PDF4480075 ผศ.ดร. พิมพ์เพ็ญ พรเฉลิมพงศ์

รายงานวิจัยฉบับสมบูรณ์

การพัฒนาและทดสอบความถูกต้องของโปรแกรมคอมพิวเตอร์เพื่อประเมินคุณภาพอาหารประเภทบรรจุแน่นหลังแปรรูปด้วยความร้อน

โดย ผศ.ดร. พิมพ์เพ็ญ พรเฉลิมพงศ์

กันยายน 2546

สัญญาเลขที่ PDF/75/2544

รายงานวิจัยฉบับสมบูรณ์

โครงการการพัฒนาและทดสอบความถูกต้องของโปรแกรมคอมพิวเตอร์เพื่อประเมินคุณภาพอาหารประเภทบรรจุแน่นหลังแปรรูปด้วยความร้อน

ผู้วิจัย

ผศ.ดร. พิมพ์เพ็ญ พรเฉลิมพงศ์

สังกัดภาควิชาวิศวกรรมอาหาร คณะวิศวกรรมศาสตร์

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

(ความเห็นในรายงานนี้เป็นของผู้วิจัย สกว. ไม่จำเป็นต้องเห็นด้วยเสมอไป)

Executive Summary

The research title "Development and Validation of Computer Simulation Program for Quality Retention of Conduction Heating Food after Processing" was divided into three main sections; Part 1 was a study on kinetics of thermal degradation of sensory qualities in canned tuna; Part 2 was to develop the computer program using finite difference method for evaluate qualities retention of conduction heating food after thermal processing and to use of the developed computer model for optimizing some quality retention. Part 3 was to conduct experimental validation to investigate effect of processing condition including level of Fo on qualities of tuna after thermal processing. The published paper for each part was attached.

การพัฒนาและทดสอบความถูกต้องของโปรแกรมคอมพิวเตอร์ เพื่อประเมินคุณภาพอาหารประเภทบรรจุแน่นหลังแปรรูปด้วยความร้อน

Development and Validation of Computer Simulation Program for Quality Retention of Conduction Heating Food After Thermal Processing

ความสำคัญของปัญหา

การแปรรูปอาหารด้วยความร้อนบรรจุในภาชนะที่ปิดสนิท เช่น กระป๋อง ขวดแก้ว หรือภาชนะอ่อนตัวรูปทรงต่าง ๆ เป็นกระบวนการแปรรูปอาหารที่สำคัญและได้รับความนิยมมากในระดับอุตสาหกรรม วัตถุประสงค์หลักของการใช้ความร้อน เพื่อทำลายจุลินทรีย์และที่เป็นสาเหตุของอาหารเน่าเสีย และเป็นอันตรายต่อสุขภาพของผู้บริโภค อาหารประเภทนี้จะสามารถเก็บได้นานที่อุณหภูมิห้อง มีความหลากหลายของผลิตภัณฑ์และปลอดภัยต่อการบริโภค แต่ข้อเสียที่หลีกเลี่ยงไม่ได้ เมื่ออาหารได้รับความร้อนคือ การลดลงของคุณภาพด้านต่าง ๆ ได้แก่ คุณค่าทางโภชนาการ สี กลิ่นรส เนื้อสัมผัส และคุณภาพอื่น ๆ ที่มีผลต่อการยอมรับของผลิตภัณฑ์อาหาร ดังนั้นการเลือกอุณหภูมิและเวลาที่ เหมาะสม จึงเป็นสิ่งสำคัญอย่างยิ่งที่ผู้ผลิตต้องคำนึงถึง

การใช้อุณหภูมิสูง เวลาสั้น (High Temperature Short Time , HTST) เพื่อการฆ่าเชื้ออาหารใช้ได้ผลดีในการรักษาคุณภาพของอาหารเหลว เช่น นม น้ำผลไม้ กะทิ ที่มีการถ่ายเทความร้อนแบบพาความร้อนซึ่งทุกส่วนของอาหารมีการเคลื่อนที่ผสมกันตลอดการให้ความร้อน ทำให้อาหารมีอุณหภูมิสม่ำเสมอ แต่การฆ่าเชื้อโดยวิธี HTST ไม่สามารถใช้เพื่อรักษาคุณภาพของอาหารที่มีการถ่ายเทความร้อนแบบนำความร้อน เช่น ปลาทูน่า อาหารสัตว์ ผักผลไม้หรือเนื้อสัตว์ที่บรรจุแบบอัดแน่น ซึ่งเนื้ออาหารไม่มีการเคลื่อนไหวหรือเคลื่อนไหวน้อยมากระหว่างการให้ความร้อน การใช้อุณหภูมิสูงเกินไป อาจทำให้อาหารบริเวณผิวนอกของภาชนะไหม้ก่อนที่ภายในจะได้รับความร้อนเพียงพอในการทำลายจุลินทรีย์ การใช้อุณหภูมิต่ำเกินไป อาจมีผลให้คุณภาพอาหารบางชนิด ถูกทำลายจนผู้บริโภคไม่สามารถยอมรับได้ เช่น เนื้อนิ่มเละ หรือสีคล้ำ และยังสิ้นเปลืองพลังงานมาก สภาวะที่เหมาะสมในการแปรรูปผลิตภัณฑ์อาหารประเภทนี้ ขึ้นอยู่กับปัจจัยหลายประการ เช่น คุณสมบัติทางความร้อนของเนื้ออาหารเองซึ่งมีผลต่อความเร็วในการแพร่ความร้อนเข้าสู่เนื้ออาหาร ความทนทานต่อความร้อนของปัจจัยคุณภาพของอาหาร ตลอดจนรูปทรงและชนิดของภาชนะที่บรรจุ ซึ่งยากต่อการตัดสินใจของผู้ผลิตที่จะเลือกสภาวะที่เหมาะสมเพื่อคงคุณภาพของอาหารหลังจากการแปรรูป การลองผิดลองถูกต้องใช้เวลามากและสิ้นเปลืองค่าใช้จ่าย

โปรแกรมคอมพิวเตอร์ที่สามารถทำนายอุณหภูมิภายในของอาหารประเภทบรรจุแน่นระหว่างการแปรรูป ได้รับการพัฒนาและนิยมอย่างแพร่หลายในการคำนวณหาเวลาในการฆ่าเชื้อด้วยความร้อน มีการประยุกต์ใช้โปรแกรมดังกล่าวควบคู่กับจลนศาสตร์การเสื่อมลงของคุณภาพด้านต่างของอาหารระหว่างให้ความร้อน เพื่อทำนายคุณภาพที่เหลือหลังจากการให้ความร้อนและใช้ตัดสินใจเลือกสภาวะที่เหมาะสมในกระบวนการ แต่เป็นโปรแกรมที่พัฒนาเพื่องานวิจัยไม่เหมาะสมกับการใช้งานจริงและการทดลองเพื่อทดสอบความถูกต้องในการใช้งานโปรแกรมคอมพิวเตอร์ดังกล่าวมีน้อยมากประกอบกับค่าจลนศาสตร์ที่ใช้ก็เป็นค่ามักที่อ้างอิงจากเอกสาร ซึ่งอาจไม่เป็นตัวแทนที่แท้จริงของคุณภาพอาหารที่ใช้

วัตถุประสงค์

1. ทดลองหาค่าจลนศาสตร์ ของการเปลี่ยนแปลงคุณภาพอาหารด้วยความร้อน (ค่า D และ Z)
2. พัฒนาโปรแกรมคอมพิวเตอร์เพื่อทำนายคุณภาพของอาหารหลังการฆ่าเชื้อ
3. นำค่าจลนศาสตร์ที่ได้จากการทดลองมาใช้ร่วมกับโปรแกรมคอมพิวเตอร์เพื่อทำนายคุณภาพของอาหารหลังการฆ่าเชื้อในสภาวะแปรรูปต่าง ๆ และเปรียบเทียบผลกับคุณภาพอาหารที่ทดสอบได้หลังขบวนการผลิตจริง

ขั้นตอนและผลการวิจัย

เพื่อให้การวิจัยบรรลุวัตถุประสงค์ ได้ดำเนินการโดยแบ่งออกเป็น 3 ขั้นตอนหลักดังนี้

<u>ตอนที่1</u> การคัดเลือกชนิดของอาหารและปัจจัยคุณภาพของอาหารดังกล่าวที่มีผลต่อการยอมรับของผู้บริโภค และหาค่าจนลศาสตร์การเปลี่ยนแปลงคุณภาพเนื่องจากความร้อน ของปัจจัยคุณภาพอาหารนั้น

ได้เลือกปลาทูน่าสายพันธุ์ Longtail เพื่อศึกษาจนลศาสตร์(ค่า D และค่า Z)การเปลี่ยนแปลงของคุณภาพ ทางประสาทสัมผัส ได้แก่ สี กลิ่นปลา กลิ่นสุก และความแข็ง ที่อุณหภูมิ 90 100 110 และ 120

<u>หมายเหตุ</u> รายละเอียดของวิธีการและผลการศึกษาได้แสดงไว้ในภาคผนวก (เอกสารแนบหมายเลข 1)

Pornchaloempong, P., Narkrugsa. W.. Chrdareekit K.. Piyaaphantawong K.. and Peerajit S. 2002. Proceeding of the International Conference on Innovations in Food Processing Technology and Engineering. 11-13 December 2002. AIT. Bangkok. Thailand.

ตอนที่2 **พัฒนาโปรแกรมคอมพิวเตอร์เพื่อทำนายคุณภาพอาหารหลังการให้ความร้อน**

พัฒนาโปรแกรมคอมพิวเตอร์เพื่อทำนายอุณหภูมิของเนื้ออาหารที่มีการถ่ายเทความร้อนแบบการนำ ด้วยวิธี Finite difference โดยใช้หลักการของสมดุลพลังงานของวัตถุหลังจากแบ่งเป็นชิ้นเล็ก ๆ กำหนดตำแหน่งของจุดอ้างอิงอุณหภูมิที่อยู่บริเวณผิวของภาชนะจะเป็นชนิดไม่มีมวลความร้อน (Non capacitance surface nodes) ส่วนตำแหน่งภายในภาชนะจะเป็นชนิดที่มีมวล (Capacitance nodes) แล้วเขียนสมการสมดุลพลังงานในทุกชิ้นย่อยของวัสดุและแก้สมการหาการเปลี่ยนแปลงอุณหภูมิภายใน ณ ตำแหน่งต่าง ๆ อย่างต่อเนื่องตลอดเวลาของขบวนการให้ความร้อน

โปรแกรมคอมพิวเตอร์ถูกพัฒนาบน Microsoft Visual Basic เพื่อสะดวกต่อการใช้งาน ผู้ใช้เพียงกำหนด ชนิดของอาหาร คุณสมบัติทางความร้อนของอาหาร สภาวะที่ใช้ในการฆ่าเชื้อ (เช่นอุณหภูมิชนิดของตัวกลางความร้อนที่ใช้ ขนาดและรูปร่างของภาชนะที่บรรจุเป็นต้น) ค่า D และ ค่า Z ของปัจจัยคุณภาพอาหารที่สนใจศึกษาและกำหนดค่า F_o โปรแกรมจะคำนวณหาเวลาในการฆ่าเชื้อเพื่อให้ได้ค่า F_o ที่ต้องการและประเมินค่าคุณภาพโดยรวมของอาหารที่เหลือจากการให้ความร้อนด้วยการอินทริเกรดผลรวมของคุณภาพภายในปริมาตรแต่ละชิ้นย่อยจากสมการ

$$\left(\frac{N}{N_0}\right)_{\text{โดยรวม}} = \frac{1}{V}\int_0^V 10^{-\frac{1}{D_{ref}}\int_0^t 10^{\frac{T-T_{ref}}{z}}dt}\,dV \qquad \text{----------- 1}$$

โดยที่ N ค่าปริมาณปัจจัยคุณภาพของอาหารหลังให้ความร้อน ณ. เวลาใด ๆ

N_0 ค่าปริมาณปัจจัยคุณภาพอาหารเริ่มต้น

V ปริมาตรรวมของภาชนะบรรจุ (m^3)

D_{ref} ค่าที่ที่อุณหภูมิอ้างอิงของคุณภาพอาหาร (นาที)

t เวลา (นาที)

T_{ref} อุณหภูมิอ้างอิง (°C)

Z ค่า Z ของคุณภาพอาหาร (°C)

ซึ่งค่า F_0 เป็นการอินทริเกรดผลรวมของ F_o ในตลอดระยะเวลาการฆ่าเชื้อสามารถคำนวณได้จากสมการ

$$F_o = \int_0^t 10^{\frac{T-T_{ref}}{z}}dt \qquad \text{--------------- 2}$$

ค่า Z สมการที่ 2 นี้เป็นค่า Z ของเชื้อ Clostridium botulinum = 10°C

หมายเหตุ รายละเอียดของวิธีการและผลการศึกษาได้แสดงไว้ในภาคผนวก (เอกสารแนบหมายเลข 2และ3) ส่วนหนึ่งของ Output หมายเลข 2 และ 3 เป็นผลงานระหว่างการศึกษาระดับปริญญาเอกของผู้วิจัยซึ่งได้นำมาศึกษาเพิ่มเติมและเรียบเรียงต้นฉบับเพื่อตีพิมพ์ระหว่างที่ดำเนินโครงการนี้

เอกสารแนบ หมายเลข 2

Pornchaloempong, P., Balaban, M.O., Chau, K.V., and Teixeira, A.A. 2003. Numerical simulation of conduction heaing in conically shaped bodies. Journal of food process engineering. Vol. 25 (6), 539-555. *

เอกสารแนบ หมายเลข 3

Pornchaloempong, P., Balaban, M.O., Chau, K.V., and Teixeira, A.A. 2003. Optimization of quality retention in conduction-heating foods of conical shape. Journal of food process engineering. Vol. 25 (6) 557-570. *

ตอนที่3 การทดลองเพื่อทดสอบความถูกต้องของโปรแกรม

การทดลองเพื่อทดสอบความถูกต้องของโปรแกรมได้ใช้ปลาทูน่าสายพันธุ์ Albacore เพื่อศึกษาผลของความร้อนที่อุณหภูมิการฆ่าเชื้อ 112 117 122 °C ที่ระดับ F_0 = 4 และ 8.5 และตรวจวิเคราะห์คุณภาพหลังการฆ่าเชื้อ

หมายเหตุ การทดลองนี้ได้รับความอนุเคราะห์วัตถุดิบและสถานที่ ตลอดจนการตรวจวิเคราะห์จากบริษัทไทยรวมสินจำกัด อ.เมือง จ.สมุทรสาคร โดยแบบเสนอโครงงานที่ทำร่วมกับบริษัทได้แสดงไว้ในภาคผนวก(เอกสารแนบหมายเลข4) และผลการดำเนินงานได้แสดงไว้ในภาคผนวก (เอกสารแนบหมายเลข5)

Pornchaloempong, P., Narkrugsa, W., Balaban, M.O., Prinyawiwatkul, W. Effect of Processing Temperature on Color and Yield of Albacore Tuna. (Manuscript).

Output ที่ได้จากโครงการ

1. **Pornchaloempong, P.**, Narkrugsa. W., Chrdareekit K., Piyaaphantawong K., and Peerajit S. 2002. Proceeding of the International Conference on Innovations in Food Processing Technology and Engineering. 11-13 December 2002. AIT. Bangkok. Thailand.

