NUMERICAL MODELING AND EXPERIMENTAL INVESTIGATION OF A HEAT EXCHANGER USED IN INDUSTRIAL OVENS[1]

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Abstract: Industrial ovens are widely used equipment in many areas of the food industry. Heating in these ovens is provided using electricity, natural gas, or solid fuel. Some of the thermal energy obtained from these fuels is transferred to the inner environment of the oven through heat exchangers. The remaining energy is discharged into the atmosphere through the oven chimney as hot air. This unused heat constitutes a significant part of the fuel cost. The heat exchangers' efficiency in these ovens should be increased to reduce energy losses. In this study, the thermal analysis of the heat exchanger of an industrial-type oven is performed using the finite element method, and the internal flow of hot air is examined. Finite element analyses are experimentally verified, and the efficiency of the heat exchanger is reviewed. In experimental studies, an industrial-type oven with a natural gas heat exchanger produced by FİMAK Makina Inc. is used. The temperature values of the air leaving the heat exchanger operated under 50 mbar gas pressure are determined. In addition, side surface temperatures are recorded during the experiment using six thermocouples. At the end of the study, the hot air flow behavior inside the heat exchanger is demonstrated.

Keywords: Heat Exchanger, Industrial Oven, Numerical Modeling, Thermal Analysis

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INTRODUCTION AND THEORETICAL FRAMEWORK

Industrial ovens are quite large cooking equipment. These are also furnaces that use large heat exchangers. Studies on the performance and efficiency of heat exchangers used in industrial-type ovens are limited in the literature. In their research, Boujelbene et al. investigated the effects of fins of different numbers and geometries on a heat exchanger. As a result of their experimental studies to verify the numerical results, they determined that using finned pipes instead of traditional pipes increased the efficiency of the heat exchanger. In addition, they developed four different equations to estimate the Nu number and friction factor. At the end of the study, they determined that using more fins than the ideal number of fins caused adverse effects. Apart from these findings, they found that the pipe with no fines had the highest thermal resistance (Boujelbene et al., 2024:107224).

Amini et al. studied the effects of segmented and spiral fins on thermal performance. Within the scope of the study, a heat exchanger with six baffles and seven tubes was modeled. They found that the increase in fin height affected the performance of the heat exchanger more than the fin pitch. Another important finding of their study was that helical fins increased the heat exchanger's performance more than vertical ones by causing vortex formation. Similar to the previous research, they determined that using fins increased the heat exchanger's performance by 9.5% to 6% (Amini et al., 2018:750–760).

Mansour et al. analyzed an industrial oven by modeling it with ANSYS Design Modeler. The study can be considered a pioneer in the three-dimensional analysis of an industrial-type oven. The study modeled the unmixed combustion of diesel fuel in the burner and the airflow in the cooking chamber. The results showed that the oven examined had an energy efficiency of approximately 16%. In addition, it has been determined that the most significant heat loss in the oven originates from the chimney (55%). It was determined that the remaining heat losses were from the oven surfaces (Mansour et al., 2024:121467).

Geum et al. performed a thermal performance analysis of a heat exchanger to determine waste heat recovery. In the study, a heat exchanger was designed to recover waste thermal energy from high-temperature exhaust air. Ninety-five heat pipes were used in the heat exchanger to minimize thermal resistance. It has been observed that the recovery rate gradually decreases as the condenser height increases from the ideal value due to the decrease in the rate of change in the convective heat transfer coefficient. Thermal

performance was evaluated using heat transfer rate and efficiency (Geum et al., 2024:107223).

Al-Nasser et al. modeled an industrial-type convection oven and performed finite element analysis. This study examined the dough surface's baking behavior by revealing the oven's hot air flow. Researchers have developed a model that can predict expansion depending on loaf content by examining oven performance and loaf baking behavior simultaneously. In addition, the study analyzed different oven parts separately, and the hot air flow was discussed in each section. They determined that the average air temperature at the exit from the heat exchanger was around 420 K, but they did not provide any information about the oven's efficiency (Al-Nasser et al., 2021:116252).

PURPOSE

The target of this study is to model a heat exchanger used in industrial-type food ovens with the finite element method to determine the hot air flow behavior. In addition, thanks to findings related to energy efficiency, it is to pioneer research and development activities in future studies on industrial-type heat exchangers.

SCOPE

In this research study, it is assumed that the natural gas in the burner burns ideally. In addition, possible welding defects in the heat exchanger have been neglected. Although the analyzed heat exchanger operates in the interior volume of the oven, in this study, it is assumed that it works outdoors under atmospheric conditions. Finally, throughout all the studies, it is accepted that there is no forced flow on the outer surface of the heat exchanger.

