then heating occurs to the operating temperature.

The way No 3. The first six minutes have a heating rate of 2 °C/min, the next five minutes at 10 °C/min, and the remaining nine minutes at 1 °C/min, which takes 38 minutes.

Thus, the most optimal heating mode in terms of time is obtained at a temperature holding of 37 minutes, when the arising thermal stresses (compression, expansion) does not exceed the limit values.

There are factory lining heating methods. In many cases, they do not take into account the initial stage of drying up to 110 °C, the so-called temperature holding (horizontal section on the temperature graph). In the case when they even take into account the time to reach this temperature, the resulting limiting stresses are ignored [2]. Studies of drying samples have shown that the rate of evaporation of capillary moisture falls within the temperature range from 55-65 °C to 100-110 °C.

The values of many parameters are taken for calculations as constant, i.e., independent of temperature when developing thermal regimes for heating high-temperature units. For example, the values of the specific volumetric heat capacity c, thermal conductivity coefficient λ and ultimate strength σ are taken constant for calculations.

Meanwhile, the value of such a parameter as the ultimate compressive strength of a material is highly dependent on temperature.

Research results

The initial stage in the development of rational heating schedules for high-temperature units is the construction of existing heating schedules and their analysis from the standpoint of the arising temperature stresses. The program developed by the authors has the ability to calculate temperature fields and stresses by temperature at one point - on the inner surface of the lining for analyzing heating graphs. That is, if the temperature is measured during heating at one point, then the desired values of temperature stresses can be obtained over the entire section of the lining.

Such work was carried out on 25-ton steel-pouring ladles in the process of heating them up after overhaul. The operation of these ladles according to the appropriate technology assumes a major overhaul after 40 heats on average. Complete replacement of the lining, including the reinforcing layer, takes place during the overhaul. After that, the ladles are heated to operating temperature on special benches by burning a propane-butane mixture in a burner.

Periclase-carbon refractories are widely used for lining steel-pouring ladles. Let's take a look at the drying and heating schedule for a 25-ton steel ladle lining with a 135 mm working layer of periclase carbon. The heat up time to an operating temperature of 938 ° C is 24 hours (Figure 1).

