Chapter 11
Innovations in Thermal Treatment of Food

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11.1 Introduction

Thermal processing (heat treatment) for sterilization of shelf-stable foods has been one of the most widely used methods of food preservation during the twentieth century, and has contributed significantly to the nutritional well-being of much of the world's population. For most solid and semi-solid foods, thermal processing is accomplished after the product has been filled and hermetically sealed in airtight containers. Thermal processing consists of heating food containers in pressurized retorts at specified temperatures for prescribed lengths of time. These process times are calculated on the basis of achieving sufficient bacterial inactivation in each container to comply with public health standards and to ensure that the probability of spoilage will be less than some minimum. Many liquid food products, such as milk or fruit juices, are pasteurized or sterilized by heat treatments applied before filling and sealing into packages. These heat treatments are accomplished by pumping the liquid product through a series of heat exchangers and hold tubes that deliver a high temperature-short time (HTST) heat treatment for pasteurization, or an ultra-high temperature (UHT) short time treatment for sterilization.

This chapter presents a review of recent innovations that have been made in the field of thermal processing for food preservation, and attempts to foresee the impact these innovations may have on the marketplace. Three categories of innovation are addressed: (i) improved methods in estimating kinetic parameters for establishing optimum process conditions, (ii) a review of new equipment systems for retorting and materials handling to improve cookroom operations, and (iii) new and novel packaging systems, and their potential impact on markets for shelf-stable foods.

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11.2 Microbial Kinetics for Process Calculations

The manner in which populations of microorganisms decrease in response to lethal heat treatments is fundamental to the engineering design of thermal inactivation processes (pasteurization and sterilization) and important in the food, pharmaceutical, and bioprocess industries. In order to determine the optimum process conditions needed to achieve desired results, the effect of these conditions on rates (kinetics) of population decrease needs to be characterized and modeled mathematically. This chapter section will focus on the use of new methods for estimating kinetic parameters more accurately. Use of more accurate parameters in appropriate mathematical models will enhance the accuracy of these models. When properly developed and validated, these models can predict the extent to which a population of viable spores will be reduced in response to a lethal heat treatment at specified temperature and time. These models are essential tools in establishing process conditions, i.e., time and temperature, needed to achieve a specified level of bacterial lethality.

Thermal inactivation of bacteria generally follows first-order kinetics; it can be described by logarithmic reduction in the number of bacterial spores with time during exposure to a constant lethal temperature. The logarithm of number of bacterial spores when plotted against time normally produces a straight line known as a survivor curve. The slope of this curve will give the first order rate constant at this temperature. Alternatively, the reciprocal of this rate, known as decimal reduction time, D, is expressed as time in minutes to achieve one log cycle reduction in spore population when subjected to a specified constant lethal temperature.

The temperature dependency of the rate constant is also an exponential function that can be described by the Arrhenius equation. This is the equation used for a straight line on a semi-log plot when the natural log of the rate constant is plotted against the reciprocal of absolute temperature. Likewise, the temperature dependency of the decimal reduction time, D, is also logarithmic (straight line on a semi-log plot of D versus temperature within the lethal range), and can be expressed as the temperature difference, Z, required for the curve to transverse one log cycle. Thermal death-time kinetic parameters "D" and "Z" are widely used in the food science community, while the first order rate constant and the Arrhenius relationship are most often used in the chemical and biochemical communities. In either case, these parameters must be estimated as accurately as possible to calculate optimum thermal process conditions that ensure public safety with maximum product quality.

Traditional methods for estimating these kinetic parameters consist of plotting a series of survivor curves at different lethal temperatures, and measuring the slope or D-value from each curve. Data for these curves are obtained from carefully executed microbiology laboratory procedures. Typically, a series of small glass vials containing a known high concentration of viable spores are immersed simultaneously into a heated oil bath maintained at a known constant lethal temperature. At predetermined time intervals one of the vials is quickly removed and immediately cooled until all vials have been removed. Thus, each vial contains spores exposed to a lethal temperature for a different length of time. The contents of each vial are plated onto appropriate growth media and incubated for subsequent enumeration of survivors. The logarithm of number of survivors from each vial is plotted against time to produce the log-linear survivor curve, and the *D*-value at that temperature is taken from the slope of that curve.