METHOD

The heat exchanger studied in analysis and experimental studies is given in Figure 1 (FİMAK Makine Inc., Türkiye). In the study, the heat exchanger is operated under a natural gas pressure of 50 mbar. The thermal conductivity coefficient of the material used in the pipes in the heat exchanger is 16 W/(m. K). In addition, the material's specific heat is assumed to be 500 J/(kg. K). Heat exchanger surface temperatures are measured with six K-type thermocouples in different locations. The burner power is set at 130 kW to ensure the ideal fuel-air mixture. The data acquisition system uses a PhoenixTM controller with a temperature control module.



Figure 1. The Heat Exchanger Studied in Experimental Studies

RESULTS

The efficiency of a heat exchanger is directly related to internal flow. The internal flow rate affects the life and performance of the exchanger. Analyzes connected to the heat exchanger were made using Ansys Fluent. Heat exchanger internal flow analysis results are given in Figure 2. Analysis results show that the internal flow of the pipe in the middle parts of the heat exchanger is slower than the others. Additionally, it shows that the flow of some pipes in the heat exchanger is different. It was determined that the flow in the pipes was slower, especially in the middle region.

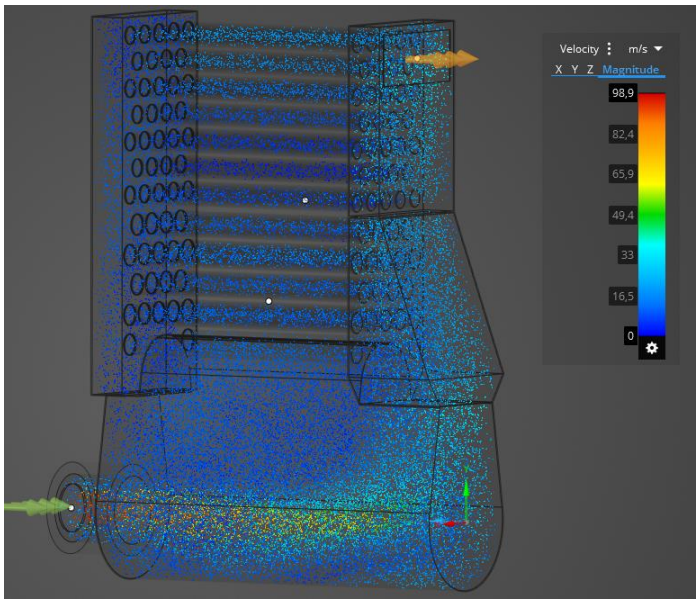


Figure 2. Heat Exchanger Internal Flow Analysis

It was observed that the flow in the pipe was laminar in all pipes. The results of the experimental analysis are given in Figure 3. Experimental measurements were carried out for 14 minutes. Consistent with the analysis results, it was observed that the temperature values in the same region were lower than others. It has been observed that the rate of temperature increase is slower in this region, in line with the temperature difference.

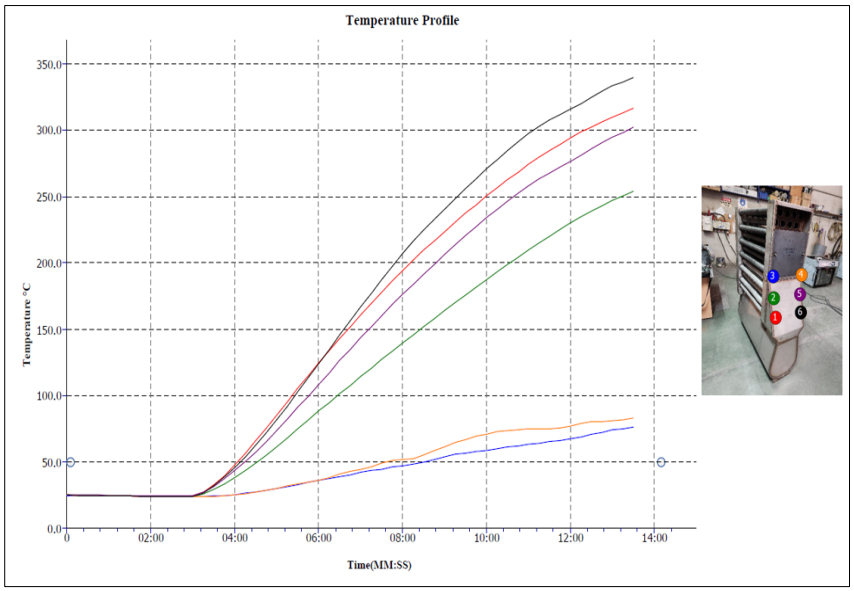


Figure 3. Heat Exchanger Internal Flow Experimental Analysis Results

While the temperature measured in other regions exceeded 300 °C, it was around 100 °C in this region. The comparison of the experimental and analysis results is given in Table 1. In the analysis results, the temperature of the same area was found to be lower. The temperature at points P3 and P4 is expected to be relatively low. However, the temperature difference in this study is not due to heat transfer but to the difference in internal flow rate.

