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N.V. Michajlovskiy, associate professor, c.t.s.
S.V. Bejttsun, associate professor, c.t.s.
S.I. Dyomin, student
A.A. Iov, student

MODELLING OF WARMING-UP OF STEELPUORING LADLES

National metallurgical academy of Ukraine, Dnipropetrovs'k, Ukraine

As a result of the decision by final element method of the boundary value problem, describing by elliptic differential equations in partial derivatives, in the software package «ELCUT» it is obtained the change of the lining temperature field for ladle at its preparation under discharge of steel on high temperature heating device.

Keywords: steelpuoring ladle, lining, temperature field, final element method, modeling

Introduction. The warming-up of steelpuoring ladles is carried out with the purpose of decline of thermal losses of liquid metal and prevention of destruction of working fettling ladle, that it is related to the sharp temperature gradient in an initial period of producing of fusion [1]. Device of drying and high temperature warming-up of steelpuoring ladles is intended for drying of the heat-resistant staking preparations of ladle to pouring of steel.

Temperature conditions, and also duration of warming-up, are set on basis of experimental data for fettling of this type depending on its physical properties. The expense of fuel depends on external conditions and construction of devices [2]. The warming-up of working layer of steelpuoring ladles is carried out by presentation in working space of ladle of products of burning of natural gas [3].

Problem formulation. The large lack of modern devices is a necessity of constant control by the operator of warming-up of ladles. An operator does not have a line of information about readiness of ladle. A conclusion about a warming-up is the result of chart of warming-up marker comparison of supplier of heat-resistant fettling and chart of warming-up, got by means of recording device at the warming-up of ladle. The basic task of control system by the bench of warming-up of steelpuoring ladles is working off by an operator chosen the temperature-time diagrams with control of all basic parameters of technological process.

Thus, the task of process control of heating for ladle consists in choose and to maintenance of working regime which will provide the receipt of the high-quality dried up heat-resistant staking with the minimum possible specific expense of fuel in the conditions of variable productivity of aggregate.

For the reasonable choice of the regimes of drying and high temperature heating of steelpuoring ladles it is necessary to imagine the dynamics of the temperature field of fettling of walls and bottom of ladle. As existent techniques facility do not allow at productive conditions operatively for control the temperature of fettling ladle, then for technological process control it must to forecast.

Basic material of research. For the modeling of process of warming-up of steelpuoring ladles the programmatic package «ELCUT», which is intended for the two-dimensional modeling of the electromagnetic, thermal and resilient fields by the method of eventual elements is used [4]. A package allows to decide regional tasks which are described by elliptic differential equations in the partial derivatives.

At a temperature analysis it is been of interest distribution of temperature, temperature gradient and thermal stream. The package of «ELCUT» allows to execute linear and nonlinear stationary temperature analysis in flat and to the axisymmetric raising.

A mathematical model contains equation in partial derivatives, boundary conditions with which these equations decide, and a model of material - constants which determine its thermophysical properties.

In the context of task of non-stationary heat-conducting in the package «ELCUT» of is used equation for a axisymmetric task

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda(T)\cdot r\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda(T)\frac{\partial T}{\partial z}\right)=-q(T)-C(T)\cdot\rho\frac{\partial T}{\partial t}\ , \tag{1}$$

where z, r are co-ordinates; T is a temperature; $\lambda(T)$ is a heat-conducting; $q(T)$ is specific power of heat generation of internal sources of warmth; $C(T)$ is a specific heat capacity; ρ is a closeness of material; τ is time.

The noted equations decide jointly with boundary conditions which in the package of «ELCUT» meet standard conditions. For the purpose of modeling of the thermal state of ladle used the condition of Dirichlet - temperature on the surface of material, which can be set by both a number and by formula which describes dependence of temperature on co-ordinates and time, if a task is non-stationary.

