IMPROVEMENT OF QUALITY ATTRIBUTES OF COMMERCIALLY STERILE EGG PRODUCT BY THE USE OF IMPROVED FORMULATION AND OPTIMIZED THERMAL PROCESS

by

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(Under the Direction of Romeo T. Toledo)

ABSTRACT

Improved formulations and high temperature short time thermal processing produced good quality shelf stable ready-to-eat retorted eggs in quad-laminate pouches. Processing at 130°C reduced browning discoloration, and minimized off-flavors. Formulations consisting of liquid whole egg, liquid margarine, citric acid, and hydrocolloids prevented green discoloration, rubbery texture development, and syneresis. Use of xanthan effectively stopped syneresis and consumer panelists gave the highest preference for the formulation with 0.2% xanthan.

The effective heat transfer coefficients (h) during the various stages of retort processing of the egg mix in quad-laminate pouches and half steam-table trays were determined using a best-fit between the measured centre-point temperature and values calculated by a finite difference heat transfer model using retort temperatures measured during actual thermal processes in three different retorts. The h-values were dependent on the type of retort, container type, container holding racks, exposure of the container to the heat transfer medium, and the product.

Quality retention values for the egg mix processed in quad-laminate pouches and half-steam-table trays in the three retorts were calculated using a formula that took into account the D-value for quality degradation. The D-value for quality degradation of the eggs was determined as a change in color expressed as the a*-value and was calculated to be 910 min at 100 C. Data on a*-value of cooked egg processed at 100, 115, and 130°C was used to calculate a z-value of about 25°C. Using these values, the volume average quality retention for the quad-laminate pouches was between 0.67-0.78 when processed to commercial sterility in the three retorts. The quality retention values in eggs processed in the half-steam table trays were between 0.55 and 0.58. When thermal processes were simulated using the heat transfer model and values of effective heat transfer coefficients determined under actual thermal processing conditions, it was shown that processing at the higher temperature of 130°C resulted in higher quality retention values compared to traditional processes at 122°C. A pre-heat step at 100°C before raising retort temperature to the scheduled processing temperature also resulted in higher quality retention values compared to direct processing at the designated processing temperature.

INDEX WORDS: Retorted egg, MRE, effective heat transfer coefficients, quality retention, pre-heating, heat transfer model, optimization

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A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2005

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May 2005

DEDICATION

This work is dedicated to my parents whose sacrifices have made me what I am today.

ACKNOWLEDGEMENTS

My sincere thanks to Dr. Toledo for being my major professor and mentor during my stay at UGA. His text book on Food Engineering first drew me to this field and was instrumental in my pursuit of doctoral studies in Food Science. His suggestions and contributions to this project and towards my development are immense. The experience and knowledge I gained by working in his lab is invaluable. I also wish to recognize my committee members: Dr. Chinnan, Dr. Kerr, Dr. Singh and Dr. Thai. Their insights were very useful in the final shaping of this dissertation.

I thank the USDOD for funding this project and also the UGA Graduate School and the Food Science Department for funding my stay at UGA.

I am most thankful to Jegan who worked with me on every experiment in the last two years of this project. He was my right hand man and the work accomplished on this project would not have been possible but for his assistance and ideas at every step. But for him, the experiments at Rutgers could never have come to fruition. Thanks to Rieks Bruins for facilitating the conduction of experiments at Rutgers. I thank Edwin for conducting the sensory analysis on the products. My sincere thanks to Aswin for his contribution to this project via his Thermocal program for recording real time temperatures and calculation of F-values. His program greatly facilitated the development of optimal thermal processes. I am also deeply thankful to David Peck for all his technical contributions, from the soldering of thermocouples to fitting the retort with the pump to ensuring the smooth operation of my experiments. This project would

definitely not have succeeded without his help in the pilot plant. Thanks to Carl Ruiz for lending a helping hand wherever it was needed.

I would like to acknowledge all my lab mates over the years: Edwin, Aswin, Poom, Yusuf, Amr, Jegan, Ben, PJ, Heather, Inci, and all the other friends I made in this department and at the University over the years who made my stay at UGA so pleasurable. Sincere thanks to Mrs. Toledo for being the lab's matriarch and organizing the numerous parties and cooking innumerable lunches in the lab to relieve the drudgery of graduate life. Thanks to UGA cricket club which provided me with a distraction from my studies during my stay here.

Lastly, I thank my family, my parents for their sacrifices, my brother Ravi for his friendship. I thank my uncle and aunt, Drs. Chari and Vijaya Kandala, and cousin Sridhar for letting me live in their house and being my home away from home. I acknowledge the support of all my other family members, cousins and friends who helped me spend these long years away from home.

I finally acknowledge my fiancée Shipra for her love, caring, support and encouragement.

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CHAPTER 1

INTRODUCTION

The United States Military is currently the biggest consumer of commercially sterilized Meals- Ready-to-Eat (MRE) products but the convenience of these products has generated demand in the civilian market as well. A variety of products in pouches and rigid plastic containers are currently produced by military contractors and some of these products are available for the civilian market. For the military, MRE products are the primary sustenance of troops in the field. A quality meal is essential to maintain high troop morale and to provide adequate nutrition. Unconsumed product because of its poor quality would be a waste and would risk soldiers' ability to safely and efficiently perform their duties. To be commercially successful, processors must produce the best possible quality MRE products for consumers.

Commercially sterile, plain scrambled egg packaged in half steam-table trays and in quad-laminate pouches are the poorest quality products in the military ration program. Consumers of these products complain primarily about a rubbery texture, lack of egg flavor, undesirable red-tinge/brown color as opposed to the normal light yellow color, off-flavor and undesirable aftertaste. These deficiencies develop because of an unsuitable formulation and thermally induced chemical reactions. Plain egg in the meals-ready-to-eat (MRE) military ration is no longer produced because of unacceptable quality (Kluter 2002).

A desirable shelf-stable egg product should have the typical yellow color, and the odor and flavor should be characteristic of freshly scrambled eggs. In addition, the product should be

moist and slightly spongy but not rubbery, free of noticeable agglomerates, and devoid of liquid caused by syneresis/weeping. The commercially sterile product must meet the minimum shelf life requirement of 36 months at 26.7°C (80°F). Nutritionally, the product should have protein content not less than 8.0%, fat content not more than 17%, and salt content between 0.5% and 1.0% (Anon 2003).

In order to produce a desirable product a three pronged approach was adopted. The first part of the project dealt with development of a formulation and mix preparation techniques. The second part consisted of developing a scheduled thermal process that would result in commercially sterile products with acceptable quality. The third part consisted of using a 3-D finite difference based mathematical model developed using Matlab to determine the effective heat transfer coefficients for the retort process and use them to compare different retort schedules to find the process with the highest quality retention. The objectives of the study can hence be summarized as:

1. Determine the effects of pre-treatments on the liquid egg formulation prior to filling, the thermal processing schedule and formulation on color, instrumental texture parameters and sensory properties of the thermally stabilized egg product
2. Determine the effective heat transfer coefficients during the retort processing of an egg mixture in quad-laminate pouches and polymeric half steam-table trays
3. Compare the quality retention values for various experimental and simulated retort process schedules based on heat transfer coefficients obtained from (2) above to determine the best thermal process.

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CHAPTER 2

THEORY AND REVIEW OF LITERATURE

Eggs

Hydrogen sulfide is produced by the breakdown of S-S bridges in the protein molecule when the protein is heated above 60°C. The formation of volatile sulfur containing -compounds requires the presence of oxygen and is favored by alkaline pH (Germs 1973). Preventing hydrogen sulfide formation also prevents the formation of green color in the processed eggs. The green color is the reaction product of hydrogen sulfide from the albumen and iron from the yolk (Baker and others 1967). The pH of liquid whole egg can vary from 7.0 to 7.6 depending on the history of the in-shell egg (age, oiling of shell, temperature of storage, etc.). The pH within this range is a function of the amount of carbon dioxide in the shell eggs at the time of breaking (Cotterill and McBee 1994).

Freezing of cooked egg white or whole egg causes them to become tough or rubbery with separation of water (syneresis). Hawley (1970) prevented syneresis in cooked frozen egg white by adding 2 to 4% of a water-binding carbohydrate such as algin, carrageenan, agar or starch. Davis and others (1952) observed that a yolk-white ratio of 40:60 to 80:20 when diluted with 20% water and adjusted to pH 6.0 – 7.0 before cooking is suitable for freezing with no adverse manifestations in quality (Cotterill 1994).

A wide range of ingredients have been added to whole egg to prepare commercial scrambled-egg mixes. The most common added components are nonfat dry milk, whey,

vegetable oil, water, gums (CMC and xanthan being the most common), organic acids or other chelators (citric acid, lactic acid or phosphates), salt and egg white. Cooked egg from scrambled-egg mixes have good reheating stability, color and texture but a frequent complaint is their lack of flavor. This may be because there is not enough hydrogen sulfide formed when the mix is adjusted to a low pH to avoid greening (Cotterill 1994).

Hydrocolloids

Food hydrocolloids are high-molecular-weight hydrophilic biopolymers. They are used in foods for altering the texture, flavor and shelf-life. 'Hydrocolloids' refers to polysaccharides extracted from plants, seaweeds and microbial sources as well as gums derived from plant exudates, and modified biopolymers made by the chemical or enzymatic treatment of starch or cellulose (Dickinson 2003). All gums thicken and impart viscosity to aqueous solutions and some can from gels. Some gums can also be used as syneresis inhibitor in foods like cheese and frozen foods (Glicksman 1982).

Xanthan

Xanthan gum is derived from the microorganism *Xanthomonas campestris*. It is completely soluble in hot or cold water and forms high viscosity solutions at low concentrations which contributes to its effective stabilizing properties. General concentrations of use in food systems are between 0.1 and 0.3%. In some cases concentrations up to 0.9% have been used for frozen foods (Glicksman 1982).

Carrageenan

Carrageenans are linear polysaccharides of D-galactose and 3,6-anhydro-D-galactose extracted from various red sea weeds. Three principal forms of carrageenan are kappa (gelling), iota

(gelling) and lambda (non-gelling). All carrageenans are soluble in hot water at temperatures above 70°C. λ-carrageenan and sodium salts of κ– and ι-carrageenan are soluble in cold water (Glicksman 1983).

Texture Analysis

Instrumental Texture Profile Analysis (TPA) was developed as a way of analyzing a series of textural parameters in only one test and to serve as a bridge between the instrumental and sensory evaluation of texture. In 1963, Szczesniak's team used the General Foods (GF) Texturometer to perform the TPA (Friedman and others 1963). The unit composed of a plate supported by a flexible arm attached to a strain gauge, and a plunger which acted upon a piece of the food sample, compressing it twice in a reciprocating motion intended to imitate the action of the jaw on the food inside the mouth. The strain gauge measured the resistance force and recorded it on a chart recorder. The plunger was originally constructed in five sizes and made of three different materials: lucite, aluminum and brass. The sizes varied from 2 cm to 5 cm in diameter and all of them were 2.5 cm in height (Pons and Fiszman 1996). The curve generated by the GF Texturometer was a plot of force as a function of time. Szczesniak (1963) interpreted the texturometer curves and defined hardness, cohesiveness, elasticity, adhesiveness, brittleness, chewiness, gumminess and viscosity.

Various researchers (Drake 1966; Bourne 1968; Sherman 1969) as reported by Breene (1975) and Pons and Fiszman (1996) pointed out the deficiencies of the pioneering tests performed by Friedman and others (1963). Bourne and others (1966) adapted the Instron Universal Testing Machine to perform the TPA that addresses some of the deficiencies of the

Texturometer method of Friedman and others (1963). Bourne (1978) defined seven textural parameters from the TPA curve and they are as follows (Figure 2.1):

1) ***Fracturability*** is "the force at the first significant break in the curve." It is identified as a change in the inflection of the curve.
2) ***Hardness*** is defined as "the peak force during the first compression cycle."
3) ***Cohesiveness*** is defined as "the ratio of the positive force area during the second compression portion to that during the first compression, excluding the areas under the decompression portion in each cycle."
4) ***Adhesiveness*** is defined as "the negative force area for the first bite, representing the work necessary to pull the plunger away from the food sample."
5) ***Springiness*** is defined as "the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite."
6) ***Gumminess*** is defined as "the energy required to disintegrate a semisolid food product to a state of readiness for swallowing" (Szczesniak 1995). As per the definition, gumminess is only reported for semisolid foods. Instrumentally, it is defined as "the product of hardness x cohesiveness".
7) ***Chewiness*** is defined as "the energy required to masticate a solid food product to a state of readiness for swallowing" (Szczesniak 1995). As per the definition, chewiness must only be reported for solid foods and not for semisolid foods. Instrumentally, it is defined as "the product of gumminess x springiness" (equivalent to hardness x cohesiveness x springiness).

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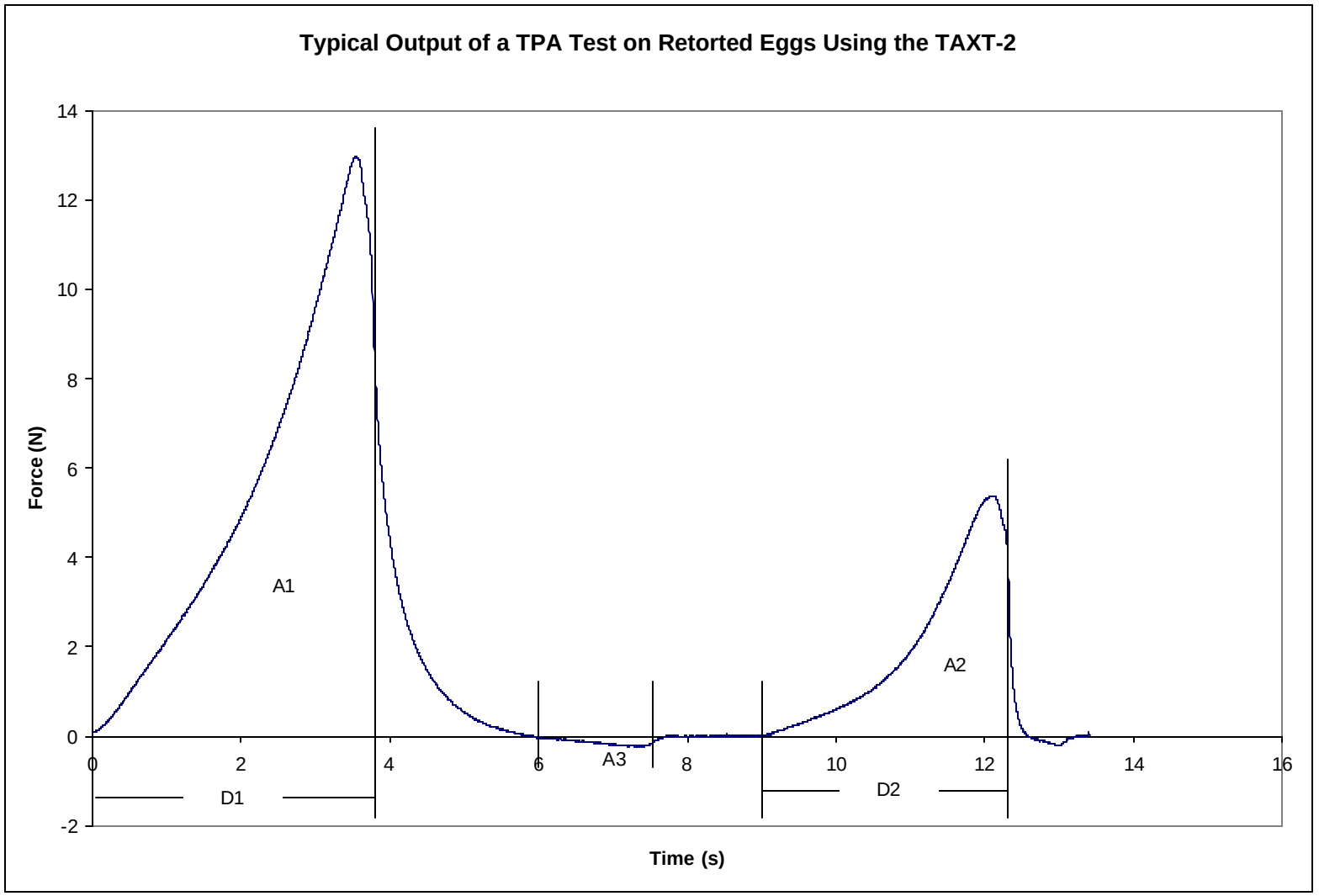

Figure-2.1: Typical output of a TPA test on retorted eggs using the TAXT-2

Testing Conditions

Gels are mostly sampled by cutting into standard sized cubes or cylinders or by allowing the sol to set into a gel in molds of desired shape and size. Most researchers have used sample sizes of 1-3 cm side or diameter for cubes and cylinders respectively and a sample height of 1.5-3 cm in both cases (Pons and Fiszman 1996).

The size of the compressing unit (or probe or plunger) is important with respect to the sample cross-sectional area. When the probe is larger than the sample, the forces measured are largely a result of uniaxial compression of the sample. In the opposite case, where the sample is larger than the probe, the forces can be from puncture or a combination of compression and shear. Most recent work done on TPA uses compression devices larger than the sample cross-section, in order to measure only the uniaxial compression forces. (Pons and Fiszman 1996).

Gel type systems completely breakdown at compressions greater than 70-80%. In that case, the second compression cycle would only encounter portions or small pieces of the initial sample and not a weakened sample with just the first internal cracks as a result of the first compression. Pons and Fiszman (1996) in their review paper report that deformation levels between 20-50% have been commonly applied in recent works on gel systems. At these levels, samples do not break but it is still possible to obtain valuable information on important parameters such as hardness, springiness, cohesiveness and their derivatives gumminess or chewiness. They also suggest conducting tests at two deformations might be helpful in gathering all possible information about different aspects of mechanical behavior of a given sample. Pons and Fiszman (1996) found that most TPA tests have been performed on gel food systems with crosshead speeds in the range of 10-250 mm/min.

Variable Retort Processes

Durance (1997) in his review paper on variable retort temperature (VRT) processes pointed out that the concepts used to justify high-temperature - short-time (HTST) and ultra high temperature (UHT) processing used on liquid foods in containers or continuous aseptic processing are not directly applicable to solid foods processed in thick profile packages. The outer portions of the solid foods in the thicker containers receive much greater heat than the centre and the surface overcook became much worse as the temperature increased.

Teixeira and others (1975) evaluated the effects of variable retort temperature profiles and different cylindrical container geometries on thiamin degradation in a conduction heated food during thermal processing. For variable retort temperature (VRT) profiles, they considered step functions, ramp functions and sinusoidal functions. They found that maximum thiamin retention was similar for all the VRT profiles tested when processes had an equivalent sterilizing value. In case of the container geometries, they found a maximum retention of 60% in containers with height-to-diameter ratios less than 0.2 and greater than 10.0. The worst thiamin retention of 40% was obtained for containers with the ratio close to 1. This result shows the potential of thin profile retortable pouches in improving quality of commercially sterile egg.

Holdsworth (1985) in his review paper on the optimization of thermal processing reported about a study by Sjöström and Dagerskog (1977), where they evaluated VRT processes by trying to reduce the difference in heating effect between the surface and centre for a conduction heated food (chopped fish) and a part convection heated food (liver paste) for specific can sizes. The results of computer simulation were compared with experimental work using the sterilization effect, enzyme inactivation and a sensory quality *C* value that was based on the rate of browning in fish (z = 26°C). For constant temperature processes, the optimum

processing temperature to produce the minimum *C* value increased with increasing *z* value. Hence, it is necessary to know the *z* value for the particular heat-induced change under consideration to evaluate processing effects. In their VRT experiments to the same maximum processing temperature, the authors found that a double-ramp (a linear increase in temperature followed by a linear decrease) produced the smallest cook value whereas a combination of a ramp and constant holding was significantly better than a step (constant holding for the total time period).

Saguy and Karel (1979) in their experiments with VRT processes concluded that each combination of container geometry, product and critical quality attribute would yield a unique VRT solution. Banga and others (1991) used surface quality instead of optimum nutrient retention to evaluate VRT processes and showed that surface quality improved up to 20% with the best VRT processes. Balsa-Canto and others (2002) in a recent study on optimization of thermal processes came up with a VRT profile that had three ramps (decreasing, increasing and decreasing) of temperature between end of come-up and the beginning of cooling down of the retort.

Heat Transfer Coefficients During Retort Processes

The rapid heating rate of the conduction heated foods processed in thin profile quad-laminate Meals Ready-to-Eat (MRE) pouches and polymeric half steam-table trays is the reason for their popularity in replacing traditional cylindrical metal cans. To ensure the high quality of the final product expected from these packages, it is essential to know the constraints to heat transfer during the thermal processing. The heating rate at the 'cold spot' of a conduction heated food is limited by the internal resistance of the food to heat transfer (which is a function of its

thermophysical properties, geometry and dimensions) and the total external resistance to heat transfer from the heating medium to the outside surface of the food. The total external resistance includes the convective resistances from the heating medium to outer surface of the container and from the inner surface of the container to the outside layer of the product, and the resistance of the packaging material (Silva and others 1992b). Earlier computer models developed to model retort processes to determine the temperature distribution within the product usually assumed infinite surface heat transfer coefficients (h). This assumption of negligible surface resistance to heat transfer is valid when foods in metal containers are processed in a saturated steam medium (Tucker and Holdsworth 1991). Heat sealed plastic containers such as quad-laminate pouches and half steam-table trays require processing under overpressure to maintain the integrity of the container during the process. These types of containers are hence processed in steam/air mixture where the air provides the overpressure or in full water immersion retorts with air or steam overpressure. In heating media other than condensing steam, h at the surface is finite and has to be accounted for while modeling the heat transfer into the containers during processing. Tung and others (1984) determined surface heat transfer coefficients using brick-shaped metal blocks. McGinnis (1986), Bhowmik and Tandon (1987), Chau and Snyder (1988), Tucker and Holdsworth (1991) were some of the researchers who used finite h values in their heat transfer models to containers processed in steam/air mixtures or under full water immersion with air overpressure.

Tung and others (1984) found that the surface h increased exponentially with the mass fraction of steam in the steam/air mixture. Values of h were also influenced by the flow rate of the medium but were independent of the medium temperature. Lebowitz and Bhowmik (1990) determined the values of h using a computer-based optimization method that incorporated the

process data, a two-dimensional finite difference model, and optimization criteria. They concluded that h values during come-up, heating and cooling cycles were not significantly different from each other. They also found no significant differences in h values whether heating aluminum/plastic laminate pouches or other types of plastic pouches during the combined come-up and heating stages. Tucker and Holdsworth (1991) developed a three-dimensional rectangular model that could be used with different h values in the three directions to apply to semi-rigid plastic containers that contained headspace gases trapped under the lid. The difference in the material of the lid and the air under its surface resulted in h value different from that in the other two directions. Silva and others (1994) found that the optimum average quality retention is independent of the surface heat transfer resistance.

