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Experimental investigation of French bread baking under conventional conditions or short infrared emitters

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HIGHLIGHTS

- Improve energy efficiency of bread baking oven.
- Characterization of traditional baking with steam injection.
- Comparison between two heating techniques: conventional or short infra-red emitter.
- Energy supply is compared for the baking of one baguette.
- Low temperature baking under infrared emitters leads to 20% energy saving.

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ABSTRACT

The objective of this study is to improve energy efficiency of an oven used for the conventional baking of French bread. Experiments performed to validate a numerical model and test different infrared emitters are presented. In order to provide a relevant experimental database, we first instrumented an industrial electrical static oven. The modifications made to the oven and instrumentation installed allows monitoring baking kinetics. The quantities measured are bread mass, temperature field, volume expansion and pressure. An energy balance is calculated to define the energy necessary to cook one "baguette". Heat is provided by natural convection, direct conduction and mainly by infrared radiation to the dough. To improve energy efficiency, short infrared emitters are arranged on the vault instead of traditional electrical resistances made of reinforced metal alloy. These emitters allow increasing radiation heat transfer. Then, baking under short infrared emitters is carried out at lower air temperature, for the same total baking time. Energy consumption is analyzed and compared in both cases.

1. Introduction

Bread baking is a complex process where temperature is the dominant factor [1]. Heat and mass transfer phenomena occur simultaneously inducing physical, chemical and structural transformations [2]. During the baking process the fermented dough is transformed into bread with significant changes in structure. The temperature increase generates different physicochemical reactions in the dough (gluten changes, C02 production, starch gelatinization, etc.) which result in a change in the alveolar structure and in expansion of the product. The next steps are the formation of crust and browning (Maillard reaction and caramelization of sugars) [3–5]. All these phenomena occur with a progressive mass loss.

The objective of our studies is to improve the energy efficiency of oven used for traditional baking (natural convection with steam injection) of a loaf of white bread called "French baguette". "Good baking" is difficult to characterize as it depends on sensory properties. Developing a general methodology to verify the baking of a product is a difficult task. Therefore, optimizing oven operating conditions requires good understanding of the influence of heat input on baking kinetics.

Consequently, we modified our oven and installed instruments in it to characterize these kinetics. Local temperatures and dough mass loss are measured continuously. Punctual measures of local pressure and monitoring of the deformation are also performed. A pyrometer is used to define the typical evolution of the surface temperature of a dough roll during traditional baking. Here, we use these measurements to define the process of a "traditional baking".

Many studies have been performed to optimize bread baking that integrate physical transformations obtained from experiments [1] or from heat and mass transfer models [6–12]. Purlis [13]

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optimized the set point to be applied to the oven in order to obtain a target value of bread surface color and a minimum value of 96 °C at the product center.

Here we opted to test another technology to decrease the energy consumed during baking. All the models developed assume that surface heat flux contributions drive the transformations that take place in the dough during baking. The thermal mechanisms involved in the oven are direct conduction, natural convection and mainly infrared radiation. Therefore the aim is to decrease the share of convection around the product, and to decrease conduction by contact with the sole (cement slab) to favor the contribution of more intense radiation heat transfer. The same hypothesis was also employed by Ref. [14] and they assumed that the same amount of heat was absorbed by the product while the contributions of different (mainly convective) heating modes vary.

Consequently, we decided to conduct baking experiments under short infrared emitters in view to reducing air and "sole" temperatures to minimize energy consumption.

Although the possibility of baking cereals using short wave infrared radiation was investigated in the early 1970's [15] this IR technology has not yet been applied in craft bakeries. Several studies have been performed on this technological solution [15–17], but during the tests carried out, the IR emitters were not controlled and the surface temperature of the dough increased rapidly. These studies aimed at reducing total heating time. This is not the solution adopted here, which is the originality of our approach: the same temperature kinetics at the dough surface is ensured for both baking processes, i.e. traditional baking and baking under infrared emitters.