2. **Pornchaloempong, P.**, Balaban. M.O., Chau. K.V., and Teixeira. A.A. 2003. Optimization of quality retention in conduction-heating foods of conical shape. Journal of food process engineering. Vol. 25 (6) 557-570. *

3. **Pornchaloempong, P.**, Balaban. M.O., Chau. K.V., and Teixeira. A.A. 2003. Numerical simulation of conduction heaing in conically shaped bodies. Journal of food process engineering. Vol. 25 (6).539-555. *

4. **Pornchaloempong, P.**, Narkrugsa. W., Balaban. M.O., Prinyawiwatkul. W. Effect of Processing Temperature on Color and Yield of Albacore Tuna. (Manuscript)

*** หมายเหตุ ส่วนหนึ่งของ Output หมายเลข 2 และ 3 เป็นผลงานระหว่างการศึกษาระดับปริญญาเอกของผู้วิจัยซึ่งได้นำมาศึกษาเพิ่มเติมและเรียบเรียงต้นฉบับเพื่อตีพิมพ์ระหว่างที่ดำเนินโครงการนี้**

ภาคผนวก

เอกสารแนบหมายเลข 1

Proceedings of the International Conference

INNOVATIONS IN FOOD PROCESSING TECHNOLOGY AND ENGINEERING

11-13 December 2002

Edited by
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Proceedings of the International Conference on Innovations in Food Processing Technology and Engineering, 11-13 December 2002, AIT, Bangkok, Thailand

OPTIMIZATION OF SENSORY QUALITYIN CANNED TUNA

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ABSTRACT

This research was to study effect of heat (from 90 to 120°C) on sensory qualities (color, fish flavor, cooked flavor, and hardness) of Longtail tuna using trained panels. The changes of color, fish flavor and cooked flavor have a first order reaction rate and kinetic parameters, Z value, were found to be 29.07, 17.06 and 31.31 °C respectively. The experimental kinetic parameters of each sensory attribute were used in the simulation for volume average sensory quality of canned tuna after thermally processed at retort temperature of 90 to 120 °C. The effects of Fo and can size were also investigated. The optimum retort temperature range for maximizing average sensory quality was estimated between 100 to 110 °C. Increasing can size decreased optimum retort temperature while Fo had minor influence on the optimum retort temperature.

Keywords. Canned tuna, thermal processing, sensory, optimization

INTRODUCTION

Canning of food results in an extended shelf-life but affects sensory quality of the product. One of the challenges to food canning industry is to guarantee commercial sterility and ensure a desirable product quality (Lund, 1977). Canned tuna is the major seafood product produced in Thailand. Because the fish is packed tightly in a can, the high temperature short time (HTST) process is not always benefit to the product quality (Teixeira et.al., 1969; Lund, 1977; Silva et.al., 1992). Very high processing temperatures will cause severe quality degradation near the can wall long before the food at the center of the can has raised in temperature. A relatively low processing temperature will also cause great quality loss because of the long time necessary to achieve sterility. Tools to optimize quality in this type of food are a numerical model to predict temperature distribution in a container, together with kinetics of thermal destruction of target organisms and quality attributes (Holdsworth, 1985).

Sensory qualities including appearance, flavor and texture are the most important characteristics of canned tuna because they are attributes that the consumer can readily access. Few researches had been worked on kinetics of thermal degradation of sensory quality determined by trained panel (Hayakawa and Timbers, 1977; Ohlsson, 1980 and Loey et.al., 1995). However, kinetics of thermal degradation of sensory in tuna has never been investigated.

The objectives of this study were to determine the kinetic parameters (D and Z values) of sensory qualities (color, cooked flavor, fish flavor and texture) of tuna using trained taste panels within the temperature range of 90-120 °C and to apply the experimental kinetic parameters together with the heat transfer models for conduction heat transfer in a cylindrical container for calculating volume average quality retention under various process conditions, with the goal of quality optimization.

MATERIALS AND METHODS

Preparation of steamed tuna

Frozen Longtail tuna obtained from the local fish canning company was transported to our laboratory in insulated tanks. Upon arrival, they were beheaded, cut into 5 inches piece (portion 1- 4 in Figure 1) and stored at -18 °C until treatment. Before the processing, the frozen fishes were thawed under running tap water until backbone temperature of 1-5 °C and eviscerated. They were streamed to a final backbone temperature of 65 °C. Then skin, dark meat and bone were removed. The white meat was flaked and mixed to ensure an equal composite sample.

Thermal treatment

Flaked tuna was packed tightly in a small can (NO 211 × 109). Each can contained 100 g of fish and was filled with 15g of distilled water. The use of small cans reduced temperature gradient so that the difference in temperature at the surface and in the center of the cans was minimal and steady state was assumed.

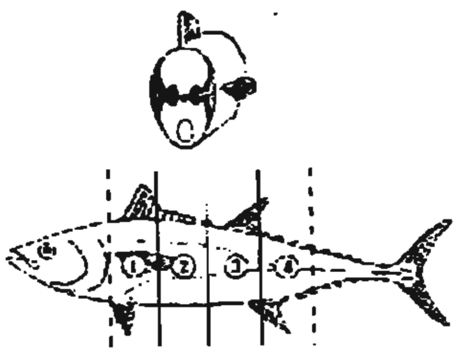

Figure 1. Portion of tuna (only white meat) used in the experiment

The cans were exhausted until can center temperature reached 85 °C to reduce lag periods for come-up heating and cooling times. Then they were hermetically sealed and heated in a temperature controlled oil bath. Predetermined time-temperature combinations used for the heat treatments were shown in table 1. After heating, the cans were cooled in the ice bath (0-2 °C) to stop heating process.

Table 1. Time and temperature combinations for heating canned tuna

Temperature (°C)	Heating Time (min.)				
90		120	240	360	480
100	0	90	180	270	360
110	0	60	120	180	240
120	0	30	60	90	120
	0				

Sensory evaluation

Prior to evaluation, cans that had the same heat treatment were mixed to obtain homogeneous samples. Samples were evaluated by 10 selected and trained panels that had experience in 20 training sessions. The quality attributes were color, cooked flavor, fish flavor, and hardness. Sensory evaluation was

$$F_0 = \int_0^t 10^{\frac{T-121.1}{Z}} dt$$

Where Z is Z value of target microorganism (10 °C)

The simulation performed using the value for thermal diffusivity of 1.42×10^{-7} m^2/s. The target F_o was the accumulated F_o contributed during both heating and cooling. A uniform initial temperature of 50 °C, and different constant retort temperatures ranging from 90 to 120°C at 5°C intervals were used. After heating at the specified temperature, the can was then cooled at a constant cooling temperature of 25°C until the center temperature was less than or equal to 50 °C.

The experimental values of kinetic parameters ($D_{121.1}$ and Z) and other process variables including can size and target F_o were investigated for their effect on sensory quality.

RESULTS AND DISCUSSION

With increasing of heating time, the fish meat was darker and tougher, fish flavor decreased while cooked flavor increased. This corresponds to increases of color, cooked flavor and hardness score and decreases of fish flavor score. The sample plot of common logarithms of average score values of fish flavor versus heating time at different heating temperatures was demonstrated in figure 2. From the slopes of the straight lines obtained by linear regression analysis, the decimal reduction time (D) of sensory qualities at different heating temperatures were calculated and shown in Table 2. The kinetic models of the thermal degradation for color, fish flavor and cooked flavor except for hardness of the tuna were assumed to be first-order since the straight lines had high coefficients of correlation ($r > 0.8$). Z values, representing the temperature change necessary to change the rate of the D value one order of magnitude, for color, fish flavor, cooked flavor were estimated to be 29.07, 17.06 and 31.31° C respectively. The coefficients of correlation of the linear regressions were above 0.9 (Table 2). Our determined Z values close to the values of 26-28°C for sensory quality of fish pudding estimated by Ohlsson (1980).

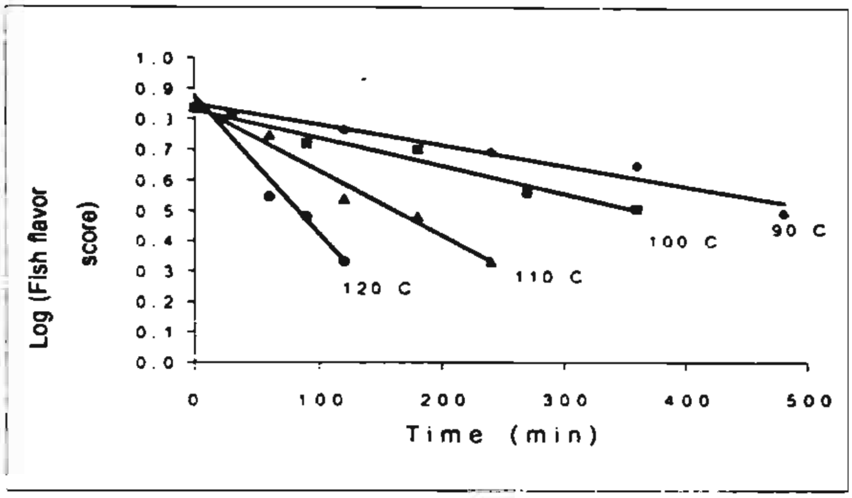

Figure 2 Plot of common logarithms of average score values for fish flavor versus heating time at different heating temperatures

Table 2 Kinetic parameters and coefficients of correlation for thermal degradation of tuna sensory quality evaluated by trained panels

Temperature	Color		Hardness		Fish Flavor		Cooked Flavor	
	D		D		D		D	
(°C)	(min)	r	(min)	r	(min)	r	(min)	r
90	1111.11	0.81	2000.00	0.32	14285.71	0.95	2500.00	0.84
100	1111.11	0.83	2500.00	0.71	1000.00	0.96	909.09	0.90
110	270.11	0.90	714.29	0.61	476.19	0.97	588.24	0.93
120	126.58	0.91	303.03	0.69	204.08	0.96	250.00	0.83
Z (°C)	29.07		-		17.06		31.31	
r	0.90		-		0.90		0.98	

The estimated $D_{121.1}$ together with Z values for each sensory quality attributes were used in the simulations. The effect of retort temperature on change of volume average fish flavor, color and cooked flavor were presented in figure 3. These simulations performed for tuna packed in a 211 x 109 can to achieve target Fo of 8. The Z value for fish flavor (17.06°C) which is lower than the values for cooked flavor and color (31.31 and 29.07 °C) illustrated that fish flavor are more sensitive to changes in retort temperature (Teixeira et.al . 1969 and Silva et.al. 1992) and has a lower optimum retort temperature range. The optimum retort temperature range for maximizing the fish flavor was between 95-100°C. Deviation of retort temperature from the optimum temperature decreases fish flavor rapidly. The profile of the curve for cooked flavor and color are flatter compares to the profile for fish flavor indicated that increasing of color and cooked flavor are less sensitive to deviations from the optimum temperature. The temperature range for minimizing fish color was found between 100-110°C. Cooked flavor has a broadest optimum range. With this processing condition, change of retort temperature will not benefit in decreasing cooked flavor.

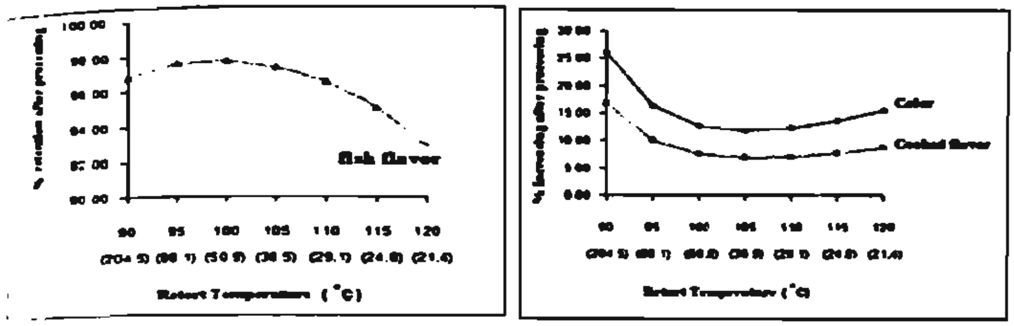

Figure 3. Volume average change of sensory qualities in canned tuna simulated for a can No211 x 109 to achieve a target Fo value of 8

The temperature range for optimum sensory quality was low and may not be a practical processing temperature because it required long processing time. However, it indicated that canned tuna processed at lower temperature range would results product that have better sensory quality.

Effect of can size on increasing of volume average cooked flavor was shown in figure 4. The simulations were performed for Fo = 8. The result showed that with increasing of can size, the tuna had more cooked flavor for any retort temperatures. This emphasizes the benefit of chosen small cans. The optimum processing temperature for minimizing cooked flavor moves toward lower temperature when can size is larger. In a larger can size, the cooked flavor increase rapidly when retort temperature move from optimum retort temperature.

Influence of Fo value on cooked flavor was shown in Figure 5. The simulation performed for tuna packed in a 211 x 109 can to achieve target Fo of 8. The result showed that for sterilization to higher Fo values has a minor effect on optimum retort temperature. Lower Fo value results lower cooked flavor for all retort temperatures.

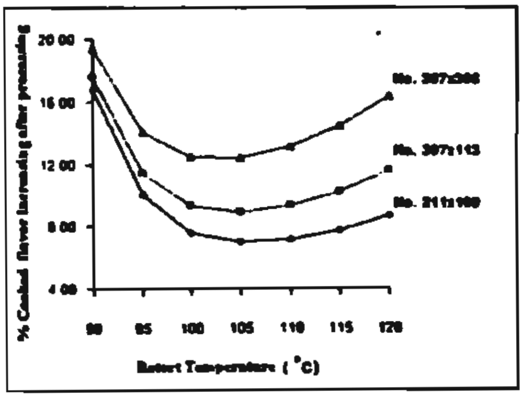

Figure 4. Effect of can size on increasing of volume average cooked flavor (%) in canned tuna processed at Fo value of 8

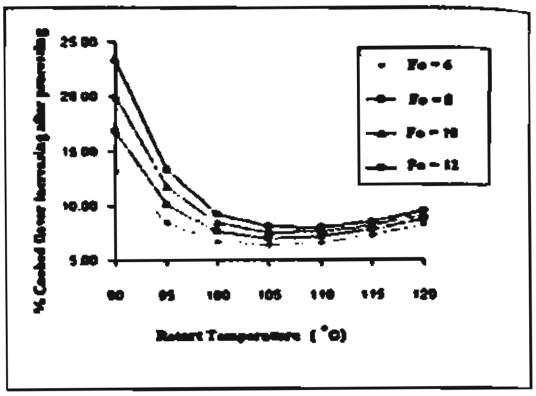

Figure 5. Effect of Fo on increasing of volume average cooked flavor (%) in canned tuna simulated for a can No211 x 109

CONCLUSIONS

The kinetics study for thermal degradation of sensory qualities of Longtail tuna at temperature between 90 and 120 C, showed that the sensory attributes; color, fish flavor and cooked flavor; followed a first order reaction. The temperature dependence of sensory quality deterioration, Z value, is in the range 17 –31 C.

The value of $D_{121.1}$ and Z value obtained from the experiment allows the estimation for optimum temperature range to achieve optimum sensory quality in canned tuna with different can size and Fo value.

ACKNOWLEDGEMENTS

Financial support provided by the Thailand Research Fund (TRF) are gratefully acknowledged

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JOURNAL OF FOOD PROCESS ENGINEERING

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VOLUME 25, NUMBER 6 BIMONTHLY

เอกสารแนบหมายเลข 2
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NUMERICAL SIMULATION OF CONDUCTION HEATING IN CONICALLY SHAPED BODIES[1]

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Accepted for Publication August 30, 2002

ABSTRACT

A 2-dimensional energy balance approach was used to model temperature distribution in conduction heated conically shaped bodies. A numerical solution by finite differences to the second order partial differential equation for heat conduction served as basis for the model. The cone was divided into small volume elements. The inner elements were concentric rings of rectangular cross section while those at the side surfaces had triangular cross-sections. Energy balance equations for the volume elements were solved explicitly. Acrylic of known thermal properties was used to fabricate cones in 3 different geometries and sizes, varying from a frustum to a point cone. Every cone had 3 or 4 thermocouples (36 gauge, T type) inserted at different locations. Heat penetration tests were carried out in a water bath with constant and variable water temperatures. Experimental temperatures at different locations within the cones agreed well with temperatures predicted by the model. Use of the model to predict the location of the slowest-heating point or "cold point" under different processing conditions was also demonstrated.