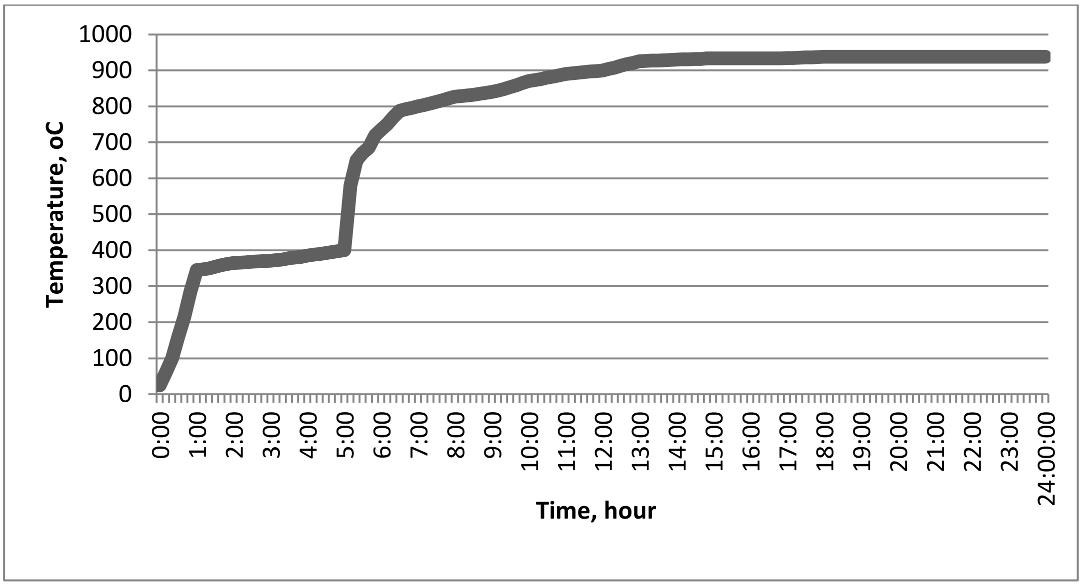


Figure 1. Drying and heating of steel ladle lining

The first stage (0-1:20 hours) has an interval of 20-350 °C and is carried out at an average speed of 37.2 °C/hour. At the same time, heating proceeds quickly, but evenly, without holding at a temperature of 100-110 °C to remove moisture. Further, from 1:20 to 5:00, the heating rate decreases to an average rate of 2-3 °C/hour, forming a horizontal section in the figure. Based on the figure, this horizontal section is necessary for relaxation of temperature stresses, after which the temperature rises from 400 °C to 650 °C in 20 minutes with an average heating rate of 75 °C/hour. Further, heating goes from 650 °C to 800 °C in 1:40 hours at an average rate of 13.6 °C/hour. Then a long period of temperature rise follows up to 900 °C in 5 hours. After that, slow heating takes 3 hours at a rate of 2 °C/hour to the holding temperature at 933 °C (horizontal section in the figure) for relaxation of temperature stresses. The lining temperature has been maintained at 938 °C for the last six hours instead of heating up. Thus, the average heating rate of the lining of a steel-pouring ladle from 20 °C to 938 °C is 40 °C/hour.

Analysis of this figure shows that thermal stresses arise in the lining when it is heated (Figure 2), which leads to the appearance of cracks and further to its destruction (Figure 3).

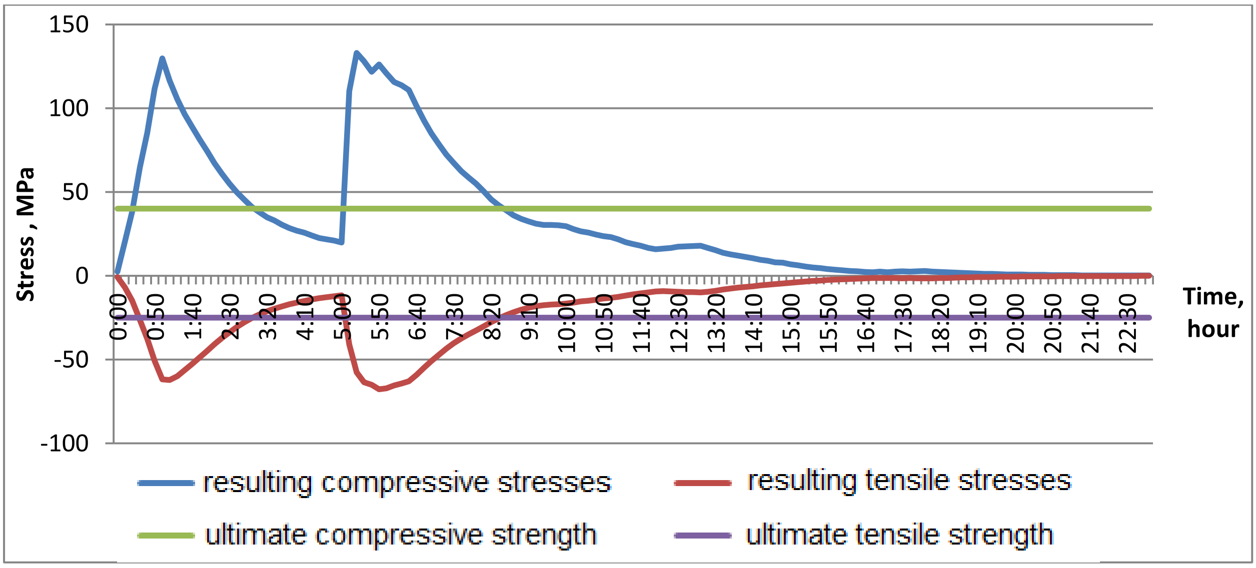


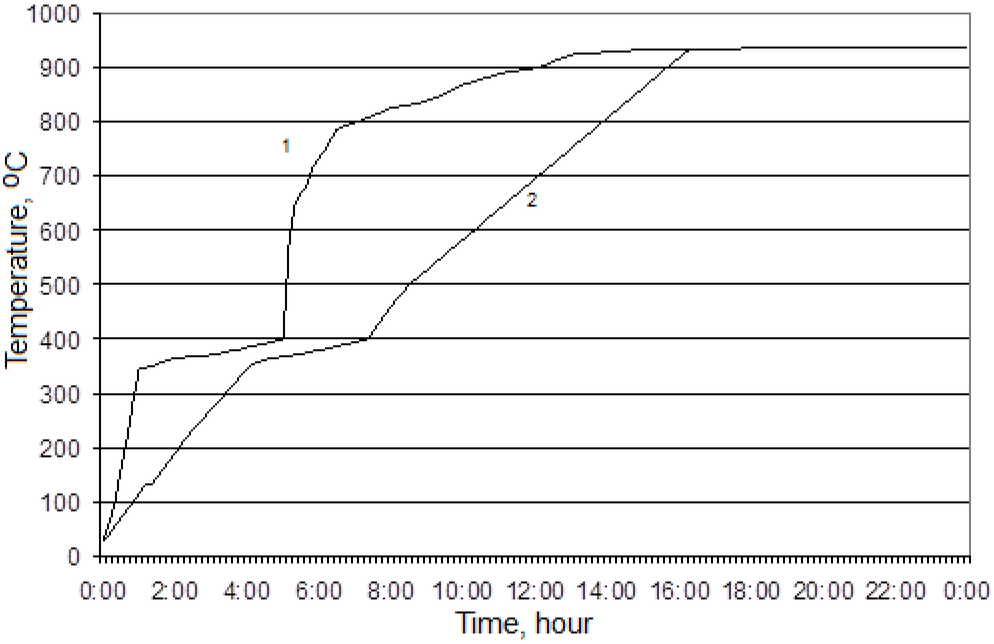
Figure 2. The resulting temperature stresses