Optimization of Thermal Processes

Improvement in quality of products produced by high temperature short time (HTST) thermal processes is possible since the rate of inactivation of microorganisms increases more rapidly with temperature than the rate of heat-induced deterioration of quality attributes(Lund 1977). However in case of non-agitated in-container processed high-viscosity or solid foods the primary mode of heat flow is through conduction, the need to sterilize the slowest heating point in the container results in prolonged high temperature exposure of product near the container walls, thus, the theoretical advantage of a HTST process may not be successfully achieved.

Teixeira and others (1969) developed the first computer program based on finite difference equations for two dimensional heat transfer to predict the time-temperature distribution within a cylindrical container. Their program assumed infinite surface h and predicted the spatial temperature distribution as a function of processing time using only the

thermophysical properties of the solid product as inputs. Other researchers tried to minimize the effect of thermal treatment on foods. Ohlsson (1980a) advocated that surface quality was the best optimization criterion for appearance and odor, and volume average quality criterion worked best for taste, consistency, and/or nutrient retention. While some studies have advocated the use of variable retort temperatures for better product quality, others have concluded that a constant optimal temperature is as effective (Silva and others 1992b). Silva and others (1994) found that the optimum temperature for maximum average quality is always higher than the corresponding one for surface quality, but this rule is not consistent for all products. While several objective functions can be considered for optimization of a retort process, Silva and others (1992b) concluded that maximization of nutrients and quality attributes are usually the most appropriate factors that address the needs of consumers. They also concluded that the optimal sterilization temperature to maximize the surface quality and nutrient retention is independent of the rate of degradation (D-value) of a quality attribute and depends only on the z-value or the temperature dependence of the rate of change in the quality attribute. Ohlsson (1988) tabulated the optimal cook values for various products and the z-values for the most relevant quality factor for each product based on published data from other researchers. Optimal cook values for various package shapes were also tabulated. However, no cook values for eggs or egg products or the relevant z-value to be used for quality optimization were mentioned in the paper.

Calculation of Target Lethality

Thermal inactivation of microorganisms follows first-order reaction kinetics. First-order inactivation kinetics is mathematically represented by Equation (2.1) (Silva and others 1992a):

$$\frac{dN}{dt} = -k_T M \tag{2.1}$$

where t is the time, k_T is the rate constant at temperature T, and M is the number of microorganisms.

Food scientists and microbiologists use the concept of D-value or the decimal reduction time, instead of k. The z-value gives the temperature dependence of the D-value. D_T is defined as the time required to reduce the microbial population M by one-log unit at the temperature T and z is defined the temperature rise needed to reduce the decimal reduction time by one log-unit. They can mathematically be defined by the following equations (Silva and others 1992a):

$$D_T = \frac{\ln(10)}{k_T} \tag{2.2}$$

$$D_T = D_{refm} \times 10^{\frac{(T_{refm} - T)}{z}} \tag{2.3}$$

where D_{refm} is the D-value at temperature T_{refm}.

The target lethality at the coldest spot (F) is defined as (Stumbo 1973):

$$F = \int_0^t 10^{\frac{(T - T_{refm})}{z}} dt \tag{2.4}$$

Cook Value

The definition of cook value in the present study was based on the expression for retention of a nutrient or a quality index. Knowing the D-value (D_{refq}) at a reference temperature (T_{refq}) and the z-value (z_q) for the loss of a nutrient or a quality index, the time-temperature profile at a single point in a food can be utilized with the above parameters to calculate the retention of a nutrient or a quality index using the following equation (Silva and others 1992a):

$$\frac{N}{N_0} = 10^{\left[-\frac{1}{D_{refq}} \int_0^t 10^{\frac{(T - T_{refq})}{z_q}} dt\right]} \tag{2.5}$$

where N is the level of nutrients or quality factor at time t, N_0 is the initial level of nutrients or quality factor and T is the temperature at a particular point as a function of time t. N/N_0 may be considered as the fraction of the original quality factor retained after thermal processing. The closer N/N_0 is to unity, the better the processed product quality. Mansfield (1962) proposed the concept of cook-value to compare thermal processes in terms of quality degradation. Similar to the F-value, the cook-value (C) was defined as:

$$C = \int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt \tag{2.6}$$

Mansfield (1962) proposed this concept for processes where the time-temperature profile can be assumed to be uniform spatially, such as in aseptic processing of low viscosity foods.

Ohlsson (1980a,b) defined volume average cook value to evaluate the mean impact of a thermal process as:

$$C_{ave} = \frac{1}{V}\int_0^V \int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt dV \tag{2.7}$$

The above equation defined by Ohlsson (1980a,b) is independent of D-value for quality factor (D_{refq}) degradation. A desirable process is one that would result in the least C_{ave} value. The C_{ave} value defined by Eq. 2.7 has also been used by Tucker and Holdsworth (1991).

Silva and others (1992a) showed that D_{refq} values can play an important role in process optimization of a conduction heated food. In order to optimize the overall quality retention in the case of a homogeneous conduction-heated food as is the case in our study, the quality retention must be integrated over the total volume taking into account the different time-temperature profiles as a function of position in the container. The definition for volume average quality retention is (Silva and others 1992a):

$$\left(\frac{N}{N_0}\right)_{ave} = \frac{1}{V}\int_0^V 10^{\left[-\frac{1}{D_{refq}}\int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt\right]} dv \qquad (2.8)$$

where T is the time-temperature profile as a function of position and V is the volume. This approach takes into account the D_{refq} value for the quality factor or nutrient retention and is suggested by Silva and others (1992a) as a better approach to optimization of a conduction heating process compared to the average cook value (C_{ave}) approach suggested by Ohlsson (1980a,b). The maximization of nutrient retention $(N/N_0)_{ave}$ is desired. An optimization algorithm based on maximal $(N/N_0)_{ave}$ is not mathematically equivalent to that based on minimal C_{ave}.

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CHAPTER 3

DEVELOPMENT OF A QUALITY READY-TO-EAT RETORTED EGG PRODUCT IN MEALS READY-TO-EAT (MRE) POUCHES[1]

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Abstract

Improved formulations and high-temperature, short-time thermal processing produced good quality shelf stable ready-to-eat retorted eggs in quad-laminate pouches. Processing at 130°C reduced browning discoloration, and minimized off-flavors. A holding step at a retort temperature of 100°C with no overpressure raised product temperature to 70°C before the scheduled process was applied. Formulations consisting of liquid whole egg, liquid margarine, egg flavor, citric acid and hydrocolloids prevented green discoloration, rubbery texture development, and syneresis. Xanthan effectively stopped syneresis without imparting undesirable flavor or mouthfeel. Consumer sensory panelists gave the highest preference for the formulation with 0.2% xanthan. Instrumental Texture Profile Analysis (TPA) did not discriminate sufficiently between samples with different types and levels of hydrocolloids. A retorted product with a fluffy texture resulted from a combination of xanthan in the mix and a high speed gear mixer to homogenize the egg formulation prior to filling into the pouches.

Introduction

Commercially sterile, plain scrambled egg packaged in half steam-table trays and in quad-laminate pouches are the poorest quality products in the military ration program. Consumers of these products complain primarily about a rubbery texture, lack of egg flavor, undesirable red-tinge/brown color as opposed to the normal light yellow color, off-flavor and undesirable aftertaste. These deficiencies develop because of an unsuitable formulation and thermally induced chemical reactions. Plain egg in the meals-ready-to-eat (MRE) military ration is no longer produced because of unacceptable quality (Kluter 2002).

A desirable shelf-stable egg product should have the typical yellow color, and the odor and flavor should be characteristic of freshly scrambled eggs. In addition, the product should be moist and slightly spongy but not rubbery, free of lumps and devoid of liquid caused by syneresis/weeping. The commercially sterile product must meet the minimum shelf life requirement of 36 months at 26.7°C (80°F). Nutritionally, the product should have protein content not less than 8.0%, fat content not more than 17%, and salt content between 0.5% and 1.0% (Anon 2003).

Hydrogen sulfide is produced by the breakdown of S-S bridges in the protein molecule when the protein is heated above 60°C. The formation of volatile sulfur containing -compounds requires the presence of oxygen and is favored by alkaline pH (Germs 1973). Preventing hydrogen sulfide formation also prevents the formation of green color in the processed eggs. The green color is the reaction product of hydrogen sulfide from the albumen and iron from the yolk (Baker and others 1967). The pH of liquid whole egg can vary from 7.0 to 7.6 depending on the history of the in-shell egg (age, oiling of shell, temperature of storage, etc.). The pH within this

range is a function of the amount of carbon dioxide in the shell eggs at the time of breaking (Cotterill and McBee 1994).

Freezing of cooked egg white or whole egg caused them to become tough or rubbery with separation of water (syneresis). Hawley (1970) prevented syneresis in cooked frozen egg white by adding 2 to 4% of a water-binding carbohydrate such as algin, carrageenan, agar or starch. Davis and others (1952) observed that a yolk-white ratio of 40:60 to 80:20 when diluted with 20% water and adjusted to pH 6.0 – 7.0 before cooking is suitable for freezing with no adverse manifestations in quality (Cotterill 1994).

A wide range of ingredients have been added to whole egg to prepare commercial scrambled-egg mixes. The most common added components are nonfat dry milk, whey, vegetable oil, water, gums (CMC and xanthan being the most common), organic acids or other chelators (citric acid, lactic acid or phosphates), salt and egg white. Cooked egg from scrambled-egg mixes have good steam-table stability, color and texture but a frequent complaint is their lack of flavor. This may be because there is not enough hydrogen sulfide formed when the mix is adjusted to a low pH to avoid greening (Cotterill 1994).

Food hydrocolloids are high-molecular-weight hydrophilic biopolymers. They are used in foods for altering the texture, flavor and shelf-life. 'Hydrocolloids' refers to polysaccharides extracted from plants, seaweeds and microbial sources as well as gums derived from plant exudates, and modified biopolymers made by the chemical or enzymatic treatment of starch or cellulose (Dickinson 2003). All gums thicken and impart viscosity to aqueous solutions and some can from gels. Some gums can also be used as syneresis inhibitor in foods like cheese and frozen foods (Glicksman 1982).

Xanthan gum is derived from the microorganism *Xanthomonas campestris*. It is completely soluble in hot or cold water and forms high viscosity solutions at low concentrations which contributes to its effective stabilizing properties. General concentrations of use in food systems are between 0.1 and 0.3%. In some cases concentrations up to 0.9% have been used for frozen foods (Glicksman 1982).

Carrageenans are linear polysaccharides of D-galactose and 3,6-anhydro-D-galactose extracted from various red sea weeds. Three principal forms of carrageenan are kappa (gelling), iota (gelling) and lambda (non-gelling). All carrageenans are soluble in hot water at temperatures above 70°C. λ-carrageenan and sodium salts of κ– and ι-carrageenan are soluble in cold water (Glicksman 1983).

Durance (1997) in his review paper on variable retort temperature (VRT) processes pointed out that the concepts used to justify high-temperature, short-time (HTST) and ultra-high-temperature (UHT) processing for liquid foods in containers or continuous aseptic processing are not directly applicable to solid foods processed in thick profile packages. The outer portions of the solid foods in the thicker containers receive much greater heat than the centre and the surface overcook becomes much worse as the temperature increases.

Teixeira and others (1975) evaluated the effects of variable retort temperature profiles and different cylindrical container geometries on thiamin degradation in a conduction heated food during thermal processing. For variable retort temperature (VRT) profiles, they considered step functions, ramp functions and sinusoidal functions. They found that maximum thiamin retention was similar for all the VRT profiles tested when processes had an equivalent sterilizing value. In case of the container geometries, they found a maximum retention of 60% in containers with height-to-diameter ratios less than 0.2 and greater than 10.0. The worst thiamin retention of

40% was obtained for containers with the ratio close to 1. This result shows the potential of thin profile retortable pouches in improving quality of commercially sterile egg.

Holdsworth (1985) in his review paper on the optimization of thermal processing reported about a study by Sjöström and Dagerskog (1977), where they evaluated VRT processes by trying to reduce the difference in heating effect between the surface and centre for a conduction heated food (chopped fish) and a part convection heated food (liver paste) for specific can sizes. The results of computer simulation were compared with experimental work using the sterilization effect, enzyme inactivation and a sensory quality *C* value that was based on the rate of browning in fish (z = 26°C). For constant temperature processes, the optimum processing temperature to produce the minimum *C* value increased with increasing z value. Hence, it is necessary to know the z value for the particular heat-induced change under consideration to evaluate processing effects. In VRT experiments to the same maximum processing temperature, the authors found that a double-ramp (a linear increase in temperature followed by a linear decrease) produced the smallest cook value whereas a combination of a ramp and constant holding was significantly better than a step (constant holding for the total time period).

Saguy and Karel (1979) in their experiments with VRT processes concluded that each combination of container geometry, product and critical quality attribute would yield a unique VRT solution. Banga and others (1991) used surface quality instead of optimum nutrient retention to evaluate VRT processes and showed that surface quality improved up to 20% with the best VRT processes. Balsa-Canto and others (2002) in a recent study on optimization of thermal processes came up with a VRT profile that had three ramps (decreasing, increasing and

decreasing) of temperature between end of come-up and the beginning of cooling down of the retort.

Overpressure during processing is required to maintain the integrity of containers that have limited resistance to internal pressure. Overpressure refers to the pressure supplied to a retort in excess of that exerted by the heating medium at a given process temperature. Such containers include semi-rigid plastic containers with heat sealed lids, flexible pouches, metal trays and glass jars. With small temperature fluctuations during the process and in the early part of cooling, the internal pressure may exceed the saturated steam pressure, thus overpressure must be applied. Retorts operating under overpressure use either water as the operating medium in which the containers are fully immersed, water that cascades over the containers or a mixture of water sprays and steam/air, or just a steam/air mixture as the heating medium. Air or steam usually is used as the source of overpressure. Irrespective of the processing medium used, a means to circulate the heating medium is to be provided to ensure uniform temperature distribution within the retort during processing. In case of total immersion water retorts a pump is used to circulate the water. In case of steam/air retorts, a fan located in the back or front of the retort circulates the heating medium. In the absence of a fan, a spray or cascading water system should be present to ensure circulation of the heating medium (Gavin A and Weddig LM 1995). Bhowmik and Tandon (1987) used a centrifugal pump to recirculate water inside a still retort to improve the rate of heat transfer while processing retort pouches with steam/air medium under overpressure.

This study was conducted to determine the effects of pre-treatments on the liquid egg formulation prior to filling, the thermal processing schedule, and formulation on color, instrumental texture parameters and sensory properties of the thermally stabilized egg product.

Methodology

Thermal Process

The effect of different thermal processes on quality of the retorted egg product was determined using the modified formula given in Table 3.1. The modified formula was a modification of a formula specified in the DSCP document PCR-E-005 which is also given in Table 3.1 (Anon 2003). The modified formula was arrived at to achieve the textural requirements of the product and arrived at by an iterative procedure. Plain eggs result in a hard product if retorted without additives, hence water and fat (liquid margarine) were added to the eggs. Citric acid to be added to the mix was determined by titration to prevent the formation of green color in the finished product. The amount of water, fat and citric acid to be added to the mix were optimized by formulation experiments conducted at the University of Tennessee, Knoxville and confirmed with the amounts used in the modified formula (Weiss 2003).

Table-3.1: Recipe for plain scrambled eggs from PCR-E-005 and the modified recipe used for evaluation of thermal processes

Ingredients	**Percent by Mass**	
	PCR-E-005	Modified Formula
Liquid or frozen whole eggs	71.000	74.516
Water	17.646	21.858
Vegetable Oil	5.500	
Liquid Margarine	3.000	2.981
Modified waxy maize pre-gelatinized instant starch	2.000	
Salt	0.650	0.497
Ground white pepper	0.150	
Citric acid	0.050	0.149
Dry or liquid annatto color (15% norbixen)	0.004	

The process was carried out in a Sterilmatic retort simulator (Steritort, FMC Food Tech, Madera, CA). The reel was removed and a supporting structure was installed over which a perforated stainless steel rack which confined the laminate pouches, was positioned. A centrifugal pump was plumbed into an intake port located at the lowermost point in the retort and the discharge from the pump was directed to a manifold at the uppermost point in the retort where multiple openings directed a steady stream of water over the laminate pouch rack. Thus the retort operation simulated a cascading water retort. The cascading water system provided moist heat at the pouch surface improving the heat transfer compared to only the steam/air mixture. The water cascade was applied throughout the process until the cooling step was started at which time the pump was turned off and cold water was directed into the manifold to shower the pouches with cold water. The pouch rack consisted of perforated steel envelopes which held each pouch between two plates. The envelopes were spaced avoiding contact between two adjacent pouches and permitted the water cascade to flow down both sides of each pouch which was positioned in the rack with the large area positioned parallel to the cascading water flow. Two retort temperatures were tested initially, 116°C and 121.1°C, the temperatures used commonly in the industry. During the initial trials, the process was carried out without any air overpressure but this procedure caused most of the pouches to burst at the seal areas. After a succession of processing runs, it was found that a minimum air overpressure of 34.5 kPa (5 PSIG) over the steam pressure was essential throughout the process to maintain the pouch integrity.

Finally, the process adopted to evaluate the effect of pretreatment and formulation consisted of a preheating step at a retort temperature of 100°C with no air overpressure until the internal temperature of the pouch contents reached 70°C. The temperature of the retort was then

ramped to 130°C and air overpressure was applied to attain 206.8 kPa (30 PSIG) overpressure and the process was carried out until the targeted F_0-value at the center of the pouch was achieved. Cooling was then initiated while maintaining the air overpressure. Cooling was initiated by stopping the hot water recirculating pump, shutting off the steam by lowering the setting on the temperature controller and turning on the valve that delivers cold water to the manifold. When the internal temperature of the pouch reached below 100°C, air was released slowly to lower the pressure until pressure was zero. Water was periodically released from the retort to avoid a rise in water level in the retort beyond the level of the bottom of the pouches in the tray.

The temperature inside the pouch was monitored using flexible Type-T thermocouple wires that were introduced into the pouch using thermocouple receptacles for pouches (Ecklund Harrison Technologies, Inc., FL, USA). The receptacles were made out of a plastic material, Delrin to avoid heat conduction through the receptacles. The thermocouple end was placed approximately at the center of the pouch to monitor the temperature at the coldest spot in the pouch. Since the heat transfer inside the product is mainly through conduction, once the egg has gelled, the coldest spot is at the geometric center of the pouch.

The temperature of the retort was monitored and controlled by a recorder/controller device built into the control system panel of the retort. The temperature could also be verified using a liquid in glass thermometer installed on the retort. The temperatures of the retort and the product in the pouch were recorded using thermocouples and a Hydra data bucket (Fluke Corp., Everett, WA, USA). A Visual Basic program developed by Aswin Amornsin at the University of Georgia provided a means of monitoring the temperatures of the retort and the pouch continuously while also calculating the F_0-value (lethality). The data was recorded by the Hydra

at intervals of 15 seconds. The desired F_0-value was 6 min, which would give an 6-log reduction of spores having a D-value of 1 min at 121.1°C. A common index microorganism in thermal processing, *Clostridium sporogenes*, PA 3679, has a *D*-value of around 1 min at 121.1°C. A minimum thermal process required for 12 decimal reduction of *Clostridium botulinum* is 3.0 min at 121.1°C. Thus, an F_0-value of 6.0 min would be adequate for product safety. To avoid over-stepping the target F_0-value of 6.0 min, cooling step was started when the F_0-value was below 6.0 min to account for the lethality from residual heat in the initial phase of the cooling process.

Pre-process treatments

Several pre-process treatments were tried to improve the final product. One of the main challenges was the mixing of the ingredients. It was very difficult to get a homogenous mix of all the ingredients. Various mixing techniques were tried including a hand operated kitchen style mixer (Black and Decker, Cat. No. M-175) with two whisk like rotating paddles and a single rotating blade style hand blender (Braun, Multiquick MR 400). An agitating kettle was also tried, both cold and pre-warmed to melt the liquid margarine but all three procedures did not produce a homogenous mix. The Megatron® (Kinematica, Inc., OH), a high-speed gear homogenizer consisting of a high speed rotating element within a stationary receptacle with slits on the side, resulted in a very homogenous mix of the ingredients. The Megatron had a variable speed control for the rotor and usually 7000-11,000 rpm speeds were used with recirculation of the sample for about five minutes to achieve full homogenization. CO_2 was applied over the container that held the mix while mixing with the Megatron to reduce oxygen uptake by the mix.

Par-cooking is the process where a small part of the mixture was pre-cooked followed by homogenization of the whole batch prior to filling into the pouches. The reason for par-cooking was to introduce the desirable flavors produced by browning eggs to the product through the

browned top layer. Par-cooking was done using the Radiant Wall Oven (RWO). The RWO consisted of a gas heated cylinder with a belt running through the middle. The sample was placed in metal baking trays and passed through the RWO, which had a wall temperature of 1000°F. The belt speed was set to give a residence time of 60-70 seconds for the sample to travel through the length of the hot cylindrical wall. This resulted in gelling and browning the top layer of the sample while the main part of the mixture was still liquid. The whole batch was then homogenized in the Megatron, filled into pouches and then processed in the retort. The same technique was also tried by cooking a part of the mix (about 10%) in a pan and adding it back into the liquid mix and mixing it in the Megatron.

Glucose oxidase was also tested by adding to the mix at 0.13% prior to processing. The objective of adding glucose oxidase was to consume oxygen in the egg mix and to convert glucose in the egg to gluconic acid. The removal of glucose was hypothesized to reduce the intensity of the brown color that resulted from the reaction between the N-terminal amino acids of proteins and glucose.

Formulation

The product made using the modified formulation given in Table-3.1 was found to be acceptable by the technical panel but synerisis was observed on opening the pouch. The technical panel consisted of the authors and a few other graduate students, technicians and faculty in the Food Science department at the University of Georgia, who were familiar with the product and could short list products that showed promise for further development. The amount of water that separated was up to about 5% of the mass of the contents of the pouch. To prevent synerisis, some starches and hydrocolloids were added to the formula. The additives tried were:

cyclodextrin, xanthan gum, ι-carrageenan, λ-carrageenan, κ-carrageenan, guar gum and locust bean gum, and xanthan gum and starch.

To improve the flavor of the final product a natural egg flavor and white pepper/black pepper/liquid pepper flavor were also tried. Natural egg flavor from Summit Hill Flavors, NJ was tried at 1% and 0.5% levels. White pepper/black pepper were tried at 0.2%. Liquid pepper flavor was tried at 0.005% and 0.01% levels. Other flavors such as chicken flavor, various natural and artificial butter flavors and other egg flavors were also tried and discarded based on input from the technical panel.

