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Impingement Heat Transfer Effects on Baking of Flat Bread

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An impingement oven designed for flat breads baking was instrumented to monitor the processing conditions and record variables responsible for changes in dough characteristics. Image processing was used to monitor the volume and surface color changes during baking. Fluctuations of oven temperature and jet velocity were minimized using electronic controllers, leading to better repeatability and accuracy. Impingement heat transfer distribution effects on flat bread baking was investigated by numerical simulation and related to the bread color. Considerable effect of local variations in impingement heat transfer and nonuniform nozzle exit velocity distribution on the color of baked bread was observed. At H/D > 4, jet temperatures $< 200^{\circ}C$, and jet velocity of 10 m/s, local heat transfer distribution and surface darkening was negligible and a uniform surface color was obtained. Notably, velocity variations of ±20% inherent in the finger nozzles used in the oven design did not result in significant color change, which depends more on the local temperature attained by the bread surface.

Keywords Baking; Color; Flat bread; Impinging jets; Numerical simulation

INTRODUCTION

About a third of the world population consumes various types of flat breads. They are typically baked in traditional ovens, but there is limited knowledge about the cooking conditions and oven performance, which makes their design and operation empirical and not necessarily optimal in terms of energy consumption and quality of the baked products.

In the domestic forced convection oven (“hot air oven”) the temperature distribution in the cavity is much more even than in a traditional static (“top-bottom” heated) oven. However, the surface browning of food cooked in hot air ovens can be uneven. This is an effect of the inherent nonuniformity of the air velocity distribution, resulting in different local heat fluxes.[1] The hot air oven is one type of forced convection oven where the air flow is largely parallel to the bread surface; another is the impingement oven, in which the hot air jets impinge normally on the baking surface, giving higher but more nonuniform heat transfer distributions.

Air jet impingement units are used in various industrial processes for efficient heat and mass transfer operations such as in textile and paper drying, electronics cooling, metal annealing, glass tempering, etc., because of the high heat and mass transfer rates attainable with such convection designs. Mujumdar[2] has given a concise but comprehensive summary of impingement drying.

These systems have found many applications in industrial food processing in the last two decades. Li et al.[3] compared large impingement ovens and the combination of impingement and microwaves and found large differences to industrial hot air ovens. Walker et al.[4] and Henke et al.[5] in general describe impingement ovens. Considerable reduction in process time and improvement in product quality can be obtained using this technique.[6–8]

In impingement oven design, it is important to select the jet configuration very carefully since a two- or four-fold decrease can occur due to errors in the selection of nozzle geometry, spacing, etc. Polat[9] provided an excellent review of impinging jet heat transfer. Several recent papers also deal with impinging jet heat transfer with a variety of jet designs and include important effects such as those of jet multiplicity,[10] complex geometries such as noncircular nozzles,[11] effects of cross-flow,[12] effect of large temperature differences,[13] etc. The jet configuration used in this study cannot be considered truly optimal but is a reasonable design based on literature recommendation.[14,15]

A point of concern when using air impingement systems is the wide variation of heat transfer coefficient on the surface of a product. This can cause undesirable variation in certain quality attributes. Previous studies have indicated that air impingement systems can result in localized hot and cold spots on the surface of a food.[16] Practically, two sources of nonuniformity exist: local convection heat

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