The same experiment is repeated at different constant lethal temperatures in order to obtain *D*-values at different temperatures, from which the temperature dependency factor, *Z*-value, can be determined. These methods are prone to error because of heat transfer limitations causing thermal lag in the temperature response in each vial. The spores themselves do not rise instantly to the oil bath temperature, nor do they cool instantly in response to the quenching temperature. In those cases where the kinetics are needed for mesophylic spores in a liquid product, errors can be minimized by use of a three-neck flask containing the liquid product heated to a known constant lethal temperature. One neck is used to accommodate a thermometer for temperature measurement, a second neck holds an inoculation needle through a rubber stopper, and the third neck holds a number of extraction needles for removing and quenching samples of spore suspension at predetermined time intervals (Rodriguez et al 1988). Although this method minimizes errors from lag in thermal response, it is still prone to errors in timing, particularly when samples must be extracted within a few seconds of each other at higher temperatures where the lethal rate is very high.

An entirely new and different experimental approach for estimating kinetic parameters in liquid products was first developed by Swartzel (1984) and called the Equivalent Point Method (EQM). It was later modified by Welt et al (1997), and called the Paired Equivalent Isothermal Exposure (PEIE) method. These methods do away completely with the use of constant temperature baths (isothermal experiments). Instead, a batch of liquid product inoculated to a known high initial concentration of spores is "processed" through an HTST or a UHT heat exchanger-hold tube system that delivers a precisely known dynamic temperature-time profile experienced by the inoculated product. Samples of the "processed" product are plated, incubated, and enumerated to determine the number of survivors, thus giving the extent of reaction accomplished. By knowing the extent of reaction from two different sets of process conditions and the precise dynamic temperature-time profiles of each, a nearly "true" estimate of kinetic parameters can be determined.

This was confirmed by work carried out at the University of Florida, in which kinetic parameters for thermal inactivation of *Escherichia coli* in orange juice were estimated using the new PEIE method with a Microthermics® HTST Lab 25 pasteurizer, as well as the traditional isothermal bath method with the three-neck flask (Moody 2003). *D*-values obtained from both methods at different temperatures are shown in Table 11.1. For the two temperatures used in common by both methods (58 and 60°C), *D*-values estimated by the new PEIE method were lower than those estimated by the traditional isothermal bath method. Lower *D*-values mean faster kinetics and would justify shorter process times if known to be true. In order to determine which method produced estimates closest to the "truth," inoculated samples of orange juice were processed through the HTST pasteurizer at temperatures

Table 11.1 Comparison of kinetic parameters (*D*- and *Z*-values), estimated using traditional isothermal and new PEIE methods (Reproduced from Moody 2003. With permission)

Temperature (C)	Isothermal (Three-neck flask)		Dynamic (PEIE)	
	D-value (s)	Standard Deviation	D-value (s)	Standard Deviation
52	353	39.08		
55	148	2.18		
58	34.7	2.27	29.8	3.3
60	18	1.52	13.27	1.54
62			6.93	0.47
z-value (C)	5.99		6.16	

Table 11.2 Results of validation experiments comparing the number of survivors measured experimentally with those predicted using traditional and new PEIE methods (Reproduced from Moody 2003. With permission)

Experiment	Hold Tube				Survivors (cfu)	
	Time (sec)	Temp. (C)	Initial (cfu)	PEIE Predicted	Isothermal Predicted	Experimental
I	15	65	5.4×10^8	3.5×10^3	5.0×10^4	5.2×10^3 2.8×10^3
II	10	65	5.4×10^8	2.0×10^3	8.6×10^4	1.0×10^3 1.3×10^3

above the range used to estimate the parameters (65°C). Two different processes were used, one with a hold tube residence time of 15 s, and 10 s for the other, in order to obtain distinctly different numbers of survivors from each process. Processed samples were plated, incubated, and enumerated to determine the number of survivors from each process. These experimental results were compared with numbers of survivors predicted by the mathematical model using both sets of parameters.