It was eventually decided based on the preliminary experiments that two complete block designs, one involving xanthan gum and starch and the other with xanthan gum and ι-carrageenan would be investigated. Three levels of xanthan (0.2, 0.35 and 0.5%) were used in both the experimental blocks. Starch was tried at three levels (0, 0.5 and 1.0%). The three levels of ι-carrageenan used were 0.15, 0.3 and 0.45%. The upper limit of the levels of gums to be tried was limited by the ability to hydrate the gums in the water used in the formulation. All the experiments were repeated thrice. The percentage of xanthan, starch and ι-carrageenan are a proportion of the total amount of the basic ingredients: eggs, water, margarine, salt and citric acid as given in Table-3.1. The aim of the experimental design was to obtain a response surface for various textural attributes from TPA tests on the TAXT-2. All the experiments were performed with the mixing done in the Megatron, no pre-process treatments, with natural egg flavor and the thermal process at 130°C with a pre-heat step at 100°C without overpressure.

Preparation of the Mix, Packaging and Processing

The first step in the preparation of the mix was the hydration of the gums (xanthan, starch and/or ι-carrageenan). The salt and citric acid were dissolved in the water and the gums were

slowly added to the water while continuously agitating using a kitchen mixer. This gel was then added to the eggs. The liquid margarine was lightly heated in the microwave and the egg flavor was added to the margarine. This mix was then added to the rest of the ingredients and the mix was then passed through the Megatron and recirculated until a homogenous mixture was achieved. A CO_2 atmosphere was maintained on top of the sample holder container of the Megatron to minimize the amount of air incorporated into the mix during the mixing operation.

The mix was then poured into laminate pouches and hand sealed using a pneumatic sealer (Toss Machine Components, Inc., PA). Each pouch contained 8 oz (227 g) of the mix. The pouches were then placed in the custom made tray made with perforated steel and processed in the retort.

The retorting process consisted of five steps: heating to initial holding temperature, holding at initial holding temperature, ramping up to processing temperature, holding at processing temperature till desired lethality is achieved and cooling. The first two steps were performed with the vent open on the retort. The initial holding temperature was 100°C. This step was performed since it was found that when using the plain mix without the hydrocolloids in the initial experiments, holding the product at 100°C with the vent open till the internal temperature of the product reached about 70°C resulted in a fluffier product. The vent was closed during the ramping of the temperature from the holding temperature of 100°C to the processing temperature. The cascading water shower was maintained throughout the process until the start of cooling. The sample was held at the processing temperature until the desired lethality was achieved and the cooling step was started.

TPA Analysis

The finished product was subject to TPA analysis at room temperature on the TAXT-2 texture analyzer. After some preliminary tests to determine the optimum speed of the crosshead, 2 mm/s crosshead speed was used for the TPA tests. This speed was the fastest speed at which meaningful data could be collected from the test without completely crushing the sample in the first bite. At the end of the tests, the crosshead was retracted at 10 mm/s. There was a one-second gap between the bites. A No. 12 cork borer (17 mm diameter) was used to cut cylindrical samples. The sample was cut to a height of 15 mm. The diameter of the plunger used to compress the samples was 25.4 mm. The samples were subject to deformations of 50% and 60% of the original sample height. Those two deformation levels were chosen since most samples stayed intact after the first bite at the 50% deformation level, while most samples crumbled during the first bite at the 60% deformation level. A macro was written to determine the texture parameters of hardness, adhesiveness, springiness, cohesiveness and chewiness from the results of the TPA experiments.

Sensory Analysis

To supplement the texture results from TPA and also to evaluate the sensory properties of the final product sensory analysis was performed on the samples. Two different sensory tests were performed on the products: 9-point hedonic scale affective testing using a consumer panel, and Quantitative Descriptive Analysis (QDA) using a trained panel. Since, it was beyond the scope of this project to evaluate all 18 different products in the sensory evaluation, a representative sample of products was short listed from among the 18 products with the help of the technical panel. The samples were short listed based on sufficient differences between the

samples, desirable texture and absence of synerisis as evaluated by the technical panel. The samples that were short listed are listed below:

i) Xanthan: 0.20%; Starch: 0.0%

ii) Xanthan: 0.35%; Starch: 0.50%

iii) Xanthan: 0.50%; Starch: 1.0%

iv) Xanthan: 0.50%; ι-carrageenan: 0.30%

In addition to the above products, a plain egg product (without starch or hydrocolloids) using the modified recipe listed in Table-3.1 was also made and evaluated along with the above samples. The original sensory analysis was conducted on seven different samples and only the results relevant to this study were extracted from that report (Appendix B).

9-Point Hedonic Scale Affective Testing

Panelists who enjoyed eating scrambled eggs were chosen for the panel. The panelists were asked to rate the overall quality, appearance, aroma, flavor and texture. An additional question was asked to the panelists whether they would eat the MRE products as a part of their meal with the choice of a yes/no answer. Two sessions with 36 panelists each were used for the affective testing.

The samples were held under a controlled temperature between 60-71°C (140-160^{o}F) before being given to the panelists. Presentation of the products to the panelists followed a balanced-block design. PROC GLM procedure was used in the statistical analysis of the data.

Quantitative Descriptive Analysis (QDA)

A panel was created to conduct QDA on MRE products. The panel was composed of 8 individuals recruited from the Food Science Department. Prior to actual evaluation of the MRE products, the panelists were trained for familiarization to the following attributes: (1) Hardness,

(2) Cohesiveness, (3) Chroma (inside surface and outside surface), (4) Sulfur aroma, and (5) Cooked egg flavor.

The panel training involved the use of different standards that resembled or possessed the same characteristics of the attribute evaluated. The group performance was monitored. After the performance of the trained panel was determined to be ready to test the MRE products, the panel was asked to evaluate the five kinds of MRE products listed earlier. A total of at least 12 hours of training was spent to train the panel before actual MRE product testing.

A 15-cm scale was used for the intensity rating of each of the MRE product attributes. In the case of the chroma evaluation, the MRE product was evaluated as a whole product both for outside and inside chroma evaluations, since the color of the product was different between the inside and the outside. For the cooked egg flavor, the higher the intensity value of the MRE product the more were the extraneous flavors present in the sample. The extraneous flavors could be either desirable or undesirable. A nose clip was provided when the cooked egg flavor attribute was evaluated. The nose clip eliminated any confusion that could be caused by the volatile aroma being perceived by the panelists from their nasal passages. The experimental design was an incomplete-balanced block design with 4 replications. PROC GLM procedure was used in the statistical analysis of the data.

Density

It was determined that a fluffy product with lower density was more desirable than a more compact product with higher density. Hence, the effect of mixing method, presence of CO_2 during mixing, the effect of xanthan in the formulation, and the effect of the holding step with no overpressure during the thermal process on the density of the final product was evaluated.

Results and Discussion

Formulation, Pre-process treatments and Processing

The pH of the thawed frozen eggs was 7.21. Citric acid at 0.15% lowered the pH to 6.1. Various gums and starches were added to the mix to prevent synerisis in the final product. Cyclodextrin and κ-carrageenan were not effective in preventing synerisis. Guar gum and locust bean gum, and λ-carrageenan resulted in products with a slimy texture. ι-carrageenan formulation had some synerisis but the texture was acceptable. Xanthan gum, and xanthan gum combined with starch formulations had no synerisis and had good texture. Formulations with xanthan, and xanthan combined with starch or ι-carrageenan were the most promising. Natural egg flavor from Summit Hill Flavors, NJ was the most appealing of the flavors tested. Addition of glucose oxidase to the mix did not achieve the desired result of reducing the browning in the final product as evidenced by the color readings.

Par-cooking treatments like the RWO cooking and pan frying, both produced good cooked flavor in the final product but added an additional steps to the process and hence were discontinued.

The thermal processes that were run at 116°C and 121°C needed a long time to achieve the desired center lethality. Processing at 130°C reduced the processing time by half and did not result in any objectionable changes to the product. During the thermal process, the holding step at 100°C with no overpressure resulted in a desirable texture with the basic formulation with no gums but in case of formulations containing xanthan, the step did not result in any apparent change in the texture of the final product.

TPA Analysis

The products made using the experimental design were subject to TPA analysis using the methodology described earlier. There were no significant differences ($p<0.05$) in the instrumental texture parameters between samples in most cases. There were also no noticeable trends with respect to xanthan, starch or ι-carrageenan levels in the mix. Complete tables of the instrumental texture properties are given in Appendix A.

Plain eggs

In order to serve as the reference, the values of instrumental texture parameters are given for the samples made with the modified formulation as given in Table 3.1. This formulation did not contain any hydrocolloids.

50% deformation

Hardness was 13.71 N, adhesiveness -0.08 N.s, springiness 0.9, cohesiveness 0.58 and chewiness was 7.09.

60% deformation

Hardness at 60% sample deformation was 19.02 N, adhesiveness -0.10 N.s, springiness 0.87, cohesiveness 0.46 and chewiness was 7.63.

Xanthan - ι-Carrageenan formulations

50% deformation

When the TPA test was performed at 50% level of sample deformation, hardness of the samples varied between 10.5 N and 11.5 N. Adhesiveness varied between -0.17 N.s to -0.27 N.s. Springiness was in the range of 0.75 to 0.84. Cohesiveness ranged between 0.27 and 0.34 while chewiness was between 2.36 and 3.11.

60% deformation

At 60% level of sample deformation, hardness of the samples varied between 10.4 N and 11.6 N. Adhesiveness varied between -0.14 N.s to -0.27 N.s. Springiness was in the range of 0.67 to 0.78. Cohesiveness ranged between 0.18 and 0.21 while chewiness was between 1.43 and 1.78.

Xanthan - Starch formuations

50% deformation

In the TPA tests with samples made from formulations containing xanthan and/or starch at 50% level of sample deformation, hardness of the samples varied between 9.9 N and 12.4 N. Adhesiveness varied between -0.13 N.s to -0.26 N.s. Springiness was in the range of 0.84 to 0.89. Cohesiveness ranged between 0.34 and 0.45 while chewiness was between 3.17 and 4.72.

60% deformation

At 60% level of sample deformation for samples with xanthan and/or starch in the formulation, hardness of the samples varied between 9.9 N and 12.1 N. Adhesiveness varied between -0.13 N.s to -0.20 N.s. Springiness was in the range of 0.75 to 0.89. Cohesiveness ranged between 0.17 and 0.22 while chewiness was between 1.38 and 2.24.

Sensory Results

The sensory results for the products relevant to this study were extracted from a sensory report (Appendix B) conducted with seven different samples.

9-point Hedonic Affective Testing

The individual attribute quality ratings of the MRE products are shown in Table-3.2. For the overall quality, MRE product with Xanthan: 0.2%, Starch: 0% was found to have the highest quality rating among samples but was not statistically different to the other products ($p<0.05$).

The plain product that was produced with no hydrocolloids in the mix received lower scores on three out of the five attributes ($p<0.05$).

Table-3.2: Consumers quality evaluation on different attributes of five MRE products Data in a row with different letters are significantly different ($p<0.05$) by Duncan multiple range test

Quality Ratings: 9-point Hedonic Scale (1 dislike very much – 9 like very much)					
Attribute	Formulations*				
	X: 0.5 S: 1.0	X: 0.35 S: 0.5	X: 0.2 S: 0	X: 0.5 IC: 0.3	Plain
OVERALL Quality	6.11[a]	6.44[a]	6.72[a]	6.42[a]	6.11[a]
APPEARANCE Quality	6.22[ab]	6.72[a]	6.75[a]	6.44[ab]	5.67[b]
AROMA Quality	5.81[ab]	5.94[ab]	6.31[a]	6.14[ab]	5.42[b]
FLAVOR Quality	6.27[a]	6.11[a]	6.83[a]	6.08[a]	6.17[a]
TEXTURE Quality	6.19[ab]	6.31[ab]	6.86[a]	6.19[ab]	5.78[b]
ACCEPTANCE Quality**	70.27[a]	72.22[a]	88.89[a]	72.22[a]	80.56[a]

* X: Xanthan; S: Starch; IC: ι-carrageenan
** Percent of consumers who would eat the product as part of their meal.

Quantitative Descriptive Analysis (QDA)

The attribute intensity ratings of each MRE product are given in Table-3.3 and show statistical differences among the MRE products. Chroma intensity value differences between the outside and inside surfaces of the MRE products show that the outside surface had a higher

chroma value compared to the inside surface, thus necessitating the need for the two to be evaluated separately.

Table-3.3: Trained panel intensity ratings of different attributes of five different MRE products. Data in a row with different letters are significantly different ($p<0.05$) by Duncan multiple range test.

Intensity Ratings (0 none – 15 extremely high)					
Attribute	Formulations*				
	X:0.5 S:1.0	X:0.35 S:0.5	X:0.2 S:0	X:0.5 IC:0.3	Plain
CHROMA IN-SURFACE Intensity	2.45^{a}	2.12^{ab}	1.95^{b}	2.02^{ab}	1.17^{c}
CHROMA OUT-SURFACE Intensity	6.87^{a}	6.65^{ab}	5.97^{b}	7.07^{a}	3.17^{c}
SULFUR AROMA Intensity	4.62^{a}	3.95^{ab}	3.26^{bc}	4.09^{ab}	2.52^{c}
COOKED EGG FLAVOR Intensity	3.48^{b}	3.91^{ab}	4.56^{a}	4.34^{ab}	3.75^{ab}
COHESIVENESS Intensity	2.65^{b}	2.83^{b}	3.17^{b}	4.31^{a}	2.81^{b}
HARDNESS Intensity	2.06^{c}	2.76^{b}	2.63^{b}	2.48^{bc}	3.40^{a}

* X: Xanthan; S: Starch; IC: ι-carrageenan

Comparison of instrumental and sensory results

A comparison of instrumental and sensory hardness values are given in Table-3.4. However, sensory cohesiveness values could not be correlated to any of the instrumental values. Some differences between the instrumental and sensory hardness values could be due to inherent differences between different samples, since the exact same pouch was not used for instrumental

and sensory testing. The differences could also arise from the fact that the instrumental hardness was measured at room temperature while the sensory samples were evaluated at an elevated temperature and the heating could affect different samples differently.

Table-3.4: Comparison of hardness values as evaluated by the trained panel and the instrumental hardness values measured from the TPA tests on TAXT-2

Product*	Instrumental hardness (N)	Sensory hardness
X: 0.5, S: 1.0	8.64 ± 1.60	2.06
X: 0.2, S:0	9.92 ± 2.03	2.63
X: 0.5, IC: 0.3	11.25 ± 0.58	2.48
X: 0.35, S: 0.5	12.40 ± 0.79	2.76
Plain	13.71 ± 0.91	3.40

* X: Xanthan; S: Starch; IC: ι-carrageenan

Density

Several experiments were performed to determine the effects of xanthan in the mix, mixing technique (Megatron vs. handheld kitchen mixers), CO_2 exposure during Megatron mixing, and the intermediate holding step during processing in the retort on the density of the final product. The density of the final product affected the texture perception of the product by the consumer. The density was measured by cutting three different pieces of known volume and weighing them.

Xanthan

The effects of using xanthan in the mix and without xanthan in the mix on the density of the final product are given in Table-3.5. All the other ingredients and procedures were kept the same for both mixes. There was a significant difference in the means ($p<0.05$) when the data was analyzed using SAS (SAS Institute, Inc., NC).

Table-3.5: Effect of xanthan in the mix on the density of the final product

Effect of Xanthan on Density		
Mix Type	**Mean Density (kg/m^3)**	**Tukey Classification of Means**
No Xanthan Megatron	1020.13 ± 9.12	A
Xanthan Megatron	947.19 ± 25.06	B

Mixing Technique

The effect of mixing technique on the density of the final product was studied. The ingredients were mixed by passing through the Megatron in one case and were mixed by a Braun kitchen hand blender (Braun, Multiquick MR 400) in the second case. The density of the final products is given in Table-3.6. The mean densities are significantly different ($p<0.05$) when analyzed using the Tukey HSD method in SAS.

Table-3.6: Effect of mixing technique on the density of the final product

Effect of Mixing (with Xanthan: 0.35; Starch: 0.5)		
Mixing Method	**Mean Density (kg/m^3)**	**Tukey Classification of Means**
Handheld kitchen blender	1022.50 ± 13.60	A
Megatron	947.19 ± 25.06	B

Effect of CO_2 exposure during Megatron mixing

The possible effect of the CO_2 blanket on the sample vessel during the Megatron mixing was studied to determine its effect on the final density of the sample. The sample was mixed in the Megatron without any CO_2 blanket, with CO_2 blanket for 5 minutes, and with CO_2 blanket for 10 minutes. In all the cases the sample was mixed in the Megatron for 10 minutes. The results

are given in Table-3.7. The results show that the use of CO_2 resulted in a product of higher density when compared with a product mixed in the absence of CO_2.

Table-3.7: Effect of CO_2 exposure on the density of the final product

Effect of CO_2 during Megatron mixing		
Time of CO_2 exposure	**Mean Density (kg/m^3)**	**Tukey Classification of Means**
10 min	975.39 ± 18.25	A
5 min	964.92 ± 19.14	A
No CO2	947.19 ± 25.06	B

Effect of intermediate holding step during processing in the retort

The effect of the intermediate holding step during processing in the retort was studied. As described earlier, the product was allowed to set in the retort with the retort at a temperature of 100°C with the vent open and no overpressure to allow the free expansion of the product. The effects of processing the product with and without the intermediate holding step were studied and the results are given in Table-3.8. The results show that there is no significant difference in the density of the final product ($p<0.05$).

Table-3.8: Effect of intermediate holding step on the density of the final product

Effect of holding at 100 C during processing		
Processing Method	**Mean Density (kg/m^3)**	**Tukey Classification of Means**
With holding	962.50 ± 23.74	A
Without holding	961.71 ± 17.23	A

The results presented in Tables-3.5 to 3.8 show that the density of the sample is affected by the presence of xanthan and the mixing method. The combination of presence of xanthan in the mix and mixing in the Megatron gave the sample with the least density. The intermediate holding step during processing did not have any effect on the final product which had xanthan in the mix. But it was noticed in earlier experiments that the intermediate holding step during processing did produce a product with a fluffier texture when the product was made with the modified mix given in Table-3.1 with no hydrocolloids. There were other factors which would also contribute to the density of the final product: extent of overpressure during processing, size of the slot in the rack in which the pouch is processed in the retort, and vacuum packaging.

Conclusions

The recipe previously specified by the US Dept. of Defense for contactors of retorted ready-to-eat egg products was modified using xanthan, ι-carrageenan and starch in the recipe. Megatron, a high speed gear mixer gave the best results in mixing the ingredients. The traditional processing conditions were also modified by processing at a higher temperature (130°C) - shorter time rapid-retort process was proposed with an intermediate holding step in the retort. TPA analysis on the samples showed little differences in instrumental texture parameters between treatments within the experimental design. TPA analysis could be used in case of drastically different formulations or processes to identify the differences. In case of samples with statistically indistinguishable instrumental texture parameters, sensory analysis might be the only recourse to differentiate and identify the desirable sample. Sensory analysis identified the product with no hydrocolloids to be the least preferred product among consumers. The product received the lowest hedonic scores in three of the five quality attributes evaluated. Several tests

were also performed to determine the cause for the fluffy nature of the final product. It was shown that the combination of xanthan in the mix and mixing in the Megatron resulted in the fluffiest sample (sample with the least density). In case of mix with no xanthan, the intermediate holding step during processing played an important role in the final fluffy nature of the sample.

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CHAPTER 4

EFFECTIVE HEAT TRANSFER COEFFICIENTS AT VARIOUS STAGES OF RETORT PROCESSING OF EGGS IN QUAD-LAMINATE POUCHES AND POLYMERIC HALF STEAM-TABLE TRAYS[1]

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Abstract

The effective heat transfer coefficients (h) at various stages of retort processing of an egg mix in quad-laminate pouches and half steam-table trays (poly-trays) were determined by iteration to obtain a best-fit between the experimental centre-point temperature and temperature determined by a finite difference heat transfer model. The h-values were determined on thermal processes conducted in three different retorts: a pilot plant sterilmatic retort simulator (PPS), and commercial units operated in a full water immersion (FWI) and cascading water spray (CWS) mode. The values for h were highest in the PPS due to pouch placement which exposed the maximum surface area to steam and cascading water. The h-values for pouches during the heating stage in the PPS varied between 100 and 710 $W/m^2.K$ and for the cooling stage between 200 and over 710 $W/m^2.K$. In the large FWI retort the h-values during heating of pouches varied between 28 and 72 $W/m^2.K$ while those for the poly-trays were between 30 and 130 $W/m^2.K$. During cooling of pouches in the FWI retort, h-value was 200 $W/m^2.K$ compared to 600 $W/m^2.K$ for the poly-trays. While processing in the CWS retort, the h-values during heating of pouches were between 32 and 77 $W/m^2.K$ and between 30 and 100 $W/m^2.K$ for the poly-trays. During cooling the h-value varied between 20 and 63 $W/m^2.K$ for the pouches and between 40 and 60 $W/m^2.K$ for the poly-trays.

Introduction

The rapid heating rate of the conduction heated foods processed in thin profile quad-laminate Meals Ready-to-Eat (MRE) pouches and polymeric half steam-table trays is the reason for their popularity in replacing traditional cylindrical metal cans. To ensure the high quality of the final product expected from these packages, it is essential to know the constraints to heat transfer during the thermal processing. The heating rate at the 'cold spot' of a conduction heated food is limited by the internal resistance of the food to heat transfer (which is a function of its thermophysical properties, geometry and dimensions) and the total external resistance to heat transfer from the heating medium to the outside surface of the food. The total external resistance includes the convective resistances from the heating medium to outer surface of the container and from the inner surface of the container to the outside layer of the product, and the resistance of the packaging material (Silva and others 1992). Earlier computer models developed to model retort processes to determine the temperature distribution within the product usually assumed infinite surface heat transfer coefficients. This assumption of negligible surface resistance to heat transfer is valid when foods in metal containers are processed in a saturated steam medium (Tucker and Holdsworth 1991). Heat sealed plastic containers such as quad-laminate pouches and half steam-table trays require processing under overpressure to maintain the integrity of the container during the process. The processing medium is a steam/air mixture where the air provides the overpressure. When the heating medium is not saturated steam, the surface heat transfer coefficient is finite and must be included in the heat transfer model for containers' internal temperature during processing. Tung and others (1984) determined surface heat transfer coefficients using brick-shaped metal blocks. McGinnis (1986), Bhowmik and Tandon (1987), Chau and Snyder (1988), Tucker and Holdsworth (1991) were some of the researchers who used

finite h values in their heat transfer models to containers processed in steam/air mixtures or under full water immersion with air overpressure.

