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EXPERIMENTAL AND EMPIRICAL TECHNIQUE TO ESTIMATE ENERGY DECREASING AT HEATING IN AN OVAL FURNACE

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Preliminary Note – Prethodno priopćenje

In this paper an experimental and empirical methods are proposed to estimate the heat transfer enhancement in industrial heating processes in oval furnaces. An investigation was conducted to study the suitability of inserting radiant panels of different positions and radiation surface. Two case studies were considered. The maximum energy saving was obtained for case 5: 32,89 % off from the standard experiment (with no panels). The minimum energy saving was obtained for case 10: 11,72 % off from the standard experiment (with no panels). Finally, based on the results of this study, a correlation was developed to predict the inner configuration of an oval furnace.

Key words: oval furnace, heat transfer, experimental method, energy saving

Eksperimentalna i empirijska tehnika procjene smanjenja energije pri zagrijavanju u ovalnoj peći. U članku su predložene eksperimentalne i empirijske metode procjene povećanja prijenosa topline u industrijskom zagrijavanju u ovalnoj peći. Istraživanje je provođeno proučavanjem usklađivanja postavljenih radijacijskih panele na različita mjesta radijacijske površine. Dva položaja su uzeta u razmatranje. Maksimum očuvane energije je polučen za slučaj 5:32,89 % u odnosu na standardni eksperiment (bez panela). Minimum očuvane energije je polučen za slučaj 10:11,72% jednako u odnosu na standardni eksperiment (bez panela). Završno, na temelju rezultata ove studije razvijana he konfiguracija predkazivanja unutarnje konfiguracije ovalne peći.

Ključne riječi: ovalna peć, prijenos topline, eksperimentalna metoda, očuvanje energije

INTRODUCTION

Energy Efficiency covers all changes that result in a reduction in the energy used for a given energy service or level of activity. This reduction in the energy consumption is not necessarily associated to technical changes, since it can also result from a better organization and management or improved economic efficiency in the sector (e.g. overall productivity gains). Energy efficiency is generally the largest, least expensive, most quickly deployable, least visible, least understood, and most neglected way to provide energy services [1].

Process heating is vital to nearly all manufacturing processes, supplying heat needed to produce basic materials and commodities. Industry's heavy reliance on these processes creates a critical need to optimize their performance for improved energy efficiency, and competitiveness [2 - 4]. Process heating systems are made up of four components including:

- Heating devices that generate and supply heat;
- Heat transfer devices to move heat from the source to the product;
- Heat containment devices, such as furnaces, heaters, ovens, and kilns;
- Heat recovery devices.

For many industrial applications, 15 % -85 % of the energy supplied is used for heating the materials. Many factors, such as process temperature, equipment design and operation, and the type of heat recovery systems used, determine the energy efficiency of a process heating system. Hence, industrial process heating systems offer opportunities to save significant amounts of energy. Therefore, an attempt to reduce the heating time will lead to significant saving of energy in the condition that the quality is guaranteed. However, currently, the thermal schedule for the heating up process of workpieces is mainly determined by experience in industrial production [5].

In this paper, the main research objective is to establish an experimental method and then to develop an efficient tool for the workpieces heating.

METHODOLOGY

The chamber geometry re-design or improvement can potentially lead not only to energy saving but also reduced furnaces production costs. Previous studies as well as the larger community have already highlighted such potential. However, these studies were largely based on smaller scale furnaces [6]. There is a pressing need to expand previous research to industrial scale furnaces and deliver novel design that will lead to significant reduction in energy consumption and environment footprint [7, 8].

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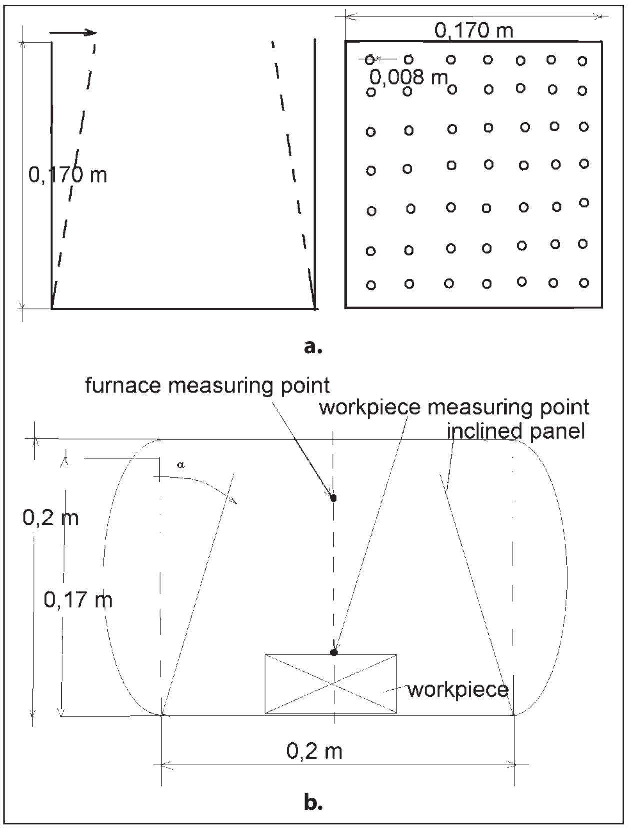

