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Research Article

Application of Venturi effect for Convection oven door cooling

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Abstract

Cooking is an everyday activity and appliances for this purpose are expected to be user friendly and safe for user operations. One of the home appliances is a convection oven which operates on the electric resistance heater. The convection air currents within the oven cavity, distributes heat to the food stuff intended to be cooked in the oven. During self-cleaning operation the temperature within the oven cavity reaches a maximum of 450°C. Due to such a high temperature the oven door attends relative high temperatures by conduction and convection from the oven cavity. Oven door being a user interface to the oven cavity, it must be maintained at safe operating temperatures which can be achieved by cooling the oven door. At present, ambient air is forced through the oven door to cool the door to safe operating temperatures of 70°C. The paper discusses performance of venturi effects to increase the ambient air flow rate through the oven door. The parameters affecting the venturi effect performance are studied using CFD tools. The results show that the flow rate from the door region is a linearly proportional to the inlet velocity from the vent channel. Also the front frame opening affects the flow rate from the door region. The flow rate increases with the increase in front frame opening but at large openings reverse flow is observed which reduces the flow rate through door regions.

Keywords: *Venturi Effect, Oven door cooling, CFD.*

1. Introduction

Cookery is the Art of preparing healthy food for human consumption using heat energy. Food is one of the largest contributors as energy source for human being. Cooking appliances with time has evolved from a clay stove to a glass or Ceramic Cooktop. The Energy sources for cooking have also evolved from burning fuels to electric, induction heating and microwaving. Various ways of cooking are undertaken nowadays which include Baking, Grilling, Frying, Broiling, Barbecuing, Smoking, Roasting, Steaming, Braising, Poaching, Simmering, Boiling and recently known technique is microwaving.

Oven is a completely insulated enclosure with electric or gas fired heating elements within the cooking chamber. Classification of ovens is based on enclosure, type of energy, oven supports and mode of heat transfer. In case of enclosures the ovens are further classified on basis of material used as masonry, ceramic, cast iron, steel with glass wool insulation. The different types of energy sources used for ovens are electricity, gas, electromagnetic waves, solar, wood and halogens. Based on the supports ovens are further termed as built in range and free standing range. The built in ovens are assembled in a cavity within wall or furniture of the kitchen. Free standing range oven are separate system assembly with its own supports. Depending on the mode of heat transfer the ovens are classified as, convection and radiation, microwaved or mixed oven. The convection oven transfers heat by natural and forced convections. For microwave ovens, the heat is generated within the food stuff due to the vibrations of the dipolar molecules of water under the influence of the microwaves.

Oven finds its applications in all kinds of food, textile heat treatment industry. One of the major applications of ovens is in home appliances, cooking section. Convection and microwave ovens are extensively used as home appliances. The Food industry, restaurants, Barbecues and most of the business related to food have every day use of various types of ovens. Apart from home appliances oven also find applications in Heat treatment industry, metallurgical labs and research departments. The various task like curing, drying, sterilizing, melting, aging and autoclaving are carried out in ovens. Autoclaving is a process of heating under high pressure environments.

2. Subsystems of a Convection Oven

The convection oven is an assembly of cavity, oven door, ventilation system, console, oven structure. The oven structure is an enclosure for the oven assembly.

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Convection oven are free standing range and built in wall oven. Depending on the type of oven the structure is modified. The functions of oven structure is to support the oven components and help in placing the oven into the kitchen infrastructure. The console is a control panel with display for user. The console provides various cooking control settings, heater power settings, cooking time and such various oven control settings. The oven door is a user interface to the oven cavity. The user should be able to visualize the process within the cavity to monitor the cooking process. Hence the oven door is made up of transparent material. Glass with a decor coating and rail supports forms the oven door. The oven cavity is the cooking space. Cavity is made of special coated stainless steel. Rack are provided within the cavity for placement of food stuff. Bake and broil heater are placed at top and bottom portion of the cavity. The electric coil heaters are commonly of 2500 watts which transfers heat to the food stuff by radiation and convection through air. A cavity radial fan is assembled at the center portion of the back wall of cavity. The cavity radial fan recirculates the air within the cavity for a proper heat distribution. A ring heater is also present on the periphery of the cavity radial fan. Cavity air recirculates from the cavity fan and receives heat from the ring heater as it reenters the cavity region. Ventilation system maintains a flow of ambient air within the oven structure and oven door for cooling purpose. The electronic components like microchip and processors in console region heats up due continuous operations. The ventilation system is intended to maintain the appropriate operating temperatures of the oven door, console and the structure where the user interface is likely to occur. A gas fired oven includes a gas piping system and burners instead of electric coil heaters.