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Journal of Food Process Engineering 25 (2003) 539-555. *All Rights Reserved.*
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INTRODUCTION

The never ending quest for finding thermal process conditions that will maximize quality retention without compromise to food safety in canned foods has become an important objective in food engineering research. Mathematical heat transfer models capable of accurately predicting the nonuniform spacial temperature distribution within a solid body in response to constant or dynamic boundary conditions at the surface have become an important tool in process optimization for thermally processed foods. In the case of conduction heated canned foods, thermal degradation of quality retention is a function of the nonuniform temperature distribution within the container that continually changes over time. Accurate volume-average quality retention in response to a given process can be calculated mathematically by integration over space and time with the use of numerical solutions to the heat transfer equations appropriate for the specific container shape. The work reported here is the first of a 2-part study in which development and validation of a numerical heat transfer model specific to cone-shaped solid bodies was carried out and reported here as Part 1. Subsequent application of the model to address the extent to which optimum process conditions are affected by container shape is reported in a companion paper as Part 2 of the study (Pornchaloempong *et al.* 2003).

Modeling of conduction heating foods in cylindrical cans has been extensively reported in the literature (Teixeira *et al.* 1969; Ohlsson 1980; Nadkarni and Hatton 1985; Shin and Bhowmik 1990). The conical container is an alternative container shape used to pack various thermally processed foods. The conical shape could be varied from a pointed cone to almost a finite cylinder. There is little research reported in the literature on the numerical modeling of transient heat transfer involving the cone geometry. Chau and Snyder (1988) and Erdogdu (1996) used a finite difference model with the energy balance technique and noncapacitance surface nodes to predict temperature distribution in thermally processed shrimp. The shrimp shape was approximated by a short cylinder followed by a right circular cone. A stair step approach was used to approximate the radial boundary of the cone. The volume elements were a series of concentric rings stacked upon each other with each consecutive set containing one less node. Experiments measuring the center temperature in a shrimp during heating and cooling were conducted in a water bath. Measured temperatures compared well with model predicted temperatures. Sheen and Hayakawa (1991) applied a finite volume method to a curvilinear boundary to develop a model for conduction heated food in a bowl-shaped plastic container. An experimental validation was carried out in an autoclave using bentonite and apple sauce. They found satisfactory agreement between the model prediction and experimentally measured temperatures at two points within the bowl of bentonite solution. However, a heat transfer model of any conically shaped container could not be found in the literature.

The position of the cold point of food undergoing thermal processing is crucial for the calculation of a safe process. The cold point is the location of slowest heating within a food container, which receives the least accumulated process lethality (Fo). Therefore, process calculations must be based upon the temperature-time profile experienced at the cold point. Inaccuracy in locating the position of the cold point may result in under-processing. The cold point for conduction heated foods in novel-shaped containers such as pear, bowl or cone is not necessarily at the "geometric" center. Sheen and Hayakawa (1991) found that the cold point in a bowl-shaped container with curved boundary and a metal lid during heating in a circulated superheated water-type retort was located at a fraction of 0.46 of the height of the container from the bottom, on the rotation axis. The cold point moved slightly further toward the bottom during cooling with water because of the change in surface heat transfer coefficient.

The objective of this study was to develop a heat transfer model for conduction heat transfer in conically shaped containers capable of predicting internal temperatures at any location over time in response to constant or dynamic surface temperatures, and to experimentally validate the model by comparing temperature predicted by the model with those experimentally measured during heat penetration tests for various surface temperature conditions. Subsequent application of the model in process optimization for maximum quality retention is reported in a companion paper by Pornchaloempong *et al.* (2003).

MATERIALS AND METHODS

Development of Heat Transfer Model

A two dimensional finite difference model derived from an energy balance approach was developed to simulate conduction heat transfer in a cone frustum. The dimensions of the frustum were given by specifying: major radius (R), minor radius (r) and height (H). The cone frustum was subdivided into volume elements consisting of a series of concentric rings with rectangular cross sections (Fig. 1). The volume elements at the side surfaces were given triangular cross-sections. The number of volume elements increased by one for every successive layer along the longitudinal axis going from the minor towards the major radius. Because of axial symmetry, only one-half of the cone need be considered. Each volume element contained a node as a reference point, as shown in Fig. 2. The temperature at the node is the temperature at that location within the volume element. The number of nodes along the major radius in the R-r region was set equal to the number of nodes along the height. The number of nodes in the minor r region was set independently.

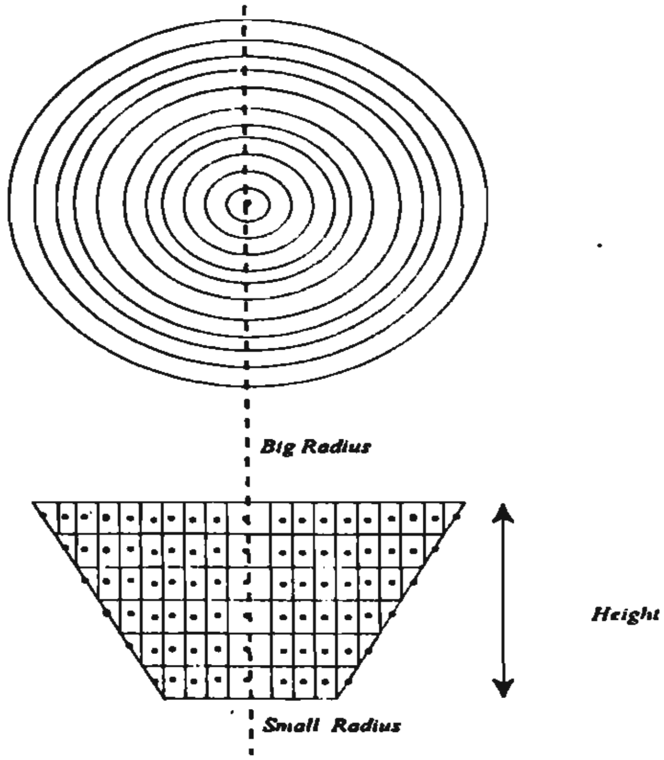


FIG. 1. GRID GENERATION FOR USE OF FINITE DIFFERENCES IN A CONE FRUSTUM

Basic assumptions in development of the models included: heat transfer is by conduction, the product is homogeneous and isotropic; i.e. its properties are uniform and constant with location and temperature. The initial temperature of the product is uniform. The surface heat transfer coefficient can be assigned a finite value or assumed infinite.

Energy Balance Equations

Energy balance equations were developed for eight different node types (Fig. 2) and solved explicitly. The nodes on the top and bottom surfaces are noncapacitance surface nodes (NCSN) having no thermal mass. The energy balance equations for the nodes associated with NCSN (type 1, 2, 3, 4, and 8 in Fig. 2) were derived as a combination of heat transfer by conduction and convection. The nodes on the side surfaces of the cone (type 5) are capacitance surface nodes located on the surface of the volume element. They have thermal mass and are affected by convective heat transfer coefficient (h). Node types 3, 4, 5 and 6 are interior nodes involving heat transfer by conduction only. The energy balance equations for all nodal types are summarized in Table 1. In order not to violate the second law of thermodynamics, the maximum time step used for each volume element was found by setting the coefficient of the term $T_{i,j}^{p}$ ≥ 0.

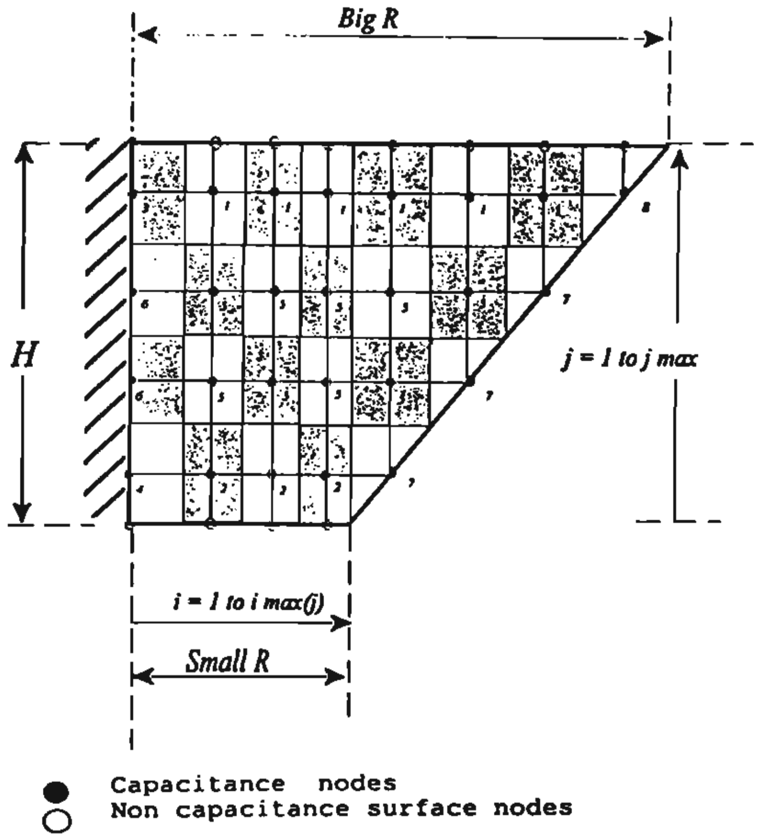
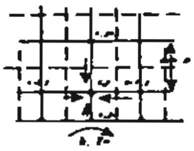
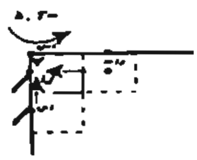
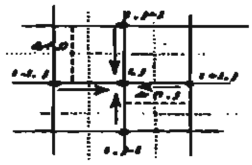
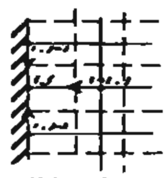
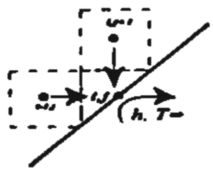


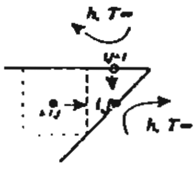
FIG. 2. CONFIGURATION OF VOLUME ELEMENTS AND NODAL POINTS FOR SIMULATION OF HEAT TRANSFER BY FINITE DIFFERENCES IN A CONE FRUSTUM

TABLE 1.
ENERGY BALANCE EQUATIONS FOR 8 VOLUME ELEMENT TYPES OF A CONE FRUSTUM

Diagram	Energy balance equation
 Node type 1	$T_{i,j}^{p+1} = \frac{\alpha \Delta t\, Ar_{i-1,j}}{V_{i,j}\, \Delta r_{i-1,j}} T_{i-1,j}^{p} + \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{i,j}} \right)} T_{\infty}^{p} + \frac{\alpha \Delta t\, Ay_{i,j-1}}{V_{i,j}\, \Delta y_{i,j-1}} T_{i,j-1}^{p} + \left(1 - \frac{\alpha \Delta t\, Ar_{i-1,j}}{V_{i,j}\, \Delta r_{i-1,j}} - \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} - \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{i,j}} \right)} - \frac{\alpha \Delta t\, Ay_{i,j-1}}{V_{i,j}\, \Delta y_{i,j-1}} \right) T_{i,j}^{p}$
 Node type 2	$T_{i,j}^{p+1} = \frac{\alpha \Delta t\, Ar_{i-1,j}}{V_{i,j}\, \Delta r_{i-1,j}} T_{i-1,j}^{p} + \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha \Delta t\, Ay_{i,j}}{V_{i,j}\, \Delta y_{i,j}} T_{i,j+1}^{p} + \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j-1}} + \frac{\Delta y_{i,j-1}}{Ay_{i,j-1}} \right)} T_{\infty}^{p} + \left(1 - \frac{\alpha \Delta t\, Ar_{i-1,j}}{V_{i,j}\, \Delta r_{i-1,j}} - \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} - \frac{\alpha \Delta t\, Ay_{i,j}}{V_{i,j}\, \Delta y_{i,j}} - \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j-1}} + \frac{\Delta y_{i,j-1}}{Ay_{i,j-1}} \right)} \right) T_{i,j}^{p}$
 Node type 3	$T_{i,j}^{p+1} = \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{i,j}} \right)} T_{\infty}^{p} + \frac{\alpha \Delta t\, Ay_{i,j-1}}{V_{i,j}\, \Delta y_{i,j-1}} T_{i,j-1}^{p} + \left(1 - \frac{\alpha \Delta t\, Ar_{i,j}}{V_{i,j}\, \Delta r_{i,j}} - \frac{\alpha \Delta t}{V_{i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{i,j}} \right)} - \frac{\alpha \Delta t\, Ay_{i,j-1}}{V_{i,j}\, \Delta y_{i,j-1}} \right) T_{i,j}^{p}$

 Node type 4	$T_{i,j}^{p+1} = \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} T_{i,j+1}^{p} + \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_g\,Ay_{i,j-1}} + \frac{\Delta y_{i,j-1}}{Ay_{i,j-1}}\right)} T_{\infty}^{p} + \left(1 - \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t}{V_{i,j}\left(\frac{K}{h_g\,Ay_{i,j-1}} + \frac{\Delta y_{i,j-1}}{Ay_{i,j-1}}\right)}\right) T_{i,j}^{p}$

Diagram	Energy balance equation
 Node type 5	$T_{i,j}^{p+1} = \frac{\alpha\,\Delta t\,Ar_{i-1,j}}{V_{i,j}\,\Delta r_{i-1,j}} T_{i-1,j}^{p} + \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} T_{i,j+1}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}} T_{i,j-1}^{p} + \left(1 - \frac{\alpha\,\Delta t\,Ar_{i-1,j}}{V_{i,j}\,\Delta r_{i-1,j}} - \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}}\right) T_{i,j}$
 Node type 6	$T_{i,j}^{p+1} = \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} T_{i+1,j}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} T_{i,j+1}^{p} + \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}} T_{i,j-1}^{p} + \left(1 - \frac{\alpha\,\Delta t\,Ar_{i,j}}{V_{i,j}\,\Delta r_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j}}{V_{i,j}\,\Delta y_{i,j}} - \frac{\alpha\,\Delta t\,Ay_{i,j-1}}{V_{i,j}\,\Delta y_{i,j-1}}\right) T_{i,j}^{p}$
 Node type 7	$T_{i,j}^{p+1} = \frac{\alpha\,\Delta t\,Ar_{avg\,i-1,j}}{V_{mixing\,i,j}\,\Delta r_{i-1,j}} T_{i-1,j}^{p} + \frac{\alpha\,h\,\Delta t\,Ar_{slope\,i,j}}{K\,V_{mixing\,i,j}} T_{\infty}^{p} + \frac{\alpha\,\Delta t\,Ay_{avg\,i,j}}{V_{mixing\,i,j}\,\Delta y_{i,j}} T_{i,j+1}^{p} + \left(1 - \frac{\alpha\,\Delta t\,Ar_{avg\,i-1,j}}{V_{mixing\,i,j}\,\Delta r_{i-1,j}} - \frac{\alpha\,h\,\Delta t\,Ar_{slope\,i,j}}{K\,V_{mixing\,i,j}} - \frac{\alpha\,\Delta t\,Ay_{avg\,i,j}}{V_{mixing\,i,j}\,\Delta y_{i,j}}\right) T_{i,j}^{p}$



Node type 8

$$T_{i,j}^{p+1} = \frac{\alpha\, \Delta t\, Ar_{avg\,i-1,j}}{V_{triang\,i,j}\, dr_{i-1,j}} T_{i-1,j}^{p} + \frac{\alpha\, h\, \Delta t\, Ar_{diag\,i,j}}{K\, V_{triang\,i,j}} T_{\infty}^{p} + \frac{\alpha\, \Delta t}{V_{triang\,i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{avg\,i,j}} \right)} T_{\infty}$$

$$+ \left(1 - \frac{\alpha\, \Delta t\, Ar_{avg\,i-1,j}}{V_{triang\,i,j}\, dr_{i-1,j}} - \frac{\alpha\, h\, \Delta t\, Ar_{diag\,i,j}}{K\, V_{triang\,i,j}} - \frac{\alpha\, \Delta t}{V_{triang\,i,j} \left(\frac{K}{h\, Ay_{i,j+1}} + \frac{\Delta y_{i,j}}{Ay_{avg\,i,j}} \right)} \right) T_{i,j}^{p}$$

The computer program to solve the resulting equations was written in Visual Basic 5 for Windows (Microsoft 1997).

