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Thermal Diffusivity Variations of Potato during Precooling in Natural Convection Environment

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Abstract

The present work is development of a simple method to evaluate the skin temperature and thermal diffusivity variations of regular shaped food products subjected to natural convection cooling at constant pressure. Experimental investigations were carried on the sample chosen (potato), which is approximately of spherical geometry. The variation of temperature within the food product is measured at several locations from center to skin, under natural convection environment using a deep freezer, maintained at -10°C. Skin temperature is obtained based extrapolation of temperature profile from center towards skin. Thermal diffusivity variation iscalculated using one-dimensional Fourier's equation and is plotted against skin temperature of the product.

Keywords: Natural convection; precooling; regular shaped; skin temperature; thermal diffusivity.

1. Introduction

Fruits and vegetables are highly perishable products. In developing countries, like India, each year upto 25 to 30% of the most perishable fruits and vegetables are lost due to spoilage, physiological decay, water loss, and mechanical damage during harvesting, packaging and transporting, or due to transportation (Otero&Sanz, 2003). These losses have been estimated to be more than 40 to 50% in the tropics and subtropics. Post-harvest losses of fruits and vegetables in developing countries is therefore of serious concern (Otero, Ramos, Elvira &Sanz, 2007). Moreover, in many developing countries only a limited quantity of fruit and vegetable products are produced for local markets or for exportation due to lack of machinery and infrastructure. Reduction of the high wastage of fruits and vegetables requires various measures to be adopted to minimize these losses during harvesting, handling, storage, packaging and processing of fresh fruits and vegetables into suitable products with improved storage characteristics.

For many decades now, refrigeration industry has found its significant application in the preservation of food and perishable products through storage at low temperatures (Heldman, 1975).

One engineering aspect of the cooling process is to predict the time required for a product to cool to its surrounding temperature. This calculation for food products is often complicated by irregular geometries and non-homogeneous distribution of pulp under the skin. Cooling times of selected food products is presently tabulated by approximating the product as a spherical body because temperature response curves for this geometryis available in literature for comparison.

Most of the work available in literature concerns with meat products. Thermal properties of a very few fruits and vegetables are available in literature. The objective of this work is to device a simple method to determine the thermal diffusivity of the selected food product as a function of temperature.

2. Materials and Methods

2.1 Experimental Setup

Experiments were carried out on regular (cylindrical and spherical) shaped food products. The main aim of these investigations is to analyze the heat transfer behavior during pre-cooling of solid food products. For this purpose experimental measurement of transient time-temperature behavior during pre-cooling of food products is done.

Before exposing the fruits and vegetables to the deep freezer, constant temperature of -10°C was maintained by operating the deep freezer for sufficient time to attain steady state.

Table 1: Specifications of natural convection chamber (deep freezer).

Deep freezer	**Compressor**
Model RQF-265(D) Volume 265 lt. Recommended voltage stabilizer 2 KVA Minimum temperature -35 to -40°C Frequency 50 Hz	Make Tecumsha Model MCB 2410 Discharge pressure 150 Back pressure +5 Compressor fan motor 1/83Hb AC/E Fan blade 9 inch(Al)

The sample was suspended with the help of hook. Product temperatures were measured using Copper-Constantan thermocouples. These thermocouples were inserted in the food product radially. Temperature variations with time were measured at five locations from center to skin. The data for temperature variation was recorded at regular interval using stop watch.

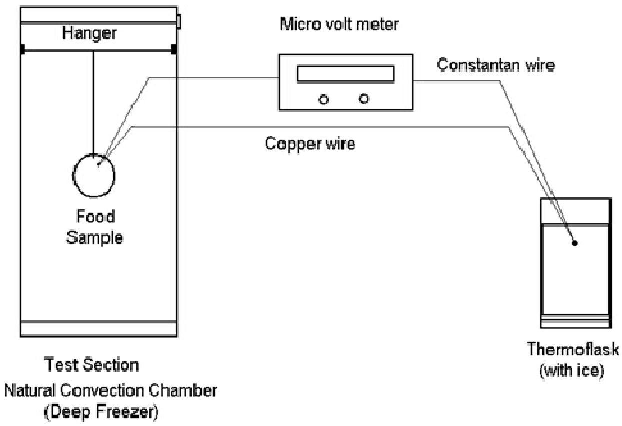

Figure 1: Experimental scheme for measurement of temperatures at various locations within a food product.

