# Study and analysis of optimization approaches for insulation of an industrial grade furnace with electrical resistance heaters

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*Abstract* – **The paper discusses several approaches for optimal sizing of a multilayer insulation of an industrial grade furnace with electrical resistance heaters. The analysis is based on an iterative mathematical procedure, that allows simultaneous test of the thermal processes and the design on the device based of an initially set limitations and a dedicated function.**

*Keywords* – **Energy efficiency, Mathematical methodology, Optimization, electric heating.**

## I. Introduction

Industrial furnaces with electrical resistance heaters are designed for thermal treatment of steal parts – hardening, tempering and others. They are powerful electric loads, and all the efforts about increasing their efficiency are major concern [4, 7].

The mathematical methods for optimization and their application in electro technological apparatuses are discussed in different papers [1, 2, 8]. The possibilities for optimization of multilayer isolation of electric heater furnace (EHF) are considered a special case which makes the description incomplete.

The main goal of the following paper is to summarize the possibilities and the features of the models with concentrated parameters in the research and development of thermal devices with optimal construction, according to predefined constraints or objective function.

The suggested approach for investigation is based on mathematical model [3,4,5,6], realized by a system of differential equation, solved by numeric methods in MATLAB.

## II. Analysis

Using mathematical models [3,4,5,6] allows significant expanding of the possibilities for analysis of the processes taking places inside a EHF.

The suggested model [3] is used to optimize the parameters of the isolation. It allows taking into account the specific particularities of the technological process independently of the construction. The process is defined by heating speed, allowed temperature difference according to the thickness of the part and other parameters.

It is also possible to enter the custom operation modes of the EHF and investigate the best ranges in which the optimization criteria are fulfilled with less than the maximum error.

The construction of the EHF sets the optimization procedure as multivariate with different objective function for each case. As a result of this, the scanning method is used, and the constraints are used to choose the construction type.

Major factor, that determines the energy efficiency of EHF are the losses. The following cases for objective function with the set of constraints are examined:

- *Objective function* – minimal heat losses. *Set of constraints* – allowed weight and volume. *Goal* – to find a construction of EHF with given volume and/or weight between two values, for which the losses are minimal.
- *Objective function* – minimization of weight and volume. *Set of constraints* – allowed losses. *Goal* – to find a construction of EHF with smallest external volume for which the losses are in the allowed range.
- *Objective function* – minimal price. *Set of constraints* – allowed volume, mass, losses. *Goal* –to determine the heat isolation materials for the given price range. It is necessary to obtain an up-to date prices for the materials.

With all of the three optimization tasks, the working environment and the load are unchanged. Realization of these tasks is than simplified to find: the minimal losses – for stationary furnaces working in continuous mode (industrial, heavy duty furnaces and so on); the minimum mass and volume for furnaces that are not so often used and are not major equipment – mobile furnaces placed on a platform, laboratory furnaces and others.

Several scanning method approaches are formulated:

- *Calculation of the heat isolation (walls) of the EHF.* A model is created, for which the selected materials are unchanged. Than the thickness of the isolation is recalculated according to the objective function and constraints. This approach is used with all objective functions, but because the type of the material is fixed it is not flexible enough.
- *Selection of isolation materials for EHF.* A model is created with fixed wall thickness (constant volume). Then

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fireproof heat isolation materials are selected from a given database. Possible objective function is minimization of mass and or losses. This requires full information for the database.

- *Calculation of the wall thickness and selection of the material.* A model is created that allows simultaneous work of the former two approaches – variable wall thickness and material. This approach allows great flexibility and gives a multivariate solution to the problem.

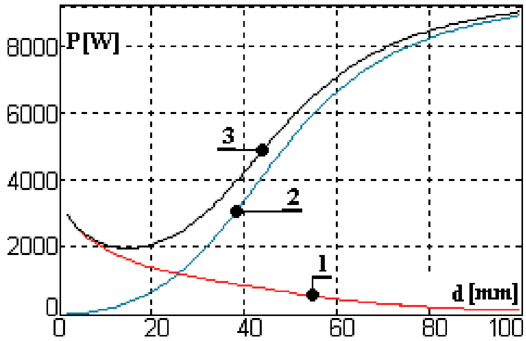


***Fig.1. Losses versus wall thickness.***
***1 – losses to the environment; 2 – energy accumulated in the wall; 3 – total losses***

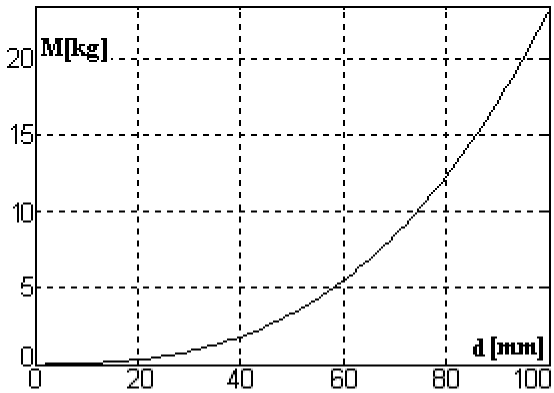


***Fig.2. Mass of the wall as function to its thickness.***

The calculation process is iterative and realized by changing the wall thickness with predefined step. An EHF is investigated with objective function loss minimization. The set of constraints are minimum wall thickness *gD1* = 10 *mm* and maximum *gD2* = 40*mm*. These are standard dimensions of isolation materials, supplied by various manufacturers. In order to obtained more detailed analysis the range for the wall thickness is expanded from 3mm to 100mm. The obtained results are graphically presented as follows:

