REFINING THE PROCESS OF DESIGNING AN ELECTRICAL RESISTANCE HEATER FOR VACUUM FURNACE IN NON-STATIONARY PROCESS

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Abstract: *Designing an electrical resistance heater for vacuum furnace is a result of multiple thermo-technical and electro-technical calculations in order to determine the optimal power. The process of heating must also comply with the technological requirements for temperature differences between the inside and the surface of the processed products. Considering the complicated heat transfer in the furnace, there is no complete methodology for determining the heat conditions of the participants in the heat transfer differentiating in time and space. In this paper it is systemized a sequence of applied mathematical and numerical models as well as geometric dependence for deriving the angular coefficients of radiant interchange in the process of determining the temperature of every participant in the heat transfer in order to refining the process of designing an electrical resistance chamber.*

KEYWORDS: *VACUUM, FURNACE, HEATER*

1. Introduction

The main purpose of the vacuumed furnace, as with all other furnaces, is to provide certain temperature condition for implementing a predetermined technological process. Usually, in the terminology, by furnace it is meant the chamber where the products are thermally processed. As a consequence of the specificity in heating in vacuum, most commonly used are the electrical resistance heaters.

When designing a new vacuum chamber the most significant calculations are those related to determining the power of the heater. It has to ensure the necessary optimal speed for heating the product. Usually the diversity of products that are processed in the same furnace impede determining the optimal power since it depends on multiple factors.

Designing an electrical resistance heater for vacuum furnace is a result of multiple thermo-technical and electro-technical calculations in order to determine the optimal power. The process of heating must also comply with the technological requirements for temperature differences between the inside and the surface of the processed products. Considering the complicated heat transfer in the furnace, there is no complete methodology for determining the heat conditions of the participants in the heat transfer differentiating in time and space.

In this paper it is systemized a sequence of applied mathematical and numerical models as well as geometric dependences for deriving the angular coefficients of radiant interchange in the process of determining the temperature of every participant in the heat transfer in order to refining the process of designing an electrical resistance chamber.

2. Exposure

In a vacuum furnace there are available all methods for heat transfer

- radiation – screens, all objects in the chamber
- convection – the water layer of the cooling water
- conduction – between the layers of the wall

and combined heat transfer processes;

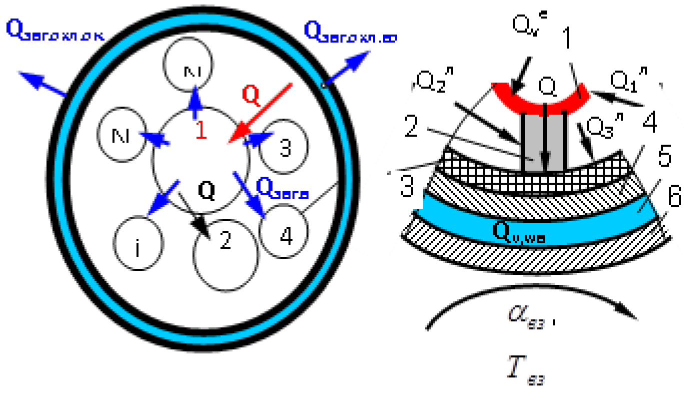
-conductive – radiant – electrical conductor, heater, processed product, stand

-conductive – convective - outer layer with ambient environment

A selection has been made from three objects (fig. 1), that covers all kinds of heat transfer that exist between the objects in the chamber.

In [1] it is represented a system of differential equations that with motivated simplifications describe the thermal condition of the objects in the vacuum furnace. In fact, the main problem with conjugated limit equation are two: first – defining the limit conditions and second – finding appropriate method for solution.

Fig.1 *Distribution of electrical energy in the system*



1 – heater 2 – electricity conductor
3 – insulation 4 - innerskkin
5 – water jacket 6 – outer skin

DESCRIPTION OF THE MODEL

№	**Differential equations**	**Conjugated limit equations**
1.	$C_1 \frac{\partial T_1}{\partial t} = \frac{Q_1^{л}}{F_1^{\wedge}} - q_k + q_v^{ел.}$	
2.	$C_2 \frac{\partial T_2}{\partial t} = \frac{Q_2^{л}}{F_2^{\wedge}} + q_k$	
3 **4** **i** **6** } **5**	$C_i \frac{\partial T_i}{\partial t} = \frac{1}{R} \frac{\partial}{\partial R}\left(\lambda_i R \frac{\partial T_i}{\partial R}\right)$ $C_5 \frac{\partial T_5}{\partial t} = \frac{1}{R} \frac{\partial}{\partial R}\left(\lambda_5 R \frac{\partial T_5}{\partial R}\right) + q_v$	$\lambda_3 \frac{\partial T_3}{\partial R} = \frac{Q_3^{л}}{F_3} \quad \lvert R = R_3$ $\lambda_i \frac{\partial T_i}{\partial R} = \lambda_{i+1} \frac{\partial T_{i+1}}{\partial R} \quad \lvert R = R_i$ $\lvert T_i = T_{i+1}$ $\lambda_6 \frac{\partial T_6}{\partial R} = \alpha_{b3}\left(T_{b3} - T_6\right) \quad \lvert R = R_7$

