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Research Paper

An aspirating cooling system for regulating temperature of pyrolytic oven glass

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HIGHLIGHTS

- Active suction cooling system of oven was modeled as a three dimensional using CFD.
- The aerodynamic design of the ASC system developed based on parametric studies.
- The maximum temperature at the oven door decreased 65 K by active cooling system.
- An extra 11.5 K cooling sustained at the pyrolytic oven door by parametric study.

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ABSTRACT

The aim of this study is to investigate the design parameter effects of an aspirating cooling system on the outer surface temperature of a household pyrolytic oven glass. Pyrolytic ovens include complicated components, such as an oven door, a cross-flow fan and an aspirating cooling system, and their complex interactions should be investigated in detail. In this study, the oven door and cross flow fan and aspirating cooling systems were modeled as a three dimensional system using a computational fluid dynamics and heat transfer method to investigate the fluid flow and temperature distribution of outer surface of the oven door. The simulation model predicted the temperature distribution based on the cross flow fan speed, cross flow fan position and channel design of the aspirating cooling system. The numerical results were validated against results obtained from an experimental study. The computational results show that the rotational speed of the cross flow fan, the cross flow fan position and the channel design of the aspirating cooling system play important roles in affecting the outer surface temperature distribution of the oven glass of a pyrolytic oven.

1. Introduction

In the design of domestic ovens, one of the most important parameters is outer glass temperature, especially in pyrolytic-type domestic ovens. Pyrolytic ovens have a self-cleaning function during which the temperature inside of the oven is increased over 500 °C. When the temperature inside the oven reaches these values, any food residue and grime adhered to the walls is simply burned off. This feature provides great convenience for users. However, this high-temperature increase should be considered with regards to safety. The outer surface temperature of the oven should be reduced to a safe level not harmful to the environment and living beings. An aspirating cooling system (ACS) has been designed to reduce the temperature of the outer surface of the oven door. This system circulates air between panes through the door, thereby reducing the external surface temperature of the door by convective cooling. Here, the velocity of the suctioned air and the design of oven door are very important. If excessive cooling takes place, the temperature within the oven could decrease and affect the self-cleaning function. This would lead to low energy efficiency and performance of the door.

Rek et al. [8] examined a newer generation, multifunctional oven and modeled radiative, conductive, natural and forced convective heat transfer mechanisms. They investigated many parameters that influence conditions inside an oven, such as the shape and power capacity of heaters, fan rotor rotational speeds, the thickness and quality of insulation and the design of the oven doors. Shaughnessy and Newborough studied radiative heat transfer mechanism of the oven door [9]. They suggested a low-emissivity oven (LEO) provides an energy efficient alternative to a conventional domestic electric ovens. Abraham and Sparrow [1] developed an algebraic method for predicting the time-based temperature variation of a thermal load situated in an electrically

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heated oven. Mistry et al. [6] studied transient, natural convective heat transfer in ovens. A computer-aided design using computational fluid dynamics and heat transfer (CFDHT) modeling of an electric oven involves a three dimensional, unsteady, natural convective flow-thermal field coupled with radiative heat transfer. Mistry et al. [7] developed a CFDHT-based methodology to evaluate the performance of a domestic gas oven. Fahey et al. [2] studied cooling on circuit of the door of a pyrolytic oven. They used CFD and experimental techniques to understand the flow behavior of the oven. The CFD results were validated with experimental hot-wire velocity measurements. The study established an understanding on oven door's cooling circuit but they did not determine the effect of it or determine the design parameters. Verboven et al. [13] investigated forced convection in an oven using CFDHT methods. They compared their numerical results with experimental results. Smolka et al. [11] investigated forced convection inside a drying oven by using experimentally validated three dimensional CFDHT analyses. To improve the temperature uniformity within the oven cavity, they changed parameters, such as the rotational speed of the device fan, the effectiveness of the distribution gaps and the rate of heat generated by the electric heaters. Smolka et al. also changed configurations, such as the locations of the heaters, the fan and the fan baffle. Overall, they improved the temperature uniformity and validated the results with an experimental test of the modified prototype.