Model-predicted results using parameters estimated by the new PEIE and traditional isothermal bath method are compared with experimental results in Table 11.2. The number of survivors predicted by the model, using parameters estimated by the PEIE method, agrees very closely with those measured experimentally (within a fraction of one log cycle). In contrast, the number predicted by the model using parameters estimated by the traditional isothermal bath method differed from those measured experimentally by one and two log cycles for processes I and II, respectively. The significance of these differences can best be appreciated when the two sets of parameters are used to calculate the process time needed to accomplish a 6-log cycle reduction in the *E. coli* population in orange juice at a typical pasteurization temperature of 65°C. At this temperature, the *D*-value estimated by the traditional isothermal bath method would be 1.8 s leading to a hold tube residence time of 1.8 (6) = 11 s. In contrast, the *D*-value estimated by the new PEIE method would be 1.3 s leading to a hold tube residence time of 1.3 (6) = 8 s. This 30% reduction in process time is made possible by adopting better methods for estimating kinetic parameters more accurately.

11.3 Retort Equipment Systems in Cookroom Operations

The preponderance of thermally processed shelf-stable foods in the marketplace today continues with products processed in batch retorts that must be repeatedly loaded and unloaded between each process cycle throughout the workday. In years past, this was performed by teams of workers with the help of chain hoists and rail carts moving from retort to retort around the cookroom floor, while retort operators kept vigilance as time keepers, temperature monitors and record keepers. Recent innovations in retort control and materials handling systems have essentially revolutionized traditional cookroom operations. Today's modern retorts such as that shown in Fig. 11.1 are equipped with sophisticated computerized electronic control systems that can be remotely monitored from a control room by a single operator who may be responsible for an entire battery of retorts. These control systems are capable of operating each retort through its entire process cycle, while controlling and recording temperatures and pressures, as well as monitoring process conditions at all critical control points. At the end of each process cycle, a complete set of batch records is provided for compliance with record keeping requirements of the FDA Low-acid Canned Food regulations.

The introduction of automation and robotics for the materials handling operations on the cookroom floor has perhaps had the greatest impact in reducing the cost of manufacturing thermally processed products. An automated batch retort system in a modern cookroom today consists of a battery of retorts laid out in a row on the cookroom floor to accommodate automated loading and unloading (Fig. 11.2). Both track-guided and trackless systems are available for this purpose. In track-guided

Fig. 11.1 Modern Retort with pressure vessel, field devices, and process control system (Photo courtesy of JBT FoodTech, formerly FMC FoodTech, Madera, CA)

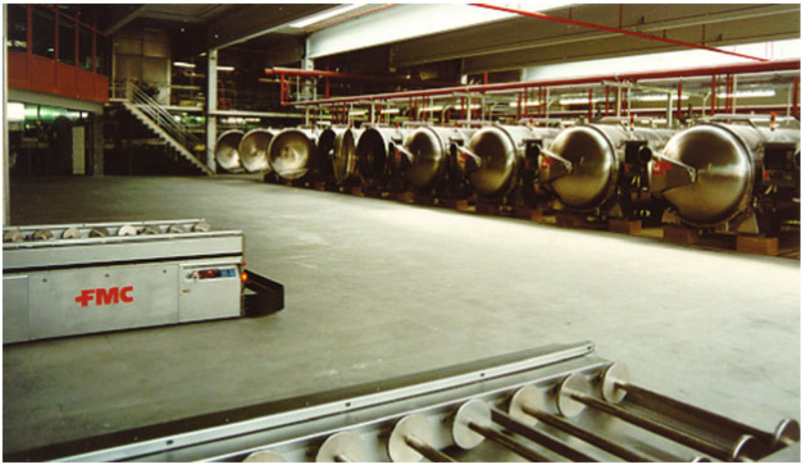

Fig. 11.2 Modern cook room showing battery of retorts arranged for automated loading and unloading (Photo courtesy of JBT FoodTech, formerly FMC FoodTech Madera, CA)