- *Fig.1.* Minimum losses are calculated at wall thickness $gD = 18$ *mm*, fulfilling the original constraints: $gD1 < 18 < gD2$. The same approach is used for the mass constraints. Line 1 shows the decrease of the heat flow from the furnace to the environment with increase of the wall thickness. Simultaneously the accumulated energy inside the isolation is increased as shown by line 2. The total losses are increased as a result.
- *Fig.2.* The change of the wall mass is according to the density of the used materials and their volume. In this case the graph shows the mass of a single wall of a furnace that has a total of six walls, but the same approach can be used to determine the total mass of the device.
- *Fig.3.* The distribution of the temperature inside the wall, allows coordinated heat loading of the materials. The presented results are for the middle of the wall, with the transient process completed.
- *Fig.4.* The model gives information about the accumulated energy inside the walls of the furnace and the heat losses to the environment. They are similar to the graphs presented in fig. 1.

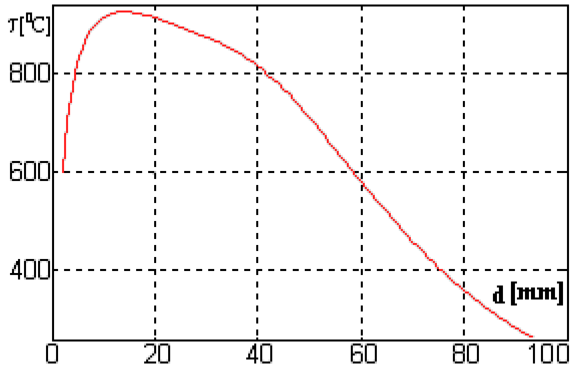


***Fig.3. Temperature in the middle of the wall as a function of its thickness.***

The optimization task is more complicated when multilayer isolation is used. This case also requires investigation, as the walls of medium and high temperature furnaces are built in exactly this way. The presented example has two layers of isolation, each having thickness from 5 mm to 100 mm. The results are presented below.

- *Fig.5.* presents the losses versus wall thickness. The behavior of graphs 3 and 4 is determined by thermal characteristics of the materials $\lambda$ and *c*, which are different for heatproof materials (layer 1) and thermal isolation material (layer 2).
- *Fig.6.* presents the mass of the furnace under test as a function of the wall thickness. The maximum weight is 221,6 kg;

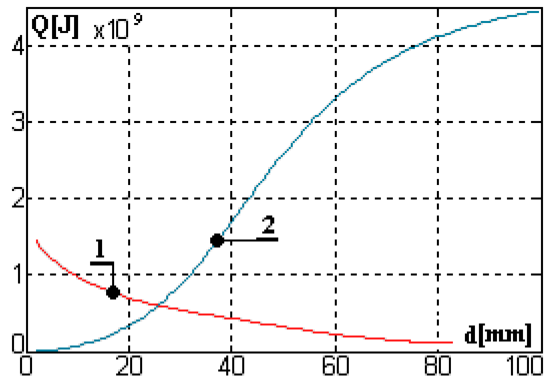


***Fig.4. Energy distribution.***
***1 – energy to the environment;***
***2 – energy accumulated in the wall;***

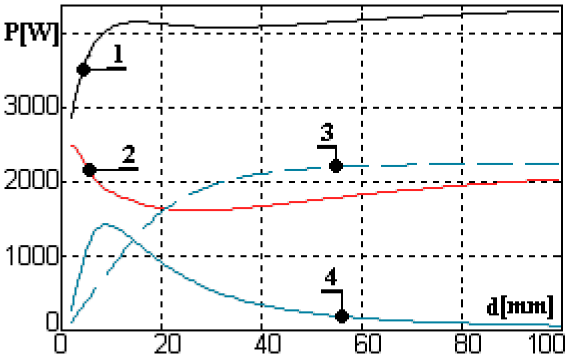

*Fig.5. Losses versus wall thickness*
*1 – total losses; 2 – losses in the environment;*
*3, 4 – accumulated in layer 1 and 2 of the isolation;*