As mentioned in the literature, the CFDHT method has been successfully applied for revealing and understanding complex flow characteristics [3,4,12]. The three dimensional modeling of an oven is essential for determining the air-side flow and heat transfer characteristics. For the first time in the literature, an oven door and an ASC are modeled together as a whole three dimensional system. Therefore, in this study, an oven door, a cross flow fan (CFF) and an ACS were simultaneously introduced in a heat transfer and fluid flow analysis to determine the outer surface temperature distribution of the oven door. Before investigating the oven door and ASC together, the ASC was first independently modeled. The mechanical structures of the ASC were developed based on parametric studies. Then, the oven door and ASC were modeled together, and the flow field and the temperature distribution were investigated. The numerical results were validated by comparison with results obtained from experimental studies. To reduce the temperature on the oven door outer surface, the influence of the fan rotational speed was numerically investigated. The results of the parametric studies showed that the rotational speed of the CFF played an important role in regulating the outer surface temperature of the oven door.

2. Numerical study

A computer-aided design (CAD) model of an oven was taken from a white goods company for the numerical study. The CAD model of a pyrolytic oven assembly is shown in Fig. 1b. The oven has an ASC for decreasing the outer surface temperature of the oven door. Details of the ASC and oven door are shown in Fig. 1b and c, respectively. The top view of the system is given at Fig. 1d which also shows that the CFF is positioned symmetry plane of the oven.

As mentioned, the main purpose of the ASC is to actively cool the oven door by drawing air between glass panes. The air suction power was provided by the CFF, which was part of the ACS. The oven door consisted of a quadruple glass layer as shown in Fig. 1c. Air from the chimney of the oven could be circulated between these glass layers, and a plastic profile was used to hold the glass pane together.

The air volume model of the oven door and the ASC is shown in Fig. 2a. The "A" side shown in Fig. 2c is the inner cavity of the oven and the "B" side is the outside of the oven.

In the regular ovens without the ACS, the heat transfer from the outdoor surface occurs via natural convection and radiation. However in the ovens with ACS with suction, air suctioned reverse direction of the natural convection and this effects the heat transfer. The outdoor air volume is added to the analysis for investigating this phenomena. The height and the width of the air volume is selected equal to the ovens size. The depth of the out air volume is related with the diameter of CFF as Shih et al. [10] suggested in their study. After some analysis were done to see appropriate size,

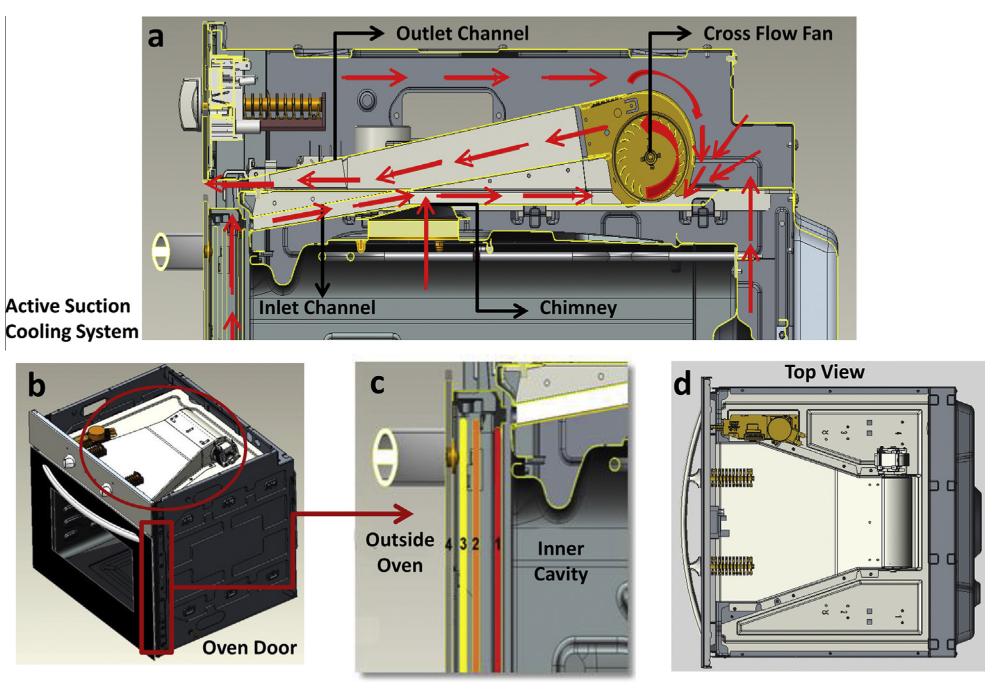

Fig. 1. Pyrolytic oven views (a) aspirating cooling system, (b) pyrolytic oven assembly, (c) oven door, (d) top view of oven.