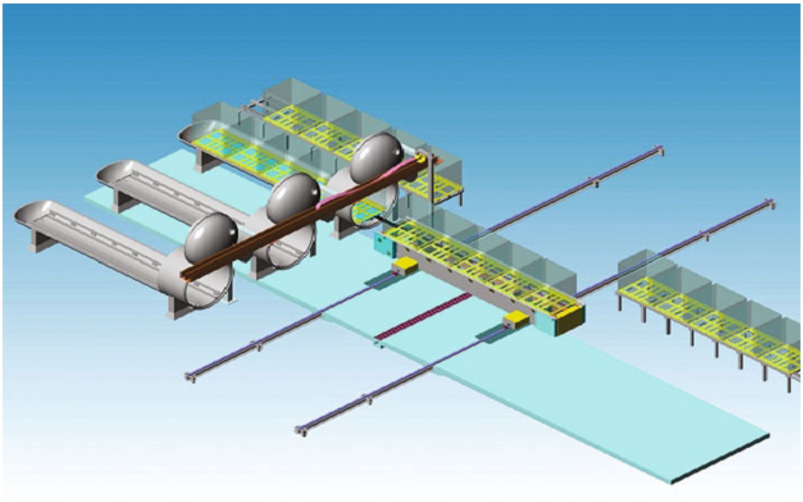

Fig. 11.3 Track-guided automated batch retort system (ABRS) (Courtesy of Allpax Products, Inc., Covington, LA)

systems, a rail cart transfers crates or baskets of products from the loading stations to the retorts, and from the retorts to the unloading stations automatically on a rail track that allows the cart to move in a transverse direction along the cookroom floor until it is aligned with the target retort (Fig. 11.3). Once the cart is aligned with the retort, the loaded baskets or crates are automatically transferred from the cart into the retort for loading operations, or from the retort onto the cart for unloading operations. Trackless systems such as that illustrated in Fig. 11.4 work much the