Figure 1 Experimental set-up: a. perforated panels; b. measuring points, panels and workpiece position in the furnace

In this paper simplified models based both on empirical and experimental methods are proposed to estimate heat transfer enhancement in heating processes. The investigations were completed to understand radiation or convection enhancement when panels are introduced. These experimental panels are showed in Figure 1.

Hence the present work is carried out with the following objectives:

(i) Evaluation of two radiant panels surfaces: one regular and one with symmetrical holes (see Figure 1).

(ii) Comparison of energy consumptions for the 12 considered cases.

(iii) Assessment of heating behaviour for panels inclination and surface variation.

(iv) Empirical estimation of energy savings for panels inclination and surface variation.

EXPERIMENTAL WORK

The investigations were started from the geometry of an oval 3 liter Barnstead (Dubuque, Iowa, USA) manufactured furnace and different panels are introduced in the working area [9] in order to study its heating behaviour. Experiments were carried out in the same conditions for every case with the same initial heating conditions. In this work, all the experiments were performed involving radiation in a closed domain and were compared with the standard heating regime (with no panels).

The heated enclosure includes two metallic radiant panels with the dimensions and the configuration depicted in Figure 1, along with the experimental set-up. It is shown in Figure 1a that the decreasing of the radiation surface is made by perforating the panel. The holes position is shown in Figure 1a. Figure 1b contains the panels position and the inclination rule, along with the considered measuring points (where additional thermocouples are inserted).

The temperatures were recorded automatically using two K type thermocouples inserted in the furnace and sealed to prevent any leakage. Their accuracy is of ± 1,6 K at 773 K according to USA National Institute of Standards and Technology (NIST). Respectively, furnace temperature control accuracy is ± 0,25 K and, further, experimental system accuracy goes to ± 1,25 - ± 1,85 K, according to USA NIST. The experiments have been performed in different days, thus maintaining the initial heating conditions for the equipment and for the charges. A data-logger (Comark, type EV) was used to collect measurements at intervals throughout each experiment.

For each panel position three experiments were conducted, in the tables being written the arithmetic average of the registered values. In these practical conditions, the experimental investigation uncertainty is diminished as much as is possible.

The following two sets of experiments were carried out:

1. Heating with regular panels, at different inclination angles, and
2. Heating with perforated panels, at different inclination angles.

In this context, two variables were established: the panel inclination (α) and the panel surface (S). The experiment has been rigorously conducted in order to assure its repeatability. As a study charge, an AlMgSi Φ 0,024 x 0,1 m cylindrical part has been used. Table 1 depicts the furnace heating regime for all cases.

Table 1 **Furnace heating regime (up to 773 K) forall the experimental cases**

panel inc-lina-tion /degree	panel type	charge heating time / sec.	furnace heating time / sec	energy / Wh	energy variation / Wh
without panels		1800	1459	744	
0	regular	1233	1121	509,6	113,7
	perfored	1508	1255	623,3	
3,5	regular	1390	1070	574,5	41,3
	perfored	1490	1305	615,8	
7	regular	1208	1092	499,3	123,5
	perfored	1507	1280	622,8	
10,5	regular	1250	1140	516,6	137,7
	perfored	1583	1370	654,3	
14	regular	1355	1030	560,0	96,7
	perfored	1589	1360	656,7	
17,5	regular	1260	1116	520,8	132,2
	perfored	1580	1310	653,0	

DATA ANALYSIS

In Table 2 the results for the centralized experiment are presented. The studied parameters were heating rate

