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# Heating furnaces efficiency improvement

Paramonov A.M.[a]*

[a]*Omsk State Technical University, 11, Mira Pr., Omsk 644050, Russian Federation*

**Abstract**

The technical and economic optimization problem of the heating furnace multi-layer lining, consisting of layers of different thickness and made of materials with different thermal physical and performance properties is considered. The solution and the algorithm to determine the most economically advantageous lining thickness of the furnace is offered. The algorithm allows to evaluate various combinations of multi-layer lining and optimize it for given functional and technical constraints. The calculation program helps to form optimally insulating and refractory furnace lining layers sequentially according to the temperature at the boundary layers, starting from the condition of ensuring lining reliability.


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*Keywords:* optimization; lining; a heating furnace; refractory and insulating material; heat loss; fuel

## 1. Introduction

Heating furnaces are power technology equipment. One of the most important factors determining the thermal furnace performance is the heat in the workspace. The furnace design should ensure optimal conditions of its occurrence and compliance with the set temperature with minimum power consumption.

Lining heating furnace is an important element of their design. It creates conditions for the process of thermal material treatment engaging in heat exchange in the working space and provides a heat losses reduction the environment. These losses are significant. When the lining thickness increases then heat conduction losses decrease; but then with the heat losses accumulation, the capital and operating costs increase. Therefore, a solution of furnace lining optimization problem in view of its thermal performance and cost characteristics is actual.

This issue investigation is devoted to a series of papers [1-5], but they examine the furnace lining with one-dimensional temperature field and provided that the heat flow density through all its layers is the same. These

* Corresponding author. Tel.: +7-3812-65-31-84.
*E-mail address:* amparamonov@mail.ru


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assumptions lead to significant errors, because it does not reflect the real thermal lining performance. We do not consider the heat loss in the unrecorded areas as well as the fact that the heat flux through the multilayer lining thickness is not the same.

We solve the problem of heating furnace lining technical and economic optimization when considering the three-dimensional heat flow from the furnace working space into the environment through the walls, the sole and the roof depending on its design in this paper. Multilayer planar wall is composed of different thickness layers and it is made of materials with different thermal and performance properties. We consider the furnace lining temperature field stationary and spatially inhomogeneous.

## 2. Study subject (model, process, apparatus, synthesis, experimental part, etc.)

The study subject is a heating furnace. The task of furnace multi-layer lining optimizing is to determine the optimum of its thickness, to provide a minimum fuel loss, the construction costs and lining operation. As the optimality criterion one has adopted performance evaluation of compared options to the minimum discounted costs ($C_i$) for the furnace lining:

$$C_i = \frac{C_f}{Q_н^р}(3{,}6\ Q_m h + Q_a N) + (\Pi + \mathrm{P_н})\ \mathrm{K} \tag{1}$$

where $C_f$ is the cost of fuel, rub./kg; $Q_н^р$ is the lowest calorific value of the fuel, kJ/kg; $Q_{m,}$ is heat conduction loss through the furnace lining, Vt; $Q_a$is heat loss for accumulation, kJ; $h$ is annual number of furnace operation hours, h/yr; $N$ is the annual number of furnace starts operation from cold state, yr$^{-1;}$P is depreciation rate, yr$^{-1;}$$P_n$ is the investments discount rate yr$^{-1;}$K is the furnace lining construction cost, rub.

## 3. Methods

Furnace heat balance analysis shows that while the heat loss changing through the furnace lining the values of all its components are proportionally varied. Therefore, without prejudice to the accuracy of the problem solution, let us consider from the heat balance equation only heat loss through the lining with thermal conductivity and accumulation.

Representing the expressions for determining the thermal conductivity of the heat loss through the lining into the environment and accumulation, as well as the construction costs of the furnace lining as a function of the thickness δ, we obtain an equation for determining an optimum thickness $\delta_{opt}$ furnace lining $\delta_{opt:}$

$$C = \frac{C_m}{Q_н^p}\left\{3{,}6h(t_0 - t_i)\left(\frac{\lambda_{FL1}(t_o - t_{FL1})F_{FL1}\alpha_{Out-w}F_{w-out}}{\alpha_{Out-w}F_{w-out}\delta_{FL1}\sum_{i=1}^{n}(t_{i-1}-t_i)_{FL} + \lambda_{FL1}(t_0 - t_{FL1})F_{FL1}} + \frac{\lambda_{S1}(t_0 - t_{S1})F_{S1}\alpha_{out-s}F_{s-out}}{\alpha_{out-s}F_{s-out}\delta_{S1}\sum_{i=1}^{n}(t_{i-1}-t_i)_S + \lambda_{S1}(t_0 - t_{S1})F_{S1}} + \right.\right. \tag{2}$$

$$\left.\left. + \frac{\lambda_{R1}(t_0 - t_{R1})F_{R1}\alpha_{out-r}F_{r-out}}{\alpha_{out-r}F_{r-out}\delta_{R1}\sum_{i=1}^{n}(t_{i-1}-t_i)_R + \lambda_{R1}(t_0 - t_{R1})F_{R1}}\right) + N\sum_{i=1}^{n}[V_i\rho_i(C_i^k t_i^k - C_i^н t_i^н)]\right\} + (\Pi + P_н)\sum_{i=1}^{n}(V_i S_i)$$

where $t_{,if}$ -$t_a$ is temperature of the inner surface of the lining and ambient air; $\lambda_{FL1}$,$\lambda_{S1}$,$\lambda_{R1}$ are indexes of thermal conductivity of the first layer walls lining material, the sole, the roof; $t_{FL1,}$ $t_{S1,}$ $t_{R1}$ are the temperature at the interface of the first and second layers of the furnace walls lining, the sole, the roof; $F_{FL1,}$ $F_{S1,}$ $F_{R1}$ are surface of heat transfer of the first layer walls lining, the sole, the roof; $F_{w\text{-}out,}$ $F_{s\text{-}out,}$ $F_{r\text{-}out}$ are the outer surface of the heat transfer of furnace lining walls, the sole, the roof; $\delta_{FL1,}\delta_{S1,}\delta_{R1}$ are the thickness of the first layer of the furnace walls lining, the sole, the