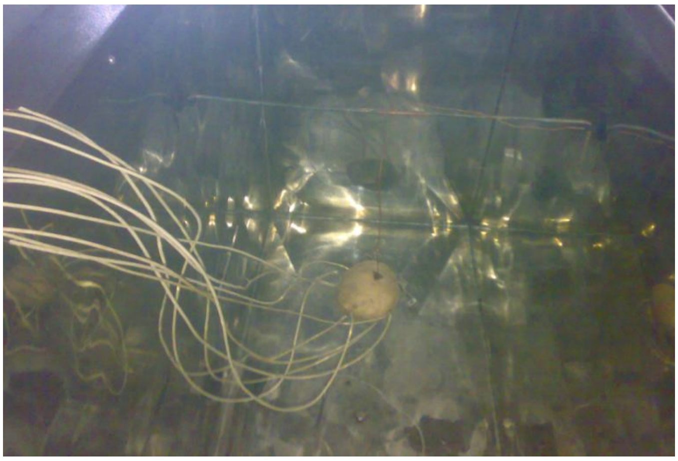

Figure 2: Laboratory view of sample (potato) in deep freezer with thermocouples inserted in radial directions.

2.2 Samples preparation

Experiments were performed on selected regular shaped food product. Sample was acquired from a local market. The sample were rinsed with tap water and stored at room temperature prior to use in experiments. The dimensions of the sample were measured using Vernier calipers (Table 2).

2.3 Assumptions

(i) Heat transfer is unidirectional i.e. it occurs only in the radial direction.
(ii) The composition of the food product is homogeneous below the skin.
(iii) There is no effect of latent heat on the heat transfer rate due to quite low moisture content of the cooling medium.
(iv) There are no transpiration losses from the surface of the product.

3. Observations

Temperatures along the radial direction were observed at five different locations (from centre to skin) within the product. The observed temperatures were plotted against X (dimensionless radius or radius ratio). Further, these temperatures points were joined to give distribution of temperature along the radial direction inside the product.

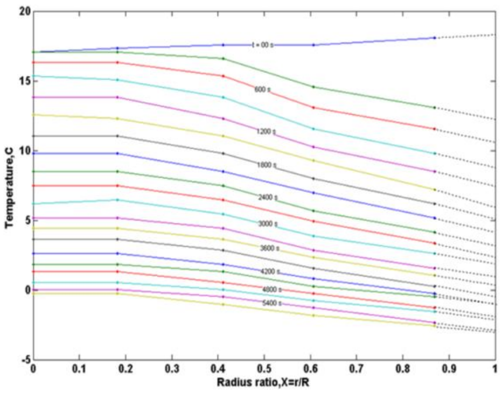

Figure 3: Temperature-radius ratio at different intervals of time for Potato.

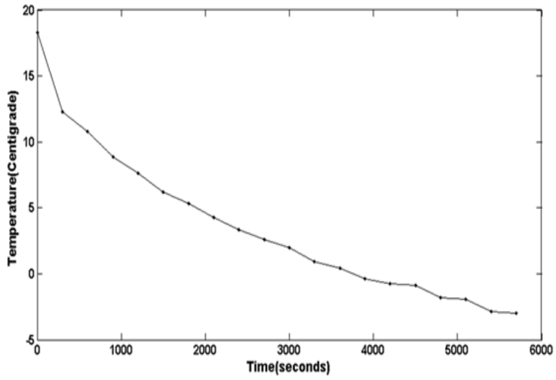

Figure 4:Variation of skin temperature with time for Potato

These curves were then extrapolated to skin (x = 1) using Matlab 7.1 as shown by dotted lines in the above figure to determine the skin temperature.The values of skin temperatures were plotted against time as shown in the following figure.