Tung and others (1984) found that values of h increased exponentially with the mass fraction of steam in the steam/air mixture. Values of h were also influenced by the flow rate of the medium but were independent of the medium temperature. Lebowitz and Bhowmik (1990) determined the values of h using a computer-based optimization method that incorporated the process data, a two-dimensional finite difference model, and optimization criteria. They concluded that h values during come-up, heating and cooling cycles were not significantly different from each other. They also found no significant differences in h values whether heating aluminum/plastic laminate pouches or other types of plastic pouches during the combined come-up and heating stages. Tucker and Holdsworth (1991) developed a three-dimensional rectangular model that could be used with different h values in the three directions to apply to semi-rigid plastic containers that contained headspace gases trapped under the lid. The difference in the material of the lid and the air under its surface resulted in h value different from that in the other two directions. Silva and others (1994) found that the optimum average quality retention is independent of the surface heat transfer resistance.

Because of the difficulty in precise positioning of thermocouples to obtain a spatial distribution of temperature in a container during a process, heat transfer modeling is necessary to obtain the spatial temperature distribution from the measured time-temperature history at a single known point. The time-temperature history at all points can then be used with kinetic data on quality factor degradation to determine a process which can deliver the target lethality for commercial sterilization while minimizing degradation of the quality factors. The objective of this study was to determine the effective heat transfer coefficients (h) during retort processing of

an egg mix in quad-laminate pouches and polymeric half steam-table trays. The h-values are a function of the convective heat transfer coefficients on the outside and inside surfaces of the containers and the thermal conductivity of the packaging material. The h-values were determined to compute the spatial temperature distribution within the sample during thermal processing which enabled the calculation of volume average quality retention factors to compare different thermal process schedules.

Theory

Heat Transfer Model

The MRE pouch (16 x 9 x 2 cm) and the half steam-table tray (29.5 x 23 x 3.8 cm) were both approximated as brick-shaped containers. Explicit finite difference equations based on those developed by Chang and Toledo (1989) were used to model heat transfer in three dimensions in rectangular coordinates. The equations were derived by conducting an energy balance on a control volume. The equations were modified to account for nodes with different incremental distances in the three dimensions. A program was written in MATLAB using the finite difference equations to calculate heat transfer into the container. Assuming symmetric conditions across the three axes, only a one-eighth volume of the brick-shaped container had to be modeled. The pouch and the tray were divided into finite elements with each element having nodes at the corners. The temperature history of each node was generated by the program. The temperature history at the geometric center was then used to calculate the process lethality and the time-temperature history from all the nodes was used to determine the volume average quality retention value for the process.

The experimental temperature of the retort was simulated using straight-line approximations for the model. The come-up and cool down temperature ramps were approximated to be linear functions of time. The hold temperature used in the model was equated to the average measured temperature over the total hold time.

There were four different types of nodes that were identified for the finite difference model. They were (1) interior nodes, (2) surface nodes, (3) edge nodes and (4) corner nodes. The explicit finite difference equation for calculation of temperature of an interior node (*i, j, k* ? 1) with indices (i,j,k) at time t+dt (T(i,j,k,t+dt)), as a function of temperature at time t (T(i,j,k,t)) is given in Equation (4.1):

$$T(i,j,k,t+dt) = (1-2*\delta x-2*\delta y-2*\delta z)*T(i,j,k,t) + \delta x*[T(i-1,j,k,t) + T(i+1,j,k,t)] + \delta y*[T(i,j-1,k,t) + T(i,j+1,k,t)] + \delta z*[T(i,j,k-1,t) + T(i,j,k+1,t)] \quad (4.1)$$

Surface nodes are the nodes with either *i*=1 or *j*=1 or *k*=1. For a surface node with *i*=1 the equation is:

$$T(1,j,k,t+1) = 2*\delta x*Bix*Tr(t) + \delta z*(T(1,j,k-1,t) + T(1,j,k+1,t)) + \delta y*(T(1,j-1,k,t) + T(1,j+1,k,t)) + 2*\delta x*T(2,j,k,t) + (1-2*\delta x-2*\delta y-2*\delta z-2*\delta x*Bix)*T(1,j,k,t) \quad (4.2)$$

where Tr(t) is the temperature of the retort at time t.

Edge nodes are those with two of the spatial coordinates (*i, j, k*) equal to 1. For an edge node with *i*=1 and *j*=1 the equation is:

$$T(1,1,k,t+1) = 2*\delta x*Bix*Tr(t) + 2*\delta y*Biy*Tr(t) + \delta z*(T(1,1,k-1,t) + T(1,1,k+1,t)) + 2*\delta x*T(2,1,k,t) + 2*\delta y*T(1,2,k,t) + (1-2*\delta x-2*\delta y-2*\delta z-2*\delta x*Bix -2*\delta y*Biy)*T(1,1,k,t) \quad (4.3)$$

For the corner node (i=1, j=1 and k=1) the equation is:

$$T(1,1,1,t+1) = 2*Bix*\delta x*Tr(t) + 2*Biy*\delta y*Tr(t) + 2*Biz*\delta z*Tr(t) + (1-2*Bix*\delta x-2*Biy*\delta y -2*Biz*\delta z-2*\delta x-2*\delta y-2*\delta z)*T(1,1,1,t) + 2*\delta x*T(2,1,1,t) + 2*\delta y*T(1,2,1,t) + 2*\delta z*T(1,1,2,t) \quad (4.4)$$

where: $dx = \frac{a\,dt}{dx^2}; dy = \frac{a\,dt}{dy^2}; dz = \frac{a\,dt}{dz^2}; a = \frac{k}{r\,C_p}; Bix = \frac{hdx}{k}; Biy = \frac{hdy}{k}; Biz = \frac{hdz}{k}$

k is the thermal conductivity, r the density and C_p the specific heat of the sample respectively. a is also referred to as the thermal diffusivity of the sample. i, j, and k are the node indices and dx, dy, and dz are the distances between the nodes in the x, y, and z directions respectively. dt is the time step chosen for the model.

The above equations can be used to generate the time-temperature history of the various nodes in the sample. Since the equations used were explicit finite difference equations, they have stability requirements to avoid divergent oscillations of the nodal temperature. For stability all coefficients in the equations must be positive. Equation (4.4) for the corner nodes with convection has the strictest condition for stability among the four heat balance equations. Stability requires that the following equation for the nodal Biot number must be satisfied by the proper selection of nodal distance dx and time increment dt:

$$(1-2*Bix*\delta x-2*Biy*\delta y-2*Biz*\delta z-2*\delta x-2*\delta y-2*\delta z) = 0 \quad (4.5)$$

Methodology

Processing

The experiments were performed with an egg mix developed at the University of Georgia and has the composition given in Table-4.1. In addition to the ingredients listed in Table-4.1, the mix also contained some or all of the following additives: xanthan gum and starch, calcium caseinate, white pepper, and natural egg flavor. The total amount of additives was less than 2% of the total amount of the mix.

Table-4.1: Recipe used for the retorted egg products

Ingredients	**Percent by Mass**
Liquid or frozen whole eggs	74.516
Water	21.858
Liquid Margarine	2.981
Salt	0.497
Citric acid	0.149

Three different retorts were used to run the experiments with two different types of packages. The two packages were the quad-laminate MRE pouches that held 227 g of the egg mix and the polymeric half steam-table trays that held 2.27 kg of the product. The three retorts used were: Sterilmatic retort simulator (Steritort, FMC FoodTech, Madera, CA) at the University of Georgia; a Stock 1100/4 operated as a non-agitated Full Water Immersion (FWI) retort (Stock

America Inc., Grafton, WI) and a Stock 1100/1 retort operated as a non-agitating, cascading water Spray retort. The latter two were located at the Centre for Advanced Food Technology (CAFT) facility of Rutgers University at Piscataway, NJ. The Sterilmatic retort at UGA was retro-fitted with a centrifugal pump that drew water from the lowermost part of the retort and forced it to cascade over the product through nozzles at the uppermost point in the retort. When processing in the CAFT facility retorts, the standard industry retort racks were used. The pouches or trays were positioned parallel to the axis of the retort. Product containers were layered alternately within the rack structure, i.e., the rack structure separated the walls of adjacent containers leaving a small space for circulation of the heating medium between two adjacent containers. The rack structure also restrained the containers and prevented excessive expansion of the containers if the internal pressure in the containers exceeded the overpressure. The experiments on the UGA retort were performed with the pouches standing in a specially constructed rack made of perforated steel that provided spacing between the pouches thereby exposing both faces of the pouches to the heat transfer medium of steam/air and cascading water.

The processes in the three retorts were carried out using different temperature stages in the first part of the process. In one process, the retort was heated to the processing temperature and held at a constant temperature until the desired center point lethality (F_0-value) was achieved. An F_0-value of at least 6 min at the end of the process was desired and the steam was cut-off and the cooling was started usually before the F_0-value of 6 min was reached to account for additional lethality during the cooling stage. In the second method, the retort was heated to about 100°C with the vent open (no overpressure) or with air overpressure and held till the internal temperature of the mix reached over 65°C which is the gelling temperature for the egg

mix. Then the temperature was increased to the processing temperature and held at constant temperature with air overpressure until the desired lethality was achieved.

Retort Processes

UGA Sterilmatic Retort Simulator

Quad-laminate MRE pouches were processed in the UGA sterilmatic retort simulator using UGA Process A and UGA Process B. In UGA Process A, retort temperature was ramped to 130°C at time zero, and held at 130°C under an air overpressure of 206.8 kPa (30 PSIG) until the desired F_0-value was achieved. In UGA Process B, retort temperature was raised to 100°C with no overpressure and the temperature was held until the sample temperature reached at least 70°C and then the retort temperature was ramped up to the processing temperature of 130°C while applying 206.8 kPa(30 PSIG) air overpressure and held at 130 C until the desired lethality was achieved.

Full Water Immersion Retort

Processes FWI/MRE and FWI/poly were run in the FWI retort using quad-laminate MRE pouches and polymeric half steam-table trays, respectively. In both processes the retort was first heated to a temperature close to 100°C with minimal overpressure (ca. 13.8 kPa or 2 PSIG) and held at this temperature until the product temperature was at least 65°C and then the retort temperature was ramped up to 130°C and held at 130°C with 275.8 kPa (40 PSIG) air overpressure until the desired lethality was achieved. Cooling was then initiated.

Spray retort

The cascading water spray retort was used for the Spray/MRE and Spray/poly for MRE pouches and polymeric half steam-table trays, respectively. Two runs were made using the Spray/MRE Process and two were done using the Spray/poly Process. The Spray/MRE Process

A was carried out at 122°C. Air overpressure of 103.4 kPa (15 PSIG) was initially applied and then the retort temperature was raised to 122°C, at which point the air overpressure was increased to 206.8 kPa (30 PSIG). Once the desired F_0-value of 6.0 min was obtained, cooling was started and the pressure was gradually decreased to 124.1 kPa (18 PSIG) and then released completely after sufficient cooling. Spray/MRE Process B involved applying 103.4 kPa (15 PSIG) air overpressure while retort temperature was raised to 100°C and held at 100°C until the internal temperature of the product was over 65°C. Then, retort temperature was increased to 130°C at the rate of 5°C/min and the air overpressure was raised to 289.6 kPa (42 PSIG). Product was processed at 130°C until an F_0-value of 4.0 min and cooling was started. The air overpressure was gradually decreased to 131.0 kPa (19 PSIG) as cooling was initiated then dropped to zero kPa after the samples had cooled sufficiently. In Spray/poly process A retort temperature was raised to 93.8°C with no over-pressure and until the internal temperature of the product was over 65°C. Then, retort temperature was increased to 130.5°C with 289.6 kPa (42 PSIG) overpressure and processed until an F_0-value of 4.0 min and cooling was initiated. Spray/poly process B was similar to Spray/MRE process B but cooling was started when F_0-value was 3.5 min and the air overpressure was 206.8 kPa (30 PSIG) on initiation of cooling.

Calculation of effective heat transfer coefficients

A Matlab program that calculated the center point lethality (F_0-value) and volume average quality retention ($[N/N_0]_{ave}$) was developed based on finite difference equations for heat transfer. The model generated the time-temperature history for all the nodes in the product. The quad laminate MRE pouch was divided into 1000 elements which resulted in 125 (5x5x5) elements for the one-eighth portion that was modeled. The one-eighth portion of the half steam-tray was divided into 1170 elements. The centre point temperature of the product was recorded

during processing. The Matlab program model was run to calculate the centre point temperature and the h values were determined by an iteration process using different values of h as input into the program and comparing calculated and measured centre point temperatures. The values of h that resulted in a good fit between calculated and measured values were selected. The time interval *dt* used for all the models was 3 seconds. The size of the elements used for the models limited the maximum effective heat transfer coefficient to 710 $W/m^2.K$ for the quad-laminate pouches and to 660 $W/m^2.K$ for the half steam-table trays to satisfy the stability requirement given in Equation (4.5).

Thermophysical Properties

The thermal conductivity (k) of the egg mix was determined using the line heat source probe method (Gratzek and Toledo 1991). Thermal conductivity of the egg mix was measured at 60, 70, 80, and 90°C. The egg mix was filled into test tubes that were placed in a hot water bath and when the temperature of the mix equilibrated with that of the bath, the probe was energized for about 25 seconds and the transient temperature in the probe was recorded. The probe was initially calibrated using glycerin at room temperature (~25°C). All measurements were replicated four times at each temperature. The thermal conductivity was also determined using the empirical equations developed by Choi and Okos (1987) based on the composition of the material as a function of temperature.

The specific heat (C_p) of the mix was determined by using a Differential Scanning Calorimeter (DSC) in the temperature range of 45-130°C. Both liquid mix and finished product were used to determine the C_p value. The specific heat was also determined based on the composition as a function of temperature from the correlations developed by Choi and Okos (1987).

Density of the cooked egg was measured by cutting a cylindrical sample using a cork borer, trimming the edges flat and measuring the height of the sample to determine its volume. The thermal diffusivity was then determined based on the relation $a = k/\rho C_p$.

Results

Thermophysical properties

The values of thermal conductivity (k) of the egg mix at various temperatures measured by the line heat source probe and those calculated by the Choi and Okos (1987) empirical equations are given in Table-4.2. All calculations using the heat transfer model were done using a constant thermal conductivity of 0.55 W/m.K.

Table-4.2: Thermal conductivity (W/m.K) of egg mix determined by two methods

Temperature (°C)	Line heat source probe method	Choi and Okos (1987) equations
60	0.498 ± 0.062	0.548
70	0.558 ± 0.074	0.553
80	0.602 ± 0.071	0.556
90	0.648 ± 0.052	0.559

The density values (ρ) measured by cutting cylindrical pieces of the final retorted sample gave a final mean density value of 1021.0 ± 13.3 kg/m^3. A value of 1020 kg/m^3 was used in all the calculations.

Values of the specific heat (C_p) of the egg mix measured using the DSC and calculated using the empirical equations of Choi and Okos (1987) as a function of temperature are given in Table-4.3. The experiments in the DSC were performed using both the liquid mix and the finished retorted solid product as the initial samples. A constant specific heat of 3702 J/kg.K was used in the heat transfer calculations.

Table-4.3: Specific heat (J/kg.K) of the egg mix and product determined by two methods

Temperature (°C)	Experimental specific heat using DSC		Choi and Okos (1987) equations
	Liquid mix	Retorted solid product	
45	3114.37	3115.63	3715.62
60	3229.67	3193.42	3725.79
75	3461.01	3341.74	3737.59
90	3609.19	3466.89	3751.01
105	3865.91	3697.64	3766.04
120	4011.68	3821.58	3782.70
130	4213.60	4109.77	3794.71

The use of constant specific heat and thermal conductivity for the model can be justified by the fact that the increase in the specific heat is countered by the increase in the thermal conductivity thus keeping the thermal diffusivity ($\alpha=\rho k/C_p$) nearly constant.

Effective heat transfer coefficients

UGA Sterilmatic Retort Simulator

Quad-laminate MRE pouches were processed in the UGA sterilmatic retort simulator using UGA Process A and UGA Process B. The h values that gave the best fit between the model generated data and experimental data for UGA Process A are given in Figure-4.1 and those for UGA Process B in Figure-4.2. All calculations with the model involved advancing the time to result in the calculated values fitting the measured values. This approach was used because the intrinsic nature of the model introduced a delay in the temperature calculation at the center point. In Figure-4.1, the time axis was delayed 1.5 min and in Figure-4.2 the time axis for the model was shifted 1 min, in order for the experimental and calculated data to fit. In Figure-4.2, corresponding to UGA Process B, the temperature calculated for the cooling phase would not match the experimental data exactly even when the highest value of h allowed by the model was used. The experimental cooling rate was too fast to be matched by the calculated values. A possible explanation for the discrepancy between calculated and measured temperatures might be a contraction of the gelled egg on cooling with an air overpressure over the packages.

The results show that values of h are highest during the ramps in the retort temperature: during initial come-up, ramp from 100-130°C and during cooling. When the retort is held at a constant temperature, h values are much lower, possibly due to the minimal steam flow rate into the retort at those times. It is also possible that when the retort temperature is ramping up, the heating medium contains a much higher concentration of steam in the steam/air mixture thus increasing the rate of heat transfer.

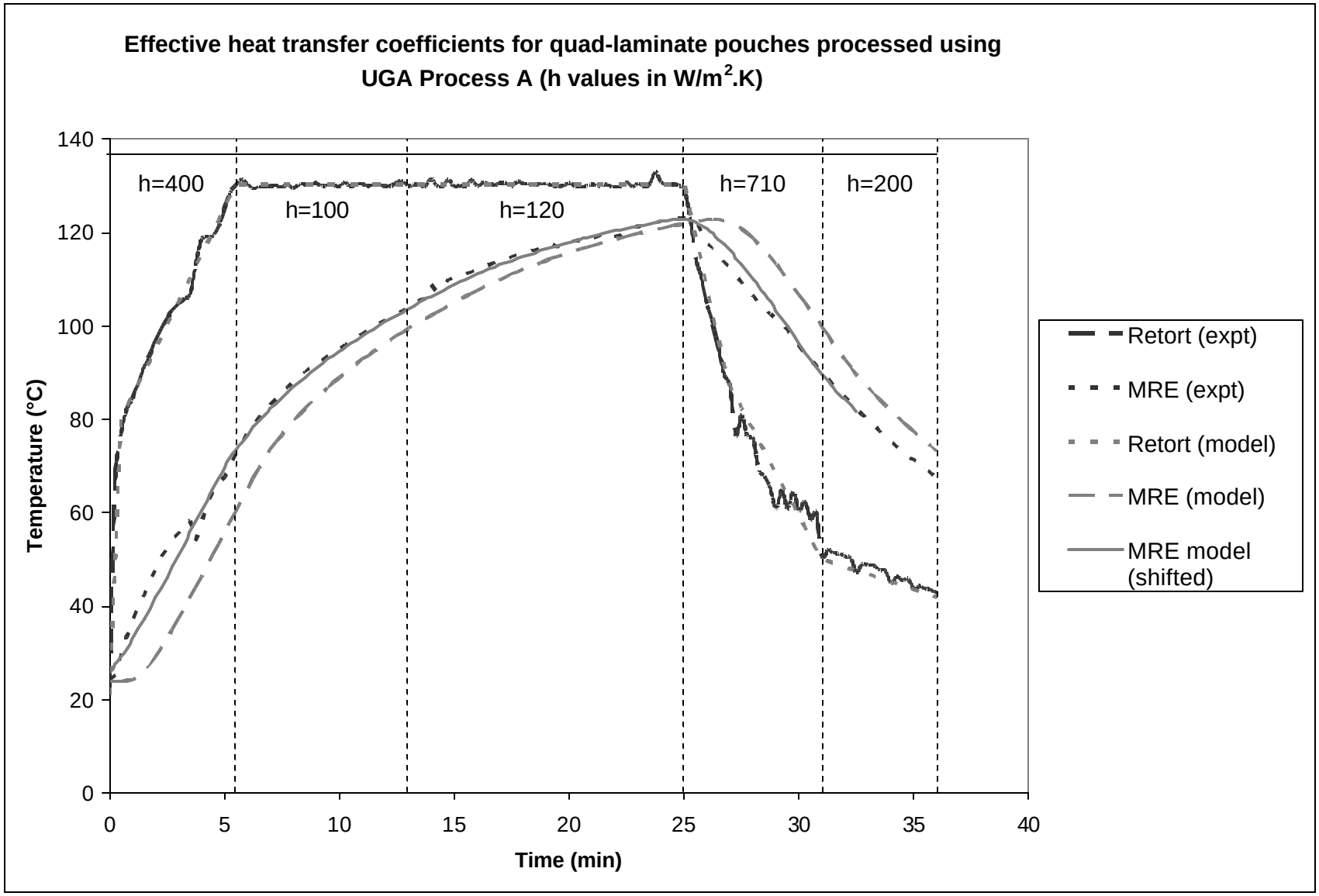

Figure-4.1: Effective heat transfer coefficients for quad-laminate pouches processed using UGA Process A

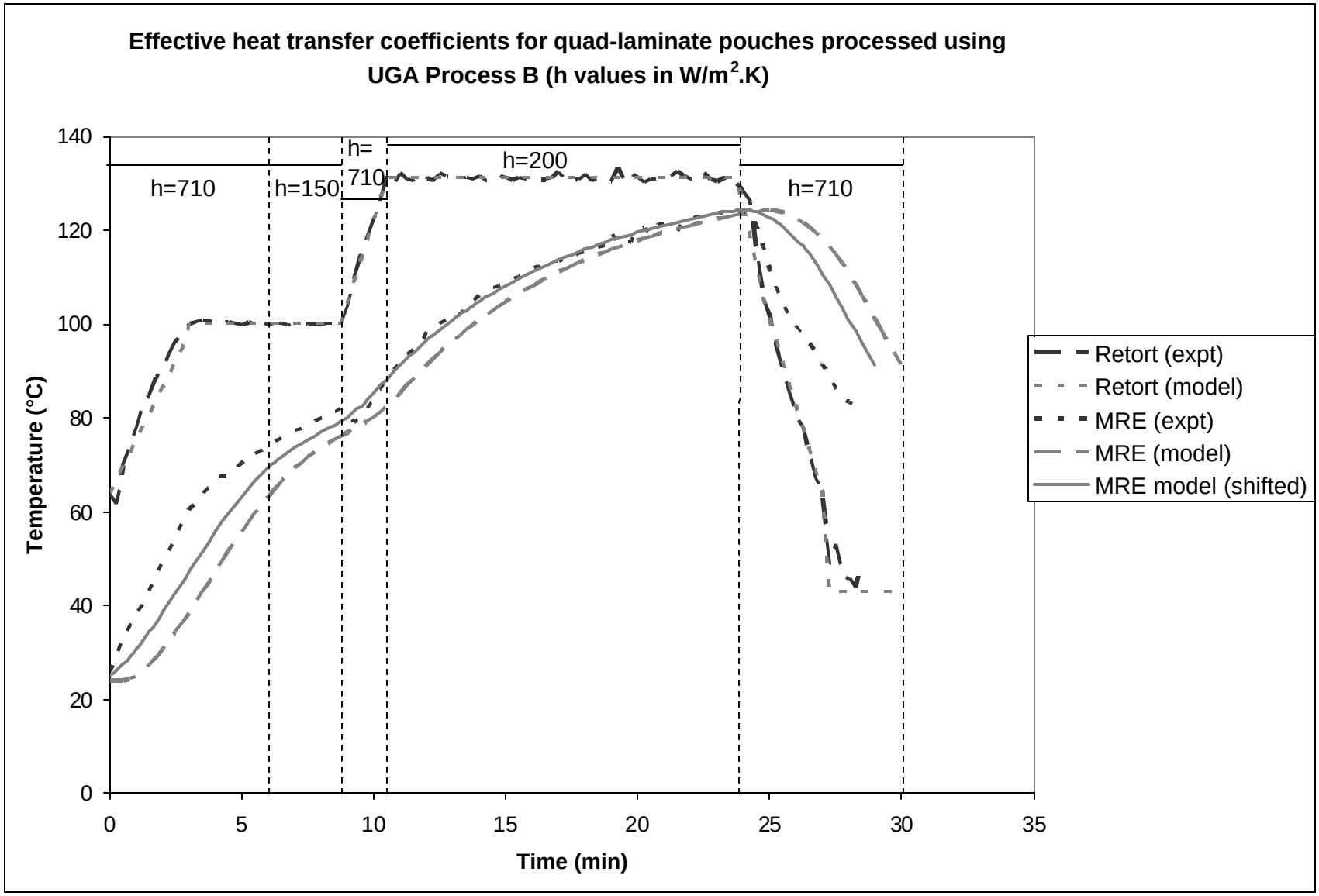

Figure-4.2: Effective heat transfer coefficients for quad-laminate pouches processed using UGA Process B

Full Water Immersion Retort

Processes FWI/MRE and FWI/poly were run in the FWI retort using quad-laminate MRE pouches and half steam-table trays, respectively. The h values that gave the best fit of the model and measured product temperatures for FWI/MRE process are given in Figure-4.3. The corresponding data for the FWI/poly process is in Figure-4.4.