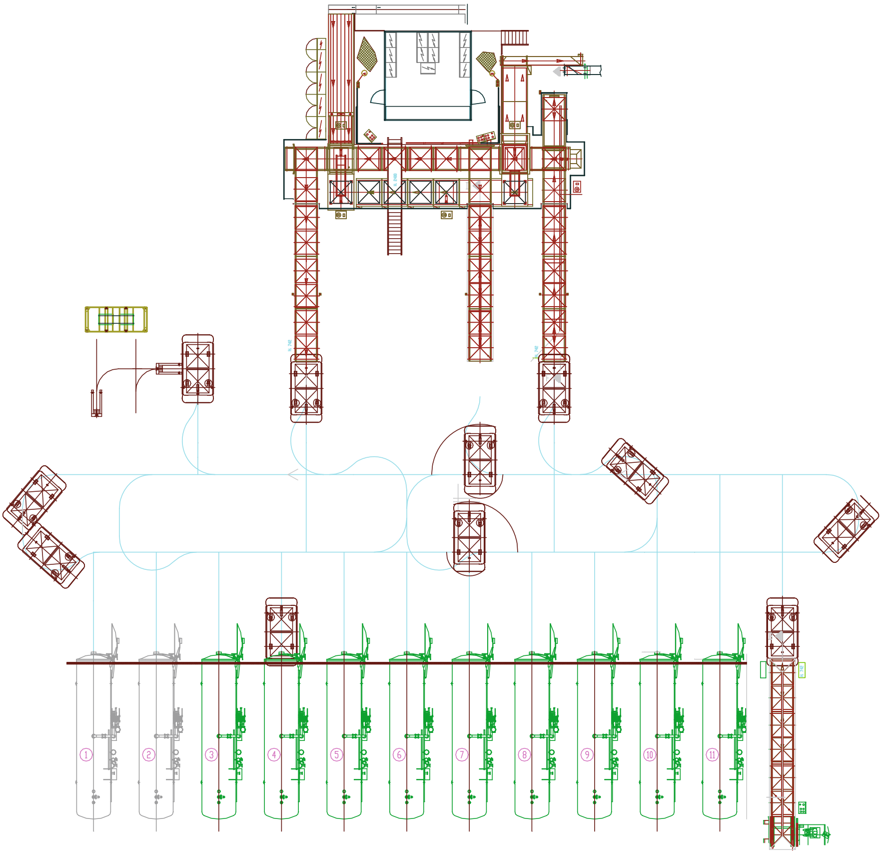

Fig. 11.4 Trackless system layout for automated guided vehicles (AGV) (Photo courtesy of JBT FoodTech, formerly FMC FoodTech, Madera, CA)

same way, except that the rails and rail carts are replaced by automated guided vehicles (AGV) that move about the cookroom floor controlled by electronic guidance systems. These systems offer the advantage of keeping the cookroom floor free of rails or tracks that could impede safe movement of workers on the floor. A close-up view of an AGV that has just been loaded or is about to unload a retort is shown in Fig. 11.5, and an automated materials handling system for retort basket, rack, or tray loading is shown in Fig. 11.6.

11.4 Flexible Retortable Packages

Perhaps the most intriguing innovation in thermal processing in recent years has been the introduction of flexible retortable pouches and semi-rigid trays and bowls in the marketplace for shelf-stable canned foods (Fig. 11.7). The relatively thin profiles

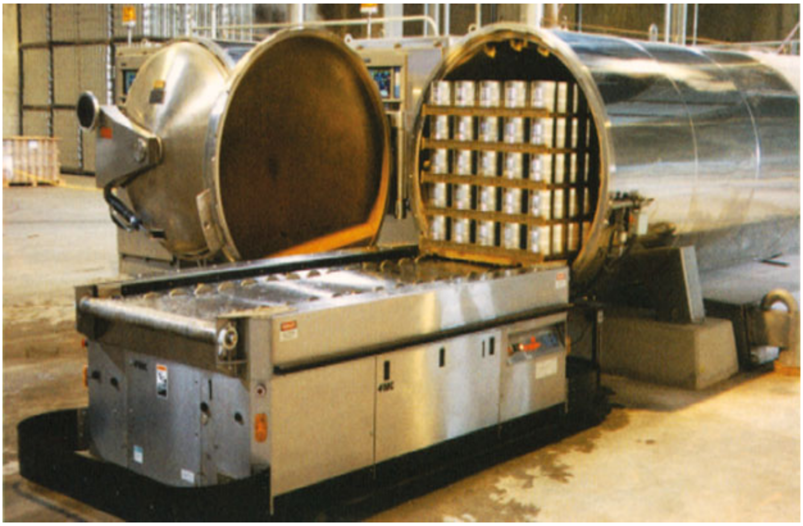

Fig. 11.5 Automated Guided Vehicle in process of retort loading/unloading (Photo courtesy of JBT FoodTech, formerly FMC FoodTech, Madera, CA)

Fig. 11.6 Automated materials handling system for retort basket, rack, or tray loading (Courtesy of Allpax Products, Inc., Covington, LA)

Fig. 11.7 New flexible and semi-rigid retortable packaging systems

offered by these flexible packages allows them to be heated more rapidly than metal cans or glass jar counterparts, often resulting in better product quality. Moreover, they offer the consumer a variety of convenient features. Flexible pouches carry less weight, occupy less space, and are easy to open with a simple pair of scissors. Semi-rigid trays and bowls can be fashioned as attractive serving dishes that are microwaveable, and can be placed on the dinner table ready to serve directly from the microwave oven. However, the flexible and semi-rigid properties that make these attractive features possible pose technical challenges in the retort processing of such packages. These flexible packages lack the strength of traditional metal cans and glass jars, and are incapable of withstanding the pressure gradients normally experienced by cans and jars during typical retort process cycles.