Experimental Validation with Acrylic Materials

Acrylic was used as the material for experimental validation of the developed heat transfer models because it is homogeneous, heats by conduction, has known thermal properties that remained essentially constant over the range of temperatures used in the study, and was easy to fabricate into different geometries. Acrylic cones of different dimensions were cut from an acrylic rod with a diameter of 10.24 cm (Acutech Plastics, Reading, PA), and used in heat penetration tests to validate the temperature predictions of the model developed. Thermophysical properties of the acrylic rod are shown in Table 2. The dimensions of the cones and locations of thermocouples are shown in Table 3, and illustrated in Fig. 3.

TABLE 2.
THERMOPHYSICAL PROPERTIES OF THE ACRYLIC ROD USED IN THE EXPERIMENTAL VALIDATION (STABLE OVER TEMPERATURE RANGE 20-100 C)[a]

Properties	Value
Thermal Conductivity (W/m-K)	0.19
Specific Heat (J/kg-K)	1464 40
Density (kg/m^3)	1190

[a] Source. Acutech Plastics, Reading, PA

TABLE 3.
DIMENSIONS OF THE ACRYLIC CONES AND LOCATIONS OF THE THERMOCOUPLE TIPS USED IN THE EXPERIMENTAL VALIDATION

Shape	Thermocouple #	x[a] (cm.)	y[b] (cm.)
Cone#1 Big Radius = 5 08 cm Small Radius = 0 cm. Height = 12.7cm.	1 2 3 4	1.59 0.00 1.27 2.54	7.62 6.35 6.35 7 62
Cone#2 Big Radius = 5 08 cm Small Radius = 2 54 cm Height = 7 62 cm	1 2 3	1.43 0.64 2.06	2.70 5 56 4 92
Cone # 3 Big Radius = 3.81 cm Small Radius = 1 27 cm Height = 12.7 cm	1 2 3	1.91 0.00 0.80	7 46 7 46 6.83

[a]x is the distance from the axis of symmetry of the cone to the location of the thermocouple
[b]y is the distance from the bottom of the cone to the location of the thermocouple

It was important to choose the locations where the temperatures were measured. Ideally the location of the thermocouple tip should be exactly at the location of a node in the numerical model, to avoid interpolation. After the thermocouple positions were assigned, small holes were drilled to insert insulated 36-gauge T-type thermocouples at those positions. The thermocouples were set using epoxy glue and sealed at the surface with silicone.

A computerized data acquisition system, CAN-CALC program® from Engineering & Cyber Solutions (Gainesville, FL) was used to read and record temperatures. Thermocouples were connected to a DAS-TC A/D board from MetraByte (Cleveland, OH). All thermocouples were calibrated with a mercury-in-glass thermometer prior to each experiment. In order to obtain uniform initial internal temperatures, the acrylic cones were immersed in a well-agitated constant temperature water container for at least 12 h. The temperatures at every thermocouple location within the cones and the water temperature were recorded until the difference was within 0.5C.

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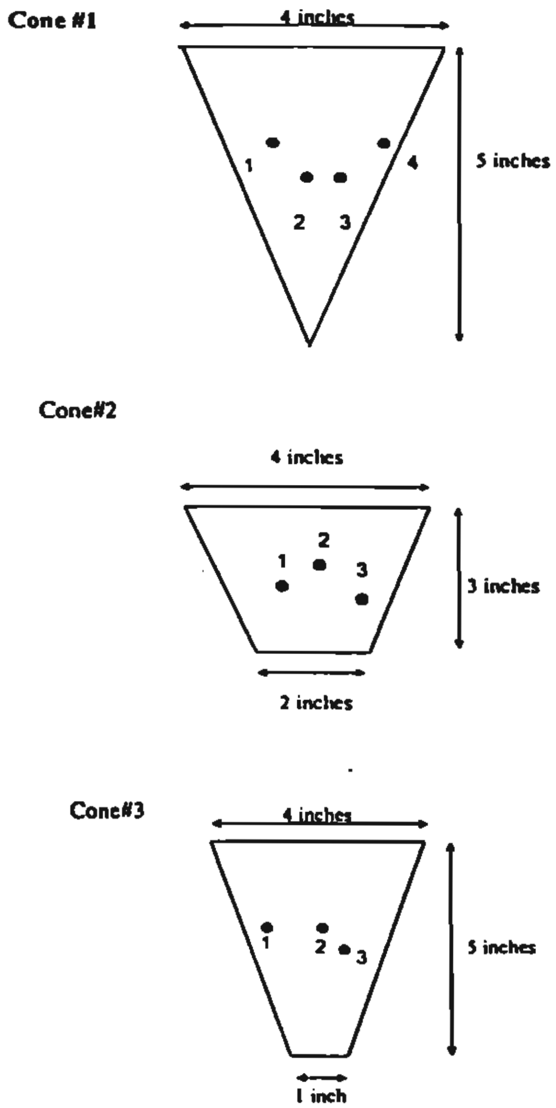

FIG. 3. SCHEMATIC ILLUSTRATION OF THERMOCOUPLE LOCATIONS AND DIMENSIONS OF CONES

Heat penetration tests were carried out in a temperature controlled water-bath (Fischer Scientific, Pittsburgh, PA) with adjustable water agitator set at the highest speed to achieve maximum surface heat transfer coefficient. Once the desired water temperature was reached and stabilized, the cone was promptly lowered into the bath to begin the heat penetration tests. The water temperature and temperatures within the acrylic were recorded every 10 s. In validation experiments where variable water bath temperature was needed to challenge model performance, ice water was added to suddenly lower the water temperature at various times during the process.

The water temperatures used as boundary conditions in the model simulations were the actual temperatures recorded during the heat penetration tests. For each cone, the optimum number of nodes was found by repeating calculations with increasing number of nodes until changes in the calculated temperatures were negligible. The surface heat transfer coefficient was selected by a search procedure to obtain a minimum absolute difference between simulated and experimental temperatures for all thermocouple locations (Pornchaloempong 1999).

Location of Cold Point

The position of the cold point in a cone frustum-shaped container depends on the relative dimensions of major and minor radii and height. Since the cone is a solid conduction-heating body with radial symmetry, the cold point must lie along the longitudinal axis or centerline (locations furthest from the boundary), assuming uniform heat transfer coefficient over the entire cone surface. Searching was accomplished by comparing temperatures of nodes predicted along the center line in the axial direction after different time periods of heating. Simulations of temperature distribution in 3 different conical geometries with similar volume (Table 4) were used to illustrate the cold point position as affected by heating time, thermal diffusivity over the range found in most foods

TABLE 4.
DIMENSION OF THE CONES USED IN THE COLD POINT POSITION STUDIES

Dimension	Cone # 1	Cone #2	Cone #3
Big Radius (cm.)	4.50	6.20	4.00
Small Radius(cm.)	2.75	5.00	2.00
Height(cm.)	8.00	3.40	11.50
Volume (cm^3)	336.60	336.60	337.20
Surface area (cm^2)	273.90	326.30	282.80
Volume / Surface	1.23	1.03	1.19

(1.2, 1.4 and 1.6 × 10^{-7} m^2/s) and heat transfer coefficient (300 W m^2/K vs infinite). The position index indicates the location along the axis expressed as a decimal fraction of the distance from the minor radius (position index = 0.0) to the major radius (position index = 1.0).

RESULTS AND DISCUSSION

The experimental temperatures at the different locations of the 3 acrylic cones were compared with the simulation (model-predicted) temperatures (Fig. 4-6). The corresponding heat transfer coefficients and thermal properties used in the experiments are included in those figures. The experimental results agreed well with the simulations for all locations of every geometrical shape in response to either constant or variable outside temperatures. Replicate experimental validations were also conducted and good agreement obtained (results are not shown). Surface heat transfer coefficient values used to obtain good agreement between experiments and simulations for all points were within 75-150 W/m^2 K. These values were in the same range of values reported by several works where experiments were conducted in well circulated water (Lebowitz and Bhowmik 1989; Peterson and Adams 1983; Sheen and Hayakawa 1991). Lebowitz and Bhowmik (1989) experimentally determined h value as 186 ± 54 W/m^2 K during thermal processing of thin retortable pouches under 120C pressurized-water with forced convection. The good agreement between experimental and simulated temperature profiles stems from the method by which surface heat transfer coefficients were obtained. Recall that these were determined by trial and error search for the values that resulted in least error between predicted and measured temperature profiles (common practice).

Figure 7 shows the simulation of temperature distribution along the axis of the 3 conically shaped containers during heating for 30 min at 10 min intervals in a constant 120C heating medium under an infinite heat transfer coefficient condition. The effect of product thermal diffusivity set at values of 1.2, 1.4 and 1.6 × 10^{-7} m^2/s on the cold point location is also shown in the same figure. The location of the cold point did not change over time during heating from 10 to 30 min regardless of cone geometry or thermal diffusivity. The position indices of the cold point for cone #1, #2 and #3 were 0.58, 0.50 and 0.71, respectively. The heat transfer coefficient also had no effect on cold point location after 20 min of heating for all the conical shapes (Fig. 8).

Cone # 1
h = 110 W/ m2 K, thermal conductivity = 0.19 W/m K,
thermal diffusivity = 1.09 x 10-7 m2/s

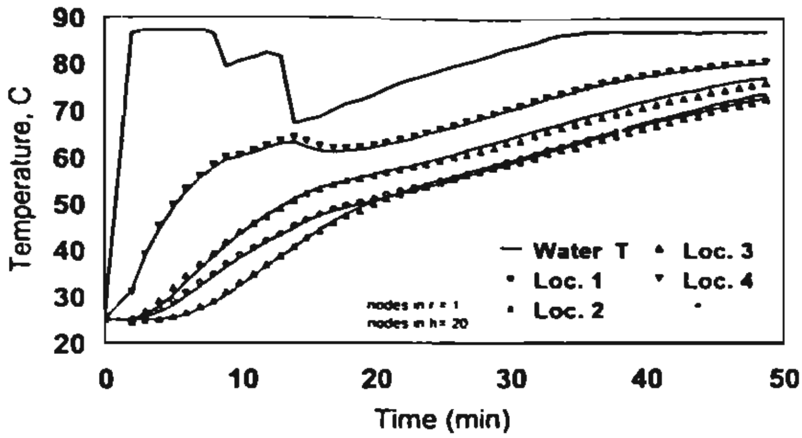

FIG 4. COMPARISON OF PREDICTED WITH MEASURED TEMPERATURE PROFILES AT THREE DIFFERENT INTERNAL LOCATIONS WITHIN A SOLID ACRYLIC CONE FRUSTUM DURING HEATING IN A VARIABLE TEMPERATURE WATER BATH (FOR CONE #1)

Cone # 2
h = 120 W/ m2 K, thermal conductivity = 0.19 W/m K,
thermal diffusivity = 1.09 x 10-7 m2/s

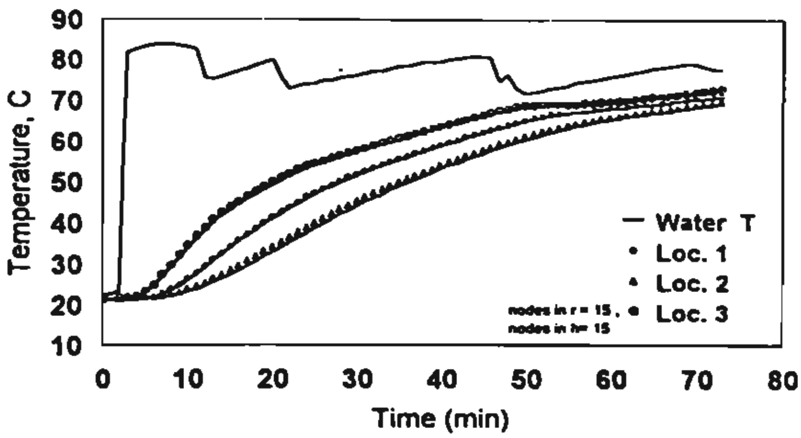

FIG. 5. COMPARISON OF PREDICTED WITH MEASURED TEMPERATURE PROFILES AT THREE DIFFERENT INTERNAL LOCATIONS WITHIN A SOLID ACRYLIC CONE FRUSTUM DURING HEATING IN A VARIABLE TEMPERATURE WATER BATH (FOR CONE #2)

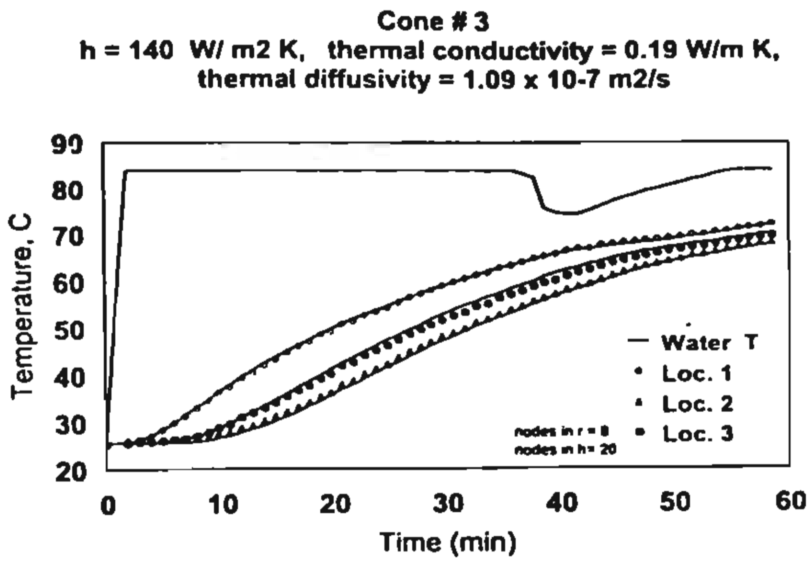

FIG. 6. COMPARISON OF PREDICTED WITH MEASURED TEMPERATURE PROFILES AT THREE DIFFERENT INTERNAL LOCATIONS WITHIN A SOLID ACRYLIC CONE FRUSTUM DURING HEATING IN A VARIABLE TEMPERATURE WATER BATH (FOR CONE #3)

CONCLUSION

The conduction heat transfer model developed in this study can accurately predict the temperature distribution in a conical shaped container (cone frustum) for any given combination of dimensions for major and minor radii and height in response to either constant or variable surface temperatures. The cold point of a cone, defined as the location of slowest heating, varied from 0.50 to 0.7 times the distance from minor to major faces along the center axis, depending on relative dimensions of major and minor radii and height.

