A. A. MINEA

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EXPERIMENTAL AND NUMERICAL SIMULATION ANALYSIS OF HEAT TRANSFER ON A CLOSED ENCLOSURE

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Preliminary Note – Prethodno priopćenje

The main objective of this work was to evaluate the behavior of an oval heated closed enclosure, when variable radiant panels were introduced. The experimental investigation showed that their efficiency was depending on their position. An experimental investigation, as well as numerical simulation was carried out. Totally, 24 test runs were performed from which the maximal heating temperature was measured. The experimental findings were also compared to the simulation results and a reasonable agreement was observed. Finally, based on the results of this study, a correlation was developed to predict the inner configuration for heat transfer enhancement of an oval furnace.

Key words: furnace, heat transfer, numerical simulation, experimental

Eksperimentalna i numerička simulacija analize prijenosa topline u zatvorenom prostoru. Glavni cilj ovog rada bila je procijena ponašanja ovalno zagrijavanog zatvorenog prostora, podijeljenog u različita polja. Eksperimentalna istraživanja ukazuju da iskoristivost zavisi od položaja. Također je provedena i numerička simulacija. Ukupno, provedena su 24 mjerenja maximalne teperature zagrijavanja. Provedena istraživanja su također uspoređivani sa rezultatima simulacije i ustanovljena su dobra slaganja. Završno, na temelju rezultata ove studije razvijena je korelacija predkazivanja unutarnje konfiguracije za povećanje prijenosa topline u ovalnoj peći.

Ključne riječi: peć, prijenos topline, numerička simulacija, eksperiment

INTRODUCTION

Furnaces are used in a wide variety of applications including power plants, nuclear reactors, refrigeration and other heating systems, automotive industries, heat recovery systems, chemical processing, food industries, metallurgy etc. [1,2]. Besides the performance of the furnace being improved, the heat transfer enhancement enables the exterior size of the furnace to be considerably decreased. Due to their compact structure and high heat transfer coefficient, oval furnaces have been introduced as one of the passive heat transfer enhancement techniques and are widely used in various industrial applications [3].

In this paper simplified models based on numerical simulation and experimental methods are proposed to predict the radiation and convection heat transfer in heating processes. The simulation investigations were done to understand forced laminar fluid flow in the furnace walls boundary layer when panels are introduced. These panels, showed in Figure 1, were used in simulation, and an experiment was carried out for the validation of the system.

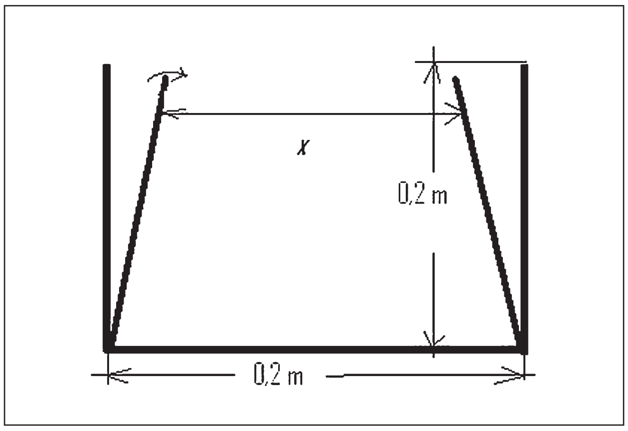

Figure 1 Panels geometry

NUMERICAL SIMULATION SET-UP

For solving the heat transfer problem it was chosed numerical simulation of radiation and convection in a closed domain.

An important first step for establishing the model accuracy was to identify the boundary conditions and the properties of materials involved in the process.

All the fluid properties were assessed at the mean temperature of the fluids (average of inlet and outlet temperatures) [4].

The models used in the simulation are collected in Table 1. The above formulation was used to build a model using FLUENT commercial CFD (Computer Fluid Dynamics) code.

The entire study has as starting point the geometry of a Barnstead manufactured oval furnace, so the oval geometry (0,11m x 0,19m) was simulated to study the effect of heat chamber geometry on heat transfer rate. The final default interior temperature was also com-

A. A. Minea, Technical University gh. Asachi Iasi, Romania

Table 1 **Simulation Models**

Model	Settings
Space	2D
Time	Unsteady, 1st-Order Implicit
Viscous	Laminar
Heat Transfer	Enabled
Radiation	Discrete Ordinate Model