Material, that modeling, is characterized by a heat-conducting, which can be set by both one number and couple of numbers in relation to different axes, and also heat capacity and power of by volume sources of warmth. It is possible also to realize functional dependences of the noted parameters from a temperature as formulas or tables. For a last case in intervals between tabular set values functional dependence is interpolated by a cube spline.

A geometrical model in the package «ELCUT» contains different geometrics objects and sets copulas between them and by properties of materials, field sources and boundary conditions. The basic types of geometrics objects, from which build a model in the system "ELCUT», are a top, rib and block. A top is a point on a plane, the co-ordinates of which are entered by a user or calculated automatically as a result of crossing of ribs. For every top it is possible to set the step of discrimination and mark. The size of step of discrimination sets approximate distance between the nearby nodes of net for eventual elements near this top. A rib is the segment of line or circle arc that unites two tops, a block is a spatial area the continuous limit of which is formed by ribs. The net of eventual elements is created in every block automatically or taking into account the step of discretisation, set in separate tops.

For a modeling warming-up the 120-ton printed steelpuoring ladle is chose. For the calculations of process of non-stationary heat exchange at heating of ladle the given are use such data: geometrical sizes of ladle (an internal diameter is 3.00 m, a height is 3.70 m, its number of taper – 0.06); thickness of layers and thermophysical properties of materials of fettling; temperature of internal surface of fettling, and also parameters of convective heat exchange in an environment.

Walls and bottom of the tamped ladle consist of a few the layers of different materials: walls - from chrome-magnesium (corundum), mullite, shamotte refectories and steel casing. In the bottom of ladle instead of shamotte refrectory use silica-alumina inself-solidity concrete (SASC). Structure of fettling ladle, and also thermo-physical properties over of its components in the function of temperature are brought in a table. 1.

Table 1 - Structure of fettling of steelpuoring ladle and thermophysical properties of its materials

Material	Thickness, mm		Number of layers		Closeness kg/m^3	Heat capacity Jou /(kg·K)	Heat-conducting W/(m·K)
	wall	bottom	wall	bottom			
Corundum	150	150	6	8	3000	790 + 0,42 T	2,10 + 1,90(10-3 T
Mullite	65	65	4	4	2600	840 + 0,25 T	1,39 + 6,10(10-4 T
Shamotte	32	–	2	–	2000	880 + 0,23 T	0,0,69 + 3,14(10-4 T
SASC	–	85	–	6	1400	840 + 0,20 T	0,0,48 + 1,40(10-4 T
Steel	20	28	1	1	7800	500	33,1

Note: T is a temperature of material

The geometrical model of steelpuoring ladle is by itself the truncated cylinder with a flat bottom. With the purpose of simplification of model geometry it is decided to shorten the quantity of layers of fettling to two, where the first, internal layer is a corundum, and by the second layer is combination of other materials (mullite, shamotte and steel casing) with the brought values over of their properties.

The values of heat capacity and closeness of the second (combined) layer of fettling calculate at formulas:

$$C_2 = \sum \frac{C_i \cdot \rho_i \cdot \delta_i}{\delta_2} \ ; \qquad (2).$$

$$\rho_2 = \sum \frac{\rho_i \cdot \delta_i}{\delta_2} \ , \qquad (3)$$

where C_i, ρ_i, δ_i is a heat capacity, closeness and thickness of layers of mullite, shamotte and steel casing accordingly; δ_2 is a thickness of the combined layer (sum of thickness mullite, shamotte and steel casing), accepted by such, that δ_2 = 117 mm is evened.

At the condition of maintenance of size of thermal resistance of the noted layers of value of heat-conducting λ_2 of the second (combined) layer of fettling wall of ladle of determined as

$$\lambda_2 = \frac{\delta_2}{\sum \delta_i / \lambda_i} \ , \qquad (4)$$

where λ_i is a heat-conducting of corresponding layers of fettling.

For a bottom the values of the noted descriptions expect like on properties of mullite, SASC and casing. Thus the thickness of the second (combined) layer of fettling equals the sum of thickness mullite, SASC and casing is presents a 178 mm.