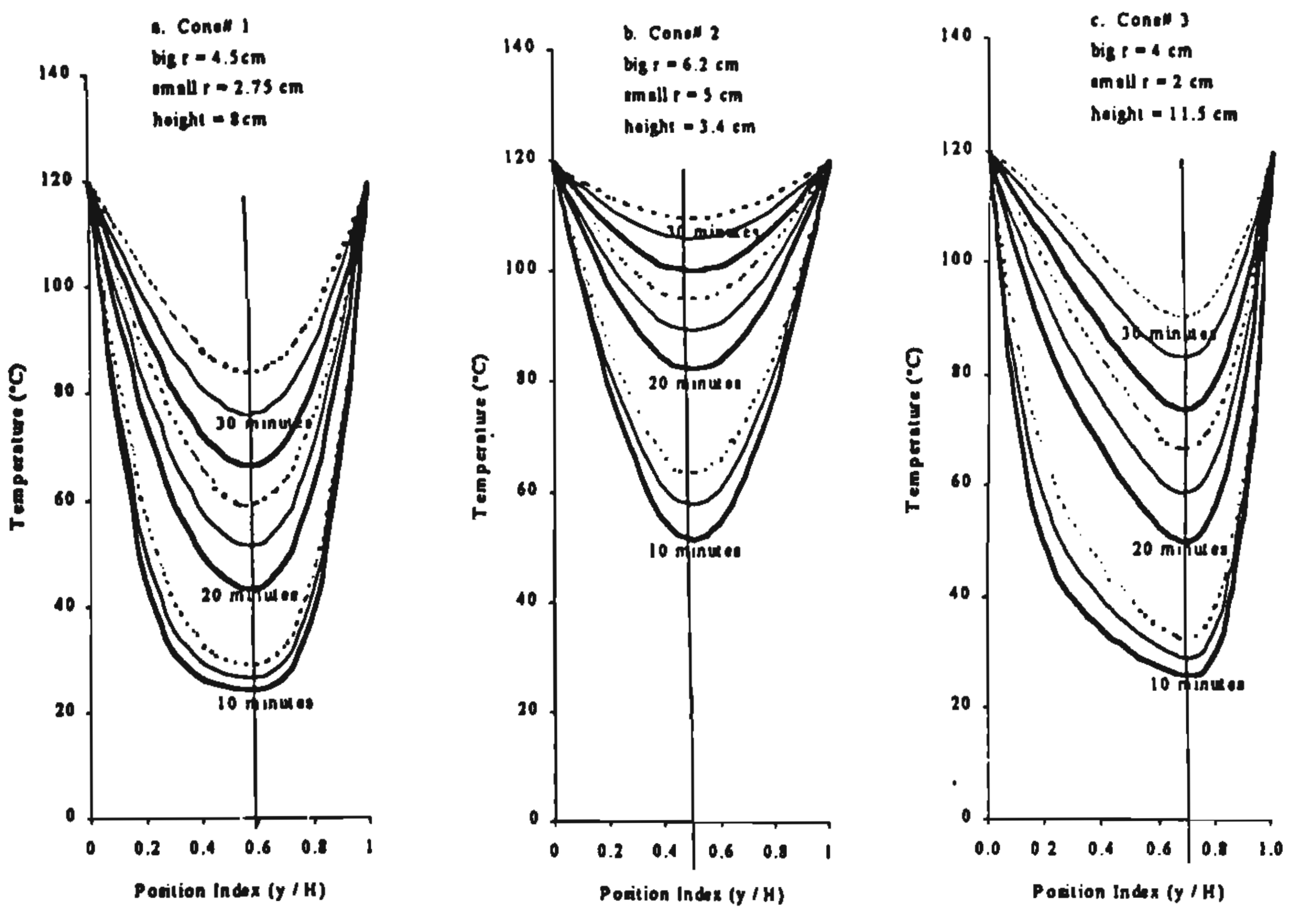

FIG. 7. SIMULATED TEMPERATURE DISTRIBUTIONS ALONG THE CENTERLINE AXIS OF A CONE FRUSTUM AFTER DIFFERENT HEATING TIMES IN A WATER BATH, SHOWING THE LOCATION OF SLOWEST HEATING (COLD POINT) FOR THREE DIFFERENT CONE FRUSTUM SIZES

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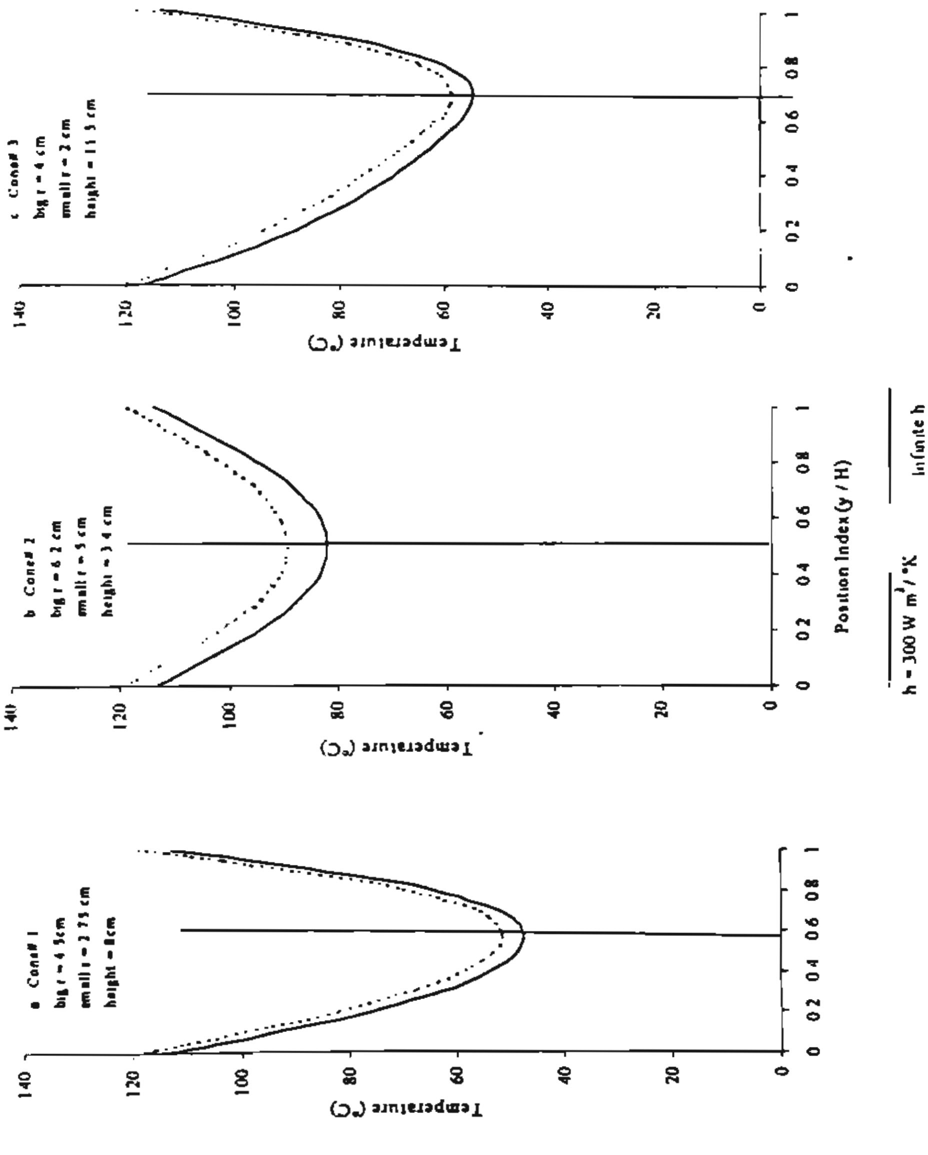

FIG. 8. EFFECT OF SURFACE HEAT TRANSFER COEFFICIENT ON TEMPERATURE DISTRIBUTION ALONG CONE FRUSTUM CENTERLINE AXIS FOR THREE DIFFERENT CONE FRUSTUM SIZES

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JOURNAL OF FOOD PROCESS ENGINEERING

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FOOD & NUTRITION PRESS, INC.

VOLUME 25, NUMBER 6 BIMONTHLY

OPTIMIZATION OF QUALITY RETENTION IN CONDUCTION-HEATING FOODS OF CONICAL SHAPE[1]

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Accepted for Publication August 30, 2002

ABSTRACT

A cone frustum is an alternative shape for packaging thermally processed foods that can be useful in modeling the increasing number of microwaveable, ready-to-eat conical-shaped food containers seen on supermarket shelves. Thermal processing in a cone frustum can be optimized by using numerical models for heat transfer to predict temperature distribution profiles, together with thermal destruction kinetics of target organisms and nutrient/quality factors. Iso-lethality curves, showing combinations of process time and retort temperature that deliver equal lethality, were developed for each of three different cone frustum geometries (different dimensional proportions of major and minor diameters and height). Total volume average quality retention was determined for equivalent process time-temperature combinations for quality factors with assumed thermal degradation kinetic parameters (D and Z-values). Response of quality retention to the equivalent process combinations (designated by their

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retort temperature) revealed optimum process conditions that delivered maximum quality retention. The effect of kinetic parameters, thermal properties, and surface heat transfer coefficient on quality retention response to equivalent process conditions was also studied and compared with findings reported in the literature for the case of more traditional finite cylinder shapes.

INTRODUCTION

Thermal processing, in which sealed containers of food are heated in pressurized retorts, is the key unit operation by which the food canning industry produces versatile, safe and convenient shelf-stable products. For processors to choose conditions yielding maximum quality retention without compromising food safety, optimization of thermal processing is required. In conduction heating foods, the nonuniform temperature distribution between container surface and center significantly dampens response to high temperature short time (HTST) processing in retorts, that may not always benefit the product quality (Teixeira *et al.* 1969; Lund 1977).

The volume average quality retention in a conduction-heating food is highly dependent upon the history of temperature distribution patterns within the food container resulting from a retort process. Heat transfer models capable of predicting these temperature distribution patterns have become useful tools in thermal process design optimization, but they must be specific to the general geometric shape of the container. Optimization of conduction heating foods has been intensively researched (Silva *et al.* 1993). Most works focused on the effects of altering dimensions with regular geometric shapes, heat transfer coefficient, food thermal diffusivity, and retort temperature profiles on the retention of quality parameters. The optimization studies are limited to foods packed in a container for which heat transfer models are available. The geometric shapes covered included finite cylinder (Teixeira *et al.* 1969; Saguy and Karel 1979; Ohlsson *et al.* 1980b; Thijssen and Kochen 1980; Nadkarni and Hatton 1985; Hendrickx *et al.* 1993; Silva *et al.* 1992; Banga *et al.* 1991 and Sablani *et al.* 1995), rectangular slab (Thijssen and Kochen 1980; Ohlsson *et al.* 1980a; Hendrickx *et al.* 1993) and sphere (Hendrickx *et al.* 1993; Silva *et al.* 1994).

A cone frustum is an alternative shape for packaging thermally processed foods. It offers a new look, and the number of microwaveable, ready-to-eat conical packages seen on supermarket shelves (lunch bowls) has been steadily increasing. The work reported here is the second of a 2-part study in which development and validation of a numerical heat transfer model specific to cone-shaped solid bodies was carried out and reported as Part 1 in a companion paper (Pornchaloempong *et al.* 2003). Application of the model to address process

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optimization and the extent to which optimum process conditions are affected by container shape is reported here as Part 2 of the study.

Specific objectives of this study were to

(1) Apply the model developed in Part 1 for conduction heat transfer in a cone frustum to calculate volume average quality retention resulting from equivalent lethality process conditions,
(2) Show how this response of quality retention to process conditions was affected by the proportional dimensions of the cone frustum, as well as by kinetic parameters, thermal properties, and surface heat transfer coefficient, and
(3) Compare results with those found in the literature for the case of traditional finite cylinder shapes.

MATERIALS AND METHODS

Heat Transfer Model in a Cone Frustum

A two-dimensional conduction heat transfer model based on the energy balance approach was developed for a cone frustum shaped body, and described in detail in a companion paper (Pornchaloempong *et al.* 2003). The frustum has three characteristic dimensions that can vary in their proportions to one another, a major diameter (big radius), minor diameter (small radius), and height. In order to carry out a numerical solution by finite differences, the cone was imagined subdivided into a series of concentric rings stacked on top of each other (Fig. 1). Each volume element had a node as a reference point. The temperature at the node was the temperature at that location within the volume element. The energy balance equation was developed for each volume element and solved explicitly using a finite difference approach. The details of model development, including boundary conditions and validation with heat penetration tests, can be found in the aforementioned companion paper by Pornchaloempong *et al.* (2003). Basic assumptions of the model were:

(1) Heat transfer into the food was by pure conduction,
(2) The food product was homogeneous and isotropic,
(3) Thermal and physical properties were constant with temperature,
(4) Initial temperature of the food was uniform, and
(5) Surface heat transfer coefficient could be specified or assumed infinite.

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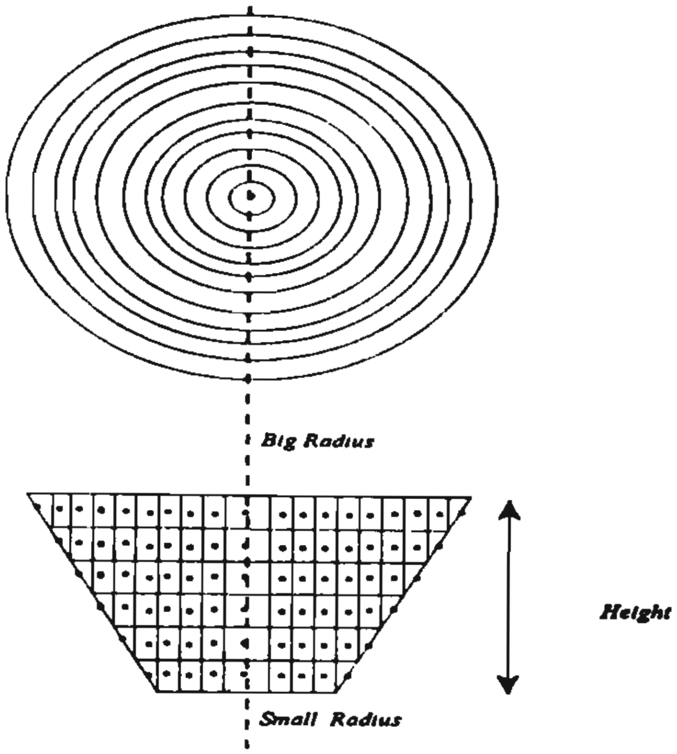

FIG. 1. GRID GENERATION IN A CONE FRUSTUM

Optimization of Quality Retention

The objective function was the volume average quality retention $(N/N_o)_{avg}$, expressed as:

$$\left(\frac{N}{N_o}\right)avg = \frac{1}{V}\int_0^V 10^{-\frac{1}{D_{ref}}\int_0^t 10^{\frac{T-T_{ref}}{z}}dt}\, dV \qquad (1)$$

where

D_{ref}	Decimal reduction time(min) at reference temperature (time required at reference temperature to cause ten-fold reduction in quality factor).
N_o	The initial quantity or concentration of quality factor
N	The quantity or concentration at time t
t	Time, s
T	Temperature, °C
T_{ref}	Reference temperature, °C

V Volume, m^3
Z Z value, °C (Change in temperature causing ten-fold change in D value).

The constraint of the optimization procedure was the need to reach a target lethality (F_o value) at the "cold point" with all process conditions. The cold point was found by comparing temperatures of nodes along the center line in the axial direction during heating using a fine grid for accuracy (Pornchaloempong *et al.* 2003).

The target F_o was the accumulated F_o contributed during both heating and cooling periods (t_h, t_c).

$$F_0 = \int_0^{t_h} 10^{\frac{T-T_{ref}}{z}} dt + \int_{t_h}^{T_h+t_c} 10^{\frac{T-T_{ref}}{z}} dt \quad (2)$$

The target F_o value was chosen as 3 min for this study. Although this value is less than those generally used in the industry (Lopez 1987), it shortened the calculation times in this study.

Quality factors with different combinations of D and Z values were used. Other process variables including thermal diffusivity of the food product, surface heat transfer coefficient, as well as proportional dimensions of the conical containers were also investigated for their effect on quality retention response to process conditions. The values chosen for these variables are summarized in Tables 1 and 2.

