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Effect of Skin Removal from Spherical Fruits and Vegetables

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Abstract: Apple, orange and potato samples were exposed to chilled air blast, first with their natural skin and then after removal of the skin and transient temperature-time variations were recorded at the center. This data record was used to determine the thermal diffusivity of each produce sample by the empirical approach of the first author and his co-workers. Thermal diffusivity was found to be higher than the literature value. This is due to additional cooling effect resulting from desiccation of the exposed samples. The value decreased with the amount of cooling of the produce. The rate of reduction was fast in the beginning and later it had slowed down. The rate of decrease of thermal diffusivity was slow in case of produce samples with natural skin. In case of peeled off samples, this rate in the decrease was more pronounced. This must be due to the removal of natural moisture barrier; the skin. The variations of thermal diffusivity have been plotted and correlations developed. Temperature calculations with these variable thermal diffusivity values agreed well with the measured temperatures.

Key words: Cooling, food produces, thermal diffusivity, with skin, without skin

INTRODUCTION

In cold storage practice, food is cooled quickly after harvesting and its temperature is reduced to the storage warehouse temperature. Cold preservation is the best and least expensive method for extending the high quality life of food. The food, after precooling, is kept in the refrigerated warehouse for preservation. Since air blast cooling is an important technique, thorough theoretical and experimental studies were carried out to investigate cooling behavior of exposed food. An empirical approach had been developed and reported by Ansari and Afaq (1986) Ansari (1986) Ansari *et al*. (1987) Abbas (2005), which yielded thermal diffusivity of food through temperature-time records during transient cooling. When this variable thermal diffusivity was used to calculate temperatures, these were found to be in good agreement with the experimental values.

Sapuan *et al*. (2003), during his comparison study; revealed that Ansari's empirical correlation was the most reliable, simplest and accurate approach among others to determine the thermal diffusivity from temperature-time records. Therefore Abbas (2005) and Mukhtar *et al*. (2006) used the above approach successively.

Although many food technologists reported the thermal diffusivity determination in the literature (Gaffiney *et al*., 1980; Ansari *et al*., 1984; Dincer, 2001; Abbas, 2005; Mukhtar *et al*., 2006) but no one investigated the effect of the skin removal on thermal diffusivity of fruit and vegetable, so the above facts justified the present research.

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MATHEMATICAL FORMULATIONS

For isotropic spherical bodies without internal heat generation, normalized one dimensional heat conduction equation can be written as Abbas (2005).

$$\frac{\partial^2 U}{\partial R^2} + \frac{2}{R} \cdot \frac{\partial U}{\partial R} = \frac{\partial U}{\partial \tau} \tag{1}$$

The live foods continuously respire, releasing heat of respiration. But, the rate is so small that it does not put any recordable effect on temperature during the short period of investigation. This justifies neglecting internal heat generation in the Eq. (1). If the produce is assumed to be initially at uniform temperature and convective heat transfer takes place from its surface, the initial condition, center boundary condition and surface boundary condition shall be defined, respectively (Ozisik, 1986; Abbas, 2005)

$$U = 1 \text{ at } \tau = 0,\ 0 \le R \le 1 \tag{2}$$

$$\frac{\partial U}{\partial R} = 0 \text{ at } \quad \tau \rangle 0, \quad R = 0 \tag{3}$$

$$\frac{\partial U}{\partial R} = -\text{Bi}.U \quad \text{at} \quad \tau \rangle 0, \quad R = 1 \tag{4}$$

Data was generated by solving the above system of Eq. (1-4) using an optimized explicit finite difference scheme by varying all the significant parameters in their practical ranges. The singularity offered by the term 2/R in the governing Eq. (1) at the center (R = 0) could be solved by using the approximation,

$$\left.\frac{2}{R} \cdot \frac{\partial U}{\partial R}\right|_{R=0} \rightarrow 2.\frac{\partial^2 U}{\partial R^2} \tag{5}$$

In the present calculations, the first order derivatives in the Eq. (1-4) have been approximated with the four-point formulae of Berezin and Zhidkov reported by Ozisik (1980), which yield higher order of accuracy. These derivatives at the center and surface are given respectively as follows,

$$\frac{\partial U}{\partial X} = \frac{1}{6.\Delta X}\left(-11U_o^{j+1} + 18U_1^{j+1} - 9U_2^{j+1} + 2U_3^{j+1}\right) \tag{6}$$

$$\frac{\partial U}{\partial X} = \frac{1}{6.\Delta X}\left(-2U_{n-3}^{j+1} + 9U_{n-2}^{j+1} - 18U_{n-1}^{j+1} + 11U_n^{j+1}\right) \tag{7}$$

Nearly 600 data points were thus generated as explained else where (Ansari *et al*., 1984). Least squire analysis of this data set was made to develop the following empirical correlation,

$$\tau = \frac{\left[0.296 + 0.228 \ln\left(\frac{1}{R+0.2}\right) - \ln U\right]}{\left[\frac{9.87}{\left(1 + \frac{2.7}{\text{Bi}^{107}}\right)}\right]} \tag{8}$$

Equation (8) is reported to yield better results for $0 \le X \le 0.6$ and $\tau \ge 0.2$. It means that near the surface and for some initial cooling time, the results are not very accurate. The reason is the non-linearity in the semi-log plot (Gaffney *et al.*, 1980) of the temperature-time curve on which the regression Eq. (8) was based. Later investigations by the first author and his co-workers established that temperature records at or near the center yield best results.