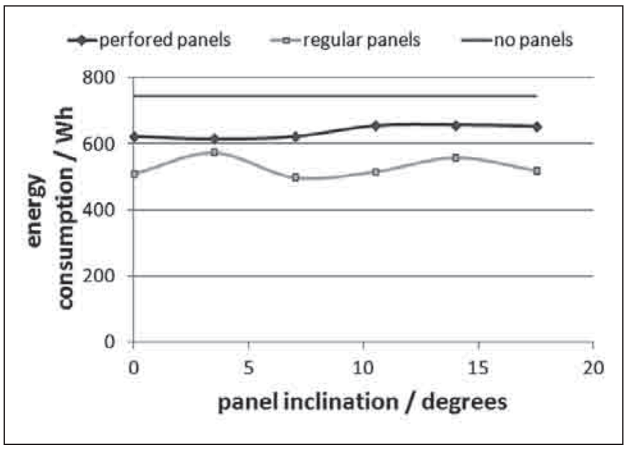

Figure 2 Experimental directions

and energy consumption. Heating rate was obtained empirical using the total heating time (provided in Table 1) and considering the final temperature imposed at 773K.

The results interpretation purpose was to find an empirical model that can describe as precisely as possible the physical processes that take place in that situation. Thus, for fitting the experimental and simulation data, a Table Curve 3D (Systat Software Inc. [SSI], San Jose, California, USA) commercial code was used. This program have wide capabilities to fit the experimental data with different equations and to calculate all the numerical data needed in order to establish its' accuracy. Data analysis starts with the most trustable equations. Final results are presented on each diagram.

Table 2 **Centralized results of inserted panels experiment**

Case number	panel inclination / degrees	panel radiation surface / m^2	energy consumption / Wh
1	0	0,029	509,64
2	0	0,026	623,31
3	3,5	0,029	574,53
4	3,5	0,026	615,87
5	7	0,029	499,31
6	7	0,026	622,89
7	10,5	0,029	516,67
8	10,5	0,026	654,31
9	14	0,029	560,07
10	14	0,026	656,79
11	17,5	0,029	520,80
12	17,5	0,026	653,07

Figure 2 contains all the experimental points considered for the study and a comparison for the two considered case studies. So, one can notice the differences in energy consumptions underlying the benefits of using the standard panels.

Furthermore in Figures 3 and 4 is the statistical analysis. Figure 3 represents the 3D representation of the energy consumption experimental data, which stood at the bases of this work, along with the fitted surface. In Figure 4 are the heating rate experimental points and surface along with the polynomial fitted surfaces. The points from Figure 4 are obtained by an empirical calculus based on the heating time and the final temperature imposed (773 K), as it was mentioned before.