A uniform initial food temperature of 22C, and different constant retort temperatures ranging from 110 to 140C at 2C intervals were used. After heating at the specified temperature, the food was then cooled at a constant cooling temperature of 20C until the center temperature was less than or equal to 50C.

The exact time to stop heating and start cooling in order to obtain the desired total F_o value was found as follows: At the end of a given time step during heating, the F_o for heating was calculated, then cooling was simulated until the cold point reached 50C, and the contribution of cooling to F_o was calculated. If the total F_o (heating + cooling) was less than the desired F_o, heating could still proceed. Otherwise, a bisection method was used within the last time step to find the exact end-of-heating time such that the total F_o would not be larger than 0.0001 min compared to the desired F_o.

The percent quality retention for each processing condition was plotted against the retort temperature of each process condition. The optimum retort temperature giving the maximum quality retention was located by a spline interpolation. The computer program to solve the resulting equations was written in Visual Basic 5 for Windows.

TABLE 1
VARIABLES USED IN THE QUALITY RETENTION STUDIES

Variable	Number of levels	Values
Kinetics of quality factors		
$D_{121.1°C}$ (min)	6	40, 80, 120, 160, 200
Z (°C)	6	10, 20, 30, 40, 50, 60
Processing Conditions		
Heating Temperature (°C)	11	110-140, at 2°C intervals
Heat transfer coef (W/m² °C)	2	300 and 2000 w/ m² K
Thermal Properties of food		
Thermal diffusivity (× 10⁻⁷ m²/s)	3	1.2, 1.4, 1.6

TABLE 2
DIMENSIONS OF THE CONE FRUSTUMS USED IN THE QUALITY RETENTION STUDIES

Dimension	Cone # 1	Cone #2	Cone #3
Big Radius (cm)	4.50	6.20	4.00
Small Radius (cm)	2.75	5.00	2.00
Height (cm)	8.00	3.40	11.50
Volume (cm³)	336.60	336.60	337.20
Surface area (cm²)	273.90	326.30	282.80
Volume / Surface	1.23	1.03	1.19

RESULTS AND DISCUSSION

Processing Time at Retort Temperature for Equivalent Lethality

Iso-process lethality curves, showing combinations of process time and retort temperature that deliver equal lethality (F_o value = 3 min) are shown in Fig. 2 for the three conical-shaped containers of different dimensional proportions. The conical shaped containers were of nearly equivalent volume (approximately 336 cm^3), but varied in volume-to-surface ratio. Cone #2 (tall-narrow) which had the smallest ratio (1.03) required the shortest processing time at each retort temperature. Cones #3 (short-wide) and #1 (in-between frustum) with ratios of 1.19 and 1.23, respectively, were slower heating and required more time at each temperature, as would be expected.

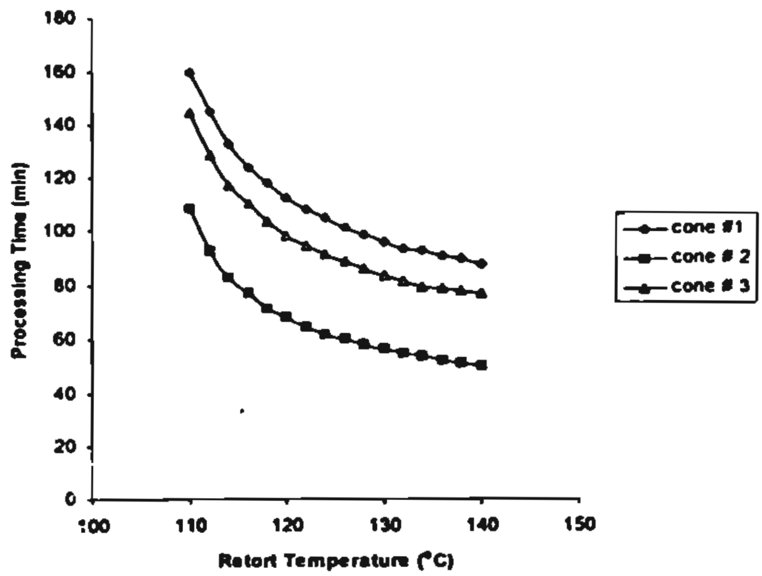

FIG. 2. ISO-PROCESS LETHALITY CURVES, SHOWING COMBINATIONS OF PROCESS TIME AND RETORT TEMPERATURE THAT DELIVER EQUAL LETHALITY (F_o VALUE = 3 MIN) FOR CONDUCTION HEATED FOODS (α = 1.4 m^2/s) PACKED IN THREE CONICAL-SHAPED CONTAINERS OF DIFFERENT DIMENSIONAL PROPORTIONS

Factors Affecting Quality Retention and Optimum Processing Temperature

Z Value. The effect of different Z values for thermal degradation of quality factors on the volume-average-quality retention is shown in Fig. 3. These simulations were performed assuming a food product with thermal diffusivity of 1.4×10^{-7} m^2/s packed in a conical container represented by cone #1, with the D_{ref} value of the quality factor fixed at 200 min. Essentially all curves depict an optimum retort temperature (T_{opt}) process yielding maximum quality retention within the range of values studied. Note that higher Z values revealed a T_{opt}. in the midrange of retort temperatures commonly employed in industry (120-130C). Z values in this higher range typify the thermal degradation kinetics of many quality/nutrient factors in foods. At these higher Z values the thermal degradation rate of quality factors (D value) is less sensitive to changes in temperature. The optimum temperature for maximizing the nutrients moves away from the lowest temperatures in order to benefit more from the shorter process time at higher retort temperature (even though degradation rate is faster). The profile of the curves also flattens because the quality retention becomes less sensitive to deviations from the optimum retort temperature. Factors with lower Z values showed increased sensitivity to retort temperature and favored lower retort temperature process conditions, benefitting more from the slower degradation rates in spite of the correspondingly longer process times. These conditions also produced greater quality retention over all, and parallel the findings for cylindrical containers reported by Teixeira *et al.* (1969) and Hendrickx *et al.* (1993).

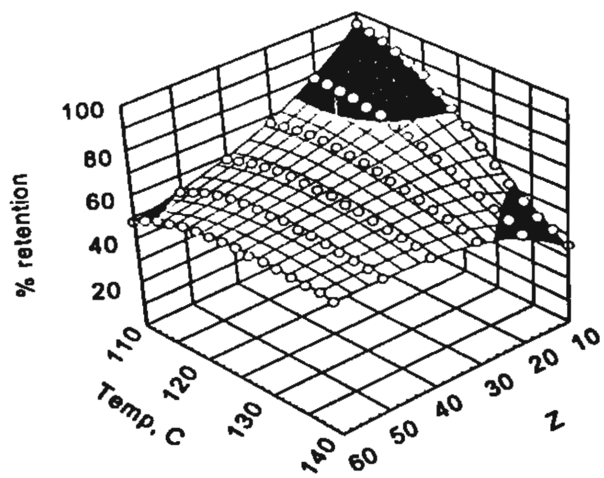

FIG. 3. EFFECT OF Z-VALUE ON QUALITY RETENTION RESPONSE TO RETORT TEMPERATURE

Reference D value (D_{ref}). The effect of different D_{ref} values for thermal degradation of quality factors on the volume-average-quality retention is shown in Fig. 4 for the same conical container and food product assumed above with the Z value held constant at 30C. Quality retention increased with increasing D_{ref} value at all processing temperatures as would be expected, since greater D value at any temperature represents slower degradation rate. These results also echo the findings of Teixeira *et al.* (1969) and Silva *et al.* (1992) for cylindrical containers. The maximum quality retention increased from 24.5 to 78.0% when D_{ref} increased from 40 to 240 min. Changes in the D_{ref} value alone (without changing Z value) simply move the response curves up or down and have little effect on the profile of the response curves.

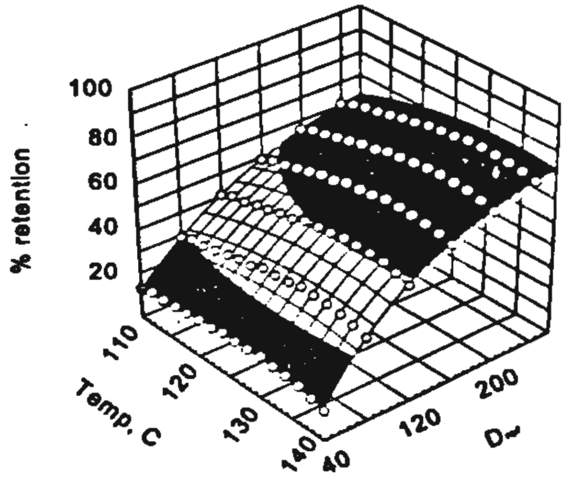

FIG. 4. EFFECT OF D-VALUE ON QUALITY RETENTION RESPONSE TO RETORT TEMPERATURE

Thermal Diffusivity. The effect of thermal diffusivity on the quality retention response curves is shown in Fig. 5. Thermal diffusivity values of 1.2, 1.4 and 1.6 × 10^{-7} m^2/s were chosen as representative of the range for most foods. The simulations were performed for foods packed in cone #1 under an infinite heat transfer coefficient, for a quality factor with D_{ref} = 200 min and Z = 30C (typical of kinetic parameters for vitamin degradation). Foods with a higher thermal diffusivity always retain higher quality for any processing temperature because they heat faster, resulting in shorter process time. Although thermal diffusivity had little influence on the resulting optimal temperature, the increase in optimal temperature when thermal diffusivity increases indicates that the faster heating rate of foods with high thermal diffusivity allows them to exploit the benefit of the HTST processing to better retain quality. This increase in quality factor retention for food with higher thermal diffusivity was also true for all kinetic parameters regardless of container shape and size, and processing temperatures in this study. This is because better quality retention results from the faster heat transfer in foods with higher thermal diffusivity, allowing temperature distributions to become uniform faster, thus reducing process time.

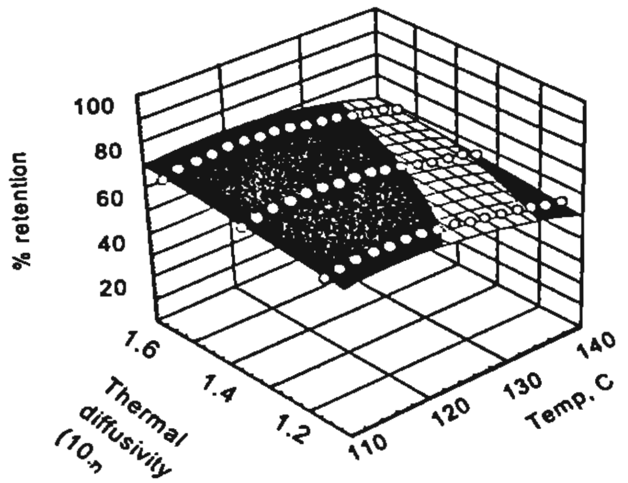

FIG. 5. EFFECT OF THERMAL DIFFUSIVITY ON QUALITY RETENTION RESPONSE TO RETORT TEMPERATURE

Surface Heat Transfer Coefficient. The infinite heat transfer coefficient (h) assumption is valid when food is packed in a metal container and heated with condensing steam. When food is packed in a nonmetal material and/or heated with water or steam/air mixtures, a finite surface heat transfer coefficient in the range 100 - 700 W/m^2 K should be considered (Tucker and Clark 1990; Bhowmik and Tandon 1987; Lebowitz and Bhowmik 1990). The simulations shown earlier in Fig. 3 (in which infinite h was assumed) were repeated with a finite h of 300 W/m^2 K and compared. Results are shown in Fig. 6 for selected Z values, and reveal clearly that surface heat transfer coefficient has no effect on the profile of the response curves. Changing h from infinite to finite simply adds further impedance to heat transfer across the container surface. This results in a slightly slower heating rate that will change percent retention slightly for any set of process conditions. In this case that change was less than ± 3% regardless of container shape, thermal diffusivity, or kinetic parameters.

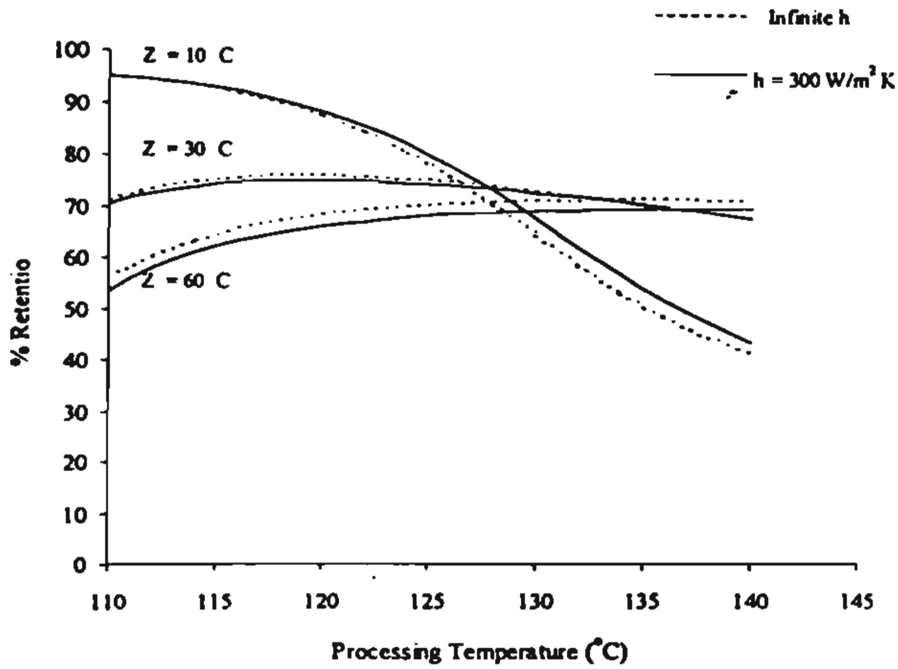

FIG. 6. EFFECT OF SURFACE HEAT TRANSFER COEFFICIENT ON QUALITY RETENTION RESPONSE TO RETORT TEMPERATURE

Even though the effect of h is very small, the response curves show that this effect can be positive or negative depending on Z value. With infinite h the interior surface temperature is highest (same as condensing steam). Therefore, in the case of low Z values, the quality near the surface (greatest proportion of container contents) is destroyed more rapidly before target lethality is reached at the cold point, producing slightly lower percent retention than with finite h (Fig. 6). In the case of higher Z values, percent retention was greater with an infinite h than a finite h. This is because the thermal destruction rate does not change as much with temperature, and benefit accrues from the shorter processing time from infinite h.

Conical Geometry. The effect of different conical geometries (proportional dimensions) on quality retention response curves is presented in Fig. 7. These simulations assumed food thermal diffusivity of 1.4×10^{-7} m²/s, infinite heat transfer coefficient, $D_{ref} = 200$ min, and Z = 30C. The three conical containers had essentially the same optimum process conditions designated by retort temperatures ranging from 117 to 119C. More importantly, these response curves have nearly identical profiles to those reported for traditional cylindrical shapes (Fig. 8). These findings confirm the expectation that results from optimization studies of this type can be translated from one container shape to another.