In the case of the model for the FWI retort, there was no need for a time shift as the heating and cooling rates in the much larger FWI retort were much slower and the conditions were within the constraints of our model. The narrow flow channels in the retort rack configuration now used by the industry reduced the exposure of surfaces of containers contained in those racks to the heating medium, therefore, lower h values were obtained compared to those in the UGA sterilmatic retort. The h values were higher during the come-up and cool-down retort temperature ramps compared to those when retort temperature was constant. This could be explained by the higher flow rate of the heat transfer medium (water) during the time that the retort was being filled or drained. In the FWI retort h value was higher at the 130°C holding temperature than at the 100°C hold. The absence of overpressure during the 100°C hold could have restricted the flow channels as the pouches were expanding during the 100°C hold period. At 130°C hold, the overpressure pressed the inside package surface against the product promoting heat transfer.

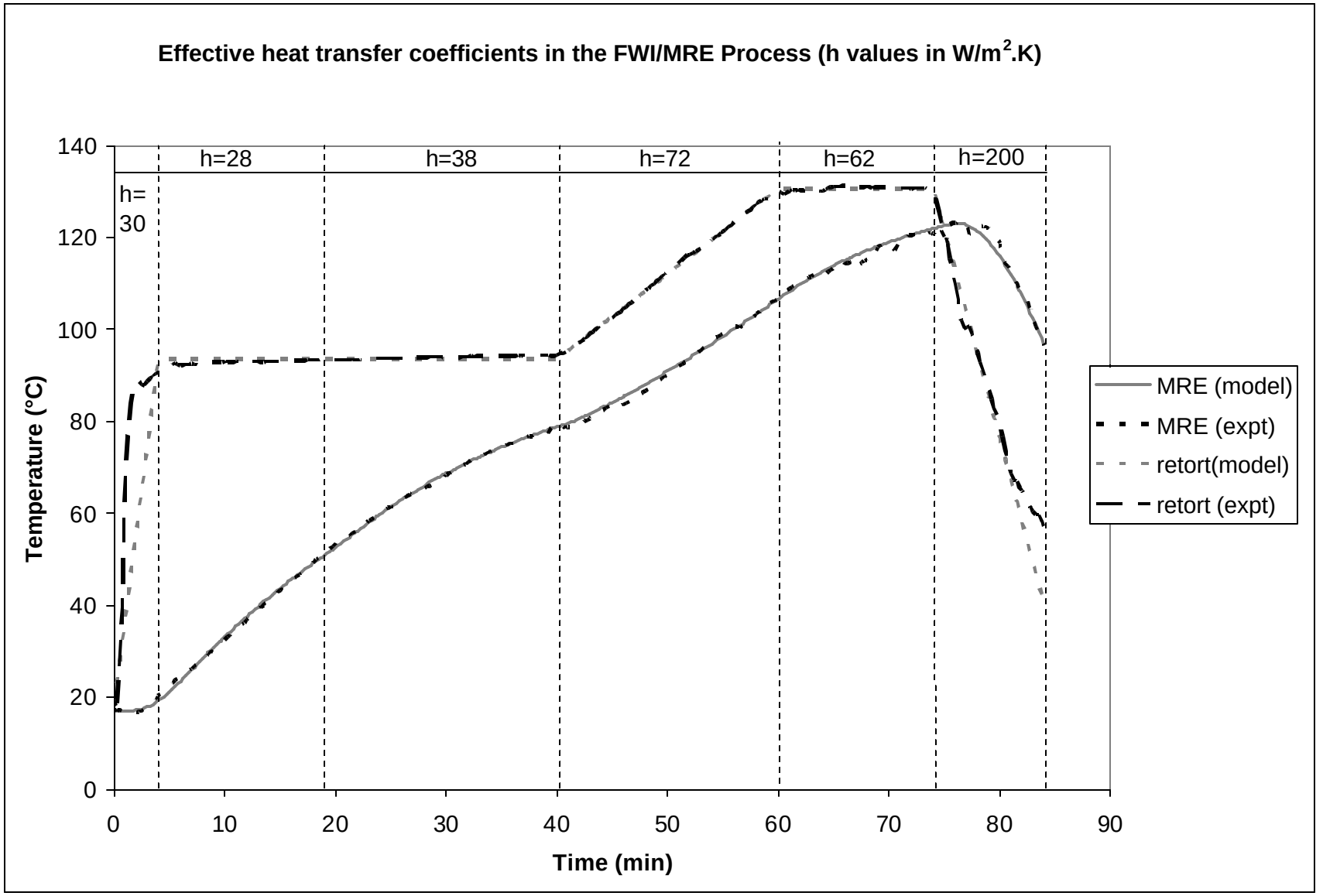

Figure-4.3: Effective heat transfer coefficients in the FWI/MRE Process

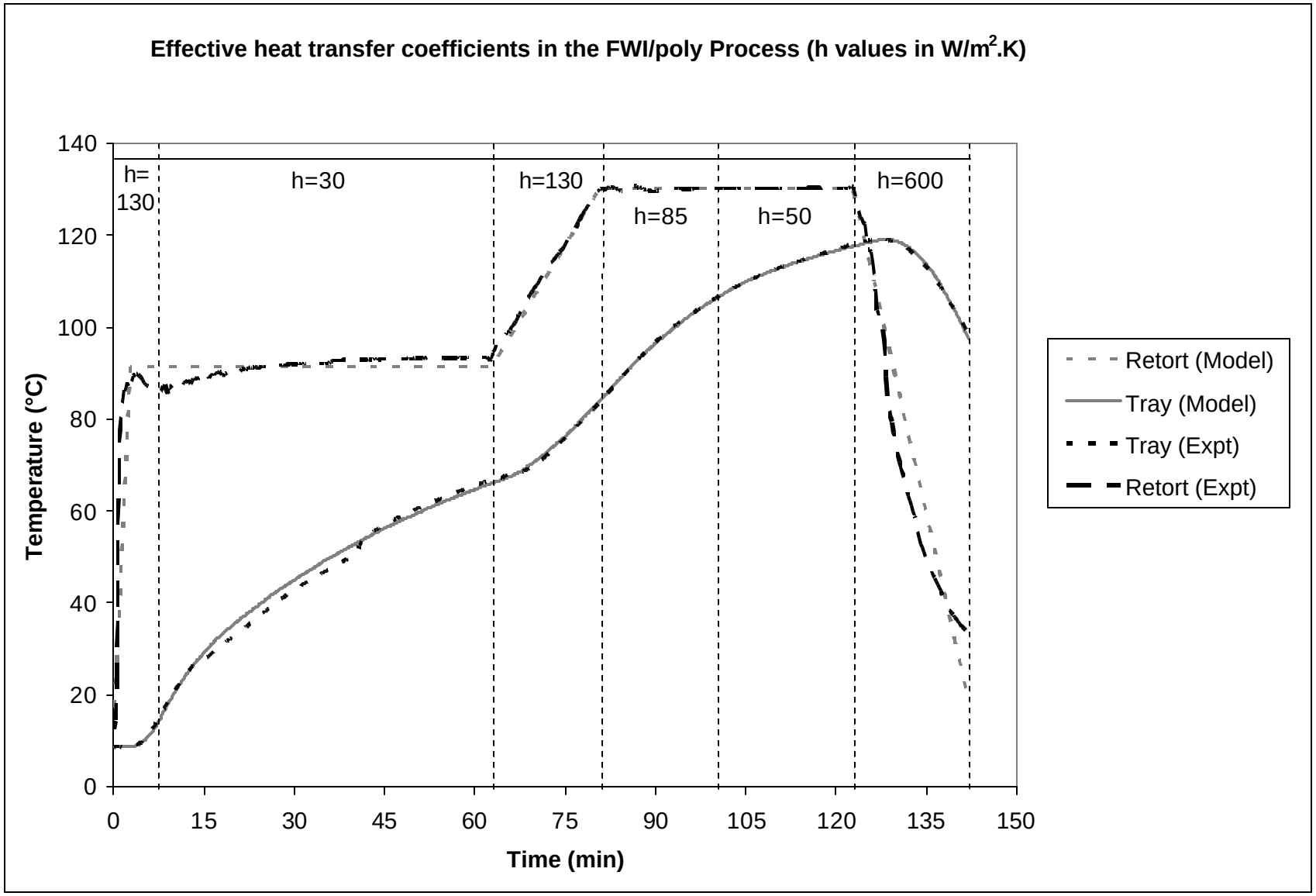

Figure-4.4: Effective heat transfer coefficients in the FWI/poly Process

Spray retort

The cascading water spray retort was used for the Spray/MRE and Spray/poly for MRE pouches and half steam-table trays, respectively. We hypothesized that the absence of a large pool of water in the spray retort would accelerate heating to the processing temperature and cooling of the retort after the desired F_0 value was reached. In the FWI Processes, a long ramp time was required for the FWI retort temperature to reach 130°C from 100°C.

The h values for the Spray/MRE Process A and the Spray/MRE Process B are given in Figures-4.5 and 4.6 and those for Spray/Poly Process A and Spray/Poly Process B are in Figures-4.7 and 4.8. It is observed that there is much less change in the h values at different stages of the process compared to h values in the FWI retort or the UGA retort. The cooling stage had especially much lower h values in the spray retort compared to the FWI and the UGA retorts. The very low h-values observed at the beginning of some of the processes was most likely due to the lag in getting the heating medium at the right temperature through the flow channels in the retort racks.