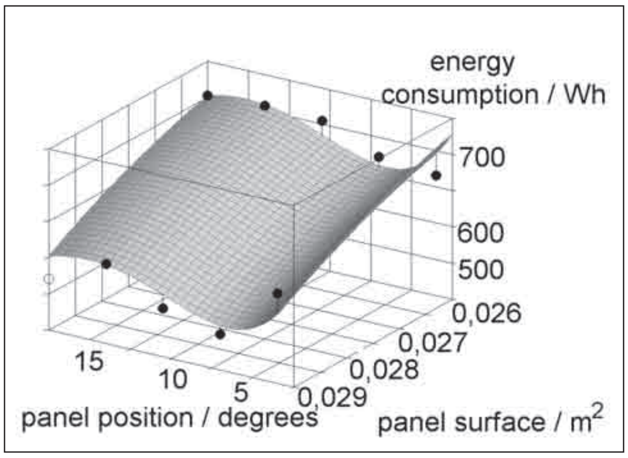

Figure 3 3D data fitting for energy consumption

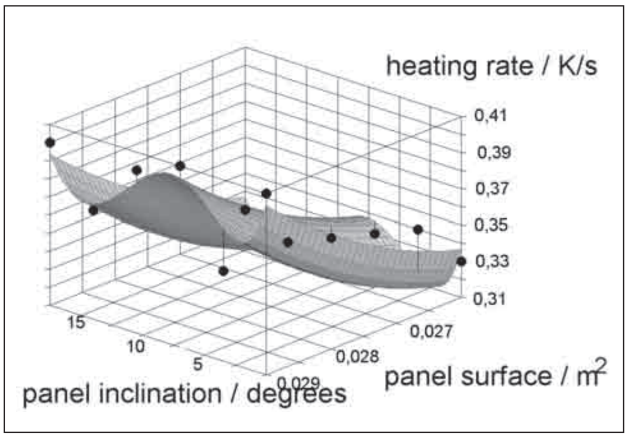

Figure 4 3D data fitting for heating rate

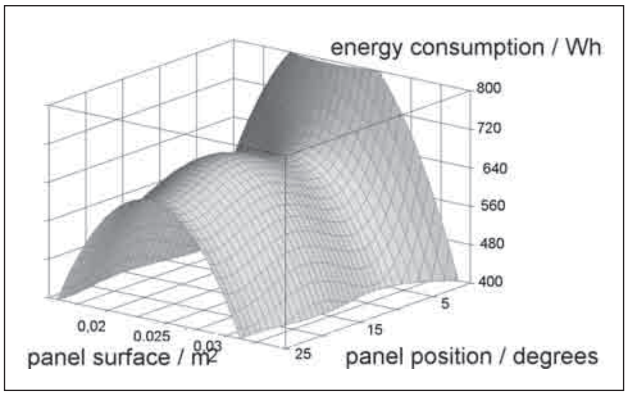

Figure 5 Energy consumption: Figure 3 extension

Further comments will be made just on Figure 3 that is extended in Figure 5. So, it can notice an important energy decreasing if the panel inclination is increasing. These results are very useful but it has to consider the decreasing of heating space inside the furnace chamber.

The hypothesis of inclining panels at angles larger than 25° have to consider the real heating space needed along with the number of heated workpieces. Also, good results it can be noticed for angles around 7° and this inclination do not minimize the heating available space inside the furnace, if it refers to Figure 5. Another observation related to Figure 5 is about panel radiation surface, which can be correlated with the total energy consumption: it is optimum to use panels with low radiation surface or regular panels. But, if it refers on how the radiation surface was decreased (see Figure 1) an important question arise about the panel resistance in service. A surface of about 0,016 m^2 (if it consider results from Figure 5) it means nearly half of the regular surface. This case will be considered for future studies.

The fitting surfaces were obtained by polynomial fitting method and represent a correlation between panel position and heating rate and energy consumptions respectively. From statistical analysis on each graph it will consider the experimental curves:

$$E = -1416{,}51 - 85{,}96\alpha + 11{,}23\alpha^2 - 0{,}56\alpha^3 + \\ -0{,}009\,\alpha^4 + 193761{,}35\,S - 4{,}13\,10^6\,S^2 \tag{1}$$

$$v = 2{,}77 - 0{,}03\,\alpha + 0{,}01\,\alpha^2 - 0{,}001\,\alpha^3 + 5{,}83\,10^{-5}\,\alpha^4 - \\ -197{,}18\,S + 3989{,}1\,S^2 \tag{2}$$

with the notations:

E – energy consumption for heating up to 773 K, Wh;
v – heating rate, K/s
S – panel surface, m^2;
α – panel inclination, degrees.

Equation (1) gets a standard deviation R^2 = 0,906 (obtained by computer fitting through Gauss elimination), and is very important because it gets a correlation between the consumed energy and panel's position. This equation can be used according to technological needs reflected in maximum heating rate and working parts dimensions. For heating rate a discussion was not included hence it was not measured, it was calculated based on the experimental data obtained. Moreover, if it refers to Figure 2 for every panel position, the lower energy consumption was observed for the regular panels, and the differences in some cases are quite high. For example, a medium value of 21,1 % energy saving was obtained for the regular panels compared to perforated ones. The physical explanation of this phenomenon is that by introducing the radiant panels inside the heating chamber, radiation heat transfer is more intense. But, when the panel surface is decreasing, the reflected heat is getting lower, depending on the radiation surface. Also, if panel surface is getting very low, convection enhancement may interfere along with increased panel inclination mainly because air rate is increasing in the favor of air circulation through the depicted holes. This accounted for the effect of the flow-channel space around and through the panels which allows the heated air to by-pass the load, thus increasing the value of the mean air velocity inside the furnace.

Furthermore, if refers to Figure 3, an optimum position can be estimated at 10 degrees inclination of the panel and S = 0,029 m^2, value that corresponds to regular panels. This graphical position corresponds to energy consumption (E) lower than 500 Wh, if it refers to Figure 3, and a total energy reduction of 33 % from the non-panel situation. The same results it can be observed on the surface from Figure 4.

CONCLUSIONS

Both, an empirical and an experimental method for heat transfer enhancement in the heating process in an oval furnace are presented.

Two case studies of experimental panels are carried out and the effects of panels position and their radiation surface are evaluated. If it refers to Figure 2 for every panel position, the lower energy consumption was observed for the regular panels, and the differences in some cases are quite high. For example, a medium value of 21,1 % energy saving was obtained for the regular panels compared to perforated ones. The most suitable case, based on experimental, is for the inclined regular panels, obtaining an average of 21,1 % energy reduction. The maximum energy saving was obtained for case 5: 32,89 % off from the standard experiment (no panels). The minimum energy saving was obtained for case 10: 11,72 % off from the standard experiment (no panels).

As a final conclusion, a correlation was developed to predict the optimum chamber configuration for heat transfer enhancement in an oval furnace.

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