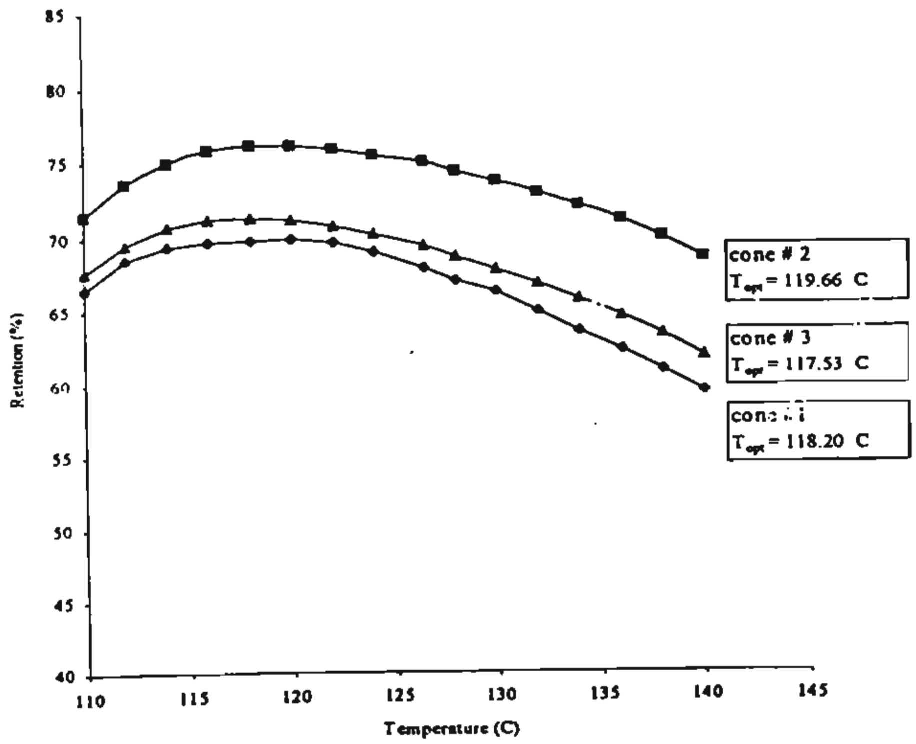

FIG. 7. EFFECT OF DIMENSIONAL PROPORTIONS OF CONE FRUSTUM SHAPE (CONES #1, 2 AND 3) ON QUALITY RETENTION RESPONSE TO RETORT TEMPERATURE

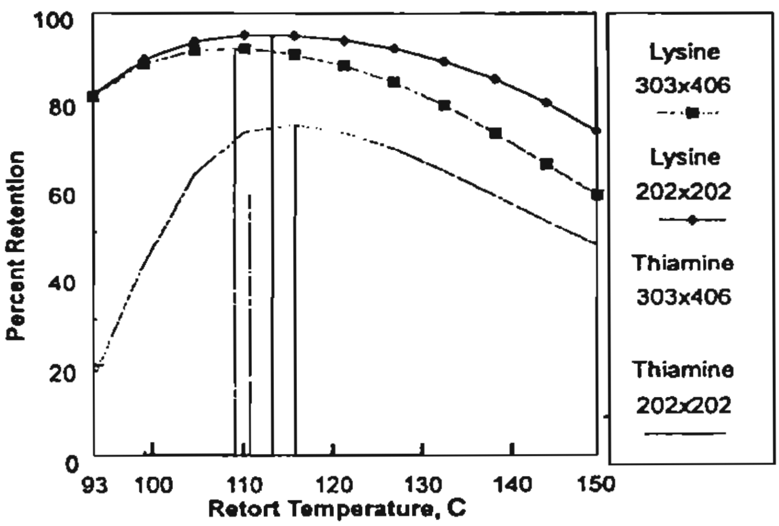

FIG. 8. PROCESS OPTIMIZATION CURVES SHOWING OPTIMUM RETORT TEMPERATURES FOR MAXIMUM NUTRIENT RETENTION IN CYLINDRICAL CONTAINERS OF DIFFERENT SIZE (BALABAN AND TEIXEIRA 1996)

CONCLUSIONS

Optimum process conditions can be found by use of numerical models simulating conduction heat transfer in a solid body to calculate volume average quality retention resulting from equivalent lethality process conditions. The profile of response curves showing quality retention as a function of process conditions remains essentially unchanged regardless of changes in thermal properties or relative geometry of the solid body. Findings from this study agree closely with those found in the literature for the case of traditional finite cylinder shapes. Thus, process conditions found to be optimum for a given quality factor and food product in a specified container shape are likely to be optimum for the same food product and quality factor in other container shapes. For this type of optimization study, results from numerical models specific to one geometry may likely apply to other geometries.

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เรื่อง ขอความอนุเคราะห์แบ่งซื้อปลาทูน่า

เรียน คุณดารณี บริษัท ทีซียูเนี่ยน จำกัด

เนื่องด้วย ดร.พิมพ์เพ็ญ พรเฉลิมพงศ์ ตำแหน่ง อาจารย์ สังกัด ภาควิชาวิศวกรรมอาหาร คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง ได้รับทุนวิจัยจาก สำนักงานกองทุนสนับสนุนการวิจัย (สกว.) เพื่อทำงานวิจัยเรื่อง "จลนศาสตร์การเปลี่ยนแปลงคุณภาพทางกายภาพและประสาทสัมผัสของปลาทูน่าด้วยความร้อน" มีวัตถุประสงค์เพื่อหาค่าจลนศาสตร์การเปลี่ยนแปลงด้วยความร้อนของคุณภาพต่าง ๆ ได้แก่ ค่าการอุ้มน้ำ เนื้อสัมผัสที่วัดได้จากเครื่องมือและคุณภาพทางประสาทสัมผัส โดยการให้ความร้อนปลาที่ระดับอุณหภูมิต่าง ๆ ในเวลาต่างกัน ค่าที่ได้จะเป็นประโยชน์ในการคำนวณเพื่อหาสภาวะที่เหมาะสมให้ได้คุณภาพเป็นที่ยอมรับมากที่สุดและประหยัดพลังงาน ซึ่งผลของงานวิจัยจะได้ประยุกต์ใช้ประโยชน์ในอุตสาหกรรมปลาทูน่ากระป๋องของประเทศไทย การวิจัยจำเป็นต้องใช้เนื้อปลาคุณภาพดีพันธุ์ Skipjack จำนวน 100 กิโลกรัม ซึ่งไม่สามารถหาซื้อได้จากท้องตลาด จึงขอแบ่งซื้อจากทางบริษัท โดยจะจัดรถไปรับเองที่บริษัทฯ

จึงเรียนมาเพื่อโปรดพิจารณาอนุเคราะห์

ขอแสดงความนับถือ

พิมพ์เพ็ญ พรเฉลิมพงศ์

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ผลของความร้อนต่อคุณภาพทางกายภาพและประสาทสัมผัสของปลาทูน่าหลังฆ่าเชื้อ"

วัตถุประสงค์

โครงงานวิจัยนี้จัดทำขึ้น โดยมีวัตถุประสงค์หลัก 3 ประการ คือ

1. เพื่อศึกษาผลของค่า F_0 และอุณหภูมิในการฆ่าเชื้อต่อคุณภาพทางกายภาพและประสาทสัมผัสของปลาทูน่าหลังฆ่าเชื้อ

2. เพื่อศึกษาความสัมพันธ์ระหว่างค่าปัจจัยคุณภาพในด้านต่างๆที่วัดด้วยเครื่องมือ กับค่าที่วัดได้ ทางประสาทสัมผัสโดยผู้ชิมที่ได้รับการฝึกฝน เพื่อเป็นแนวทางในการตรวจสอบและควบคุมคุณภาพของปลาทูน่ากระป๋องอย่างรวดเร็ว

3. เพื่อคำนวณหาค่าจลน์ศาสตร์การเปลี่ยนแปลงของเนื้อปลาทูน่าด้วยความร้อนโดยวิธี Unsteady State และใช้ค่าดังกล่าวร่วมกับโปรแกรมคอมพิวเตอร์เพื่อทำนายคุณภาพของปลาทูน่าที่สภาวะฆ่าเชื้อต่างๆ

วิธีดำเนินการทดลอง

1. การเตรียมเนื้อปลาบรรจุกระป๋อง ใช้เนื้อปลาแช่แข็งพันธุ์ Albacore (*Thunnus alalunga*) คุณภาพดี มาละลาย นึ่ง คัดเฉพาะเนื้อที่มีสีขาวสม่ำเสมอมาบรรจุในกระป๋องขนาด 307 x 113 โดยบรรจุแบบอัดแน่น (Solid pack) กระป๋องละประมาณ 120 ± 2 กรัม แล้วปิดฝา

กรรมวิธีละลาย นึ่ง บรรจุ และปิดฝา ใช้อุปกรณ์และวิธีมาตรฐานของบริษัทไทยรวมสิน

2. การฆ่าเชื้อ ใช้หม้อฆ่าเชื้อด้วยไอน้ำของบริษัทไทยรวมสิน ฆ่าเชื้อเพื่อให้ได้ค่า F_0 เท่ากับ 4 และ 6 นาที โดยแต่ละ F_0 ใช้อุณหภูมิฆ่าเชื้อที่ 112 , 117 และ 122 องศาเซลเซียส แล้วทำเย็นจนอุณหภูมิใจกลางกระป๋องได้ 50 องศาเซลเซียส รวมทั้งสิ้น 6 การทดลอง ทำ 2 ซ้ำ

เวลาที่ใช้ในช่วงการฆ่าเชื้อและทำเย็นแต่และการทดลองคำนวณโดยใช้ข้อมูลการแทรกผ่านความร้อน (heat penetration study) ของเนื้อปลาที่มีพันธุ์ ขนาดบรรจุ และหม้อฆ่าเชื้อเดียวกันกับที่ใช้ทดลองครั้งนี้ ทั้งนี้การคำนวณค่า F_0 จะใช้เฉพาะช่วงอุณหภูมิให้ความร้อนเท่านั้น ไม่รวมช่วงไล่อากาศและทำให้เย็น

ระหว่างการฆ่าเชื้อจะติดตั้งสายเทอร์โมคัปเปิล จำนวน 5 สาย รอบๆ ตัวอย่าง สำหรับบันทึกอุณภูมิภายนอก ตลอดการฆ่าเชื้อทั้งในช่วงการให้ความร้อนและทำเย็น เพื่อใช้คำนวณหาค่าจลน์ศาสตร์การเปลี่ยนแปลงของเนื้อปลาทูน่าด้วยความร้อนโดยวิธี Unsteady State

3. การตรวจสอบคุณภาพหลังฆ่าเชื้อ

3.1 คุณภาพทางกายภาพ

3.1.1 Drained weight ใช้จำนวน 20 กระป๋องต่อตัวอย่าง

3.1.2 Pressed weight โดยใช้เครื่อง Press weight (Luthi Machinery & Engineering Co ,Inc CA, USA) ใช้จำนวน 20 กระป๋องต่อตัวอย่าง

3.1.3 สี วัดโดยใช้เครื่อง JUKI COLOR METER model JC801 (Japan) วัดสีในระบบ CIE โดยวัดค่า L*, a*, b* และ Hue Angle วัดตัวอย่างทุกกระป๋อง ก่อน และหลัง การ

วัด Drained weight, Press weight และ ก่อนการทดสอบสี ทางประสาทสัมผัส ตามข้อ 3.3

3.1.4 เนื้อสัมผัส โดยใช้เครื่อง Texture analyzer (USA) ใช้หัววัดแบบ Krammer shear cell ใช้จำนวน 20 กระป๋องต่อตัวอย่าง

3.2 การดูดซับคลื่นในช่วง Near Infra red (NIR) วัดตัวอย่างทุกกระป๋อง ก่อนการทดสอบคุณภาพทางกายภาพ ตามข้อ 3.1

3.3 คุณภาพทางประสาทสัมผัส

ทดสอบโดยวิธีการให้คะแนนตามลำดับความเข้มของแต่ละปัจจัย ตั้งแต่ 1 ถึง 10 โดย 1 หมายถึง อ่อนที่สุด และ 10 หมายถึง เข้มที่สุด ใช้ผู้ชิมที่ผ่านการฝึกฝนจำนวน 14 คน เป็นชาย4 คน และหญิง 10 คน ผู้ชิมจะผ่านการฝึกฝน 20 ครั้ง ครั้งละประมาณ 45 นาที

การฝึกผู้ชิม มีวัตถุประสงค์เพื่อให้ผู้ชิมมีความสามารถในการแยกความแตกต่าง เรียงลำดับและจดจำตัวอย่างเนื้อปลามาตรฐาน ที่มีระดับความเข้มของสี กลิ่นสุก และเนื้อสัมผัส 4 ระดับ เรียงตั้งแต่อ่อนมากถึงเข้มมาก โดยกำหนดให้เป็นระดับคะแนนที่ 1 , 4 , 7 และ 10 ตามลำดับ การสร้างและเลือกตัวอย่างมาตรฐานทำโดยผู้เชี่ยวชาญคุณภาพทางประสาทสัมผัสของเนื้อปลาซึ่งส่วนหนึ่งเป็นพนักงานของบริษัทไทยรวมสิน ระดับคะแนนที่มากกว่า 7 ขึ้นไปของทุกปัจจัย ถือว่าเป็นระดับที่ผู้บริโภคเริ่มไม่ยอมรับ

การเตรียมตัวอย่าง เปิดกระป๋องครั้งละ 4 กระป๋อง และคว่ำเอาเนื้อออกไว้บนตะแกรงขนาด 100 mesh คลุกเคล้าให้เข้ากัน ทิ้งไว้ให้สะเด็ดน้ำ 3 นาที แล้วแบ่งเตรียมตัวอย่าง เพื่อแยกทดสอบ แต่ละปัจจัยดังนี้

สี บดหยาบเนื้อปลา 150 กรัม ด้วยเครื่องบดอาหารที่ความเร็วต่ำ 1 นาที แล้ว บรรจุ อัดแน่นในจานแก้ว (Petridish) ขนาดเส้นผ่านศูนย์กลาง 1.5 นิ้ว ครอบด้วยฝาแก้ว

กลิ่นสุก ใช้เนื้อปลาบดหยาบ เสิร์ฟในขวดสีชาปากกว้างที่มีฝาปิด (เส้นผ่านศูนย์กลาง 3 cm สูง 4.5 cm) ซึ่งจะเหลือที่ว่างเหนือเนื้อปลาประมาณ 1.5 cm เสิร์ฟตัวอย่างพร้อมเมล็ดกาแฟเพื่อล้างจมูกระหว่างตัวอย่าง

เนื้อสัมผัส ใช้เนื้อปลา (ไม่บด) ประมาณ 10 กรัม เสิร์ฟในถ้วยพลาสติกสีขาว พร้อมน้ำเปล่าเพื่อล้างปากระหว่างตัวอย่าง

การทดสอบ ใช้แผนการทดลองแบบ Incomplete block ทดสอบตัวอย่างเนื้อปลากระป๋องหลังฆ่าเชื้อที่ระดับความร้อน 8 ระดับ ซึ่งผู้ชิมจะได้รับตัวอย่างที่ได้จากการสุ่มครั้งละ 4 ตัวอย่าง แต่ละตัวอย่างจะถูกทดลอง 2 ซ้ำ ในการเสิร์ฟตัวอย่างจะติดรหัสเลขสุ่ม 3 หลัก

สถานที่ทดลอง

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วันศุกร์ที่ 17 มกราคม พ.ศ. 2546

Treatment	Retorf Temp (C)	Fo	Rep.	No.of can (307x113)
1	112	4	1	100 ~~making~~ standard samples for sensory evaluations
2	112	4	1	70
3	112	4	2	70
4	112	6	1	70
5	112	6	2	70
6	117	4	1	70
7	117	4	2	70
8	117	6	1	70
9	117	6	2	70
10	122	4	1	70
11	122	4	2	70
12	122	6	1	70
13	122	6	2	70

Number of canned tuna for evaluations

Drained Weight	20
Pressed Weight	20
Texture Analyzer	20
Sensory Evaluation	10

แผนการดำเนินการวิจัยผลของความร้อนต่อคุณภาพปลาทูน่ากระป๋อง

ขั้นตอนการดำเนินการ	ระยะเวลาการทดลอง																												
	Jan-46											Feb-46																	
	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. ตัดปลา Albacore	→	→																											
2. เตรียมตัวอย่างเพื่อทำ Standard สี			→	→																									
3. ทำการทดลองฆ่าเชื้อที่ 112 °C							→	→																					
4. ทำการทดลองฆ่าเชื้อที่ 117 °C									→	→																			
5. ทำการทดลอง ฆ่าเชื้อที่ 122 °C														→	→														
6. ตรวจสอบสีและ D/W																→	→	→	→	→	→	→							
7. เช็คค่า P/W																→	→	→	→	→	→								
8. [illegible]														→	→	→	→	→	→	→	→	→	→	→	→				

รายละเอียดอุปกรณ์และเครื่องมือที่ใช้ในการวิจัย

1. ปลา Albacore ประมาณ 1,000 Kg.
2. ตู้ Retort No. 17 สำหรับฆ่าเชื้อตัวอย่าง
3. กระป๋อง 307 x 108 TFC
4. เครื่องวัด P/W (รบกวนทาง QC ช่วยเช็คผลให้)

เอกสารแนบหมายเลข 5

Effect of Processing Conditions on Yield and Color of Albacore Tuna

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ABSTRACT

This research was to study effect of processing temperature from 112 to 122 °C and level of Fo (4 and 8.5 min.) on product yield as expressed by pressed weight value and color (L, a, b and total color difference,Δ E) of Albacore (Thunnus alalunga) tuna. The results found that tuna processed with the high processing temperature had a lower finished product yield because of greater loss of water and water soluble solid. However, when using the low temperature and processed to a high level of Fo a greater yield loss was found due to prolonging processing time. After processing, surface color were always darker than the overall color. The optimum temperature to maximize overall color is higher than that to maximize surface color when fish was processed to a low-level o Fo.