4. Results and Discussion

The governing equation for cooling of solid food product (with characteristic dimension X), placed in air medium at constant temperature is essentially time-dependent heat conductionequation (or Fourier's equation) without internal heat generation and moisture loss(Bairi, Karati & Maria, 2007).

where,

T = temperature, x = dimensionless radius or radius ratio, α = thermal diffusivity, t = time

Consider the left hand side of the above equation. It represents the double derivative of temperature variation within the product w.r.t radius ratio. This can be obtained by differentiating the equation of variation of temperature within the product w.r.t. radius ratio.

While the differential in right hand side of the above equation i.e. represents single derivative of temperature variation at skin w.r.t time. This is calculated from skin temperature plots for each value of time.

Thus, the thermal diffusivity is obtained as:

The calculated values of thermal diffusivity are plotted against skin temperature of food product for each of the sample as shown in the figure below.

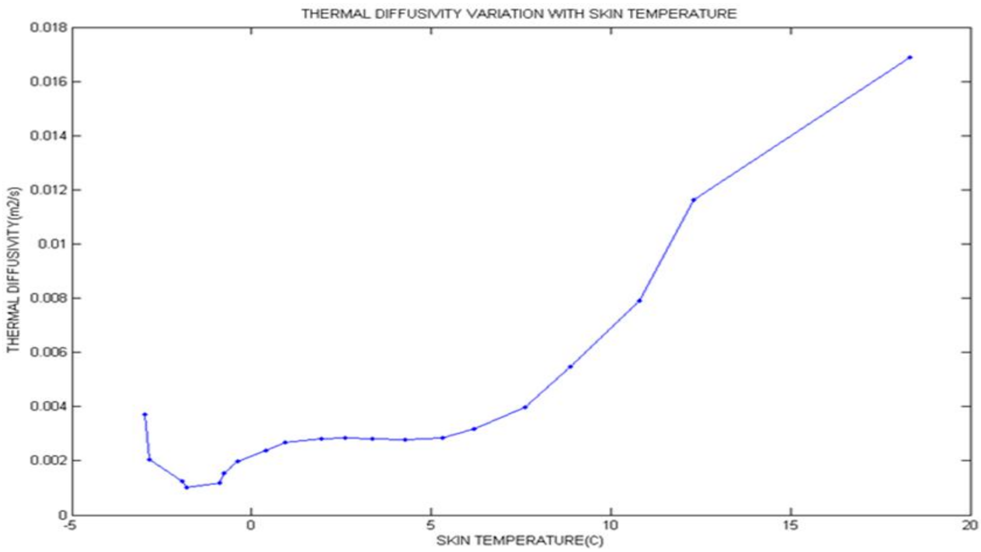

Figure 5: Variation of thermal diffusivity with skin temperature for Potato.

It is observed that at higher temperature thermal diffusivity shows strong dependence on temperature. But below -2 °C thermal diffusivity changes abruptly. These abrupt changes in thermal diffusivity could be the result of one or more of the following:

1. Change in the phase of various constituents of the products.
2. Freezing of waters at some locations and release of latent heat.
3. Changes in thermal conductivity and specific heat at low temperature.

4. Non-uniform density variations below freezing temperatures.

Since, thermal diffusivity below temperatures of -2°C shows abrupt variations and no regression curve closely represent the situation, thus we restrict ourselves to temperatures higher than -2°C.

5. Conclusions

A simple experimental approach to measure skin temperature has been developed as the same cannot be measured by ordinary means. The method comprises of extrapolating the temperature profiles within the product upto the skin. Also, thermal diffusivities of food products have been calculated and exhibited graphically.

Based on this study, it is concluded that the present method is capable of determining thermal diffusivity variation in terms of temperature for regular shaped food products during air cooling in natural convection environment in a simple and effective form.

Such temperature and thermal diffusivity profiles can be readily used with other information such as degradation rate etc. to evaluate thermal treatments based on cold air cooling methods for storage of perishable food products.

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