On fig. 1 the geometrical model of steelpuoring ladle is represented. A closeness of net of eventual elements is neat as a result of research of exactness of the got results depending on this parameter of modeling. In a result it is accepted by such, that a 0.01 m is evened, which provides the error of determination of temperature no more than 1 °C.

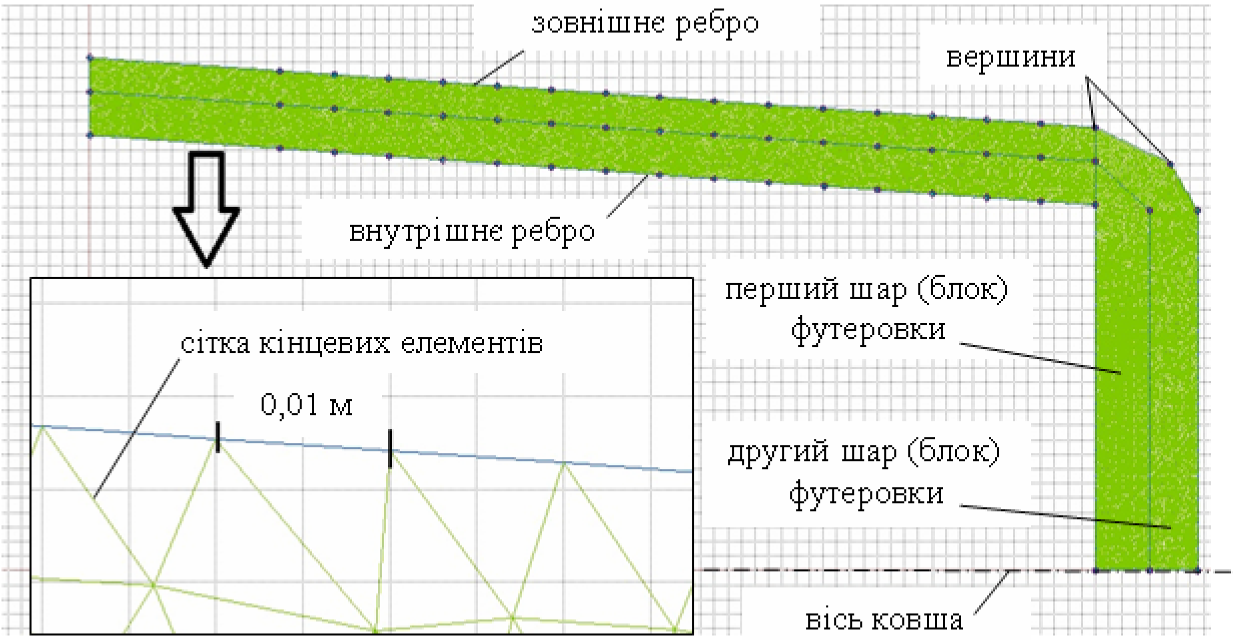


Figure 1 - *Geometrical model of ladle in system* "ELCUT"

Offered model of heating of ladle [5-8] consists in that the rational temperature chart of drying and high temperature warming-up of ladle on the internal surface (rib) of fettling set which is set by the marker of refractoriness [9], and consists of two stages:

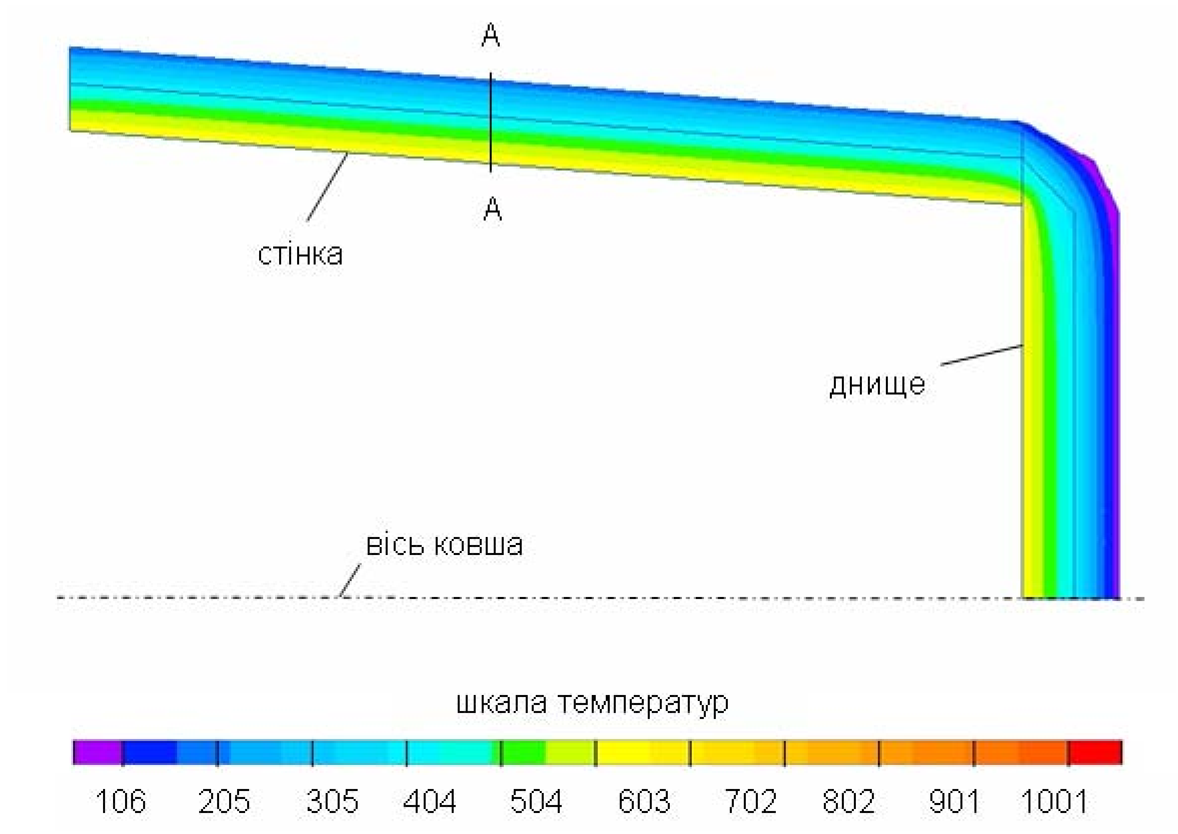
- is a linear increase of temperature during eight hours to the value 650 °C with further self-control at this temperature during four hours;

- is a linear increase of temperature during eight hours to the value 1100 °C with further self-control at this temperature during four hours.