3. Convection-Oven Door Cooling

The function of a Convection-Oven door is to provide visibility and accessibility to the oven cavity for the user. The oven door constitutes of number of glasses, glass retainers, side rails, door handle, door skin, etc. The self-cleaning cycle (pyro cycle) for the convection oven generates 450°C temperatures within the oven for burning out the food residues in the cavity. During this cycle the oven door is likely to heat up due to heat transfer from the cavity to the door by radiation, conduction and forced convection. User has to hold the door handle for oven door opening and closing operations or approach the oven door glass for visuals of the food cooked in the cavity. Oven door is one of the user interface to the cavity and thus considering user safety, the oven door temperatures should be within the safety limits. Norms for home appliances suggest that the safe operating temperatures over the convection-oven door should not exceed 70°C temperatures.

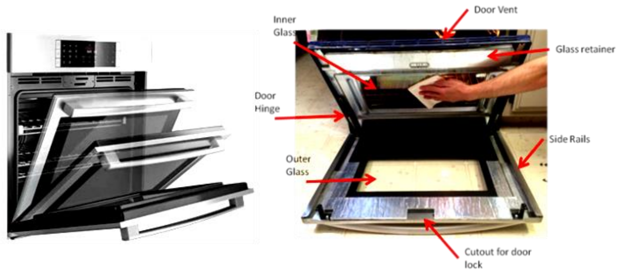

Fig 1 Convection Oven Door

To maintain the safe temperatures over the oven door a basic method utilized is providing insulation within the oven door. But as the oven door constitutes of glasses, one cannot provide a complete insulation over the door as it will interfere with the visibility for the user. A promising solution is to provide ambient air flow within the oven door which will cool the oven door by convection. Depending on the type of air flow the oven door cooling system is divided into Natural convection cooling and Forced Convection cooling.

4. Numerical Methods and CFD

Fluid Dynamics is the subject which deals with the physics involved with the fluid motion. The subject provides the mathematical models or governing equations for defining the fluid motion. But the governing equations are in the form of partial differential equations whose analytical solutions for complex problems is highly tedious job. The analytical solutions for some PDE are available, but when the domain is large calculation manually is highly time consuming work. Hence the PDE are converted into algebraic form using Numerical Methods. Numerical methods includes discretizing the model into small elements or control volumes which can be solved for the PDE in their converted algebraic form and the complete domain results can be represented as the combination of such definite control volume's results. The discretization part also termed as meshing largely affects the results of the problem defined. Various types of mesh and grids are used to discretize the problem. The grids are divided into structured and unstructured the utilization of the particular type of grid completely depends on the model and the area within the model to be captured. Depending on the way of discretization the Numerical methods available are Finite Element Method (FEM), Finite Volume Method (FVM) and Finite Difference Method (FDM). The finite element method divides the domain into finite elements and nodes and solve the governing equations for different elements and transfers the information from one element to other through nodes. The finite volume method divides the domain into small volumes and solves the governing equations for the control volumes and passes the info to other control volumes through the interface surface. The finite difference method defines the domain into a structured computational plane. The FDM defines the problem in such a way that the step size can remain constant for the entire domain even if the geometry is unstructured. In FDM a relationship is developed between the physical plane and the computational plane and the governing equations are solved on the computational plane. Some of the FDM techniques include Lex-Wendroff Technique and MacCormack Technique.

Various CFD tools are available in market and the choice of the tool is completely dependent on the parameters of study. Every tool has its advantages and limitations. The major difference is the type of solver which are FDM, FVM and FEM. Commonly available Solvers are FEM and FVM. Slight variation in availability of the solver models like SA and k-ε is also observed in the CFD tools. Also the multiphase options are not available for some CFD tools. Features like cad modeling, preprocessing and post processing varies for different CFD software.