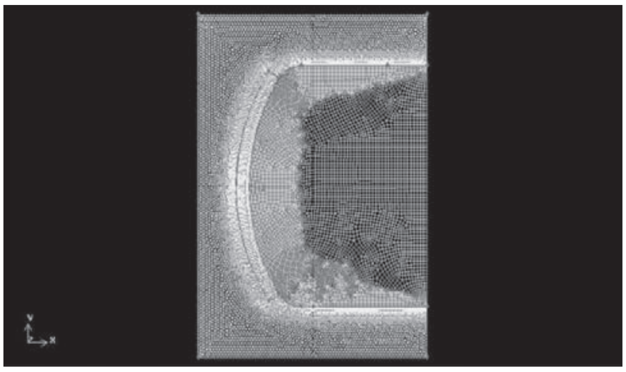

Figure 2 Configuration of the studied grid

pared and a good agreement was observed. The geometry models were completed on Gambit pre-processor for FLUENT. First of all it was made a base model, grid independent, and after this, with the help of the journal files from Gambit was obtained all the study geometries. Working with journal files in Gambit is a good technique applied in cases when modifying geometry is needed and it offers a good accuracy of experiment repeatability. So, the simulation conditions were kept the same for all the cases and 1200 iteration steps were performed.

In the Figure 2 is shown the grid for the oval furnace. The final heating temperature can be estimated by monitoring the iteration time. From the time - temperature history, heating rates at different locations could be easily calculated. The final simulation results are presented in Table 4, along with the experimental results.

EXPERIMENTAL SET-UP

As was stated before, the investigations were started from the geometry of an oval manufactured furnace. The aim was to establish a more convenient heating space [5]. Experiments were carried out in the same conditions for every case, and for the same initial heating conditions.

The experimental set-up is shown in Figure 3. The set-up is a well instrumented single-phase heat provided to measure the maximum heating temperature of both furnace and study charge. The heated enclosure includes two metallic radiant panels. The dimensions of the radiant panels were illustrated in Figure 1 and are the same with those used for simulation.

The active experiment has started with a preliminary experiment performed in order to establish the efficiency of using the radiant panels. After this, the radiant panels have been introduced in the furnace and dramatic decrease of the heating time has been noticed. 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. 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 and ± 1 K at 673 K according to USA National Institute of Standards and Technology (NIST) as it is specified in probes technical data's. Respectively, furnace temperature control accuracy is ± 0,25 K, as it is mentioned in furnace operator's manual and, further, experimental system accuracy goes to ± 1,25 - ± 1,85 K, according to USA NIST.

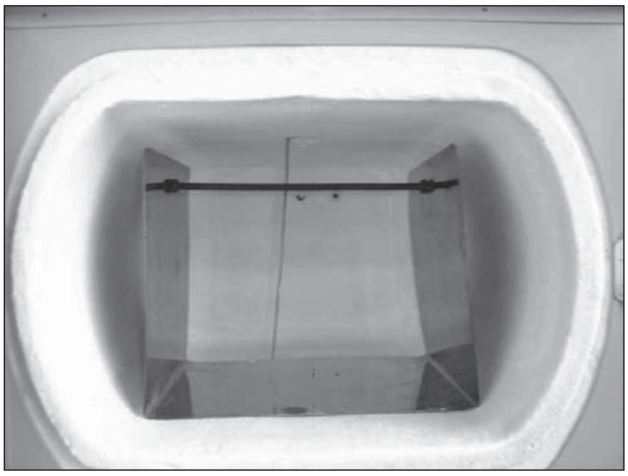

Figure 3 Experimental set-up

Kang and Rong [6] suggested that in order to accomplish the desired interpretation, the experiment has to be programmed and this implies the following:

- Set objectives,
- Select process variables and levels, and
- Select experimental design.

This method is a common one in choosing an experimental design and in this context, for each variable, there have been established the basic levels as well as the variation intervals. 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 Table 2 the variation interval and the basic level for programming the experiment are presented. Moreover, Table 3 represents the furnace heating regime for all the experimental cases.

The experiment has been rigorously conducted in order to assure its repeatability. As a testing charge, an AlMgSi cylindrical part of Φ 0,024 x 0,1 m has been used.

Table 2 **Experiment programming**

Factor	Panels' adjustment distance /m
Basic Level	0,12
Variation interval	0,02
Superior Level (+1)	0,20
Inferior Level (-1)	0,08

Table 3 **Centralized results**

panel position/ m	simulation final temperature / K	experimental final temperature / K	difference / K
0,200	756,74	765,10	8,36
0,180	758,77	759,31	0,54
0,160	760,31	764,79	4,48
0,140	758,22	760,95	2,73
0,120	751,04	765,86	14,82
0,100	751,07	756,98	5,91
0,080	751,77	756,01	4,24

DATA ANALYSIS

The first experiment was conducted for the basic furnace, without panels. A maximal heating temperature of 758,77 K was registered.

