SAVING ENERGY THROUGH IMPROVING CONVECTION IN A MUFFLE FURNACE

by

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Incompressible forced convection heat transfer problems normally admit an extremely important simplification: the fluid flow problem can be solved without reference to the temperature distribution in the fluid. Thus, it can first find the velocity distribution and then put it in the energy equation as known information and solve for the temperature distribution.
In this paper it is intended to expand the theoretic researches concerning heat processes intensification and their use in industrial practice. In conclusion the fundamental research with concrete technical applications represents a significant contribution to the development of knowledge in domain.
By centralizing the experimental results, there can be said that there has been obtained an energetic saving of approximate 20% by using radiant panels. By fitting the experimental data there has been obtained an optimum of the panels' positioning of x = 118.71 mm.
In conclusion, changing the working space by introducing some radiant panels inside the furnace leads to important energy savings in the heating process, by increasing the heating rate of charge and by decreasing its residence time in the thermal equipment.

Key words: *convection, fluid flow, applications, furnace*

Background

The critical analysis of the intensification techniques of the transfer processes is realized by the very identification of the methods that can be applied, regardless of the process nature.

In this context, the study of the heat transfer processes has become an essential thing for ensuring an optimum functioning of the industrial heating processes and this fact creates the base of the multidisciplinary study of these processes. The main priority is the development of a consistent methodology that will represent the base of the specific practical methods' development [1, 2].

Our aim in this paper is to present the analysis of a few problems and to show the progression toward increasingly empirical solutions as the problems become progressively more unwieldy. As in any forced convection problem, it first describes the flow field. The velocity profile changes greatly near the inlet to the wall. A boundary layer builds up from the front, generally accelerating the otherwise undisturbed core. The boundary layer eventually occupies the entire flow area and defines a velocity profile that changes very little thereafter.

During this experimental study, different study cases have been carefully chosen in order to compare and measure the effects of applying different intensification methods of the heat transfer processes. The study cases have also been chosen according to the technological needs for certain processes that require heat at average temperatures in optimum conditions [3].

Methodology

Establishing the research directions has been performed by a critical analysis of the intervention possibilities over the heating processes at average temperatures.

Figure 1. General view of the furnace

Thus, for the study of transfer processes' efficiency there has been chosen a muffle furnace of thermal treatment, presented in fig. 1. This is a Vulcan furnace, muffle type, with vertical door drive which assures a good sealing of the working space as well as different heating rates due to the extremely efficient controller.

The furnace has a very good productivity and assures a great security when exploited due to the heating cycles that can be automatically programmed and operated. After programming, the heating parameters remain registered in the program memory even if interruptions occur in electrical power supplying. The working method proposed for studying the constructive and functional improvement of the oval furnace used at average temperatures has the following steps:

– choosing a charge pattern and a technological process,
– choosing a heating temperature,
– changing the working space by using some adjustable radiant panels, and
– performing the experiment and interpreting analytically the results.

Programming the experiment

In order to perform the heating process optimization there has to be established exactly the thermal interval that shall represent the basis of the experimental conditions [4, 5].

Figure 2. Placing the radiant panels inside the working area of the furnace

The selection of the heating temperature has been performed according to the usual thermal field for solution heat treatment by putting the aluminum alloys at a temperature of 400-500 °C. Changing the working space, as it is presented in fig. 2, has as purpose the heat transfer intensification by convection and radiation. The convection inside the working camera suffers major changes by re-dimensioning power lines and transforming the natural convection in forced convection by modifying the air circulation rate inside the furnace. In this case, we do not talk anymore of a smooth mixing movement of air, the air being directed by the inclined panels towards the charge and maintained near it. Besides the modified convection, the phenomenon that represents the basis of heating is the thermal radiation towards the part and the air near it.

In order to accomplish the desired mathematical modeling, the experiment has to be programmed and this implies the following:

– establishing the necessary and sufficient number of experiences and the necessary conditions in order to accomplish them,
– establishing the regression equation which represent the process model, and
– establishing the conditions necessary to accomplish the optimum value of the process performance fulfilled.

In this context, for each variable, there have been established the basic levels as well as the variation intervals. By adding the variation level to the basic level there has been obtained the superior level, and by decreasing it the inferior level of the variable. Choosing the variation interval must offer the most accurate values from the functional point of view. A first step is to establish the basic levels and the variation intervals. In tab. 1, the variation interval and the basic level for programming the experiment are presented.

The interpretation of the experimental results consists of establishing the experimental variation curves of the radiant panels' position according to energetic consumption of the equipment; the interpretation of the experimental results shall be finalized by determining the analytical equations that describe the experimental curves obtained.