Keywords. *Canned tuna, thermal processing, color, Albacore*

INTRODUCTION

Thailand is the world's largest exporter of canned tuna. In 2002, value of Thai exported tuna worth 668 Million US$. World consumption of canned tuna has expanded because consumer realize of its nutritious; rich source of lean protein, omega-3 fatty acids, vitamins and minerals, and also low in saturated fats and cholesterol.

The key goal of canned tuna industry is to produce a higher quality product, ensure product safety with increasing product yields and productivity. In manufacturing of canned tuna, the precooked tuna is packed tightly in a hemectically sealed can and then heat processed to achieve the desired degree of commercial sterility. During the processing, heat may have negative effect on product qualities. Fish mussel protein is changed by heat denaturation resulting in loss of water and water soluble solid due to decreasing of water holding capacity (Perez-Martin et. al. 1989). This lost is economically importance since it leads yield lost of canned product. Moreover, heat causes color change in canned fish.

The slow heat transfer rate in solid packed food limits the applicability of high temperature short time (HTST) processes. Many studies had focused on investigating optimum processing condition, which is the temperature and time combination, for optimizing quality retention in solid packed food. Almost all studies were limited to computer simulation (Teixeira et.al. 1969; Silva et. al. 1992; Silva et. al. 1993; Lund, 1977; Pornchaloempong et.al., 2003). Since the time-temperature relationship strongly affects the quality of cooked mussel such as color, juiciness and texture (Martens et. al. 1982). Optimum processing condition for canned tuna are great important. Optimum processing condition for canned tuna could not found in literature.

Albacore(*Thunnus alalunga*) is the important tuna species to the canned tuna industry. It is the only tuna species that can be labeled as a premium white meat tuna because of its very light colored flesh. Therefore, color of canned albacore is one of the most favorable attributes for consumers.

The objective of our investigation was to determine effect of processing temperature and level of lethality (Fo) on surface and homogenized color of canned Albacore. The result of processing conditions on the product yield was also investigated.

MATERIALS AND METHODS

Fish preparation

The premium quality frozen Albacore (*Thunnus alalunga*) was used in the experiment. Fish preparation was carried out in the Thai Union Manufacturing Co. Ltd. processing plant following the usual manufacturer procedure. The processes including thawing fish until internal temperature of 1-5 °C and eviscerating. The fish were precooked by steam to a final backbone temperature of 65 °C and then cooled down. After cooling the fish were transferred to a cleaning area for loin cleaning. Head, skin, red (dark) meat and bone were removed. The white (light) meat was chopped and solid packed in water in a hermetically sealed can of dimensions 307 x 113 to filling weights of 120 g.

Heat Penetration Test

Heat penetration test was conducted in a manufacture's horizontal still retort. Six cans were equipped with stainless steel, needle type thermocouples (Ellab, Denmark) with the thermocouple tips located at the cold points. The cans initial temperature were controlled at 21 ° C by spraying cold water. The cold point temperatures and retort temperature were recorded during the entire process at 30 s interval using a data acquisition (Ellab model 9008, Denmark). Two replications were carried out. The heat penetration data were analyzed to determine the average heat penetration parameters; jh and fh. Ball's process times were calculated for Fo of 4 and 8.5 and RT of 112, 117 and 122 °C .

Thermal Processing

The cans were processed in the same retort used for heat penetration test. Initial product temperatures were controlled similar to the heat penetration test. The retort was operated in three stages: venting (5 min), heating at constant retort temperature of 112, 117, 122 ° C for predetermined time to achieve target Fo of 4 and 8.5 , then cooled with water until center temperature reached 50 °C. Two replications with eighty cans were performed for each treatment. After thermal processing, the cans were aging at room temperature for 10 days.

Product Evaluation

Pressed weight

The pressed weight was determined following the standard procedure using the Press weight machine (Luthi Machinery & Engineering Co ,Inc. CA, USA). The procedure includes draining the free liquid for 1 min and pressing the can content in the cylinder by applying pressure slowly through a cylinder plunger at a uniform rate. Then the pressed cake was weighted.

Color determination

The color was determined using a Color Difference Meter (Model MiniScan XE Plus, Hunter Assoc. Laboratory, Virginia). The apparatus was previously calibrated with white plate. Results were recorded as Hunter L a b values where L describes lightness, a redness, b yellowness. Color difference, ΔE, was calculated from a, b and L parameters, using the following equation:

$$\Delta E = (\Delta a^2 + \Delta b^2 + \Delta L^2)^{1/2}$$

Where Δa is $a - a_o$, Δb is $b - b_o$ and ΔL is $L - L_o$; subscript 'o' indicates initial color.

Two types of samples color, surface color and color of the homogenized fish, were measured. Four measurement of the surface color were scanned directly on the fish surfaced in the can after drained for 2 minutes by dividing surface area into 4 sections. For the homogenized samples, the fish was minced with a food blender for 1 min at low speed and packed back into the same can. Then the surface color was measured as the same manner. Twenty can were used for each treatment.

Initial color was measured with fish after packed in a can without water. Fifty samples cans were used to represent initial albacore color.

Statistical Analysis

The statistical were performed using the SAS software package. Ducan's multiple range test was used to separate means .

RESULTS AND DISCUSSION

The average jh value of solid packed Albacore in water was 1.16 and average fh value was 19.48 min. These values were used for calculation of the Ball's processing times using the constant retort temperature of 112, 117 and 122 ° C for equivalent Fo of 4 and 8.5 min. Processing temperature and time combinations used for the experiments were shown in table 1.

Table 1 Retort Temperature and corresponding processing time.

Processing Temperature (°C)	Fo (min)	Processing Time (min)
112	4	63
	8.5	100
117	4	40
	8.5	52
122	4	30
	8.5	36

Pressed weight

Pressed weight is weight of pressed cake after aqueous was pressed out from the content. Tuna industries used pressed weight to determine yield of canned tuna.

During processing, heat induces denaturation of miofribrilla protein resulting in damage mussel structure. This will lead loss of expressional water and also water-soluble constituents due to decreasing of water holding capacity. The result in Fig 1 shown that the fish processed to the same Fo at the temperature of 122 ° C had significantly lower pressed cake weight compared to the fish processed at 112 and 117 ° C. Processing at relatively high temperature may result in destroying protein structure more than lower temperature and cause more water loss from fish mussel. Poon et. al. (2001) also found that in ground meat patties cooked using high heat transfer rate loss more water than the one cooked on the low heat transfer rate.

At processing temperature of 112 ° C, pressed cake weight of the fish processed for achieving the target Fo = 4 was significantly higher than that of Fo = 8.5. However, there were no significant different between products which were processed at temperature of 117 and 122 at the two levels of Fo. This could be explained by a difference of holding times. At processing temperature of 112 C, the holding time different between Fo = 4 and 8.5 was 47 min which is much greater than holding time different at 117 and 122 ° C (12 and 6 min). The result suggested that prolonging cooking time causes fish lost more solid and decreases yield.

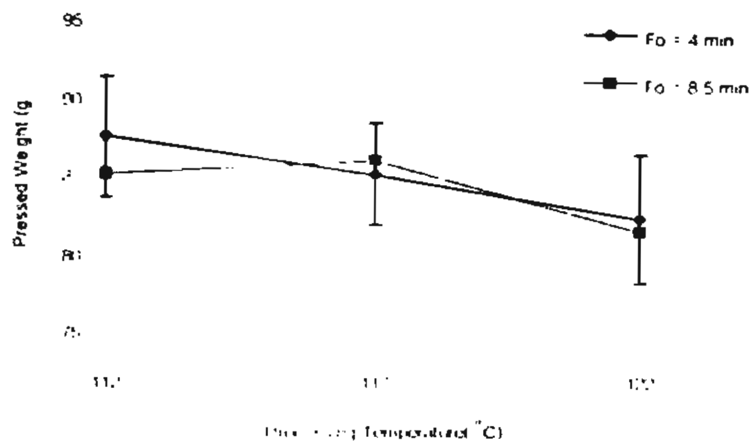
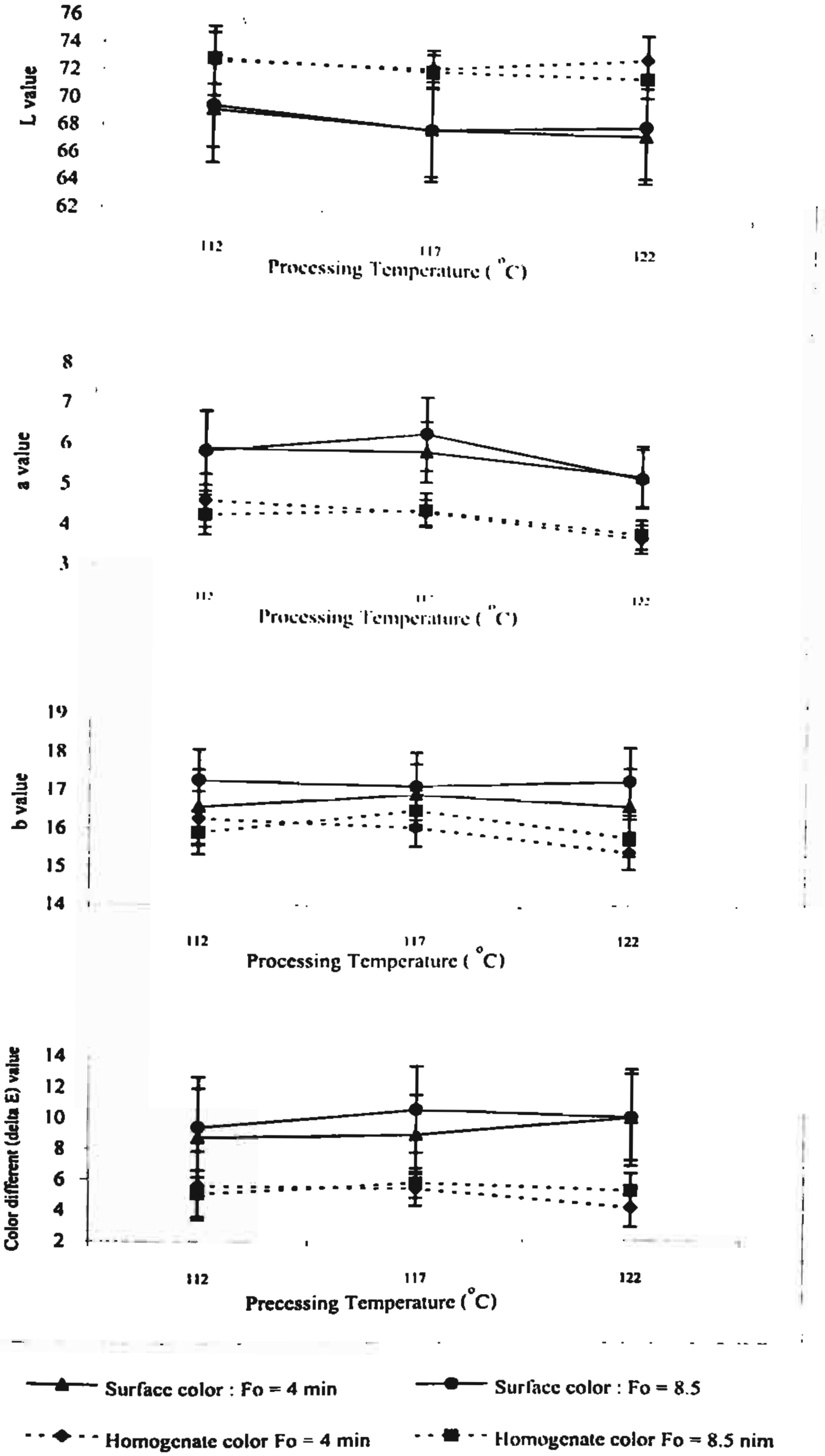


Fig 1 Effect of processing temperature and Fo on processed weight of canned Albacore

Color

The color characteristics of the precooked Albacore before processing were averaged. The lightness (L) was 76.51, redness (a) was 1.46 and yellowness (b) was 14.0. High value of L with low value in a and b indicated that the cooked Albacore flesh has a very light color. This tuna specie is the only species that could be labeled as a white meat tuna. After processed, the flesh became brown as indicated by decreasing of L value and increasing of a and b values. The color change in fish during heating might be due to oxidation of iron pigments from ferrous to ferric derivative. Brown (1967) stated that in canned tuna denatured globin ferrohemochrome breaks down into ferric derivatives. Other possible factors that may have contributed to the brown color of canned albacore include the caramelization of carbohydrates as a result of high temperature processing and Maillard reactions between reducing sugars and amino groups.



igure 2 Effect of processing temperature and level of Fo value on color of Albacore

Fig 2 presents effects of processing temperature at two levels of Fo on L, a, b and Color difference (Δ E) of canned Albacore. The result demonstrated that with the same processing condition, the change of surface color was always greater than color of the fish from the same can after homogenized. Both color attributes are important for consumer acceptability since the usage of canned tuna often required mixing or blending well before served. In this experiment, the tuna was packed tightly in solid style, heat penetrates into a can mainly by conduction. Because of slow heat flow rate, heat accumulation at the can surface causes product changing color before diffusing inside the can.

When fish processed to Fo of 4, using of the low temperature long time process benefit surface color than the high temperature short time process. These were indicated by higher of L value and lower of Δ E value. In contrast, the result indicated that to obtain a better overall color, high temperature short time process is required. This result agreed to the computer simulation results by Silva et. al. (1992) which found that optimum temperature to maximize overall quality is higher than that to maximize surface quality. However, fish process to Fo of 8.5, the low temperature long time process was preferred to achieve a better color at the surface as well as the overall fish color.

CONCLUSION

Understanding the effects of processing condition on product qualities can facilitate a canned tuna processor to balance the canned yield and improve product quality. These results suggested that tuna processed at relatively high temperature caused negative impact on the finished product yield. However processing at the low temperature but targeting a high level of Fo also cause greater yield loss due to prolonging processing time. Different processing temperature affects color differently. After processing, surface color were always darker than the overall color due to a low heat transfer rate of conduction heating food. The optimum temperature to maximize overall color is higher than that to maximize surface color when fish was processed to a low level o Fo. Results support the economic importance of selecting the optimum processing temperature and avoiding overprocessing and indicated that optimum processing condition for each product quality should be individually evaluated.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Thai Union Manufacturing Co. Ltd. for supplying fish, allowing us to used the processing plant and evaluating the products. Financial support provided by the Thailand Research Fund (TRF) are gratefully acknowledged.

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