The Nusselt number correlation (Abbas, 2005) provided the surface film conductance needed to calculate the Biot number:

$$\mathrm{Nu} = 0.1 + 0.3\mathrm{Re}^{0.5}\,\mathrm{Pr}^{1/3} \tag{9}$$

EXPERIMENTAL PROCEDURE

The experimental study was conducted in food engineering lab of Food Science and Technology Faculty of Universiti Putra Mlayasia, due to availability of all the required facilities and the air blast cooling plant (Fig. 1) as well.

In this study, temperature-time variations were recorded during air-blast cooling of apple, orange and potato samples when exposed suddenly to chilled air blast. The produce samples were selected as spherical in shape as possible. The logged temperatures were used to calculate thermal diffusivity of each produce sample at every measurement time step by the empirical method (Ansari, 1986).

Copper constantan thermocouples were fixed at the center of each sample. The thermocouple beads were fixed at the tip of wooden thorn. The thorn was inserted in the sample's body till the bead reached the center and the transient temperatures at the center were recorded. The air blast cooling plant consisted of 4 m long iron sheet air duct with a cross section of 0.3×0.25 m. The duct was well insulated with 15 mm thick glass wool. Air stream was chilled by R12 vapor compression refrigeration system. The air temperature could be changed by varying the fresh air intake through louvers A and B. Before starting the temperature records on a data logger, the refrigeration plant was run for nearly 30 min until a constant cold air stream temperature was achieved.

When the temperature of the inside air came to a steady state, the sample was suspended in the test section of the duct and temperature record was made for 1 h at 1 min time interval. Nine samples were investigated for each produce with skin. Another nine samples of each produce were investigated after removing the skin. The chilled air temperature and velocity in the duct was maintained constant at 1°C and 5.0 m sec^{-1}, respectively.

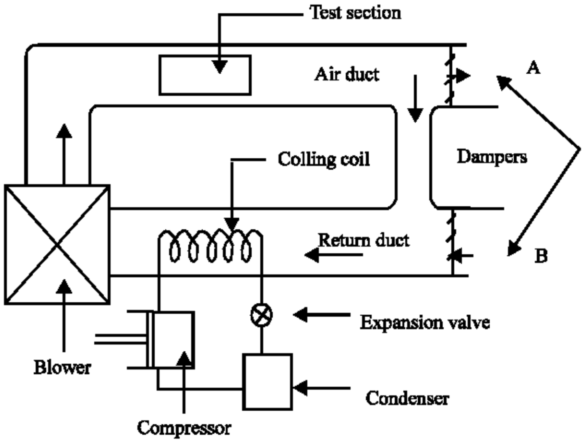

Fig. 1: Air blast cooling plant

RESULTS AND DISCUSSION

The temperatures logged at the center of each produce sample were used to solve the Eq. (8) to get produce thermal diffusivity at every measurement time step. In case of both unpeeled and peeled produces, thermal diffusivity in the beginning was high; it decreased successively and it was the lowest at the final temperature. The fall in the thermal diffusivity values was approximated by linear curves as shown in Fig. 2 for a particular potato sample. It can be observed form the two curves that fall in case of peeled produce is sharper than that in the sample with skin. This is because of enhanced moisture loss and ensuing higher latent cooling of the produced. It may also be observed that the gap in the two curves narrowed down with cooling time. At the final temperature of 2.3°C, the thermal diffusivities for unpeeled and peeled samples were almost equal.

The authors believe that the reason for this trend is formation of a moisture barrier in the peeled produces in the form of a thin layer of partly dry skin after some time. Its effect is visible in the estimated temperatures plotted in Fig. 3. The experimental values shown in Fig. 3 are those for peeled off sample. These are found to match perfectly with the calculated temperature. When temperatures were calculated with thermal diffusivity values for unpeeled sample, similar agreement was observed between the experimental and estimated temperatures. For lack of clarity, the measured temperatures for unpeeled sample are not included. It may not be misconstrued that measured thermal diffusivity for peeled sample should give correct calculations for unpeeled sample as well.