Table 1. Experiment programming

Factor	Panels' adjustment distance, *x* [mm]
Basic level	140 mm
Variation interval	20 mm
Superior level (+1)	160 mm
Inferior level (–1)	120 mm
Supplementary	200 mm

Experimental

The active experiment has started with a preliminary experiment performed in order to establish the energetic efficiency of using the radiant panels. Thus, there has been created a diagram of the studied furnace running idle.

Afterwards, the radiant panels have been introduced in the furnace and dramatic decrease of the heating time has been noticed.

The experimental results shall not be presented under a graphic form. Thus, tab. 2 represents the furnace heating regime for all the experimental cases.

In addition, there have been conducted some researches concerning other major parameters in the industrial furnaces functioning, like energy consumption. The total energy consumed when heating has been calculated by taking into consideration the functioning time at a maximum power of the equipment, having in mind the relation $E = Pt$.

Table 2. Experimental results for heating up to 400 °C

Panels' distance	Heating time [s]	Energy [Wh]
200	1070	535
160	964	482
140	973	486.5
120	940	470

Experimental data analysis

The experiment has been rigorously conducted in order to assure its repeatability. As a study charge, a cylindrical part of the following dimensions 15 x 100 mm, made of AlCu4Mg1 has been used.

The experiments have been performed in different days, thus maintaining the initial heating conditions for equipment as well as for charges. The data collection has been performed with the help of the computer by a Nomadics thermocouple acquisition system. For each panel position three experiments were conducted, in the tables being written the arithmetic average of the registered values.

In tab. 2 the results for the centralized experiments are presented for all the situations.

The interpretation of the results has as purpose finding a mathematical model that can describe as precisely as possible the physical processes that take place in that situation. Thus, in fig. 3 the experimental curves and the polynomial fitted curves are presented for saving energy study.

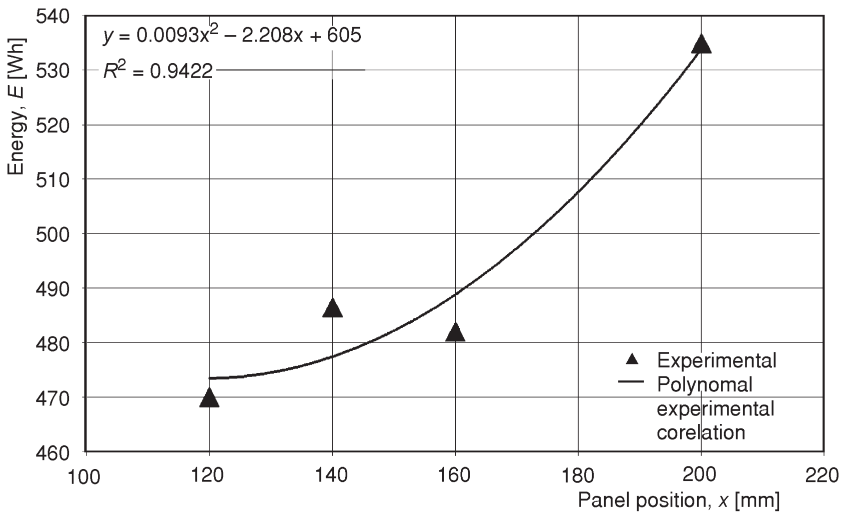

Figure 3. The variation diagram of the consumed energy with the panels' position

Thus, after the analysis and the mathematical interpretation of the experiments' data we have obtained the regression equations:

$$E = 0.0093x^2 - 2.208x + 605 \qquad R^2 = 0.9422 \tag{1}$$

The regression was obtained by least squares method (with R^2 as mean of square error) and represents a correlation between panel position (x) and energy (E). So, eq. (1) serves for the correlation of the working space form with the technological objectives of the aluminum alloys heating and is considered to be the most important, offering precise quantitative information regarding the energy saving that is obtained with the help of the proposed solution concerning the changing of the working space. In this case, an interpretation has been done following this equation.

Thus, eq. (1) admits a minimum in the following point:

$$x = 118.71 \text{ mm} \tag{2}$$

Conclusions

The chosen research methodology allows the performance of the experiments in order to study the energetic consumption of the chosen heating equipments by:

– adopting the proper thermal processing technology for the study charge,
– choosing a high quality furnace with the help of which the heating process for the performed operations can be controlled,
– changing the efficiency of the working space, and
– performing the active programmed experiment and the possibility of interpreting analytically the results.

After centralizing the results, we can say that:

there has been obtained an energetic saving of 11.32% by using the radiant panels, and

by fitting the experimental data there has been obtained an optimum of the panels' positioning of x = 118.71 mm.

In conclusion, changing the working space by introducing some radiant panels inside the building leads to important energy savings in the heating process, by increasing the heating rate of charge, and by decreasing its residence time in the furnace.

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