Measurement of thermal diffusivity for food products under natural convection cooling

Md. Reyaz Arif¹, Zahid Farhan¹ and Md. Azhar²
¹Department of Mechanical Engineering, Zakir Husain College of Engineering & Technology, Aligarh Muslim University, Aligarh-202002, Uttar Pradesh, India
²Department of Mechanical Engineering, Maulana Mukhtar Ahmad Nadvi Technical Campus, Malegaon-423203, Maharashtra,
Corresponding author’s e-mail address: reyazarif@zhcet.ac.in

Abstract. In the present communication, experimental analysis has been done for evaluation of relationship between the thermal diffusivity with temperature of Potato and Brinjal (a spherical shaped food products) subjected to a natural convection. Free convection is a type of flow of motion of fluid which is not generated by an external source but by some parts of the fluid being heavier than other parts. The analysis simulates the one-dimensional Fourier equation experimentally, applicable to the regular shapes of the product (cylindrical and spherical shaped products). The experimental setup consists of a deep freezer maintained at 263 K and 1.013 bar pressure. Variation of product temperature inside the product has been measured along the radial direction of the shape.

Keywords: Natural convection; Pre-cooling; Thermal diffusivity; Skin temperature; Spherical food products.

1. Introduction

Being healthy is not an overnight phenomenon. Natural products are healthier than man made products [1]. A diet high in fresh fruits and vegetables in the form of salad can help to protect us from many diseases [2]. Natural products are biodegradable in nature so improper food storage can lead to several problems like growth of bacteria and moulds [3]. Fruits and vegetables are highly sensitive in nature and their spoilage costs wastage of billions of dollars annually worldwide [4]. Due to negative impact on the environment include air pollution, climate changes, soil and water pollution. The cost in transport sector growth dramatically which is neither by the consumer nor by the transport services but due to environment. A study say that road transport contributes up to 92% of all the cost when compared to other transport modes. Post-harvest losses of fruits and vegetables are more serious in developing countries than those in developed countries.

Food preservation is a technique used to prevent food from spoiling. It also increases shelf life of food products. It includes method such as drying [5], irradiation [6], pasteurization [7] and the addition of chemical additives [8]. The very first stage of food spoilage can be detected through its appearance, foul. Smell, colour etc. Major factor of food spoilage is due to change in pH values and changes in climatic conditions like temperature, air etc. [9]. Zhang et al. [10] have found the thermal properties of
pea fiber and potato pulp and seen the effect of these property of extruded starch thermoplastics. Kostaropoulos and Saravacos [11] have presented the thermal diffusivity of granular and porous foods at low moisture content. Arif et al. [12] presented the experimental methods for determination of thermal diffusivity of food products in forced convection environment. The studied carried so far on the food preserving system, they have presented the effect of thermal properties for few fruits and vegetable. However deep investigation is missing in the literature. Also, the analysis on the Brinjal is lacking in the literature. Additionally, in the literature most of the works are reported on non-veg products. The aim of this work is to develop a simple method to determine the thermal diffusivity of selected fruits and vegetables (Potato and Brinjal) as a function of surface temperature. To the best of author knowledge, the present work will contribute the literature in the field of food and fruit preservation system.

2. Experimental Setup and Procedure

Figure 1(a) show the experimental setup of the deep freezer for natural convection. The inside view is shown in Fig. 1(b). Food preservation methods is an interesting area in engineering aspects. Potato and brinjal with precise spherical geometry have been chosen as a sample for testing and experiment. They are washed with tap water to remove its dirt before performing the experiment. Dimensions of the sample has been measured using Vernier calliper.

![Experimental Setup](image)

**Figure 1 (a)** Photo of deep freezer for natural convection cooling **(b)** Schematic plot of the setup to measure the temperature of food products

This is an effective experimental setup consist of a thermo flask filled with ice. Temperature is measured with the help of calibrated copper constantan thermocouple which is pre connected with a digital DC microvolt diameter. Thermocouple is inserted into the potato in radial direction. The sample is hanged in a deep freezer which is initially maintained at -10°C. Observation is recorded uniformly at an interval of five minute. Temperature is measured at five different location from centre towards periphery. In order to simplify the analysis following assumption are made:

1. The rate of heat transfer is only along radial direction.
2. Losses due to transpiration from the surface of the product is assumed to be negligible
3. The food product is assumed to be Spherical and homogenous throughout.
4. There is no moisture in the cooling medium.
5. Specification of deep freezer are as follows: (Model-RQF-265(D), volume is 265 litre, recommended voltage stabilizer is -2 KVA, minimum temperature ranges from -35 to -40 °C, frequency is 50 Hz, compressor make: Tecumseh, Model: MCB 2410.