5. Venturi effect for oven door cooling

The study of this paper introduces an oven door cooling method using venturi effect. The present cooling method utilizes a cross flow fan to generate a flow within the oven door. Due to the complex geometry of the cross flow fan it is costly than a radial fan. The long term purpose of this study is to replace the cross flow fan with the radial fan. Considering the flat geometry of the oven door the cross flow fan can effectively generate air flow pattern uniformly across the door section. Radial fan on the other hand produces a flow in radial pattern thus not suitable for flat profile geometries. The cross flow fan generates flow by creating low pressure region within the door region to develop oven door cooling by forced as well as natural cooling. But radial fan is incapable of creating enough suction within the oven door regions. Hence an effective way of utilizing the radial fan for oven door cooling is by venturi effect. The high velocity air generated by the radial fan can produce suction effects using orifice or venturi profiles within the flow regions. The flow rates generated by the cross flow fan for effective cooling within the door are **4 to 5 cfm**. Similar flow rates are expected to be generated using the radial fan with venturi profile channel. The venturi profile is developed using a deflector to restrict the flow through the vent over the door region. The air when forced through the restriction created by the deflector, creates a reduced pressure regions following the Bernoulli's Law. This reduced pressure region creates a pressure gradient across the door region which is responsible for the flow through the door region. The ambient air is sucked in to the door regions trapped between the door glasses and flow over the glass thus cooling the glass by forced convection. Some of the key parameters affecting the venturi profile operations are the front frame opening, deflector position, deflector dimensions and air velocities within the venturi regions. The effect on the flow rate within the door region between glasses is studied for different front frame opening and inlet air velocities.

The study is carried out using CFD tools like Fluid Nexus, Accusolve and Field View and Creo modeling tools. Such tools offer an opportunity to simulate the variation in the model parameters and study the effect of the variation on the required output. The convection oven model is been validated using the above tools. The correlation suggests that the tools are effective in predicting the thermal and flow distribution within the oven with respect to the experimental data.

6. CFD modeling and analysis

Model for the simulation consists of air regions surrounding the glass and deflector. The cutout of the glass and deflector is taken within the air model. The complete model is divided into the door region and the room air to avoid large mesh count. The door region is assigned a tetrahedral mesh of 2mm and the room air is having a tetrahedral mesh of 5mm. The boundary of fluid is having 3 layers of refined mesh to capture the boundary phenomenon. The figure below shows the boundary conditions applied to the model. The vent inlet is assigned with the velocity inlet conditions where the different velocities are assigned to the problem for understanding the performance of venturi effect with respect to the flow rate. 3 surfaces of the room air are assigned as the pressure outlets with a provision of reversed flow. The lower part of door region is set for stagnation inlet condition which are the normal atmospheric conditions

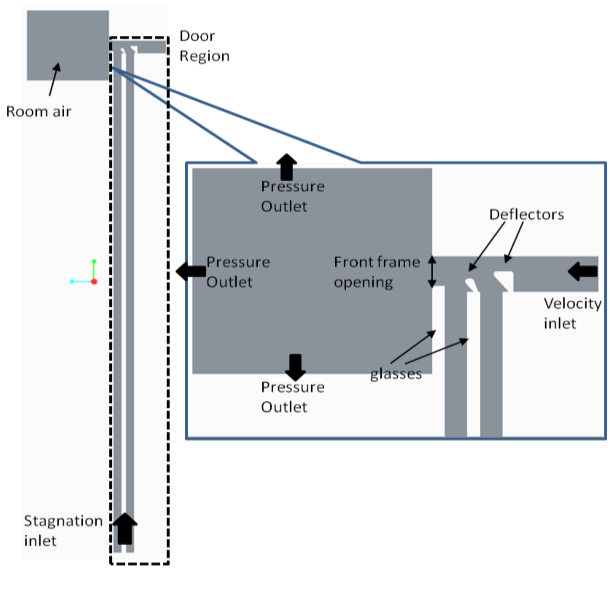

Fig. 2 Model for Simulation: various components of the door and flow channel with the boundary conditions.

The variation in the inlet flow rate is performed for 4 different flow rates as mentioned in the Table 1.