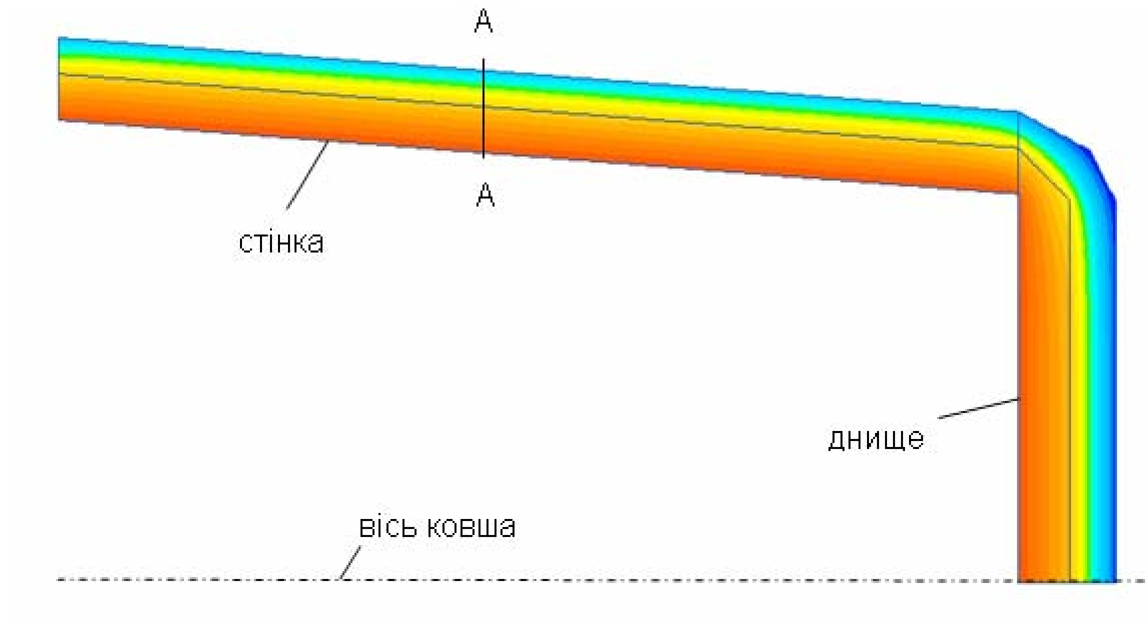
The model of the non-stationary heating of wall and bottom of ladle carried out taking into account the source field of temperatures of layers of fettling (T = 30 °C = idem). From the external surface of ladle in an environment which has a stationary temperature 30 °C, warmth is taken by convection. According to a calculation a value of coefficient heat-return taken 25 W/(m^2·K).

As a result of modeling, on fig. 2 the temperature field of fettling ladle is given after its warming-up during 12 hours (a) and at the end of warming-up during 12 hours (b).

On fig. 3 distribution of temperature after the thickness of fettling wall (in the cut of A-A) in 12 hours (and, curve 1) and in a 24 hours (b, curve 2) of its heating is represented, on fig. 3, is distribution of temperature in relation to the axis of bottom of ladle for analogical periods.

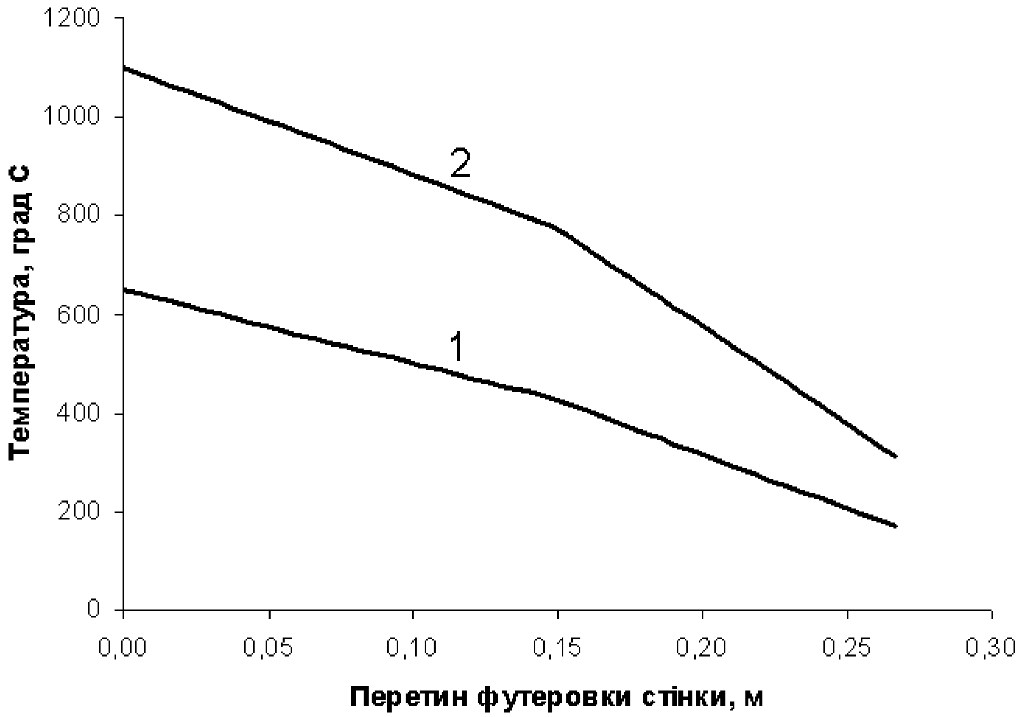


a)

