SUMMARY

of the doctoral thesis for the scientific degree of Doctor of Philosophy (PhD) **«Research and development of ways to reduce thermal stresses in the lining of high-temperature units»** onthe Specialty6D071700 – «heat power Engineering»

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Purpose: Reduction of thermal stresses in linings of high-temperature units due to rationalization of heating processes.

The relevance of the work: Condition of the lining high-temperature units determines the reliability and efficiency of their work, therefore, increasing resistance of the lining due to the reduction of thermal stresses is an actual problem, the solution of which is impossible without studying the mechanism of thermal destruction and accurate data on mechanical properties of materials in the whole range of the used temperatures.

The novelty of scientific research is as follows:

- The method of thermomechanical tests of refractory lining materials of high-temperature units is developed and protected by a patent;
- Experimental data on the dependence of the tensile strength of a number of refractories (periclase-carbon, fireclay, diatomite) on the temperature;
- Optimized heating schedules liners of high-temperature units, taking into account the dependence of the tensile strength of refractories on temperature.
- Developed and protected by a patent method for determining the thermal state of the lining of the thermal unit.

The importance of scientific results for theory and practice. Rationalization of graphs warm-up lining of high-temperature units, taking into account the dependence of tensile strength on temperature allows to increase the life of the lining

Research problem:

- To carry out the analysis of thermal work of high-temperature units.
- Improved method of thermo-mechanical testing of materials for higher temperatures.
- Conduct experimental studies of the dependence of the compressive strength of refractory materials used in high-temperature units on temperature.
- To develop a mathematical model of the thermal state of the lining of high-temperature units.
- To develop a methodology and a computer program for calculating the temperature stresses and heating rates liners high-temperature units.
- Rationalize the heating schedules of the liners of high-temperature units, taking into account the dependence of the tensile strength of refractories on temperature.
- Rationalize the way of determination of temperature fields in liners of high-temperature units.

- Develop recommendations for improving the temperature conditions of high-temperature units.

In dissertation work the analysis of theoretical and practical methods of research of rational modes of process of warming up of high-temperature units, constructions of mathematical model of thermally stressed state of linings is executed.

The method of thermomechanical tests of refractory lining materials of high-temperature units is developed and protected by a patent. On the basis of these developments was developed and created an experimental setup to determine the strength of materials at elevated temperatures. At the experimental facility, studies were conducted to determine the compressive strength of various materials at elevated temperatures of the material.

Mathematical modeling methods were used to create the model, which are widely used for the study of temperature fields in thermal units. As boundary conditions for the considered high-temperature units, the following are accepted: on the inner and outer surface of the lining - boundary conditions of the 3rd kind (the temperature of the heating medium). Initial conditions-setting the temperature of the lining section.

To solve the heat equation with initial and boundary conditions we use numerical methods of solution-six-point implicit crank-Nicholson scheme.

For adaptation of the developed mathematical model of elements of lining of VTA the research stand was developed. On the stand it is possible to make researches on distribution of temperature in samples of refractory and heat-insulating materials by means of the control and measuring equipment with sufficient degree of accuracy of measurements.

Studies have shown that the accuracy of determining the temperature over the cross section of the lining during heating in accordance with the developed methodology does not exceed 6 %, which suggests the possibility of using this technique in an industrial environment.

To determine the thermal state of the lining (lining) in the factory taking into account the specifics of the existing equipment were developed and patented "a Method of determining the thermal state of the lining of thermal unit", which allows by measuring indirect indicators to determine the temperature field of the lining unit in the operating conditions.

Three ways of heating of high-temperature units were considered and analyzed:

- maximum possible temperature rise from the initial stage with a further decrease in the heating rate;

- uniform heating to the desired temperature at a constant speed throughout the time;

- initial heating with minimum speeds and further heating with maximum speeds.

It is proved that the heating of the lining on the first option is the most rational in terms of time.

The lining temperature measurements on the operating equipment (steel casting ladle and sintering furnace) were made and the schedules of the existing heating process of the equipment were rationalized. It is shown that the values of thermal stresses exceed the tensile strength for the refractory materials used.

The rationalized heating schedules of the considered high-temperature units (25-ton steel casting ladle and sintering furnace) allow to carry out the heating process without exceeding the tensile strength of the refractory materials used and to reduce the heating process by 1 h 30 min – for the steel casting ladle; 8 h – for the sintering furnace.

The applicant's personal contribution consists in:

- in the analysis and synthesis of literature data;
- in carrying out mathematical modeling;
- in the planning, organization and carrying out of experimental researches, processing and generalization of the results;
- in the development of experimental stands for research;
- in the development of new technical solutions.
- in carrying out adaptations of mathematical model on the developed stand;

Approbation of the dissertation results.

The main results of the work were presented and discussed at international scientific conferences and forums:

- scientific forum with international participation "IV Baltic sea forum" (Russia, Kaliningrad, 2016);
- I international scientific and practical conference "modern trends in boiler construction" (Russia, Barnaul, 2017);
- XI international scientific and practical conference "science technology innovation" (Russia, Novosibirsk, 2017);
- international scientific and practical conference "Topical issues of energy" (Russia, Omsk, 2017);
- XI international scientific and practical conference "Dynamics of Systems, Mechanisms and Machines" (Russia, Omsk, 2018).

Publications. The main provisions of the work are presented in 20 publications, including 5 publications recommended by the CCSON MES RK, 2 in the journal "Glass and Ceramics", included in the Thomson Reuters database, 1 in the journal "Dynamics of Systems, Mechanisms and Machines" included in the Scopus database, 2 in the foreign journal "Glass and ceramics" in 10 international scientific conferences and forums, 2 patents.

