การทำนายอุณหภูมิภายในผลมะม่วงโดยใช้คุณสมบัติทางความร้อน

Modeling of Internal Temperature in Mango fruit by Thermal Properties

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ABSTRACT

Thermal treatments have been extensively studied to control frit flies infruit to rplace chemicalfumigation and prolong shelf life. An inherent difficulty in using them methods is that slow heating rates mayresult in long treatment times and possible damage to fruit quality. The aimof this study is to predict the internal temperature of heat treated mango cv. Nam Dok Mai See Thong by thermal properties and finite difference. The basic heat transfer equation was developed under the following assumption; the fruit was in cylindrical shape, its thermal properties were constant, and the heat transfer occurred only in radial direction. The root mean square errors were 1.65°C at 13.0 ± 0.5°C and 0.88°C at 48.0 ± 0.5°C.

Key word: thermal properties, modeling, mango

บทคัดย่อ

กระบวนการทางความร้อนถูกนำมาใช้เพื่อควบคุมแมลงแทนการใช้สารเคมี และเพื่อยืดอายุการเก็บรักษาผลิตผล ความยุ่งยากของกระบวนการนี้คือการใช้ระยะเวลาที่ยาวนาน ซึ่งอาจจะทำลายคุณภาพของผลไม้ได้ วัตถุประสงค์ของงานวิจัย คือ ทำนายอุณหภูมิภายในผลมะม่วงพันธุ์น้ำดอกไม้สีทองที่ผ่านกระบวนการทางความร้อนโดยใช้คุณสมบัติทางความร้อนและระเบียบวิธีเชิงตัวเลข ในการพัฒนาแบบจำลองนี้ กำหนดให้ผลมะม่วงมีรูปร่างเป็นทรงกระบอก สมบัติทางความร้อนมีค่าคงที่ การถ่ายเทความร้อนเกิดในแนวรัศมีเท่านั้น พบว่าการอุณหภูมิที่ได้จากการทำนายโดยใช้สมบัติทางความร้อนของผลมะม่วงน้ำดอกไม้สีทองที่ 25°C ความแตกต่างของอุณหภูมิโดยเฉลี่ยเป็น 1.65 และ 0.88 เมื่อเก็บในตู้ควบคุมอุณหภูมิที่ 13±0.5°C และเมื่อจุ่มในอ่างน้ำร้อนควบคุมอุณหภูมิที่ 48.0±0.5°C ตามลำดับ

คำสำคัญ: คุณสมบัติทางความร้อน, มะม่วง, แบบจำลอง

Introduction

Heat treatments, either hot water treatment (HWT) or vapor heat treatment (VHT), have been used extensively for postharvest disinfection and disinfestation for perishables produces as an alternative quarantine technology to chemical fumigation. Heat treatments are considered as clean technology, since they do not pose chemical residues problem and are more accepted to consumer than chemical treatment. HWT have been approved as a quarantine treatment by the USDA and Animal and Plant Health Inspection Service (APHIS) against pests, mainly fruit flies, for several perishable commodities, the mandated prohibit 9 level of flies control can be achieved by heating the core of the fruit to 43°C - 46.7°C with exposure times vary from 35 to 90 minutes (U.S. Environmental Protection Agency, 2004). In Philippines, HWT is accepted as an effective quarantine procedure in preventing anthracnose and stem-end rot on harvested mangoes (Aveno and Orden, 2004). The temperature and duration depend upon both cultivar and commodity and must be very precise to kill pests without damaging the commodity. In engineering practice, it is necessary to design the HWT plant as well as to control the process properly, to avoid a tedious and costly try-and-error experiment, we can predict the temperature history of any commodity by following the heat transfer theory. It is the objective of this study to predict the time when the core of mango fruit reached 46.5°C using the thermal properties of the fruit.

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Material and Methods

Raw materials

Exported graded mangoes cv. Nam Dok Mai See Thong were obtained from an orchard in Chachoengsao province were used in this experiment. Fruits were selected by uniformity of shape, color and size. The blemished or infected fruits were discarded.