2.1. Experimental Procedure

The governing equation for cooling of solid food product (with characteristic dimension x), placed in air medium at constant temperature (T∞) is essentially time-dependent heat conduction equation (or Fourier’s equation) without internal heat generation and moisture loss.
\[ \frac{\partial^2 \theta}{\partial x^2} = \frac{1}{\alpha} \frac{\partial \theta}{\partial t} \]

where, \( \theta (t) = \frac{T(t) - T_\infty}{T_I - T_\infty} \). \( \Box \)

where, \( \theta \) is the dimensionless temperature difference, \( T_\infty \) is the temperature of cooling medium, \( T_I \) is the initial temperature of the sample and, \( x = r/ro \), where, \( ro \) (cm) is the radius of the sample under study, \( r \) (cm) is the position of thermocouple.

The left-hand side of equation (1), \( \frac{\partial^2 \theta}{\partial x^2} \) represents the double derivative of non-dimensionlized temperature difference with respect to \( x \). This is calculated at the skin (\( x = 1 \)) and for each value of time by using temperature variation across radius of the product. While, the differential on right hand equation (1) i.e., \( \partial \theta / \partial t \) represents single derivative of temperature variation at surface of the product with respect to time.

3. Result and Discussions

In the present work, the variation of thermal diffusivity with skin temperature and their empirical corelations are presented for spherical shaped potato and Brinjal in natural convection cooling. Temperature measurements along the radial direction during pre-cooling of food products in natural convection environments are carried out. These temperature distributions were plotted against radius ratios and were extrapolated up to the skin to predict skin temperature (refer Figs. 3 and 4). Figures 4 and 5 show temperature variation with time at different radius ratio for Potato and Brinjal respectively. It is observed that at particular time temperature decreases as radius ratio increases for both Potato and Brinjal. Figures 6 and 7 show the variation of thermal diffusivity with skin temperature for Potato and Brinjal respectively and their empirical correlations are developed and is given by Eq. (2) with the coefficients listed in Table 1.

Figure 2. Variation of temperature with radius ratio for potato in deep freezer
Figure 3. Variation of temperature with time for brinjal in deep freezer.

Figure 4. Variation of temperature with time for potato.
Figure 5 Variation of temperature with time for brinjal.

Figure 6 Variation of thermal diffusivity with skin temperature for potato.
The terms of the Fourier equation were evaluated and thermal diffusivity at the skin for each value of time was calculated. Finally, thermal diffusivity was plotted against temperature of the skin. It is a general observation for all the samples that at higher temperature thermal diffusivity shows strong dependence on temperature. But below -2°C, thermal diffusivity changes abruptly. The abrupt changes observed in thermal diffusivity of the products may be the result of one or more reason discussed below:

1. due to phase change of the various constituents of the products.
2. due to decrease in temperature of water.
3. thermal conductivity and specific heat variation of the product.
4. density variations below the freezing temperatures of the product.

However, the thermal diffusivity below -2°C temperatures illustrate abrupt variations and no regression curve closely represent the situation, due to this reason we have restricted the temperatures higher than -2°C. Cubical regression curves are found to be the best fit for thermal diffusivity ($\alpha$) and are therefore fitted to data point. The thermal diffusivity ($\alpha$) with temperature in general form are represented as:

$$\alpha = AT^3 + BT^2 + CT + D$$

(2)

where the regression coefficient A, B, C and D for different samples are given in Table 1.

If a table is divided into parts these should be labelled (a), (b), (c) etc but there should only be one caption for the whole table, not separate ones for each part.

| Nucleus  | A      | B      | C      | D      |
|----------|--------|--------|--------|--------|
| Brinjal  | 1.8E-07| 6.8E-07| 1.8E-06| 8.6E-05|
| Potato   | 5.8E-06| -2.0E-05| -4.6E-04| 2.5E-03|

Table 1. Coefficient of the products/sample
4. CONCLUSIONS

In this study variation of thermal diffusivity with temperature for potato and brinjal are measured in natural convection regime. Thermal diffusivity is obtained using one-dimensional (1D) Fourier’s equation. The data obtained is shown graphically. Its shows a linear relationship of thermal diffusivity with temperature. Result obtained in the present study confirm that the variation of thermal diffusivity with temperature for proper geometry of food sample is simple and effective. Such temperature profile helps to understand various result over food product like deterioration rate shelf life, storage time for particular perishable food product. Also, the empirical relation has been developed for potato and brinjal under natural convection environment that will be help to those who are working in this area.

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