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Numerical and experimental characterization of a batch bread baking oven

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HIGHLIGHTS

- This study concerns the thermal characterization of an electric static oven used for bread baking.
- An original, experimental and numerical approach of thermal problem is proposed.
- Contributions by radiation and convection are separated.
- The goal is to provide boundary conditions for numerical models of bread baking.
- Results are encouraging to optimize energy consumption in industrial oven.

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ABSTRACT

This study deals with the thermal characterization of an electrical static oven used for bread baking. The heating is provided by natural convection, infrared radiation and conduction with a cement slab. The paper describes a methodology to apprehend the heat flux which is applied to the products during baking. The oven was experimentally investigated and a finite element numerical model is established. The monitoring of temperatures at various points in the installation and of electrical power is carried out. Then, to characterize thermal exchanges around the bread during curing, thermal responses of a cylindrical sample is also measured. The numerical model made it possible to calculate the heat flux exchanges with the product, while separating the contributions of convection and radiation. The comparison of simulated responses with experimental data shows the relevance of the model.

1. Introduction

The baking of bread is a process which transforms dough – basically made of flour, water and leavening agents – into a product which is consumed by an important part of the population [1]. The common industrial practice is to insert the dough in an oven where the ambient temperature is controlled at constant values. These values are often high: greater than 200 °C. It is therefore obviously interesting to study the energy efficiency of these industrial processes both for energetic and economic reasons.

The study of the oven requires the following analyses: heat transfer and heat utilization. During a standard cooking operation, a large proportion of the energy supply to the oven is absorbed by the structure and lost in the surrounding environment. The goal is to characterize the thermal environment of the oven and to understand its energy consumption in order to dimension heater elements. In the context of energy efficiency, we must reduce consumption by adjusting the thermal capacity of the oven and the air temperature levels, and optimize radiation whilst maintaining the quality of the product. The result for the product – in terms of browning, mass losses, crust thickness and swelling – should remain the same. Also, precise knowledge of heat transfer in the furnace is required. Various studies have been conducted on this subject [2,3]. Contact baking on a cement slab is a widely used process [4,5]. For this type of baking in a closed furnace, air speeds are very low, and radiation is the predominant mode. Convection is much more important in forced convection ovens [6], for which a computational fluid dynamics is necessary [7].

The present study deals with the ovens used for the making of traditional "French bread". The baking is done with hot air (natural convection), infrared radiation and direct conduction. Heat transfers are investigated by experimental and numerical methods. The first step of this work was to instrument a baker's oven. This gave access to temperature, radiative heat fluxes and energy consumption both during the start-up and the steady state of the oven. A two-dimensional FEM model created in Comsol® [8] was then introduced.

Its originality lies in the possibility to connect the power consumption of the furnace to the temperature field in the cavity,

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