The figure shows that the resulting thermal compressive stresses are twice the ultimate strength specified by the manufacturer for periclase-carbon refractories (40 MPa in compression and 25 MPa in tension).

Lining cracking is the result of heating at a high rate. The nature of the destruction is shown in Figure 3 for the lining of a 25 ton steel-pouring ladle after 22 melting cycles [3].

Figure 3. Cracks in the lining of a steel ladle

As a result, it can be concluded that the permissible heating rates are exceeded at the corresponding points in time. In addition, the ladle is heated up within 24 hours, and from the graph (Figure 4, curve 2) it can be seen that the inner surface of the lining reaches its maximum temperature after 16 hours of heating. Thus, the maximum lining temperature is maintained during the last 8 hours instead of heating up.



1 - factory warm-up schedule; 2- the author's warm-up schedule.

Figure 4. Steel ladle heating schedules

The rates of temperature rise were selected individually for each section of the curve. The average rate of temperature increase in areas from 18 to 500 °C (not containing drying areas) was approximately 90 °C/h. The total heat-up time to a temperature of 938 ° C is 16 hours and 20 minutes.

Conclusion

The research shows that the durability of the lining in high-temperature units is more dependent on temperature differences than on the chemical effect of the process material, etc. Thus, the main reason that determines the residual working time of high-temperature units is the wear of the lining during operation, associated with irrational processes drying and heating. Reducing the temperature stresses that arise during the heating process, taking into account the drying process, to normalized values, allows us to increase the residual working time of the high-temperature unit lining.

The heating schedules obtained by the authors allow the heating process to be carried out at the highest possible rates and to control it without exceeding the ultimate strength of refractory materials. In this case, a significant reduction in the time for the heating process occurs.

This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP09561854).

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Жоғары температуралы қондырғылардың қалдық ресурсын арттыру мақсатында жылыту процесін зерттеу

Аңдатпа. Мақалада жоғары температуралы қондырғыларды жылыту процесінің бастапқы кезеңіне талдау жасалған. Кәсіпорындарда қолданылатын жылыту режимдері әртүрлі қиындықтарға әкеледі: қыздыру процесінің кешігуі немесе жылдамдықта қыздыру. Нәтижесінде кернеулер рұқсат етілгендерден асып түседі. Кептіруге кететін уақытты ескере отырып, жылытуға арналған дамыған графикалық тәуелділіктер, отқа төзімді материалдардың шекті беріктігінен аспастан, мүмкін болатын ең жоғары жылдамдықпен қыздыруға мүмкіндік береді, бұл жылыту процесінің уақыты айтарлықтай қысқарады.

Түйін сөздер: отқа төзімді материалдар, кептіру, қыздыру жылдамдығы, футеровка, жоғары температуралы қондырғы, жылыту графигі.

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Исследование процесса разогрева футеровок высокотемпературных агрегатов с целью повышения их остаточного ресурса

Аннотация. Статья содержит анализ начального этапа процесса разогрева высокотемпературных агрегатов. Применяемые на предприятиях режимы разогрева приводят к различным трудностям: затягиванию процесса разогрева или разогрев со скоростями, возникающие напряжения при которых превышают допустимые. Разработанные графические зависимости для разогрева, с учётом затрат времени на сушку, позволяют производить разогрев с максимально возможными скоростями, не превышая предел прочности огнеупорных материалов, что приводит к значительному снижению времени на процесс разогрева.

Ключевые слова: огнеупорные материалы, сушка, скорость разогрева, футеровка, высокотемпературный агрегат, график разогрева.

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