Thermal properties

2.2.1) Specific heat, C_p, and Thermal conductivity, k, of the fruit was determined at 25.0°C by Modulated Differential Scanning Calorimeter (MDSC, Q100, TA Instrument, Texas, USA) followed the method of ASTM E 1952-98 (ASTM, 1998).

2.2.2) Density, ρ, was measured by liquid displacement method (Mohsenin, 1986).

2.2.3) Thermal diffusivity, α, was calculated by the relation;

$$\alpha = \frac{k}{\rho C_p} \qquad (1)$$

Heat transfer model

By assuming that a mango fruit was in cylindrical shape, whose diameter measured from the widest part of the fruit, the internal temperature of the fruit depended on the time and location, the following partial differential equation is a governing equation;

$$\rho C_p \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) \qquad (2)$$

And the rate of heat transfer at the surface of the fruit is due to convection, then

$$-k\left(\frac{\partial T}{\partial r}\right) = h\left(T_{a,t} - T_{s,t}\right) \qquad (3)$$

where T = Temperature, °C

T_a = Temperature of heating/cooling medium, °C

T_s = Temperature at the surface of the fruit, °C

r = distance from center point, m

h = heat transfer coefficient of heating/cooling medium, $W/m^2 \cdot {}^{\circ}C$

The numerical solution of eq.(2) can be obtained by finite difference method. The fruit was divided by 5 equally space planes labeled m = 0, 1, 2, 3, 4, and 5 as shown in Fig. 1. The distance between plane 0 and plane 1 equaled to the half of the thickness of the seed.

Measurement of temperature

The thermocouples were securely placed at location m=1, m=3, and m=5, and the fruit was placed in a stainless steel basket before immersing into a water bath (Heto, Denmark), controlled at 48.0±0.5°C. The temperature at 3 positions in the fruit as well as that of the heating medium were recorded every 1 minute by a time–temperature recorder (CMC 821, Ellab, Denmark), until the temperature at location m=1 reached 46.5°C and held further 10 minutes at this temperature. The same procedure was set up for cooling experiment where the temperature of the incubator (SANYO, MIR-553, Japan) was held at 13.0±0.5°C, the experiment was ended when the temperature at the same location reached 13.0°C.

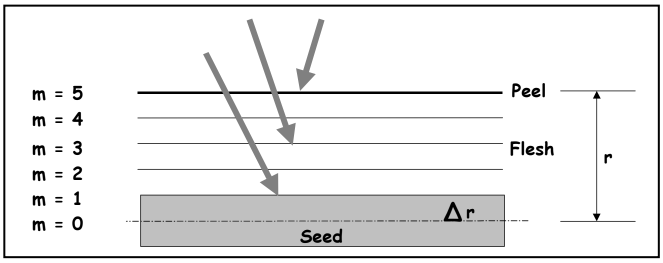

Figure 1 Temperature measurement locations

Results and discussions

The thermal properties of the mango fruit

The thermal properties of the mango fruit were shown in the Table 1. The thermal conductivity of this study was slightly lower than that of the others (Varith and Kiatsiriroat, 2004; Chowdary, 1988). This might be resulted from the procedure we used in the determination, where the sample lost some moisture content in the DSC chamber.

Prediction of internal temperature

The temperature history of the mango fruit were relatively well predicted by the numerical finite difference method as shown in Fig. 2A for the core (m=1), and Fig 2B plane m=3 for the halfway between the core and peel when the fruit was subjected to HWT at 48.0±0.5°C, the Root Mean Square Error (RMSE) were 0.88°C and 0.55 °C respectively. Also shown in Fig. 3 (A and B) for the respective location when the fruit was kept in the incubator held at 13.0±0.5°C, the RMSE were 1.65°C and 1.64°C respectively. The deviation of temperature from the simulated model occured only in the first half of heating/cooling time, when the difference of temperature between the heating/cooling medium and the fruit was high.