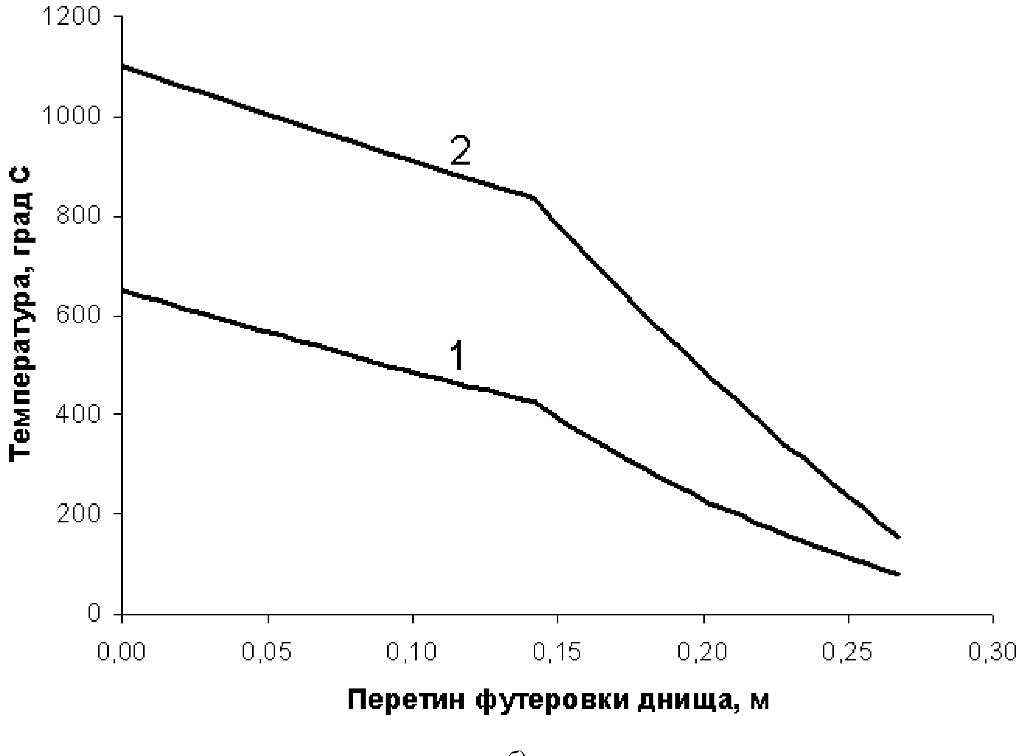


b)

Figure 2 - Temperature field of fettling ladle through 12 (a) and 24 hours (b) its warming-up



а)



б)

Figure 3 - Distribution of temperature of fettling wall of warmed-up ladle in the cut A-A (a) and fettling bottoms for the axes of warmed-up ladle (b):
1 - in 12 hours; 2 - in 24 hours

Conclusions. On the basis of analysis of construction and technology of warming-up of steelpuoring ladles a mathematical model, which is realized in the programmatic package "ELCUT", which is intended for the decision of non-stationary thermophysical tasks by the method of eventual elements for the industrial objects of difficult form, is worked out.

As a result of modeling distribution of temperature on the layers of fettling for different time of preparation of ladle is got. The created computer model can be used as quality forecasting at development ASC by preparation of ladles.

The worked out model of the thermal state of fettling is useful not only for choose optimal regimes of warming-up but also for the estimation of technical decisions at perfection of construction of ladles and other of metallurgical aggregates.

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