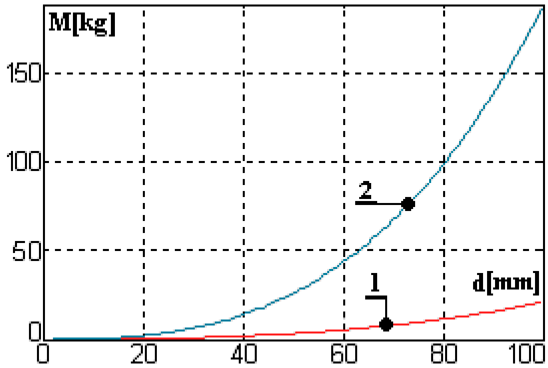

*Fig.6. Mass of the layers. 1,2 – for layer 1 and 2;*

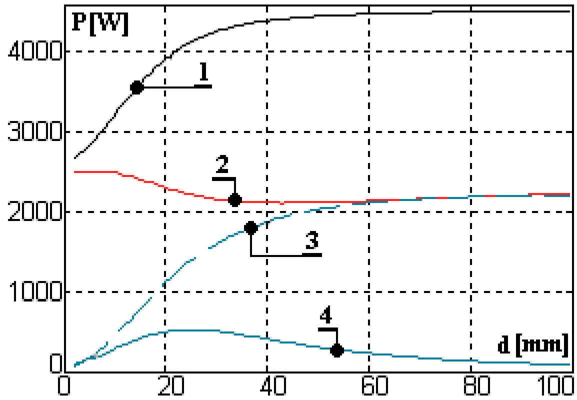

*Fig.7. Losses versus wall thickness*
*1 – total losses; 2 – losses in the environment;*
*3, 4 – accumulated in layer 1 and 2 of the isolation;*

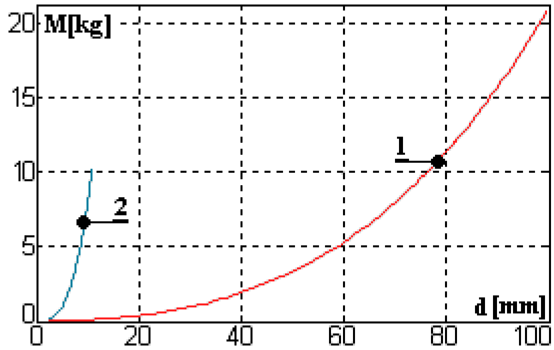

*Fig.8. Mass of the layers. 1,2 – for layer 1 and 2;*

- *Fig.7.* and *Fig.8.* show the same process but the thickness of the first layer (fireproof) is increased to 10 mm, and 100 mm for the second (heat isolation) layer. The results shows that the total losses (fig.7 graph 1) are considerably increased compared to the previous case (fig. 5 graph 1), while the mass of the furnace is reduced to 32,92 kg. This shows that the obtained results can be used to solve an optimization problem for the mass and the volume of the furnace. This is the problem to be solved for most small volume laboratory furnaces, which are not used in continuous manufacturing process.
- *Fig.9.* and *Fig.10* present the transient process when heating a component, for both the initial, and the final dimensions for both layers. According to the data, when the wall thickness is increased, the temperature inside the furnace is increased, as the supplied power is constant. The presented processes are the final result in the designed apparatus. They give information about the adaptation of the EHF for realization of the required technological process.

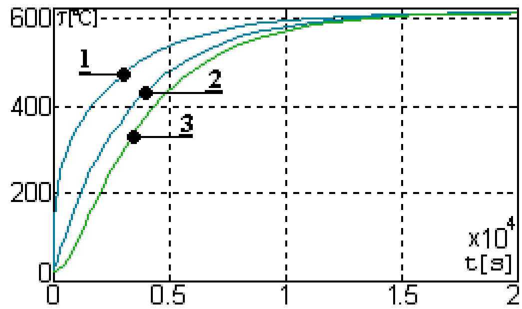

*Fig.9. Transient process when heating a component, wall thickness 5 mm. 1 – heater temperature;*
*2,3 – temperature on the surface and in the middle of the component.*

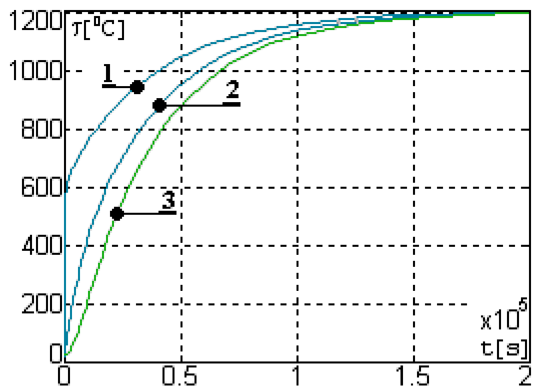

*Fig.10. Transient process when heating a component, wall thickness 100 mm. 1 – heater temperature;*
*2,3 – temperature on the surface and in the middle of the component*

## III. CONCLUSION

The results show different possibilities and applications of the suggested approach. The following advantages are observed:

- Full information, about the processes in the EHF is obtained. This allows evaluation of the influence of the corresponding factors on the furnace characteristics.
- Obtaining the dimensions of the isolation layers, with predefined constrains is in conjunction with the optimization requirements respectively creating equipment that fulfills some operation conditions.
- The mathematical models [3,4,5,6] should be used in the process of designing new equipment or reconstruction of existing one.

## ACKNOWLEDGEMENT

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