Table 1 Thermal properties of mango fruit cv. Nam Dok Mai See Thong

Thermal properties	Peel	Flesh
(C°kg/kJ) Cp	2.910 -2.622	3.571 -3.185
(C°m/W) k	0.329-0.312	0.371- 0.337
(^{3}m/kg) density	1036.0949	1085.3833
(s/^{2}m)Thermal diffusivity	7-10x 1.21-1.15	7-10x 1.02-1.00

Conclusion

From the results obtained, it could be concluded that the unsteady state heat transfer model could be used to predict the internal temperature history of the fruit relatively well either in the heating or cooling process.

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A B

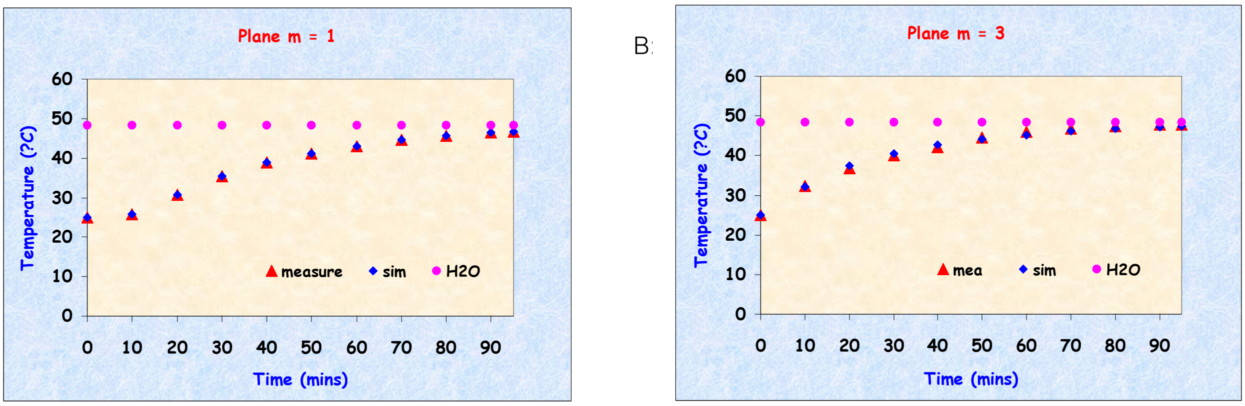

Figure 2 Temperature distribution at the core (m=1) and plane m=3 for heating process.

A B

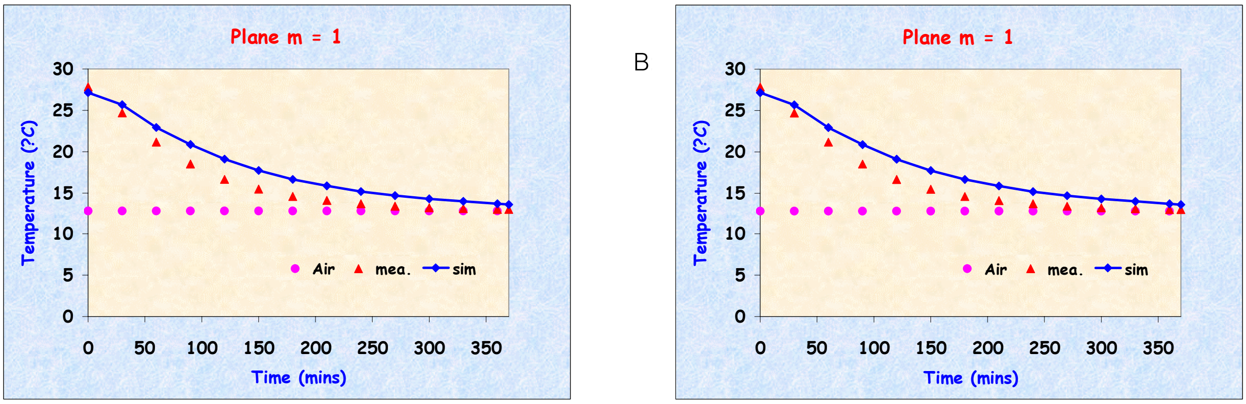

Figure 3 Temperature distribution at the core (m=1) and plane m=3 for cooling process.

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