$Q^{л}_{1,2,3}$ is calculating using Gebhart method [1]

$$Q_k^{л} = A_k \varepsilon_k \delta T_k^4 - \sum_{j=1}^{N} A_j \varepsilon_j \delta T_j^4 G_{jk},$$

$$G_{jk} = F_{j-k}\varepsilon_k + F_{j-1}\rho_1 G_{1k} + F_{j-2}\rho_2 G_{2k} + ...F_{j-k}\rho_k G_{kk} .... + F_{j-N}\rho_N G_{nk}$$

, where

G_{jk} - the share of every object in radiant heat transfer;

$$q_k = \frac{(T_1 - T_3)\lambda_2}{H};$$

$$q_v = \frac{V_{деб}}{V_o} T^*;$$

F_i - area of i^{-th} object;

R - radius;

q - heat stream;

Q - heat quantity;

F_{j-k} - angular coefficient of heat interchange;

ε - degree of blackness;

ρ - absorption coefficient

C_i -heat capacity;

δ - Stefan-Boltzmann constant;

λ - thermal conductivity coefficient;

$V_{деб}$ - water cooling flow rate;

V_0 - water layer volume;

T^* - temperature of incoming cooling water

The share of radiant interchange between objects is represented by a system of algebraic equations that after transformation can be calculating using the Gaussian method

With discrete representation with time and space there are two known main solutions

In[2] it is shown a motivation for choice of numerical method for solution of analytical models. It is necessary not only discretization in time for objects in which the heat transfer is accomplished through thermal conductivity, it is necessary to discretization in space. The choice of solution is motivated– known in literature as “obvious scheme”. In order to eliminate mistakes by inaccuracy in calculations as well as the risk of inability to continue (getting stuck) in small differences (T – T) it is necessary to set requirements for the values of two intervals – space and time. The influence of the two intervals on the result of calculations is examined in the literature [4,5].

For the flat wall it is introduced generalized criteria for resistance [5] that represent the interdependence of two intervals (1). Accomplishing that requirement make the scheme stable against unavoidable calculation errors.

$$\frac{\rho c \Delta x^2}{\lambda \Delta \tau} \geq 2 \quad \textbf{(1)}$$

By analogy it is deduced the criteria for resistance of cylindrical wall.

$$\frac{c\rho \Delta R^2}{\lambda \Delta \tau} \geq 2 \quad (2)$$

The heat transfer in vacuum furnace is predominantly radiant. For tracking the thermal condition of the objects during heating (cooling), it is necessary to determine the angular coefficients of radiant interchange for every object with the other objects. The methods known in the literature, including the geometric one, calculate the heat transfer only between two objects. The applications for real thermal systems is partial and limited.

The geometric dependencies deduced from the thermos-technical theory for determining the angular coefficients of radiant interchange, in many cases, do not cover the possible situation for two planes as well as does not take into account the impact of other objects as it is in real conditions. They are becoming even less applicable when there are intermediate objects as well as the situations where it is need to take into an account the barriers for heat radiant from its own surfaces.

In [3] it is suggested a geometric approach for determining the angular coefficients for closed thermal system with unlimited number of objects and unspecified alignment among them.

The main goal when designing a vacuum furnace is searching for such a solution for the thermal model so that it can be chosen the optimal values for the main parameters, so that, it can be ensured a high productivity with low energy intensity. An indicator for furnace efficiency is losses. The losses are consequences of forced water cooling of the walls, as well as, cooling through natural convection with air. In order to simplify the solution the dynamic water layer is substituted with stationary one. The total heat content of the dynamic layer can be expressed as a sum the of heat content of two volumes. First ($V^{in.}$) is entered for time $\Delta\tau$ volume of water with temperature $T^{in.}$. For that amount of time, from the first volume V^0, that from the beginning of the interval $\Delta\tau$ was with temperature T’, is leaving a portion of water with the same volume ($V^{in.}$), but with temperature T’.

At the end of the interval $\Delta\tau$, the rest of the overall volume (V^0-$V^{in.}$) is with temperature T’.

The new heat content of the layer corresponds a temperature T^{cor}, that is considered homogeneous throughout the overall volume.

$$c\rho V^0 T_{cor.} = c\rho V^{in.} T^{in.} + c\rho(V^0 - V^{вх.})T' \quad (3)$$

After transformation of $T_{cor.}$ the result is (3).

$T_{cor.}$=W+T’, where W=($T^{in.}$- T’) $\frac{V^{in.}}{V^0}$ - correction value (4)

The proposed approach is experimentally verified with specialized software product. Data has been taken from real heating in vacuum furnace. The result has been compared and overlap and conclusions are published in [6].

3. Conclustions

- The thermal model, represented as a system of differential equations binds all three types of heat transfer – radiant, conductive and convective that are typical for vacuum furnace

- The solution of the system of equations with the proposed numerical method gives adequate representation of the distribution of thermal field in time and space
- The limit conditions in conductive heat transfer, with chosen time interval, discretize the temperature by volume represented by the method of extreme difference between them.
- For instant thermal condition of the object`s surface in radiant heat transfer, it is represented by a system of equations (linear) using the Gibhart`s method. The solution is calculated using Gauss method
- Dependencies have been deduced and new approach has been suggested for rendering the influence of cooling water

Using the prupосed sequence of mathematical and numerical method garantees to determine the power of the heater that ensure diverse technological requirements with different heat treatments.

4.Literature

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