In Table 3 the results of the centralized simulation and experiments are presented.

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, for fitting the experimental and simulation data's a IGOR PRO commercial code was used. This program has wide capabilities to fit the experimental data with different equations and to calculate all the numerical data's needed in order to establish its' accuracy. Data analysis starts with the most trustable equations [7, 8].

Figure 4 shows the 2D representation of the experimental data, which stood at the bases of this work. Thus, in Figure 4 are the experimental and simulation points along with the polynomial fitted curves are presented for increasing heating temperature study.

The fitting curves were obtained by computer, by polynomial fitting method and represent a correlation between panel position and heating temperature. Moreover, in Table 4 are the statistical results for this interpretation.

From Figure 4 it can conclude that the differences between the simulation and the experimental curve are very low. If it consider last column from Table 3 it can see that the differences are in a range of about 0,5-2 %, which is acceptable. Further a correlation between heating time (at a maximal heating rate) and final temperature is proposed.

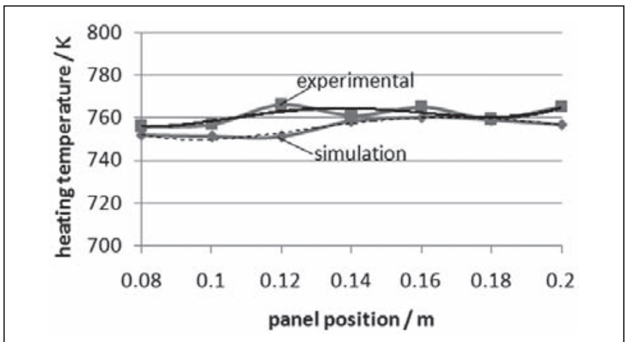

Figure 4 Data fitting

Table 4 **Statistical data interpretation for the fitting curves**

Statisticals	Experimental	Simulation
fit coefficients	1009,3; -8,87;0,11; $-5,7\cdot10^{-4}$; $1,08\cdot10^{-6}$	957,89; -6,12;0,06; $-2,7\cdot10^{-4}$; $4,1\cdot10^{-7}$
measure of the goodness of fit	29,5215	7,17
number of points that were fitted	7	7
last wave point	6	6
standard deviation of the fit coefficients	360;11,3; 0,12;0,001; $1,13\cdot10^{-6}$	177;5,59; 0,06;0,0003; $5,56\cdot10^{-7}$
coefficient values ± one standard deviation	$K0$=1009,3 ± 360 $K1$=-8,87 ± 11,3 $K2$=0,11 ± 0,129 $K3$=-0,0006 ± 0,0006 $K4=1,08\cdot10^{-6} \pm 1,13\cdot10^{-6}$	$K0$=957,89 ± 177 $K1$=-6,12 ± 5,59 $K2$=0,063 ± 0,06 $K3$=-0,0003 ± 0,0003 $K4=4,1\cdot10^{-7} \pm 5,56\cdot10^{-7}$

From the data collected in Table 4 it will consider the experimental curve:

$$T = 1009,3 - 8,8743\cdot x + 0,11064\cdot x^2 - 0,00057802\cdot x^3 + 1,0807\cdot10^{-6}\cdot x^4 \quad (1)$$

with the notations:
T – maximum heating temperature, K
x – panel position, m.

This equation is very important because it gets a correlation between the maximum heating temperatures obtained depending on panels position for a maximum constructive heating rate for the considered oval furnace.

This equation can be used according to technological needs reflected in maximum heating rate and dimensions of the working parts.

CONCLUSIONS

An experimental investigation, as well as simulation was carried out to study heat transfer in a modified closed enclosure of an oval furnace.

Furnaces with different heated enclosures were tested for counter-flow configuration. It was revealed that the empirical correlation for constant temperature boundary condition is quite in agreement with the present data. From the results of the present study, it was found out that the total heating temperature is depending on the position of the radiant panels.

If it compares the heating temperature obtained through introducing the panels with the heating temperature after 1 200 seconds heating of the furnace without panels it can remark an increase of minimal 17,25 %.

Also, the results obtained from experimental are similar with that ones obtained through simulation.

As a final conclusion, based on discussed results, a correlation was developed to predict the optimum chamber design for heat transfer enhancement of an oval furnace.

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Note: Responsible translator the lecturer from Technical University Gh. Asachi Iasi, Romania