Table 1 Inlet flow rate variation values

Flow rates, cfm	12.5	25	37.5	50
Inlet velocity, m/s	1	2	3	4

7 Results and Discussion

The study of the flow rate within the door region is carried out using CFD tools. Inlet flow rate through the vent channel is considered as a parameter of study. The results shows that the flow rate from the door region exhibits a linear relationship with the inlet flow velocity along the vent channel. The fig 3 describes the vector plot of the flow across a mid-section. The flow regime shows that the flow after striking the deflectors experiences an increase in velocity through the restriction. As the velocity increases the pressure in the restricted region reduces. The reduced pressure is lower than the atmospheric and hence the air is sucked into the door regions from the lower opening of the door. The small deflector positioned on the middle glass does not contribute largely to the generation of flow within the door region, instead it creates obstacle to the free flow of air from the incoming air from the door region. The flow regime can be improved by adjusting the deflector profile. The flow is directed upward after striking the deflector positioned on the extreme right. If the right angled geometry of the deflector is changed as per the flow then maybe the flow will be directed properly into the front frame opening instead of striking the top cover.

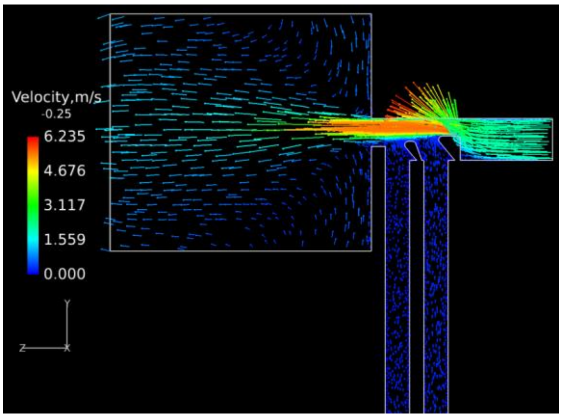

Fig.3 Vector plot of the velocity within the door region and room air

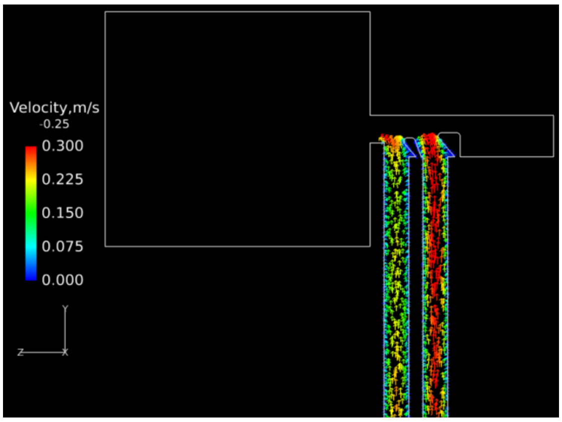

Fig.4 Vector plot of the flow only through door regions, air between the glass panels

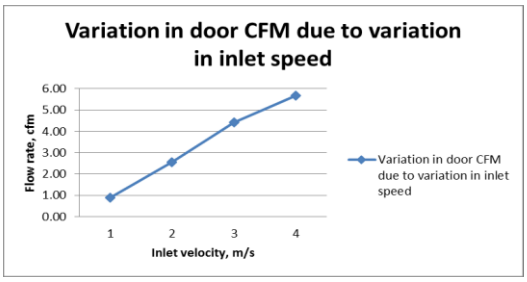

Fig.5 Flow rate between the glass panels for different Inlet flow rates.

The effect of front frame opening on the flow rate from the door region is also discussed. The study shows that the flow rate within the door regions increases for opening from 6.5 mm to 8mm but reduces for opening up above 8mm. The fig 10 illustrates the relation of the front frame opening to the flow rate within the door regions. Large front frame opening causes a reverse flow of the air from front frame opening into the venturi region. The low pressure regions is developed at the deflector and thus air is pulled towards the deflector. The flow distribution in the venturi regions for the front frame opening of 10mm and 12 mm is presented in fig 9. The flow disperses over the front frame region from the deflector. The figure shows that the high velocity regions does not occupy the complete front frame region. Thus the low pressure region is developed only on the top regions of the front frame. A swirl flow is observed at the lower front frame region which are responsible for the low flow rates from the door regions.

