



An experimental study of the local evolution of moist substrates under jet impingement drying

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ABSTRACT

Jet impingement can be successfully and efficiently employed in drying or dehydration of moist substrates, like food slices or plates, among other applications. With this intensification technique, a great deal of the available water is removed by applying heat under controlled conditions, but excessive or nonuniform local drying may cause local deterioration (i.e. in case of foods, the eating quality, the nutritional value, the mechanical consistence and so forth).

In this paper the thermal, water activity and moisture depletion histories have been measured in a food substrate, due to localized heating by a turbulent air jet impingement, to infer on the inherent driving forces and transport phenomena. It is evident that strong non-uniformity may exist in the substrate so that a local analysis as the reported one is necessary to help reach optimal processing.

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1. Introduction

Water performs a number of important functions in processing and conservation of porous materials such as food substrates. Among these, moisture serves as a medium for the transfer of energy in heating or cooling processes and, in foods, its final content dictates the duration (shelf-life) of the substrate: high moisture substrates are readily spoiled by microorganisms and chemically and enzymatically deteriorated. The total moisture content comprises the bound water (relative to the biochemistry and micro-capillarity) and the free water (kept in place by physical forces only) [1].

The free water can be measured in terms of the ratio of the vapor pressure of water in the sample to the vapor pressure of pure water, or the water activity a_w (an analog of the relative humidity, RH). This concept, along with the usual moisture content U , is commonly employed as a factor that drives keeping and operational quality of the substrate. Therefore a detailed description of such local quality is often needed to avoid poor or excessive treatment, whereas product uniformity is at stake. To this end, the appropriate conditions of design and operation of drying equipment have to be properly analyzed.

Among the available enhanced convection techniques, the jet impingement (JI) of air can be used for its excellent heat and mass

transfer characteristics, where localized and rapid surface drying or dehydration of food substrates is desirable [2,3]. Dehydration involves a rather complex combination of application of heat and removal of moisture. In addition to air temperature and humidity, the rate of moisture removal is controlled by the air velocity: when hot air is locally blown over a wet substrate, water vapor from liquid water evaporation diffuses through the boundary layer and is carried away (Fig. 1). A water vapor pressure gradient is therefore established from the moist interior to the external food surfaces.

As in every bulk convection treatment, the boundary layer acts as a barrier to both heat transfer and water vapor removal during drying. But even within its apparent simplicity, JI treatments induce fluid/substrate interaction patterns, in the stagnation and in the wall jet region (Fig. 2) [4]. These patterns contribute to boundary layer destruction, hence in increase of moisture removal but generally in a non-uniform way. Therefore local substrate conditions have to be carefully monitored as well.

Studies on gaseous JI have been performed extensively over the past five decades, nevertheless the coupling and interdependence between simultaneous mass/heat transfer and fluid dynamics still needs to be fully analyzed, with special reference to local moisture removal.

Porous media drying under bulk convection regimes has been long speculated, and a large number of studies are available, following the seminal works by DeVries [5] and Whitaker [6]. However, few contributions have been found only in the available literature, with reference to localized convective porous media

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