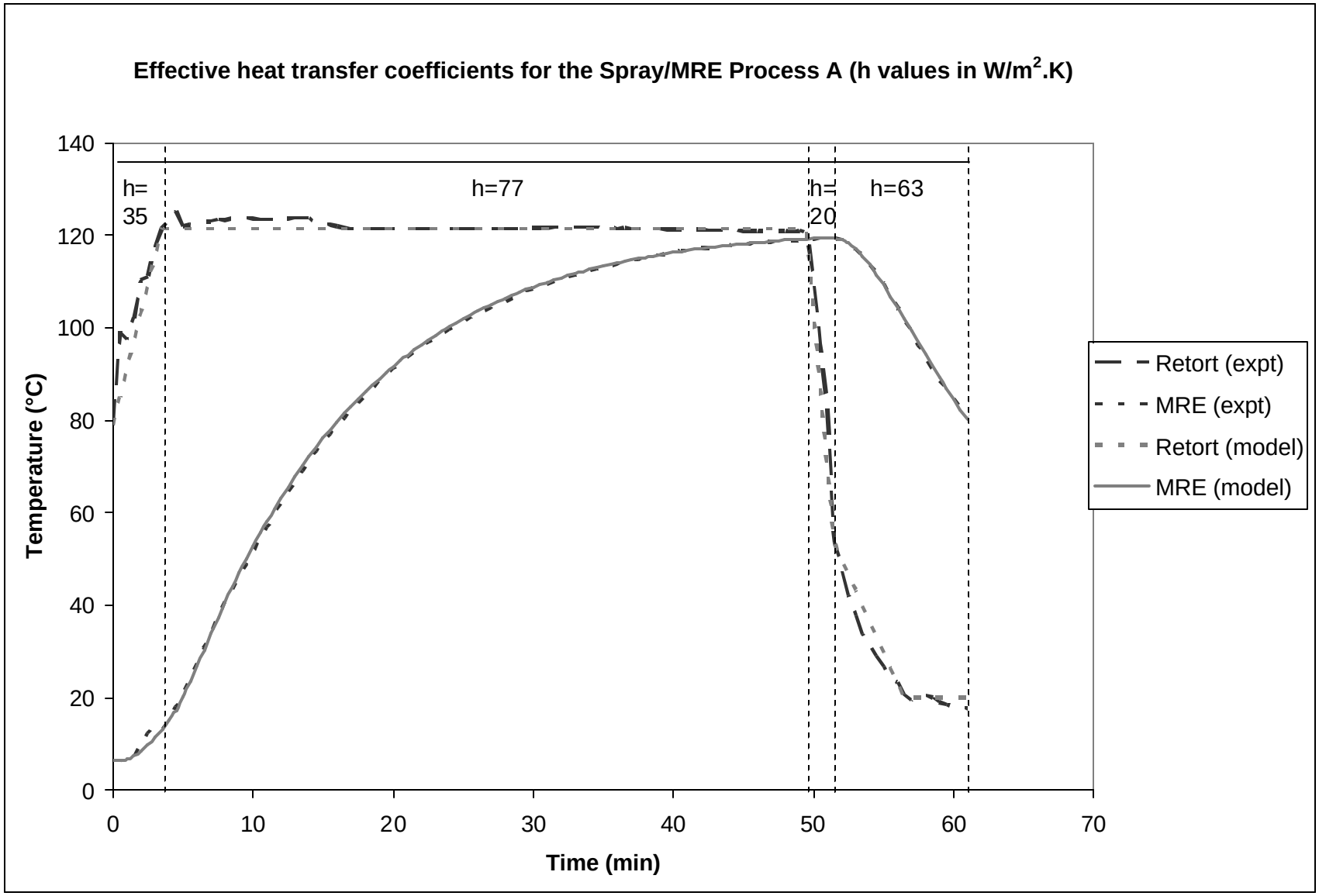

Figure-4.5: Effective heat transfer coefficients for the Spray/MRE Process A

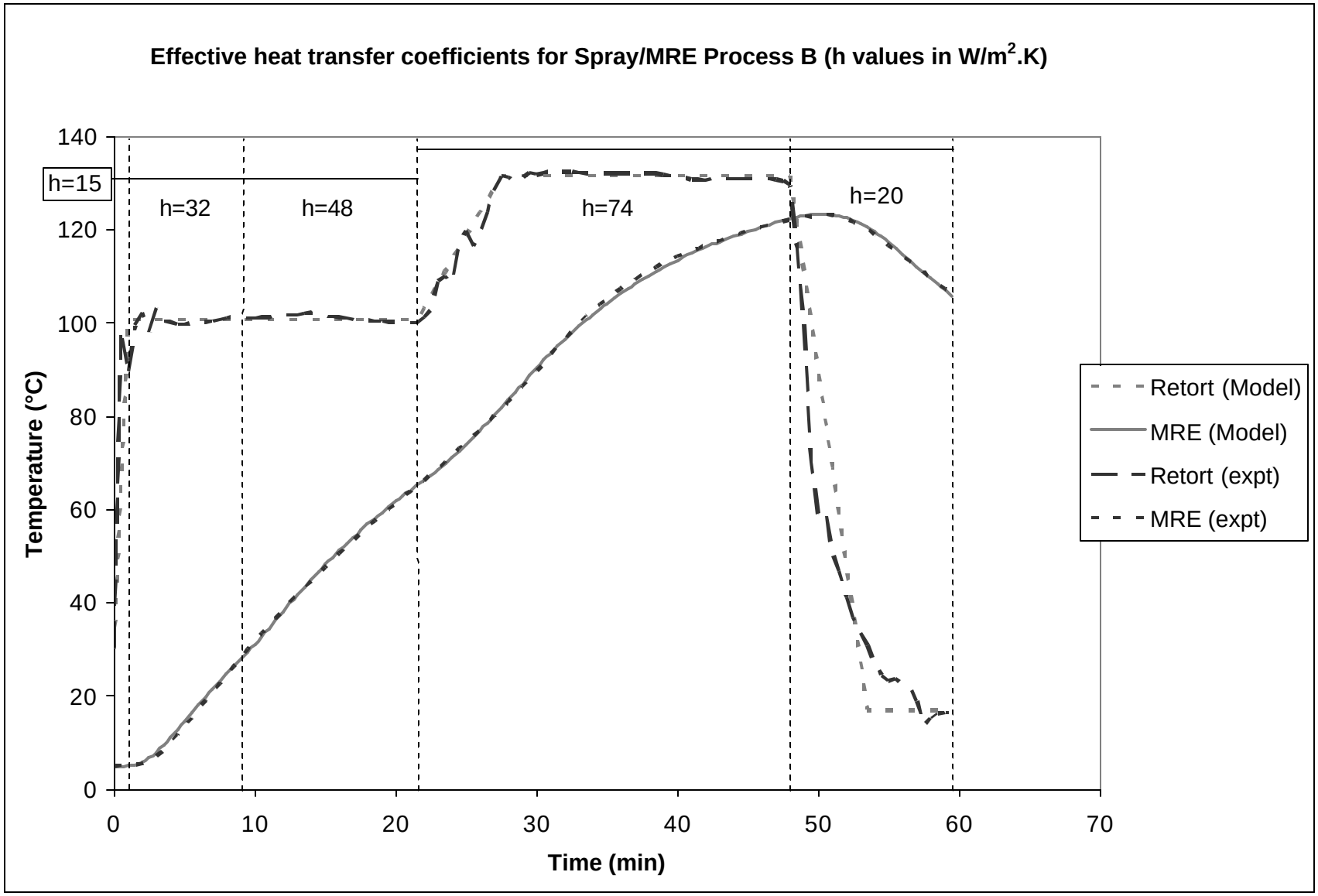

Figure-4.6: Effective heat transfer coefficients for Spray/MRE Process B

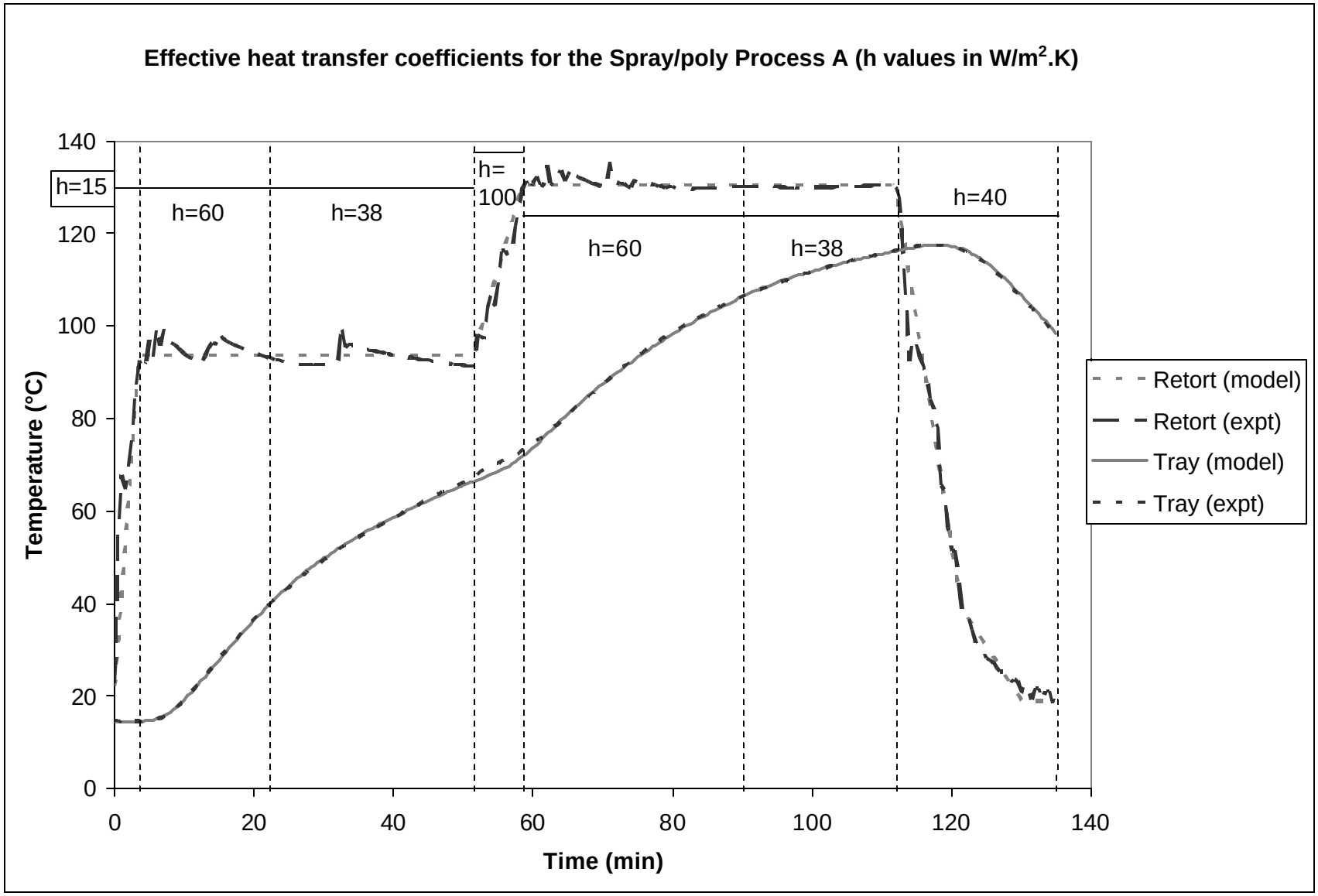

Figure-4.7: Effective heat transfer coefficients for the Spray/poly Process A

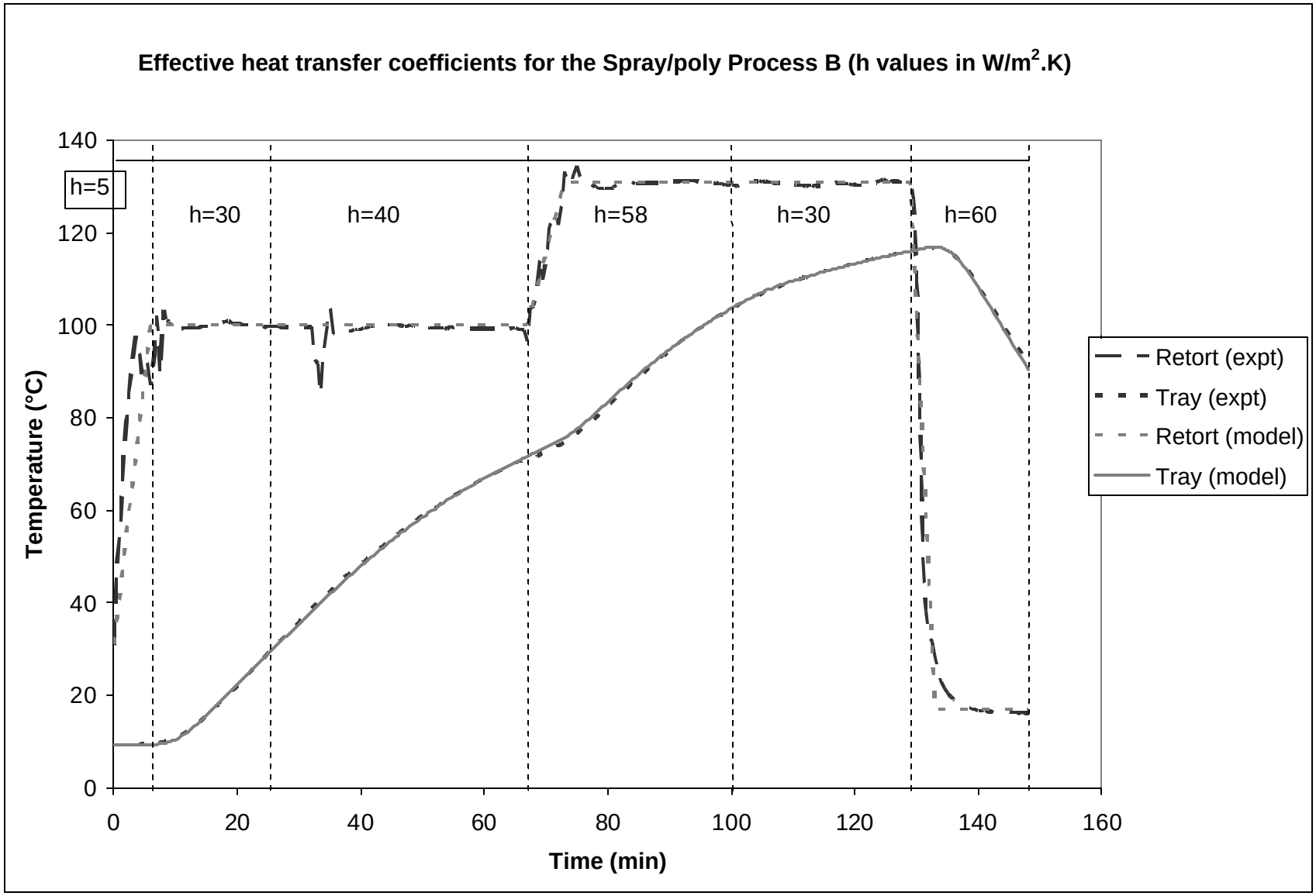

Figure-4.8: Effective heat transfer coefficients for the Spray/poly Process B

Conclusions

The effective heat transfer coefficients during the processing of an egg mix in quad-laminate retort pouches and half steam-table trays determined for thermal processes in three different retorts showed differences in values between container type, processing stages, and type of heating medium used on the same product processed. High effective heat transfer coefficients were obtained when there was more flow of the heating medium into the retort and more container surface exposed to the heating medium. Values of h were lowest when movement of the heating medium across the container surfaces was impeded by the retort rack used and heating medium temperature did not immediately reach the set point temperature. Values of h for a pilot plant retort were highest, and those in the FWI retort were lowest. Faster equilibration of the heating medium temperature in the Spray retort compared to the FWI retort, resulted in fewer processing stages with different values of h in the former compared to the latter type of retort.

Understanding the factors affecting values of h will allow a better understanding of the consequence of changes in retort hardware and processing phases and thus promote better identification of critical factors affecting process lethality and product quality. The finite difference heat transfer model adequately fitted measured center temperatures when appropriate values of h are used in the model calculations.

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CHAPTER 5

QUALITY IMPROVEMENT OF READY-TO-EAT COMMERCIALLY STERILE EGG PACKAGED IN QUAD-LAMINATE POUCHES AND HALF STEAM-TABLE TRAYS BY STAGED HIGH TEMPERATURE PROCESS[1]

[1]Kandala RN, Toledo RT. To be submitted to Journal of Food Science

Abstract

Quality retention values for an egg mix processed in quad-laminate pouches and half-steam-table trays in three different retorts were calculated using a formula that took into account both the D-value and z-value for quality degradation. The D-value for the quality degradation of the eggs was based on Maillard browning and was determined by the a*-value as a function of heating time. The D and z values were 910 min and 25°C, respectively. The volume average quality retention factor for eggs processed in quad-laminate pouches was between 0.67-0.78 calculated from spatial temperature distribution obtained by a finite difference based mathematical model. The quality retention factor is 1.0 in a product with no color degradation. In case of eggs in half-steam table trays, quality retention factor was between 0.55 and 0.58. Simulation of retort temperature effects on quality retention factor showed higher values when processing at 130°C compared to 122°C. The use of a holding step at 100°C, to raise product temperature to above 65°C followed by the scheduled thermal process also increased quality retention factor.

Introduction

The United States Military is currently the biggest consumer of commercially sterilized Meals-Ready-to-Eat (MRE) products but the convenience of these products has generated demand in the civilian market as well. A variety of products in pouches and rigid plastic containers are commercially available. For the military, MRE products are the primary sustenance of troops in the field. A quality meal is essential to maintain high troop morale and to provide adequate nutrition. Unconsumed product because of its poor quality would be a waste and would risk soldiers' ability to safely and efficiently perform their duties. To be commercially successful, processors must produce the best possible quality MRE products for consumers.

Eggs are a healthy and popular breakfast product. Eggs in half steam-table trays are currently used by the military to serve the troops at base stations. However, a good quality MRE egg product is missing from the military rations menu. Commercially sterile egg products in half steam-table trays are widely considered to be the poorest quality products in the military ration program. The primary complaints by consumers of retorted egg products are: poor texture, lack of egg flavor, undesirable red/brown color as opposed to the normal light yellow color, and the presence of an aftertaste (Kluter 2002). These product quality deficiencies are a direct result of the formulation of the product and thermally induced chemical reactions that occur during the commercial sterilization process.

A desirable cooked egg product must have a typical yellow egg color, be free of visible agglomerates, exhibit the characteristic odor and flavor of cooked eggs, and be moist and slightly spongy but not rubbery. The product should not exhibit syneresis/weeping. The US military requires a commercially sterile product with a minimum 36 months shelf-life at 26.7°C (80°F).

Kandala and others (2005a) reported on a new formulation for a MRE plain egg product that was highly acceptable in consumer sensory panels. However, when half steam-table trays were used to contain the product during thermal processing, achieving acceptable quality was a challenge since the primary mode of heat transfer during thermal processing was through conduction. Very slow heating of the critical point occurred because of the thick profile of the half steam-table tray. The need for a high quality commercially sterile egg product in meals ready to eat (MRE) pouches and half steam-table trays led to this work on optimizing the conditions for thermal processing.

Improvement in quality of products produced by high-temperature, short-time (HTST) thermal processes is possible since the rate of inactivation of microorganisms increases more rapidly with temperature than the rate of heat-induced deterioration of quality attributes (Lund 1977). However in case of non-agitated in-container processed high-viscosity or solid foods the primary mode of heat flow is through conduction, the need to sterilize the slowest heating point in the container results in prolonged exposure of product near the container walls, thus, the theoretical advantage of a HTST process may not be successfully achieved.

Teixeira and others (1969) developed the first computer program based on finite difference equations for two dimensional heat transfer to predict the time-temperature distribution within a cylindrical container. Their program assumed infinite surface heat transfer coefficients (h) and predicted the spatial temperature distribution as a function of processing time using only the thermophysical properties of the solid product as inputs. Other researchers tried to minimize the effect of thermal treatment on foods. Ohlsson (1980a) advocated that surface quality was the best optimization criterion for appearance and odor, and volume average quality criterion worked best for taste, consistency, and/or nutrient retention. While some studies have

advocated the use of variable retort temperatures for better product quality, others have concluded that a constant optimal temperature is as effective (Silva and others 1992b). Silva and others (1994) found that the optimum temperature for maximum average quality is always higher than the corresponding one for surface quality, but this rule is not consistent for all products. While several objective functions can be considered for optimization of a retort process, Silva and others (1992b) concluded that maximization of nutrients and quality attributes are usually the most appropriate factors that address the needs of consumers. They also concluded that the optimal sterilization temperature to maximize the surface quality and nutrient retention is independent of the rate of degradation (D-value) of a quality attribute and depends only on the z-value or the temperature dependence of the rate of change in the quality attribute. Ohlsson (1988) tabulated the optimal cook values for various products and the z-values for the most relevant quality factor for each product based on published data from other researchers. Optimal cook values for various package shapes were also tabulated. However, no cook values for eggs or egg products or the relevant z-value to be used for quality optimization were mentioned in the paper.

The objective of this study was to compare different experimental and simulated thermal process schedules for quad-laminate pouches and half steam-table trays based on application of pre-heat or direct heating of retort to processing temperatures and different process temperatures in three different retorts based on the volume average quality retention factor.

Theory

Cook Value

The definition of cook value in the present study was based on the expression for retention of a nutrient or a quality index. Knowing the D-value (D_{refq}) at a reference temperature

(T_{refq}) and the z-value (z_q) for the loss of a nutrient or a quality index, the time-temperature profile at a single point in a food can be utilized with the above parameters to calculate the retention of a nutrient or a quality index using the following equation (Silva and others 1992a):

$$\frac{N}{N_0} = 10^{\left[-\frac{1}{D_{refq}}\int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt\right]} \tag{5.1}$$

where N is the level of nutrients or quality factor at time t, N_0 is the initial level of nutrients or quality factor and T is the temperature at a particular point as a function of time t. N/N_0 may be considered as the fraction of the original quality factor retained after thermal processing. The closer N/N_0 is to unity, the better the processed product quality. Mansfield (1962) proposed the concept of cook-value to compare thermal processes in terms of quality degradation. Similar to the F-value, the cook-value (C) was defined as:

$$C = \int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt \tag{5.2}$$

Mansfield (1962) proposed this concept for processes where the time-temperature profile can be assumed to be uniform spatially, such as in aseptic processing of low viscosity foods.

Ohlsson (1980a,b) defined volume average cook value to evaluate the mean impact of a thermal process as:

$$C_{ave} = \frac{1}{V}\int_0^V \int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt dV \tag{5.3}$$

The above equation defined by Ohlsson (1980a,b) is independent of D-value for quality factor (D_{refq}) degradation. The desired process would result in the least C_{ave} value. The C_{ave} value has also been used by Tucker and Holdsworth (1991).

Silva and others (1992a) showed that D_{refq} values can play an important role in the optimization of a conduction heated food. In order to optimize the overall quality retention in case of a homogeneous conduction-heated food as is the case in our study, the quality retention must be integrated over the total volume taking into account the different time-temperature profiles as a function of position in the container. The definition for volume average quality retention is (Silva and others 1992a)

$$\left(\frac{N}{N_0}\right)_{ave} = \frac{1}{V}\int_0^V 10^{\left[-\frac{1}{D_{refq}}\int_0^t 10^{\frac{(T-T_{refq})}{z_q}} dt\right]} dv \qquad (5.4)$$

where T is the time-temperature profile as a function of position and V is the volume. This approach takes into account the D_{refq} value for the quality factor or nutrient retention and is suggested by Silva and others (1992a) as a better approach to optimization of a conduction heating process compared to the average cook value (C_{ave}) approach suggested by Ohlsson (1980a,b). The maximization of nutrient retention $(N/N_0)_{ave}$ is desired. An optimization algorithm based on maximal $(N/N_0)_{ave}$ is not mathematically equivalent to that based on minimal C_{ave}.

Methodology

Processing

An egg formulation developed at the University of Georgia (Kandala and others 2005a) was used to make the product. The formulation is given in Table-5.1. In addition to the ingredients listed in Table-5.1, the mix also contained some or all of the following ingredients as additives: xanthan gum and starch, calcium caseinate, white pepper and natural egg flavor. The sum of percentages of all additives was less than 2% of the total amount of the mix. The liquid

egg mixture was filled into pouches or half steam-table trays and thermally processed without agitation under 206.8 kPa (30 PSIG) air overpressure. The quad-laminate MRE pouches contained 227 g of the mix and the half steam-table trays contained 2.27 kg.

Table-5.1: Retorted egg product formulation

Ingredients	**Percent by Mass**
Liquid or frozen whole eggs	74.516
Water	21.858
Liquid Margarine	2.981
Salt	0.497
Citric acid	0.149

Two thermal processes were used. The Direct Process involved directly heating the retort to the processing temperature and holding that temperature until the desired center point lethality (F_0-value) was achieved. A total F_0-value of at least 6 min was desired therefore to account for residual heat lethality during the early part of the cooling phase, steam was cut-off and the cooling was started before F_0-value reached 6 min. The Pre-heat Process involved heating the retort to 100°C with the vent open (no overpressure) or with 103.4 kPa (15 PSIG) air overpressure and the 100°C retort temperature was maintained until the internal package temperature reached the 65°C gelling temperature of the egg mix. Then, retort temperature was raised to the processing temperature and the product was processed under 206.8 kPa (30 PSIG) air overpressure until the desired F_0-value was achieved. The products were then cooled while releasing the pressure gradually in the retort.

Retorts and product loading

Three types of retorts were used: A sterilmatic retort simulator (Steritort, FMC FoodTech, Madera, CA) at the University of Georgia; a Stock Rotomat 1100/4 (Stock America, Grafton, WI) operated stationary with Full Water Immersion (FWI), and a Stock Rotomat 1100/1 operated stationary with a cascading water spray. The latter two were located at the Centre for Advanced Food Technology (CAFT) facility of Rutgers University at Piscataway, NJ. The Steritort at the University of Georgia pilot plant was fitted with a centrifugal pump that took water from the lowermost part of the retort and forced this water to cascade over the product through nozzles at the uppermost point in the retort. Standard industry retort racks were used in the Stock retorts. The MRE pouches or half-steam table trays were positioned in the racks and oriented parallel to the axis of the retort. Product containers were layered alternately with the rack frame, i.e., the rack frame separated the walls of adjacent containers leaving a small space for circulation of the heating medium between adjacent containers. The rack frame also restrained the containers and prevented excessive expansion of the containers if the internal pressure in the containers exceeded the overpressure. A specially constructed rack made of perforated steel was used in the Steritort. The rack was constructed with spacing between the pouches thereby exposing both faces of the pouches to the heat transfer medium of steam/air and cascading water. Half-steam table trays were processed in one layer with the cascading water falling into the top of the packages. A specially constructed rack made of perforated metal was used to restrain expansion of the tray lids during thermal processing.

Model

A Matlab program that calculated the center point lethality (*F*-value) and volume average quality retention ($[N/N_0]_{ave}$) was developed based on finite difference equations for heat transfer. The model utilized finite values for effective surface heat transfer coefficients (h) and these were arrived at by iterating the calculations with different values of h until the calculated geometric centre temperature matched the experimental values over time, and the calculated geometric centre lethality matched that calculated using the experimental time-temperature profile. The effective heat transfer coefficients used in the simulations are listed in Kandala and others (2005b). The size of elements used for both the quad-laminate MRE pouches and the half steam-table trays was kept similar in order to be able to compare the quality retention values between the two cases.

Determination of kinetic data for quality degradation

Preliminary evaluation of the retorted egg products revealed that color was a good indicator of its final quality, and reflected both flavor and texture attributes. The color of the commercially sterilized product was measured using a Minolta Colorimeter (Model CR410, Minolta, Ramsey, NJ) and expressed as the L*-, a*-, b*-values.

The color change was assumed to be due to the Maillard Browning reaction and the z-value would be similar to the value for the browning of milk. This value has been reported to be between 21.3°C and 28.2°C (Holdsworth 1985). The z-value for the color change of heated eggs was determined by heating for various times at 100, 115, and 130°C in small metal cans. While the heating at 100°C was done in a steam cabinet, the heating at the other two temperatures was done inside the retort. Air overpressure of 103.4 kPa (15 PSIG) was applied in the cooling phase of the retort processes to prevent buckling of the cans. When heating at 100°C the first reading

was taken after 60 min and this was considered as the base color of minimally processed product. When heating at 115 and 130°C, the color at time=0 was taken on the product from a process where the retort was heated to the indicated temperature followed by immediate cooling.

Results and Discussion

D and z values for color degradation

The values of a* as a function of time, for eggs heated at three temperatures are given in Figure-5.1. The a*-values were measured on the egg surface located at the bottom of the cans. Products with higher a*-values showed more browning, had poorer texture (softer and mushier) and also had an overcooked flavor ("spam"-like smell and a slightly bitter aftertaste).

The graph of a*-values against time (Figure 5.1) showed that a* started from a large negative value and slowly increased to become positive after some time. The times when a* went from negative to positive values at 100, 115 and 130°C were 500, 81 and 23 minutes respectively. From the semi-log graph of time vs. temperature (Figure 5.2), a z-value for the a*-value change of 22.42°C was obtained. At 100°C when the a* value changed signs, it took 910 min for a*-value to change by one log cycle. This is the D-value for the a*-value change at 100 C. Figure 5.1 also shows that the a*-value did not become positive until after 420 min of heating at 100°C. In contrast, at 115 and 130°C the time for the a*-value to become positive was less than 90 and 32 min respectively. This shows that the product can be heated for a long time at 100°C with very little change in the a*-value, thus little change in quality of the retorted product can be expected.