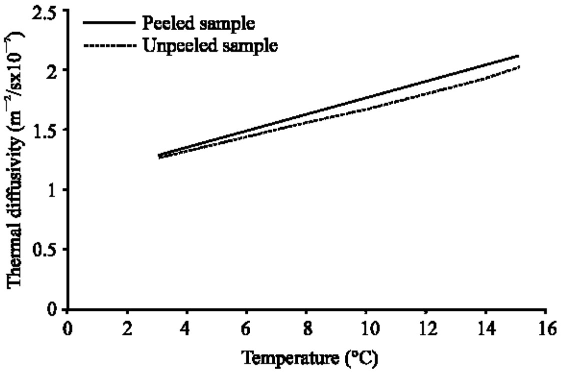

Fig. 2: Thermal diffusivity variations with temperature for a potato sample

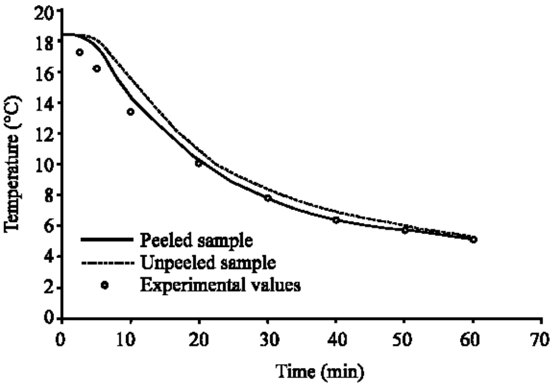

Fig. 3: Calculated and measured temperatures at the center of the potato sample

CONCLUSIONS

Investigations in the present research reveal that skin in fruits and vegetables plays an important role in retention of water in the produce, loss of weight and preservation of natural texture. Removal of natural skin increases the rate of desiccation, which in turn enhances the cooling rate of the produce. After a short time a partly dry layer is formed on the surface of the peeled produces, which works somewhat as the natural skin in retaining the moisture. This made the thermal diffusivity of the peeled sample almost equal to that of the unpeeled sample at the end of cooling. The thermal diffusivity variations obtained by the present empirical approach, when incorporated in the computational scheme of temperature calculations, yield values, which agree very well with the experimental temperatures.

Nomenclature

Bi	Biot number $= \frac{h.r_0}{k}$ (dimensionless)
c	Specific heat (J/kg.K)
h	Surface film conductance (W/m^2 .K)
k	Thermal conductivity of product (W/m.K)
n	Number of equal divisions of radius
Nu	Nusselt number $= \frac{h.r_0}{k_{air}}$ (dimensionless)
Pr	Prandtl number $= \frac{\mu_{air}.c_{air}}{k_{air}}$ (dimensionless)
Re	Reynolds number $= \frac{\rho_{air}.v_{air}.r_0}{\mu_{air}}$ (dimensionless)
t	Time (s)
t_0	Initial time (s)
T	Temperature (°C)
U	Dimensionless temperature $= \frac{T - T_{cm}}{T_1 - T_{cm}}$
v	Velocity (m/s)
r	Distance from center (m)
r_o	Radius of sphere (m)
R	Dimensionless space co-ordinate = r/r_o
Δt	Time increment (s)
Δr	Space increment (m)

Greek Letters

α	Thermal diffusivity of sample (m^2/s)
ρ	Mass density (kg/m^3)
τ	Fourier number (dimensionless)

Subscripts

cm	Cooling medium
i	Space step
j	Time step
1	Initial

REFERENCES

Abbas, K.A., 2005. Thermal diffusivity and quality deterioration of Malaysian Pangasius Suchi during cold storage. Ph.D. Thesis, UPM, Serdang, Selangor, Malaysia.

Ansari, F.A., V. Charan, H.K. Varma, 1984. Heat and mass transfer analysis in air- cooling of spherical food products. Int. J. Refrig., 7: 194-197.

Ansari, F.A., 1986. An empirical method of measuring thermal diffusivity and surface film conductance. J. ASAE Tr., 29: 1492-1497.

Ansari, F.A. and A. Afaq, 1986. New method of measuring thermal diffusivity of spherical produce. Int. J. Refrig., 9: 158-160.

Ansari, F.A., A. Mughis and A. Mukhtar, 1987. Measurement of thermophysical properties of mashed potato. Lebensm.-Wiss. U.-Technol. Switzerland, 20: 267-270.

Dicer, I., 2001. Heat transfer models for practical cooling applications, I. J. Trans. Phenomena, 3: 283-290.

Gaffney, J.J. and C.D. Baird and W.D. Eshleman, 1980. Review and analysis of the transient method for determining thermal diffusivity of fruits and vegetables. ASHRAE Trans., 86: 261-280.

Mukhtar, A.S., K.A. Abbas and S.M. Sapuan, 2006. Thermal diffusivity variation study of cold stored Malaysian Pangasius Suchi at 10°C, I. J. Food Properties, 9: 1-9.

Ozisik, M.N., 1980. Boundary Value Problems in Heat Conduction. Int. Text Book Co., pp: 419.

Sapuan, S.M., A.S. Mukhtar, K.A. Abbas, B. Jamilah, A.O. Ashraf, M.M.M. Ahmad, M.A. Wan and F. Abbas, 2003. Comparative study in thermal diffusivity measurement methods suitability of Malaysian pangasius Suchi. J. Energy Heat and Mass Transfer, 25: 217-230.