Table 1. Comparison of Side Surface Temperatures

Temperature Measuring Point	Analysis Result (°C)	Experimental Result (°C)
P1	320	313,0
P2	254	250,6
P3	82	75,2
P4	88	82,0
P5	308	298,4
P6	344	336,1

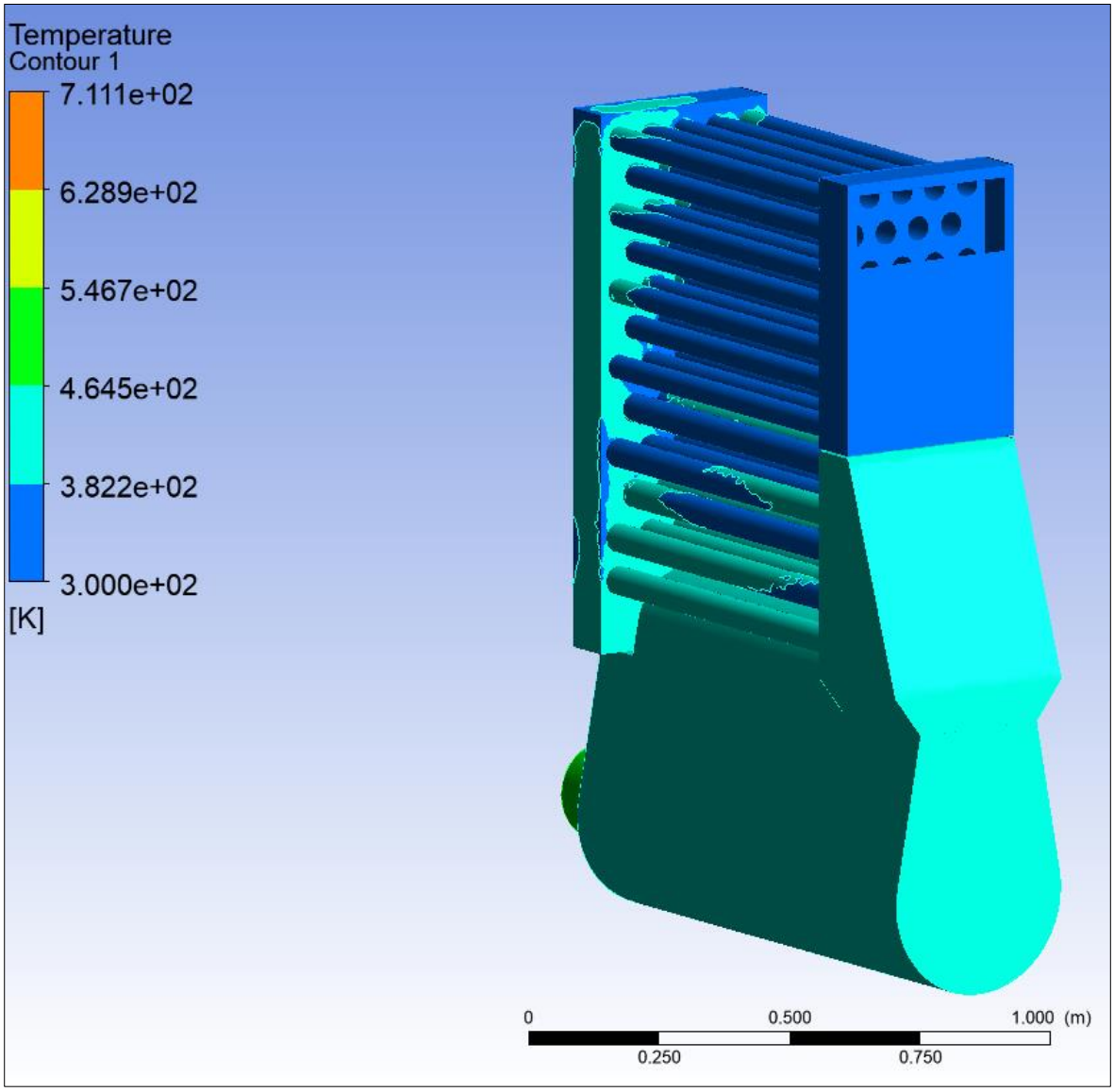


Figure 4. Surface Temperature Gradients

CONCLUSION

In this study, the heat exchanger of an industrial oven was mathematically modeled and examined. Models that improve the hot air flow in the heat exchanger have been presented. Experimental studies were carried out in the heat exchanger of an industrial oven. The temperature changes on the heat exchanger surfaces were measured with thermocouples during the experiment. It has been observed that the temperature values predicted using the mathematical model are compatible with the experimentally measured values.

The findings of this study are critical for a better understanding of heat exchangers used in industrial ovens. In addition, the study findings reveal a need to work on increasing the efficiency of industrial ovens.

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