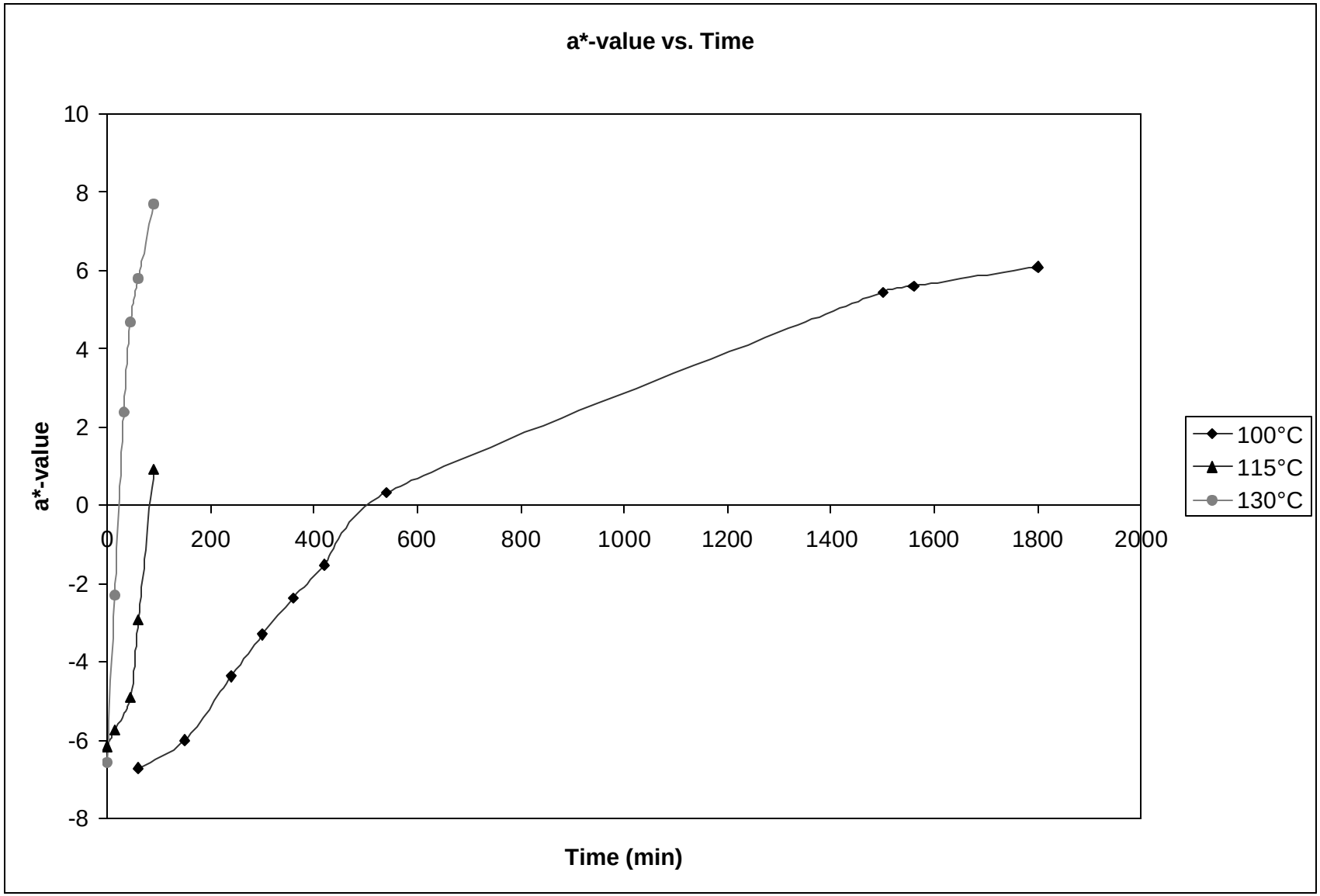

Figure 5.1: a*-value as a function of time at three different temperatures

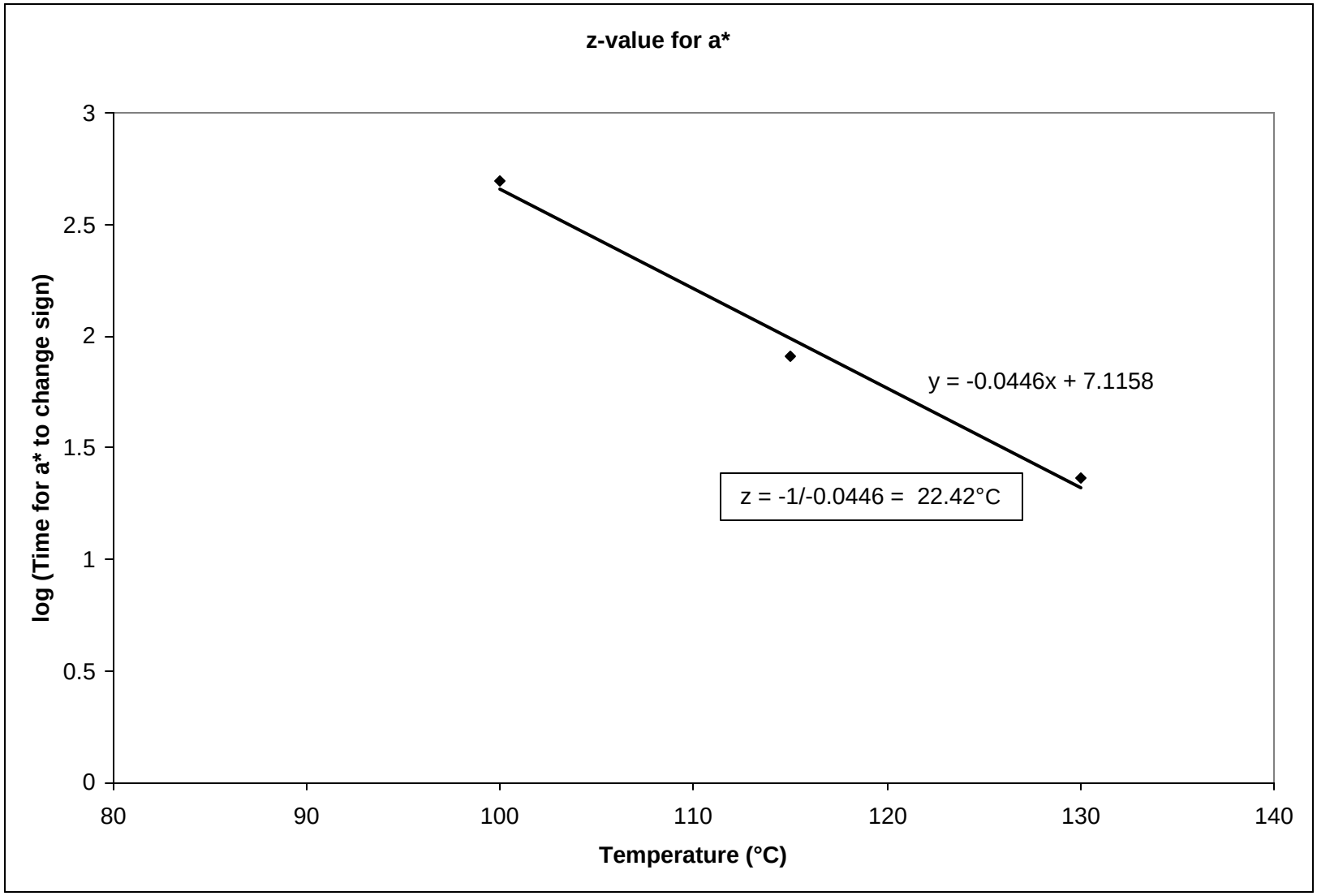

Figure-5.2: Determination of z-value for a* from D-values at three temperatures

Since quality degradation is nil near 100°C, a pre-heat process involving a holding step at 100°C could be beneficial in improving retorted product quality since the high initial product temperature during the sterilization step will require shorter scheduled process at the elevated temperature.

Modeling of quality degradation in retorted eggs was done using a z-value of 25°C based on the present data and what is available in the literature for other products. In calculating the average quality retention factor $[(N/N_0)_{ave}]$, we used a D_{100}-value of 1000 min in the model. Silva and others (1992a) used a D_{100} value of 200 min (based on thiamine degradation) in their calculations on volume average quality retention factor. The D_{100} values of 1000 and 200 min represented the extreme values for quality degradation used in previous studies.

Calculated average quality retention factors

Thermal processes on a Steritort

Heat penetration data and effective heat transfer coefficients for eggs thermally processed in a Steritort were reported by Kandala and others (2005b). The computer program for fitting geometric center temperature to experimental data and for calculating spatial temperature distribution inside packages was reported by Kandala and others (2005b) The calculated volume average quality retention factors $[(N/N_0)_{ave}]$ based on Equation (5.4) for D_{100}-values of 200 min and 1000 min and z-value of 25°C are given in Table-5.2.

Quality retention factor was calculated in the Direct Process for eggs in MRE pouches processed at 130.3°C for 18 min. Quality retention factor was also calculated in the Pre-heat Process for eggs in MRE pouches. The process consisted of 5.5 min at 100.2°C, a temperature

ramp to 131.2°C with air overpressure of 206.8 kPa (30 PSIG), and 11.5 min at 131.2°C (Kandala and others 2005b).

Table-5.2: Quality Retention Factor for eggs processed in the Steritort

Package	Expt F_0 (min)	Model F_0 (min)	$(N/N_0)_{ave}$	
			D_{100}=200	D_{100}=1000
Direct Process MRE	7.78	8.22	0.2954	0.7800
Pre-heat Process MRE	7.95	10.09	0.3126	0.7898

Data in Table-5.2 show that quality retention factor $(N/N_0)_{ave}$ was higher with the Pre-heat process even when the process ended with a higher F_0-value compared to the Direct process. The results also show that the D-value for the degradation process must be included in the modeling of quality retention factor. When the D value is low, degradation rate is fast, therefore it is expected that there will be less quality retention. Using the D_{100}=200 min for the decimal reduction time of quality degradation, a value most commonly used by previous researchers based on the degradation kinetics of thiamin results in very low values of the quality retention factor, while use of the more accurate value of D_{100}=1000 min, experimentally determined for eggs, resulted in a much higher quality retention factor. Thus, calculations to determine extent of heat damage due to processing should not be based on just the z-value of the degradation reaction.

Thermal processes in a FWI Retort

$(N/N_0)_{ave}$ values for experiments performed on the FWI retort at the CAFT facility using quad-laminate MRE pouches and half steam-table trays are given in Table-5.3. $(N/N_0)_{ave}$ values designated MRE FWI were calculated using data for processing of quad-laminate MRE pouches in the FWI retort. The process consisted of 36 min at 93.6°C with no overpressure and 13 min at 130.6°C. The process for half steam table trays in FWI was 60 min at 91.4°C with no overpressure and 42 min at 130.25°C with 275.8 kPa (40 PSIG) air overpressure (Kandala and others 2005b).

The quality retention factor for products processed in the large FWI retort which was fully loaded with product and ballast packs was much lower than the MRE. The use of retort racks which minimized heating medium flow over the packages resulted in slow heating rate prolonging the high temperature hold and therefore lowered the quality retention factor. The quality retention factor of 56% for the half steam-table tray compares with 70% for the thinner profile quad-laminate MRE pouches. Thus, processing the thicker profile half steam-table trays will require a lot of care in controlling the critical factors affecting heating rates in order to obtain an acceptable product. The lower retention factor in the half-steam table tray also reflects a more severe heat treatment received by the outer layers of the packaged product.

Table-5.3: Quality retention factor for experiments in FWI Retort

Package	**Expt F_0 (min)**	**Model F_0 (min)**	**$(N/N_0)_{ave}$**	
			D_{100}=200	**D_{100}=1000**
MRE FWI (With Pre-heat)	13.24	13.43	0.1731	0.7016
Half steam-table tray FWI (With Pre-heat)	11.11	10.91	0.0669	0.5595

Cascading water Spray Retort

$(N/N_0)_{ave}$ values for experiments performed on the spray water retort at the CAFT facility using quad-laminate MRE pouches and half steam-table trays are given in Table-5.4. The MRE pouches were processed using a Direct process and a Pre-heat process. The MRE 121 pouches were subjected to a direct process of 45.5 min at 121.5°C with air overpressure of 275.8 kPa (40 PSIG). The MRE 130 pouches were subjected to the pre-heat process of 20 min at 100.9°C with 103.4 kPa (15 PSIG) air overpressure and 20 min at 131°C (Kandala and others 2005b).

Half steam-table tray (Run 1) was subjected to the pre-heat process for 47 min at 93.8°C with no overpressure and 53 min at 130.5°C with 289.6 kPa (42 PSIG) air overpressure. Half steam-table tray (Run 2) was subjected to the pre-heat process of 61 min at 100°C with 103.4 kPa (15 PSIG) air overpressure and 56 min at 130.9°C with 289.6 kPa (42 PSIG) air overpressure (Kandala and others 2005b).

Table-5.4: Quality retention factor for experiments in Spray Retort

Package	**Expt F_0 (min)**	**Model F_0 (min)**	**$(N/N_0)_{ave}$**	
			D_{100}=200	**D_{100}=1000**
MRE 121 Spray (Direct)	9.23	9.20	0.1755	0.7041
MRE 130 Spray (Pre-heat)	14.89	15.60	0.1501	0.6791
Half steam-table tray Spray (Run 1) (Pre-heat)	8.64	8.63	0.0690	0.5595
Half steam-table tray Spray (Run 2) (Pre-heat)	6.71	6.73	0.0844	0.5819

The results in Table-5.4 support those in Table-5.3 for the FWI retort. The two half steam-table tray processes had much lower quality retention values compared with the two quad-laminate MRE pouch processes. In this case the pre-heat process for pouches at 130°C had a lower quality retention factor compared to the direct process at 121°C. This was due to the fact that the pouch processed at 130°C with pre-heat was overprocessed as evidenced by its much higher F_0-value of 14.9 min. When the model was used to cut back the hold time at 130°C by 3.5 minutes to give an F_0-value of 7.4 min (in the desired range of 6-8 min), the $(N/N_0)_{ave}$ value increased to 0.7557 (D=1000 min) which was higher than 0.7041 for the MRE 121 process.

Simulations

To prove the advantages of variations in the retort processes on the quality of processed eggs, specifically the Pre-heat process compared to the Direct process the mathematical models developed for the experimental processes were modified to simulate different processing temperatures. The effective heat transfer coefficients were assumed to be the same for these different processing temperatures and the quality retention factor $(N/N_0)_{ave}$ values were calculated and compared. The three temperatures at which these calculations were made were 122, 126 and 130°C and the $(N/N_0)_{ave}$ values were calculated for quad-laminate MRE pouches in the Steritort, the FWI retort and the cascading water Spray retort for similar F_0-values. The temperature ramps for heating and cooling were modeled to be similar to those obtained experimentally. The $(N/N_0)_{ave}$ values for processing of half steam-table trays are given for the FWI and cascading water Spray retorts. The results of the simulations are given in Table-5.5 for the quad-laminate MRE pouches and in Table-5.6 for the half steam-table trays.

Table-5.5: Quality retention factor values for simulated conditions in the various retorts for eggs in quad-laminate MRE pouches

Process	N/N_0		Model F_0-value (min)
	D_{100}=1000	D_{100}=200	
MRE UGA (Direct) (Original Process at 130.3°C)	0.7800	0.2954	8.2168
MRE UGA (Direct) (Simulated for 126°C)	0.7702	0.2753	8.0670
MRE UGA (Direct) (Simulated for 122°C)	0.7502	0.2400	8.0611
MRE UGA (Pre-heat) (Original Process at 131.2°C)	0.7898	0.3126	10.0853
MRE UGA (Pre-heat) (Simulated for 126°C)	0.7761	0.2844	9.7016
MRE UGA (Pre-heat) (Simulated for 122°C)	0.7465	0.2334	10.0052
MRE FWI (Pre-heat) (Original Process at 130.67°C)	0.7016	0.1731	13.4315
MRE FWI (Pre-heat) (Simulated for 126°C)	0.6793	0.1467	13.3311
MRE FWI (Pre-heat) (Simulated for 122°C)	0.6452	0.1130	13.4323
MRE Spray (Direct) (Simulated for 130°C)	0.7369	0.2253	9.4588
MRE Spray (Direct) (Simulated for 126°C)	0.7249	0.2051	9.5736
MRE Spray (Direct) (Original Process at 121.5°C)	0.7044	0.1760	9.2793
MRE Spray (Pre-heat) (Original Process at 131.6°C)	0.6829	0.1543	15.2133
MRE Spray (Pre-heat) (Simulated for 126°C)	0.6620	0.1301	15.1656
MRE Spray (Pre-heat) (Simulated for 122°C)	0.6295	0.1001	14.9072

Table-5.6: Quality retention factor values for simulated conditions in the various retorts for eggs in half steam-table trays

Process	N/N_0		Model F_0-value (min)
	D_{100}=1000	D_{100}=200	
Tray FWI (Pre-heat) (Original Process at 130.25°C)	0.5595	0.0669	10.9105
Tray FWI (Pre-heat) (Simulated for 126°C)	0.5394	0.0537	11.1904
Tray FWI (Pre-heat) (Simulated for 122°C)	0.5178	0.0421	11.1141
Tray Spray (Run 2) (Pre-heat) (Original Process at 130.9°C)	0.5819	0.0844	6.7335
Tray Spray (Run 2) (Pre-heat) (Simulated for 126°C)	0.5670	0.0706	6.7447
Tray Spray (Run 2) (Pre-heat) (Simulated for 122°C)	0.5498	0.0582	6.7466

The results from Tables-5.6 and 5.7 show that the quality retention factor decreases with decreasing processing temperature at 122, 126 and 130°C. The highest temperature of 130°C is constrained by the mechanical and physical effects of temperature on the retorts, retort pouches and the retort racks. Temperatures below 122°C would result in extremely long processing times. However, processing at 130°C requires vigilance on the part of the retort operator on precise temperature control and adherence to scheduled processing sequences. On thermal processes conducted at 121-122°C, there is no overshoot of package internal temperature once cooling is initiated. Internal temperature drops as soon as cool down is initiated. Thus, the cooling step may be initiated once the desired F_0-value of 6 min is reached and very little additional lethality may be obtained in the cooling stage. At the higher processing temperature of 130°C, contents near the package surface are at a high temperature with significant contribution to process lethality so

that conduction from the surface layers towards the center results in a significant temperature rise even when cooling was already initiated. Thus, the cooling phase of the process contributes significantly to the total process lethality. Hence to achieve an F_0-value of 6 to 8 min, cooling must be started when lethality at the centre point is at an F_0-value of around 3.5 min to obtain a final F_0-value of 8.0 min. A scheduled process at 130°C must be pre-determined to account for the cooling phase temperature overshoot or else the product will be over-processed and the advantages of the higher temperature process would be lost.

Conclusions

Quality retention values for various retort processes for quad-laminate pouches and half steam-table trays should be calculated using a formula that incorporates both D and z values for quality degradation. For eggs, quality degradation was modeled as a loss in color and the kinetics of color loss can be determined using the a*-value of heated eggs measured with a colorimeter. The z-value for quality degradation as a color change was 25°C and was similar to that used by previous investigators on other products. The D_{100}–value however was not available in the literature for eggs, and this was determined to be in the 900 to 1000 min range, much higher than the value of 200 min previously used for other products. Simulations involving determination of spatial temperature distribution based on a finite difference heat transfer model with values of effective heat transfer coefficients calculated from actual measured time-temperature history at the centre point, permitted calculation of a volume averaged quality retention factor defined as the fraction of the original quality index remaining after the process. Using measured D and z values for color degradation of eggs, simulations showed that the quality retention factor increased with higher processing temperature from 121.1°C to 130°C if final F_0-values were kept

constant. However, high temperature processes which result in a large overshoot of the target F_0-value could lead to more quality degradation than at lower temperature when the F_0 overshoot is easy to minimize. In case of the eggs, the product actually seemed to benefit from the rapid retort processing at the higher temperature. The quality retention factors were highest on pouches processed in the small UGA retort which had fast come-up and cool-down rates and heat transfer coefficients were high because the retort rack maximized product surface exposure to the heating medium. The quality retention factors were substantially lower for the thicker profile half steam-table trays compared to the quad-laminate pouches processed in the FWI or Spray retorts. A Pre-heat process at 100°C to raise product internal temperature prior to exposure to sterilizing temperatures resulted in higher quality retention factors compared to a direct process of exposing product to the sterilizing temperature. The pre-heat process could be applied to quality improvement of products other than eggs.

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CHAPTER 6

CONCLUSIONS

Formulation for retorted ready-to-eat egg products available in the literature was modified by adjusting the water and fat contents and by adding xanthan, ι-carrageenan and starch. Megatron, a high speed in-line gear mixer gave the best results in mixing the ingredients. Thermal processing conditions were also modified by using a high-temperature (130°C) sterilization step and a pre-heat at 100°C prior to the sterilization step. TPA analysis on the samples showed little differences in instrumental texture parameters between formulations containing the various hydrocolloid additives within the experimental design. Sensory analysis identified the product with xanthan at 0.2% to be the most preferred product among consumers. It was shown that the combination of xanthan in the mix and mixing in the Megatron resulted in the fluffiest sample (sample with the least density). In case of mix with no xanthan, the pre-heat before the sterilization step played an important role in developing a fluffy commercially sterile product.

The effective heat transfer coefficients (h) during the processing of an egg mix in quad-laminate retort pouches and half steam-table trays were determined for processes in three different retorts using a finite difference heat transfer model by matching the model temperature with the experimental temperature for the slowest heating point in the product. The h-values were highest in the UGA retort as was expected due to the way the pouches were placed in the retort. In case of the FWI and the spray retorts, the larger size of these retorts made it slower to

effect changes in the temperature of the retort. The use of the industrial racks for holding the pouches and trays in these retorts seemed to result in much lower heat transfer rates possibly due to blocked flow channels. The egg mix upon heat processing expands thus possibly cutting off the flow channels. The hindered heat medium flow could also explain the difference in the heat transfer values in the various stages of processing in these retorts and also the difference in heat transfer coefficients between runs.

The knowledge of effective heat transfer coefficients is useful in modeling heat transfer processes. Thermal processes can be designed for different processing temperature schedules with the knowledge of the heat transfer coefficients. The time of processing can be predicted as well as the time of onset of the cooling stage to prevent over-processing can be established with the models. These models could also be used to determine quality retention and cook values which can be used to compare the effect of different thermal processing schedules.

Quality retention values for various retort processes for quad-laminate pouches and half steam-table trays should be calculated using a formula that incorporates both D and z values for quality degradation. The z-value for quality degradation as a color change was 25°C for the eggs. The D_{100} –value however was not available in the literature for eggs, and this was determined to be in the 900 to 1000 min range, much higher than the value of 200 min previously used for other products. Simulations involving determination of spatial temperature distribution based on a finite difference heat transfer model with values of effective heat transfer coefficients calculated from actual measured time-temperature history at the centre point, permitted calculation of a volume averaged quality retention factor defined as the fraction of the original quality index remaining after the process. Using measured D and z values for color degradation of eggs, simulations showed that the quality retention factor increased with higher processing

temperature from 121.1°C to 130°C if final F_0-values were kept constant. However, high temperature processes which result in a large overshoot of the target F_0-value could lead to more quality degradation than at lower temperature when the F_0 overshoot is easy to minimize. In case of the eggs, the product actually seemed to benefit from the rapid retort processing at the higher temperature. The quality retention factors were highest on pouches processed in the small UGA retort which had fast come-up and cool-down rates and high heat transfer coefficients. The quality retention factors were substantially lower for the thicker profile half steam-table trays compared to the quad-laminate pouches processed in the FWI or Spray retorts. A Pre-heat process at 100°C to raise product internal temperature prior to exposure to sterilizing temperatures resulted in higher quality retention factors compared to a direct process of exposing product to the sterilizing temperature. The pre-heat process could be applied to quality improvement of products other than eggs.