The working hypothesis is the following: if the same energy is applied to the surface of the dough roll, the same baking conditions and thus the same end product will be obtained. To ensure the same kinetics for crust development and the same quality criterion [4], total baking time remains unchanged. The ambient and sole temperatures of the oven are 60 °C lower for infrared baking. Finally, oven consumption in permanent mode is estimated for both conditions.

2. Material and methods

Various physical parameters were monitored to better understand the hydrothermal behavior and deformation of the product during baking.

2.1. Bread dough

Bread dough is obtained by mixing 100 kg of wheat flour and 60 kg of water. After the growth, the pieces weighing 315 g are 53–55 cm long and 3–4 cm in diameter. The density of the dough before baking is 445 kg m^{-3}, with an initial water content of 0.78 kg/kg (dry basis) and an initial porosity of 0.84. More information on bread properties are given in Ref. [6]. Baking takes 22 min. Scarification of bread dough is made to control the development of geometry during baking.

2.2. Oven description

The cooking tests were performed in our laboratory on a single-stage electric furnace from Bongard characterized previously in Ref. [18]. The volume inside the chamber is 60 cm wide, 26 cm high and 80 cm deep. The side walls and vault are made of stainless steel (Fig. 1). This type of oven is designed for baking 8 "baguettes". When the oven temperature is steady, the dough pieces are laid on a 20 mm thick concrete slab called a heating sole. Heat gain is provided by electric heaters placed under the sole and below the vault.

The baking of a traditional French baguette requires a short injection of steam (5 s) when starting cooking. The water vapor is generated in a "steam box".

2.3. Ambient condition in the oven

The air temperature was measured by three K thermocouples inserted in radiative screens. These sensors were placed at three heights (top, middle and bottom) near the center of the oven. Previous experiments [18] showed that thermal gradients are relatively low in the enclosure. The surface temperatures of the vault heating resistances were obtained using thermocouples attached by clamps. Other thermocouples were glued on the vertical walls of the enclosure.

In the case of typical baking, vapor pressure is measured with a thermo hygrometer (Testo 650) equipped with a high temperature capacitive probe.

Except during steam injection, which brings energy to the dough by convection and condensation, heat exchanges occur by direct conduction, natural convection and infrared radiation Fig. 1. Classically, the temperature settings applied to the oven are 230 °C and 240 °C. These temperatures are regulated by an on/off control through temperature sensors placed on the vault and under the sole. The maximum surface temperatures of the sheathed electrical heating elements used are under 450 °C [18].

In the second stage of the study, vault heating elements were replaced by short wave infrared emitters equipped with reflectors, Fig. 1. The power supplied to this device was regulated by a solid-state relay (E-power from Eurotherm) controlled by an analogical signal. The solid-state-relay communicated via Ethernet with a PC and the consumption energy was recorded. The objective was to reduce air and "sole" temperature to minimize energy consumption.

2.4. Continuous monitoring of parameters

Several modifications were made to the oven and different sensors were installed. Data acquisition was performed using a

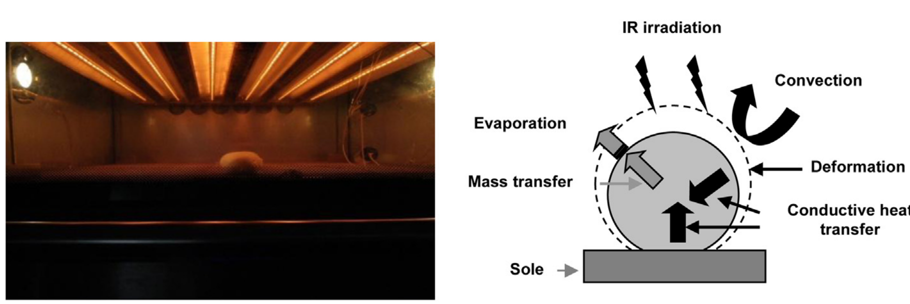

Fig. 1. Thermal mechanisms involved in the oven.