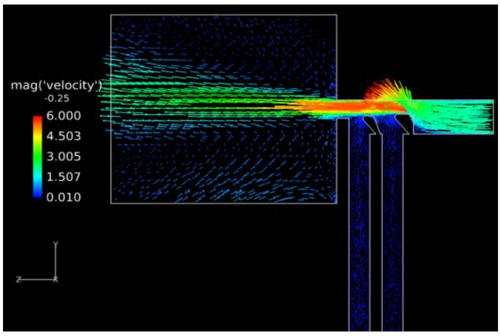

Fig.6 Vector plot of the flow only through door regions for front frame opening of 6.5mm.

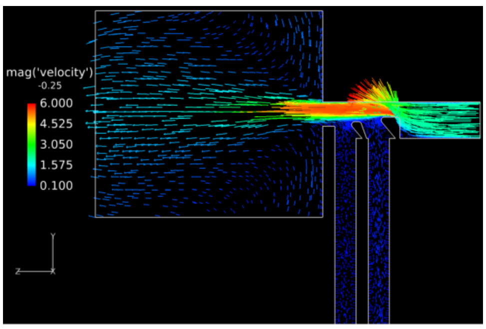

Fig.7 Vector plot of the flow only through door regions for front frame opening of 8mm

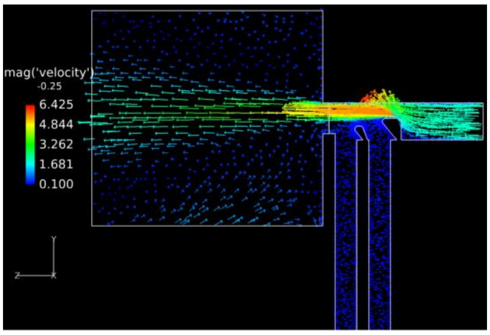

Fig.8 Vector plot of the flow only through door regions for front frame opening of 10mm

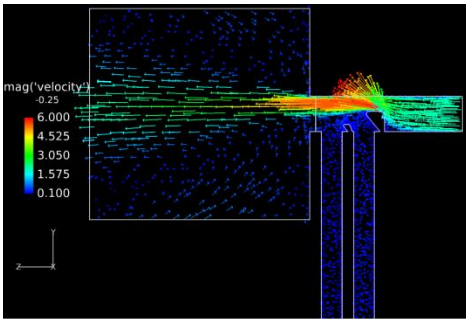

Fig.9 Vector plot of the flow only through door regions for front frame opening of 12mm.

The swirl flows of air through the front frame can be avoided by changing the deflector profile. The deflector profile should be modelled in a fashion so that the flow is dispersed on to the front frame completely. The deflector on the middle glass is not contributing to the flow rate through door regions. The deflector on middle glass can be removed as it is creating restriction to the flow from the door region.

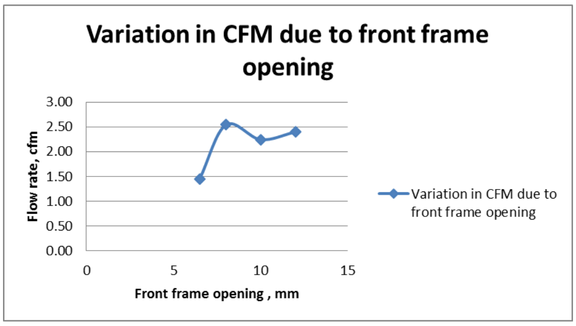

Fig. 10 Door region air flow rate for different front frame opening.

Conclusions

The convection oven door being one of the user interface is expected to be under safe operating temperatures of 70°C. The cross flow fan can maintain air flow within the oven door which helps in forced convection heat transfer thus cooling the door. On the basis of a previous study it has been concluded that for effective cooling of oven door a flow rate of 4 to 5 cfm is expected within the door regions. Radial fans are relatively less costly than cross flow fan but not suitable for the purpose. Venturi effect when utilized with the radial fan can serve the purpose of the oven door cooling. Thus the paper discusses the performance of the venturi effect in oven door cooling. The parameters considered for study include the variation in flow rates of a radial fan. The results conclude that the door region flow rates are linearly proportional to the inlet velocities from the vent channel.

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