Volume and structure.

The thesis contains an introduction, notation and abbreviations 5 sections, conclusion, references, 3 appendices. The thesis is presented on 113 pages of a computer set, including 52 figures and 14 tables, a list of references from 62 titles.

The urgency of the scientific work is revealed in **the introduction**, the investigated problem is concretized. The main idea, scientific novelty, significance of scientific results for theory and practice, as well as approbation of results and publications are presented.

The first section of the thesis presents an overview and analysis of the state of development of high-temperature units. The technological characteristics of VTA and methods of research of heat work, durability and efficiency of these units depending on liners are considered. The types of refractory and heat-insulating materials used in aggregates, as well as factors affecting the operation of refractory materials are considered. The analysis of the thermal stability of the used refractories. According to the goal formulated objectives of the study.

The second section discusses the launch operations, the necessary conditions for the development and implementation of effective start-up modes. The dynamics of drying samples of refractory materials.The analysis of the excess of thermal stresses in the liners of high-temperature units.

The third section presents experimental studies of thermal characteristics of refractory and thermal insulation materials. For these studies, there was a need for experimental determination of the tensile strength at room and elevated temperature. For this purpose, an experimental installation was developed and created to determine the strength of materials at elevated temperatures. This plant was used for studies to determine the ultimate compressive strength of various refractory materials at elevated temperatures of the material: periclase carbon, diatomite and chamotte.

The author has developed a method and obtained a patent for" method of thermomechanical testing of materials", where to improve the accuracy of measurements implemented a method of thermomechanical testing of materials, which allows to determine the ultimate strength of materials for compression at elevated temperatures of the sample using a device that allows to determine the temperature of the material by direct method.

At the experimental stand, studies were conducted to determine the ultimate compressive strength of various materials at elevated material temperatures. The curve of dependence of the strength limit of periclase-carbon refractories on the temperature has the following trends: starting from the temperature of ~ 90 ° C, the strength of the refractory increases, reaching the value of 51.2 MPa (at a temperature of ~ 200 ° C), then the strength value begins to gradually decrease, reaching 40 MPa (at ~ 400 ° C).

The curve of dependence of the diatomite strength limit on temperature has the following trends: the initial value of the material strength limit of 6 kgf/cm2, which is lower than the claimed manufacturer. With increasing temperature almost immediately begins to increase the tensile strength, which at 100 ° C corresponds to the officially declared (6 kgf/cm2) and reaches a maximum at a temperature of 450-500 ° C (13 kgf / cm2).

At a temperature of 20 ° C, the compressive strength of the fireclay refractory is 20 MPa, and at 600 ° C the strength limit is already 40 MPa.

Calculation determination of the error of material strength measurements showed that the error does not exceed 4%.

The fourth section presents a mathematical model of the thermal state of the VTA. To create a model, mathematical modeling methods were used, which

are widely used for the study of temperature fields in thermal technology units. As boundary conditions for the considered high-temperature units, the following are accepted: on the inner and outer surface of the lining - boundary conditions of 3 kinds (temperature of the heating medium). Initial conditions-setting the temperature of the cross section of the lining.

To solve the resulting heat equation with initial and boundary conditions, we use numerical methods – a six-point implicit crank-Nicholson scheme.

Taking into account the accepted assumptions, the formula for temperature stresses was obtained

$$\sigma = -E \cdot \alpha \cdot (T_2 - T_1)$$

For the convenience of using the developed methodology, a block diagram and a computer program were developed. The source code of the software developed in Delphi is written in the ObjectPascal language.

A research stand was developed to adapt the developed mathematical model of the elements of the VTA lining. At the stand it is possible to make researches on temperature distribution in samples of fire-resistant and heat-insulating materials by means of the control and measuring equipment with the sufficient steppe of accuracy of measurements.

The studies show that the error in determining the temperature of the cross-section of the lining in the heating process in accordance with the developed technique does not exceed 6 %, which indicates the possibility of using this technique in industrial conditions.

To determine the thermal condition of the lining (lining) in the factory, taking into account the specifics of the existing equipment, a "Method for determining the thermal condition of the boiler lining" was developed and an application for a utility model was submitted.

In **the fifth section**, the study of the heat-stressed state of high-temperature units the Study of the heating process of the lining of the steel ladle showed that when heating the lining in it there were thermal stresses of both compression and vacuum, which exceed the limit of compressive strength and tension of the periclase carbon. There is a clear relationship between the temperature jumps and the jumps of emerging stresses.

The existing process of heating the lining of the steel ladle is critical for emerging temperature stresses. In the process of heating on the graph of the compression stress (figure 42) are two periods of time, the temperature stresses in which exceed the allowable (0H 20m – 3h 10m; 5h 10m – 8h 40m); on the graph of the tensile stress also has two periods (0H 30m – 3h 00m; 5h 00m – 8h 30m).

In the analysis of the process of heating the sintering furnace, in which the lining is used as a refractory fireclay brick brand SCHTSU it was determined that the stress during heating also exceed the tensile strength, but a more significant role (in duration) play tensile stress.

Modes of heating the considered equipment was rationalized by the criterion – the arising thermal stresses. The resulting streamlined heating schedules of the considered high-temperature units (25-ton steel ladle and sintering furnace) allow to conduct the heating process without exceeding the strength limit of the used refractory materials and reduce the heating process by 2 hours – for the steel ladle; by 2 hours 20 minutes – for the sintering furnace.

The conclusion reflects the main results and conclusions of the thesis.