CHAPTER 7

FUTURE WORK

Some suggestions for future work are listed below:

- Thermo-physical properties (density and thermal conductivity) can be determined as a function of temperature in the entire temperature range of the experiments (20 – 130°C) and can be incorporated in the model along with specific heat as a function of temperature instead of using constant values
- Ingredients that were not investigated in this study that might be useful towards the improvement of the retorted egg product may be studied
- Product extensions that enable inclusion of meats or vegetables in the product
- Shelf-life studies for texture and flavor
- Further work into improving the quality of the product in half steam-table trays, possibly investigate container holding racks with improved flow channels for the heat transfer medium
- Investigate other retort profiles to improve the product processed in half steam-table trays
- Determine the range of instrumental texture parameters that are desirable for this product by means of sensory studies which would enable easier future product development
- More experiments needed in industrial scale equipment and retorts to come up with acceptable processing conditions for mixing and thermal processing

APPENDICES

APPENDIX A

TPA RESULTS

Table-A.1: Mean texture properties of the xanthan (X) – ι-carrageenan (IC) MRE egg products from TPA tests on TAXT-2 with 50% sample deformation

Hardness (N)	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	10.50813[a]	10.69919[a]	11.30912[a]
X:0.35	10.70263[a]	11.01385[a]	11.52342[a]
X:0.5	11.01723[a]	10.77262[a]	11.33618[a]
Adhesiveness (N.s)	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	-0.19087[ab]	-0.17735[a]	-0.19079[ab]
X:0.35	-0.22569[ab]	-0.22003[ab]	-0.18218[a]
X:0.5	-0.27279[b]	-0.24666[ab]	-0.27335[b]
Springiness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	0.817593[ab]	0.771889[bc]	0.785926[abc]
X:0.35	0.843667[a]	0.784704[abc]	0.746667[c]
X:0.5	0.831074[ab]	0.790407[abc]	0.812926[ab]
Cohesiveness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	0.287492[ab]	0.31306[ab]	0.271453[b]
X:0.35	0.341185[a]	0.310659[ab]	0.268615b
X:0.5	0.330576[ab]	0.291217[ab]	0.306665[ab]
Chewiness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	2.475515[a]	2.58819[a]	2.434123[a]
X:0.35	3.113568[a]	2.662982[a]	2.358527[a]
X:0.5	3.07038[a]	2.48449[a]	2.824865[a]

Note: Means followed by the same letters are not significantly different according to Tukey grouping ($p<0.05$)

Table-A.2: Mean texture properties of the xanthan (X) – ι-carrageenan (IC) MRE egg products from TPA tests on TAXT-2 with 60% sample deformation

Hardness (N)	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	10.89555 [a]	10.76216 [a]	11.23228 [a]
X:0.35	10.35952 [a]	11.56584 [a]	11.02122 [a]
X:0.5	10.99061 [a]	10.62503 [a]	10.97393 [a]
Adhesiveness (N.s)	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	-0.16999[ab]	-0.18579[ab]	-0.17902[ab]
X:0.35	-0.23101[ab]	-0.21747[ab]	-0.13799[a]
X:0.5	-0.27251[b]	-0.27009[b]	-0.22883[ab]
Springiness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	0.761111 [a]	0.751235 [a]	0.740062[a]
X:0.35	0.784414 [a]	0.737346[a]	0.668025[a]
X:0.5	0.776728 [a]	0.765926[a]	0.737469[a]
Cohesiveness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	0.190026[a]	0.196175[a]	0.208787[a]
X:0.35	0.20602[a]	0.189702[a]	0.188628[a]
X:0.5	0.181897[a]	0.190669[a]	0.193848[a]
Chewiness	**IC:0.15**	**IC:0.3**	**IC:0.45**
X:0.2	1.585076[a]	1.583126[a]	1.776701[a]
X:0.35	1.707316[a]	1.633021[a]	1.429701[a]
X:0.5	1.594622[a]	1.551107[a]	1.599344[a]

Note: Means followed by the same letters are not significantly different according to Tukey grouping ($p<0.05$)

Table-A.3: Mean texture properties of the xanthan (X) – starch (S) MRE egg products from TPA tests on TAXT-2 with 50% sample deformation

Hardness (N)	**S:0**	**S:0.5**	**S:1.0**
X:0.2	11.43436[a]	11.41791[a]	11.15967[a]
X:0.35	12.35068[a]	11.25239[a]	10.38379[a]
X:0.5	11.92168[a]	9.898242[a]	10.05185[a]
Adhesiveness (N.s)	**S:0**	**S:0.5**	**S:1.0**
X:0.2	-0.13061[a]	-0.15149[ab]	-0.15378[ab]
X:0.35	-0.18349[ab]	-0.17225[ab]	-0.20819[bc]
X:0.5	-0.18532[ab]	-0.18325[ab]	-0.26052[c]
Springiness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	0.885593[a]	0.845333[a]	0.843889[a]
X:0.35	0.868[a]	0.874815[a]	0.855741[a]
X:0.5	0.886667[a]	0.848778[a]	0.849222[a]
Cohesiveness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	0.453453[a]	0.388478[a]	0.399787[a]
X:0.35	0.389034[a]	0.335102[a]	0.358019[a]
X:0.5	0.417424[a]	0.362104[a]	0.366588[a]
Chewiness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	4.72464[a]	3.819012[a]	3.831892[a]
X:0.35	4.257328[a]	3.305552[a]	3.22756[a]
X:0.5	4.570964[a]	3.168929[a]	3.278214[a]

Note: Means followed by the same letters are not significantly different according to Tukey grouping ($p<0.05$)

Table-A.4: Mean texture properties of the xanthan (X) – starch (S) MRE egg products from TPA tests on TAXT-2 with 60% sample deformation

Hardness (N)	**S:0**	**S:0.5**	**S:1.0**
X:0.2	11.84306[a]	11.39878[a]	10.46186[a]
X:0.35	12.07178[a]	10.3005[a]	10.57853[a]
X:0.5	11.93448[a]	9.945079[a]	10.09241[a]
Adhesiveness (N.s)	**S:0**	**S:0.5**	**S:1.0**
X:0.2	-0.1391[a]	-0.18585[a]	-0.13097[a]
X:0.35	-0.18467[a]	-0.16766[a]	-0.19454[a]
X:0.5	-0.17684[a]	-0.1972[a]	-0.18248[a]
Springiness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	0.873395[ab]	0.83466[abc]	0.755309[c]
X:0.35	0.885062[a]	0.824506[abc]	0.778241[bc]
X:0.5	0.862654[ab]	0.79537[abc]	0.753056[c]
Cohesiveness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	0.214766[a]	0.190118[ab]	0.193858[ab]
X:0.35	0.192473[ab]	0.218987[a]	0.187052[ab]
X:0.5	0.166024[b]	0.188749[ab]	0.181325[ab]
Chewiness	**S:0**	**S:0.5**	**S:1.0**
X:0.2	2.242233[a]	1.811215[abc]	1.537311[bc]
X:0.35	2.045785[ab]	1.856728[abc]	1.546499[bc]
X:0.5	1.696658[abc]	1.498584[bc]	1.379521[c]

Note: Means followed by the same letters are not significantly different according to Tukey grouping ($p<0.05$)

APPENDIX B

SENSORY REPORT

Objectives

1. To determine consumer acceptability and quality attributes of MRE products by the 9-point Hedonic Affective Testing.
2. To measure the attribute intensities of MRE product by Quantitative Descriptive Analysis.

Methodology

I. 9-point Hedonic Scale Affective Testing

Male and female consumer panelists were recruited at the University of Georgia campus. The age ranges of the consumer panelists varied. Among the consumer panelist recruits, only qualified consumer panelists were asked to join the panel. Each consumer panelist should enjoy eating scramble eggs in order to qualify for the panel. Seven kinds of MRE products which were formulated with different levels of Xanthan gum, starch and length of retort processing were evaluated with the following:

1 - X:0.50, S:1.0, short

2 - X:0.35, S:0.5, short

3 - Plain Short

4 - X:0.40, S:0.5, long

5 - X:0.20, S:0.0, short

6 - X:0.50, IC:0.3, short

7 - C2

The consumer panel was asked to rate the quality of the following MRE product attributes:

1) Overall quality
2) Appearance quality
3) Aroma quality
4) Flavor quality
5) Texture quality

Furthermore, as part of the questionnaire, the consumer panelists were asked if they would eat the MRE products as part of their meal with an answer of yes or no. Also, an additional optional comment was provided to the panelists.

The MRE products were divided into two sets containing 3 and 4 MRE products respectively. Some of the panelists participated in both tests others participated only in one of the test sessions. The samples were heated under a controlled temperature between 140 – 160 ^{o}F before given to the panelists. Presentation of the products to the panelists followed a balanced-block design with 36 panelists (see attachment for the affective test sample ballot). PROC GLM procedure was used in the statistical analysis of the data.

II. Quantititative Descriptive Analysis (QDA)

A panel was created to conduct QDA on MRE products. The panel was composed of 8 individuals who were recruited from the Food Science Department. Prior to actual evaluation of the MRE products, the panelists were trained for familiarization to the following attributes:

1) Hardness

2) Cohesiveness

3) Chroma (inside surface, outside surface)

4) Sulfur Aroma

5) Cooked Egg Flavor.

The panel training involved the use of different standards that resembled or possessed the same characteristics of the attribute evaluated, (see attachment for the instructions, standards, and definitions of each attribute used in the panel training). The group performance was monitored. After the performance of the trained panel was determined to be ready to test the MRE products, the panel was asked to evaluate six kinds of MRE products. The MRE products were divided into two equal sets. Each of the MRE product set was evaluated in a separate day. A total of at least12 hours of training was spent to train the panel before actual MRE product testing.

A 15-cm scale was used for the intensity rating of each of the MRE product attributes (See attached trained panel ballot sample). A coffee bean was provided to cleanse the nasal passages of any residual volatile aroma in between sample evaluations. Also, for the chroma evaluation, the MRE product was evaluated as a whole product both for outside and inside chroma evaluations.

Since the chroma profile (yellowness) of the MRE products inside and outside its surface is different, both were evaluated separately. For the cooked egg flavor, it means that the higher the intensity value of the MRE product the more flavor is present in the sample. The flavor could either be desirable or undesirable. A nose clip was provided when the cooked egg flavor attribute was evaluated. The nose clip was used to eliminate any confusion surrounding the volatile aroma perceived by the panelists from their nasal passages

The following MRE products which were formulated with different levels of Xanthan gum, starch and length of retort processing were evaluated by a trained panel:

1 - X: 0.50, S: 1.0, short

2 - X: 0.35, S: 0.5, short

3 - Plain Short

4 - X: 0.40, S: 0.5, long

5 - X: 0.20, S: 0.0, short

6 - X: 0.50, IC: 0.3, short

The experimental design was an incomplete- balanced block designed with 4 replications. PROC GLM procedure was used in the statistical analysis of the data.

Results

Consumer Panel Demographics

The consumer panel was composed of 43 males and 30 females. Age distribution of the panelists is given below. Also, the frequency distribution on how many times the panelists eat scrambled or omelet egg products is given below.

Table-B.1: Consumer panelists age frequency and percentage distribution

AGE	FREQUENCY	PERCENTAGE
19 – 25	34	47.22
26 – 32	22	30.56
33 – 39	9	12.50
40 – 46	3	4.20
47 – 53	3	4.20
54 – 60	1	1.39

Table-B.2: Consumer panelists consumption of scrambled egg/omelet frequency and percentage distribution

CONSUMPTION	FREQUENCY	PERCENTAGE
At least 3 times a week	14	26.64
At least ones a week	20	38.06
At least twice a month	26	48.61
At least ones a month	4	5.56
Others	8	11.11

9-point Hedonic Affective Testing

The individual attribute quality ratings of the MRE products are shown in Table B.3. For the overall quality, MRE product #3 was found to have the highest quality rating among samples but only statistically different to MRE product #7. MRE product #3 consistently received the highest quality ratings in all attributes. Furthermore, when the consumer panel was asked if they would eat the MRE product as part of their meal, MRE product #3 received the highest approval. 88.89 percent of the consumer panel answered yes to the question for MRE product #3. The other MRE products received between 72.22 to 61.11 percent of yes response.

Table-B.3: Consumers quality evaluation on different attributes of seven MRE products. Data in a row with different letters were significantly (P<0.05) by Duncan. 1- X: 0.5, S: 1.0, short; 2 - X: 0.35, S: 0.5, short; 3 – X: 0.2, S: 0, short; 4 – X: 0.5, IC: 0.3, short; 5 – Plain Short; 6 – C2; and 7 - X: 0.4, S: 0.5, long.

Quality Ratings: 9-point Hedonic Scale (1 dislike very much – 9 like very much)							
Attribute	1	2	3	4	5	6	7
OVERALL Quality	6.11^{a}	6.44^{ab}	6.72^{a}	6.42^{ab}	6.11^{ab}	5.89^{ab}	5.72^{b}
APPEARANCE Quality	6.22^{ab}	6.72^{a}	6.75^{a}	6.44^{ab}	5.70^{b}	5.64^{b}	5.70^{b}
AROMA Quality	5.81^{ab}	5.94^{ab}	6.31^{a}	6.14^{ab}	5.41^{ab}	5.83^{ab}	5.25^{b}
FLAVOR Quality	6.27^{ab}	6.11^{ab}	6.83^{a}	6.08^{ab}	6.20^{ab}	5.94^{ab}	5.33^{b}
TEXTURE Quality	6.20^{ab}	6.31^{ab}	6.86^{a}	6.19^{ab}	5.78^{b}	6.11^{ab}	6.00^{ab}
ACCEPTANCE Quality*	70.27^{ab}	72.22^{ab}	88.89^{a}	72.22^{ab}	80.56^{ab}	61.11^{b}	63.89^{b}

*Percent of consumers who would eat the product as part of their meal.

Quantititative Descriptive Analysis (QDA)

The attribute intensity rating of each MRE product is shown in Table B.4 and shows statistical differences among MRE products. Chroma intensity values between the outside and inside surfaces of the MRE products shows that its outside surface had a higher chroma value compared to its inside surface, thus it was evaluated separately.

Table-B.4: Trained panel intensity ratings on different attributes of six different MRE products. Data in a row with different letters were significantly ($P<0.05$) by Duncan.
1- X:0.5, S:1.0, short; 2 - X:0.35, S:0.5, short; 3 – Plain Short; 4 - X:0.4, S:0.5, long; 5 - X:0.2, S:0 short; and 6 - X:0.5,IC:0.3, short.

Intensity Ratings (0 none – 15 extremely)						
Attribute	1	2	3	4	5	6
CHROMA IN-SURFACE Intensity	2.45^{a}	2.12^{a}	1.17^{b}	1.42^{b}	1.95^{a}	2.02^{a}
CHROMA OUT-SURFACE Intensity	6.86^{ab}	6.65^{ab}	3.17^{d}	4.87^{c}	5.97^{b}	7.10^{a}
SULFUR AROMA Intensity	4.62^{a}	3.95^{ab}	2.52^{c}	4.27^{ab}	3.26^{bc}	4.09^{ab}
COOKED EGG FLAVOR Intensity	3.48^{a}	3.91^{a}	3.75^{a}	4.45^{a}	4.56^{a}	4.34^{a}
COHESIVENESS Intensity	2.65^{b}	2.83^{b}	2.81^{b}	2.44^{b}	3.17^{b}	4.31^{a}
HARDNESS Intensity	2.06^{c}	2.76^{b}	3.40^{a}	2.10^{c}	2.63^{b}	2.48^{bc}

STANDARDS

Sulfur:
Standards:

1g/50solution; intensity = 6
0.5/50 solution; intensity = undetectable to some panelists
1.5g/ 50 solution; intensity = 8

Chroma:
Standards:

1:1 (whole egg); intensity = 10
2:1 (egg white;egg yolk); intensity = 3
3:1 (egg white;egg yolk) intensity = 2

Note: Intensity is measured by the presence of yellow color.

Sample evaluation:
Evaluated both surfaces. Outside and inside

Clean Cooked Flavor:

Standard:

Regular scrambled egg; intensity = 2

To the right of the scale means other flavor is more present. It is either off-flavor or desired flavor.
Clean cooked flavor is the flavor perceived absent of other notes (i.e sulfur, browning etc.)

Cohesiveness:
Standards:

Yellow American = 5.0
Sun dried Raisin = 10.0
Starburst = 12.5

Hardness:
Standards:

Cream cheese = 1.0
Egg White = 2.5
Yellow American = 4.5

TRAINED PANEL BALLOT

Name:_____
Date:_____
Sample: Scrambled Egg

Chroma: Chroma is the purity of a color. High chroma colors look rich and full. Low chroma colors look dull and grayish.

SAMPLE #_____

Instruction: Visually inspect the color of scrambled egg.
#1 = 10
#2 = 3

ATTRIBUTE INTENSITY

Descriptor	Scale
Chroma	

Sulfur Aroma: Rotten Egg
Instruction: Sniff sample. Inhale and exhale fresh air until free of sulfur aroma residue before proceeding to the next sample.
#2 = 6

ATTRIBUTE INTENSITY

Descriptor	Scale
Sulfur	

Cooked Egg Flavor: Clean cooked egg. Other flavor present either desired or undesired increases the cooked egg flavor intensity value.
Instruction: Place about ½" cube sample into mouth. Masticate and coat mouth with the sample to ensure maximum flavor pick-up.
Regular Scrambled Egg = 2

ATTRIBUTE INTENSITY

Descriptor	Scale
Cooked Egg	

Cohesiveness: Extent to which a material can be deformed before it ruptures.
Degree which a substance is compressed between the teeth before it breaks.
Instruction: Place sample between molar teeth, compress and evaluate the amount of deformation before rupture.
Standards:
American Cheese = 5.0
Raisin = 10
Starburst = 12.5

ATTRIBUTE INTENSITY

Descriptor	Scale
Cohesiveness	
	|

Hardness: Force necessary to attain a given deformation.
Force required to compress a substance between molar teeth.
Instruction:Place sample between molar teeth and bite down evenly, evaluating the force required to compress the food.
Standards:
Cream cheese = 1.0
Egg white = 2.5
American cheese = 4.5

ATTRIBUTE INTENSITY

Descriptor	Scale
Hardness	
	|

CONSUMER PANEL BALLOT

Panelist #:_____ Age:_____ Sex:_____ Date:_____

How often do you eat scrambled egg /omelet products:

At least 3 times a week____; At least ones a week____; At least twice a month____; At least ones a month; others:_____

SAMPLE # _____

Instructions:

1. Rinse mouth with water and eat a piece of cracker before evaluating the sample.
2. Before answering the questionnaire, eat the MRE-scrambled egg first. Eat the MRE-scrambled egg the way you eat a scrambled egg in a meal.
3. Mark your score of preference in the hedonic scale provided under each attribute that appears in numerical order. Do not skip to the next question without answering the previous question first.

Hedonic Scale

1 – dislike extremely	**2** – dislike very much	**3** – dislike moderately
4 – dislike slightly	**5** – neither like nor dislike	**6** – like slightly
7 – like moderately	**8** – very much	**9** – like extremely

Attributes

1. Overall Acceptability

|--------|--------|--------|--------|--------|--------|--------|--------|
1 2 3 4 5 6 7 8 9

2. Texture

|--------|--------|--------|--------|--------|--------|--------|--------|
1 2 3 4 5 6 7 8 9

3. Smell

|--------|--------|--------|--------|--------|--------|--------|--------|
1 2 3 4 5 6 7 8 9

4. Taste

|--------|--------|--------|--------|--------|--------|--------|--------|
1 2 3 4 5 6 7 8 9

5. Appearance

|--------|--------|--------|--------|--------|--------|--------|--------|
1 2 3 4 5 6 7 8 9

6. Would you eat the product as part of your meal? Yes or No

Comments:

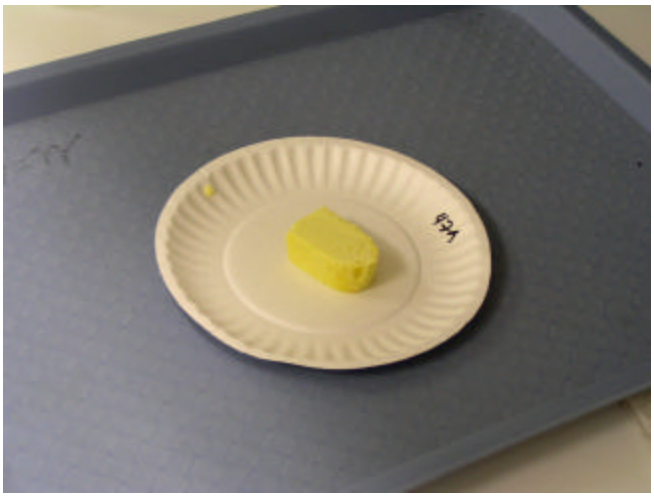

Figure-B.1: A sliced piece of MRE product sample which was served to the consumer panelists for quality attributes rating.

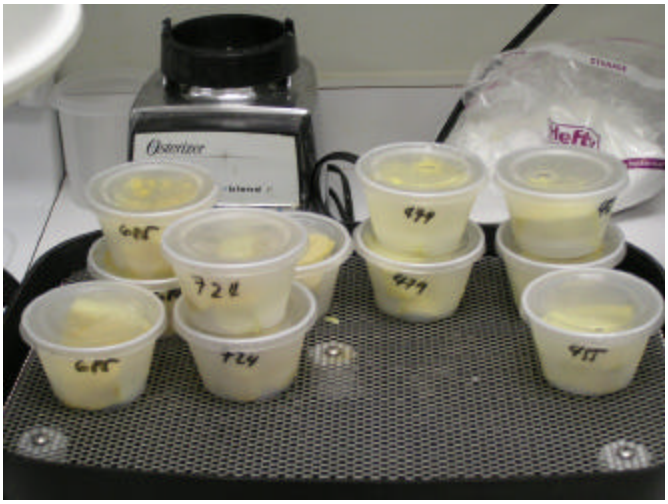

Figure-B.2: Samples placed in a covered plastic cup separately to ensure no aroma transfer occurs among samples during tempering.

COMMENTS (UNEDITED)

Product:

556 (X:0.35, S:0.5, short)

Salt percent of 628 much better.
Did not taste like egg.
It was very good, and I normally don't eat plain eggs.
Had a strange taste to it.
It taste too much like yolk.
It taste all great. This one was nice and hot.
The product having very loose and uneven texture. The product also having more moisture, as it should be.
No real flavor and burnt smell.
It is better for breakfast and lunch.
Overall very good. Still a "plastic like skin.
Good when you are hungry.
I don't like the soft texture.
The difference to the 628 and 482 wasn't significant, but it seemed a little better (maybe because it was warmer than the others).
Delicious! I felt a little processed smell.
Skin on egg is somewhat annoying to chew, apart from that acceptable taste and more solid than the last 628.

628 (X:0.5; S:1.0, short)

I could not make out the difference between 482.
Smell is weak, slightly liquid feel in mouth, but fairly pleasant to eat.
It is better for breakfast and lunch.
Texture was a little off, but not bad.
Very metallic; Good salt level!
Seems fake, left a weird taste in my mouth.
Funny aftertaste.
Too salty.
Very fluffy but needs more flavor.
Texture not as smooth.
Very little flavor.
It smells like egg shell. Tastes artificial flavor.
Texture too smooth.
The external texture of the product is too "plastic" like.

482 (X:0.2, S:0.0, short)

Some egg flavor.
Maybe stronger egg flavor.
Stronger flavor, harder texture.
Tasted better. It might have been because it was warmer than the others.
Too salty.
Good salt; 556+628 good flavor!

Most neutral tasting among 556 and 628.
The product was excellent regarding its taste and texture properties. The appearance of the product was also very good.
It is better for breakfast and lunch.
I thought it was good and very much like real scrambled eggs.
It smells like rubber.
Tough exterior to the egg and a little too much sulfur flavor.
Best taste, smell is good and liquid taste is still somewhat present.

724 (X:0.4, S:0.5, long)
It seems like an artificial flavor.
Smelled like spam.
Not very good. Good texture though!
Too much of a sulfur flavor. Too tight of the "bubble matrix".
This is more like real scramble-egg texture. Not strong odor.
Lacks characteristic scrambled egg flavor but still has good texture.
After tasting samples 557, 628 and 482, this was the best by far.
Great if not that salty.
The first sensation is good, however, there is a strange aftertaste.
No real smell.

455 (C2)
Very good.
Not fresh.
Tastes like bacon flavoring was added.
Did not taste like scrambled eggs.
There is an interesting kick.
Tasted like spam.
I like the pepper flavor.
Sample cold, despite this still preferred sample than 479.
This didn't really taste like much of anything. The flavor could easily disappear if salsa or another seasoning was added.
Just the appearance not that lovely.
Taste is more pronounced.
Too firm.

685 (X:0.5, IC:0.3, short)
It smells like an egg shell.
Darker surface appearance looks better.
Perfect texture. Good flavor! This one is the best!
Good egg flavor, texture is too much of a "small" crumple. Looks like a sponge.
Very soft flavor. Pale color.
Product better than 455, 724, and 479.
It's slightly scary that it is squarish-shaped.
Good texture. Good flavor. Good color and smell.
Soft texture, milder flavor.

I didn’t like this one at all. It tasted pretty bad.
I don’t like the appearance.

479(PLAIN SHORT)
Good.
Need a little salt.
Too shiny.
Too touch + chewy. Good flavor.
I like it.
Eggs had an over all “plastic” like mouthfeel.
It feels like Jello texture. Very pale color.
In my opinion, only drawback is the smell, but it tasted really good.
More flavorful.
It’s a little too liquidy.