Successful retorting of such flexible or semi-rigid packages requires that they be processed under carefully controlled dynamic pressure excursions (profiles) to prevent package expansion during processing. When not controlled properly, this expansion can result in permanent distortion or deformation of the final package after retorting. Design and control of these complex pressure profiles is accomplished with the simultaneous use of both pressure and deflection detectors during a heat penetration test. The electronic deflection detectors continuously monitor the package expansion or contraction, sending a signal to the on-line retort control system, which adjusts overriding air pressure as needed to counter the detected expansion or contraction, thus resulting in a dynamic pressure profile ideally suited for that product.

The need for these dynamic pressure excursions during processing requires that retort pressure be controlled independently from temperature. This means that pure

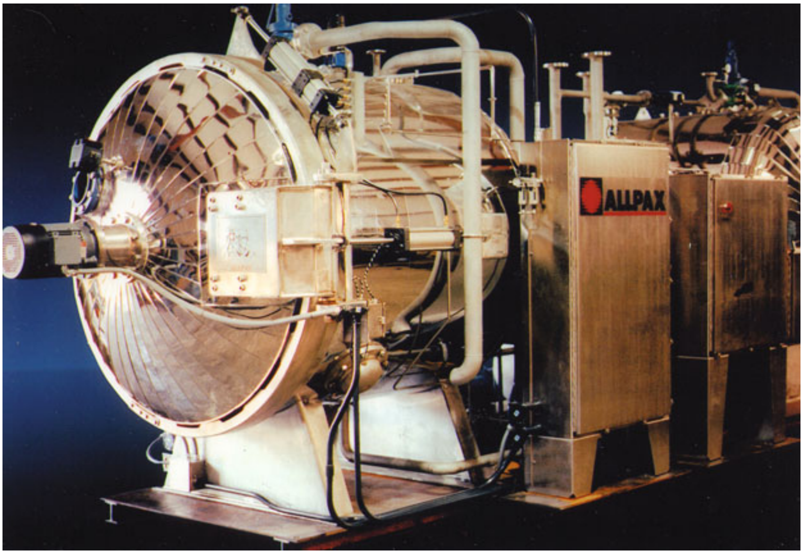

Fig. 11.8 Modern steam–air mixture retort with programmable pressure control (Courtesy of Allpax Products, Inc., Covington, LA)

saturated steam can no longer be used alone as the heating medium in the retort and that controllable overriding air pressure must be included during heating. However, the introduction of air into the retort during heating with steam poses the risk of insulating air pockets forming around packages, which could leave them underprocessed. The desire to meet the processing needs of these flexible packaging systems has created a market for new retort designs and control systems that are capable of delivering these complex process conditions. Essentially, all designs accomplish the dynamic pressure profiles with overriding air pressure, but they eliminate the problem of insulating air pockets in different ways. Some retorts heat with steam–air mixtures that are kept well mixed with the use of strong fans within the retort (Fig. 11.8). Other retort designs feature water immersion, water spray, or water cascade as a means of contacting the packages with the heat exchange medium during processing. In addition to independent pressure control for these flexible packages, their lack of strength and rigidity also requires special racking designs and systems in the materials handling of these packages to safely support them within the retort (Fig. 11.9).

11.5 Market Implications

Prepared foods in microwavable retortable dinner trays and lunch bowls have been gaining in popularity because of their convenience, attractiveness, and quality relative to their traditional “canned” food counterparts in metal cans and

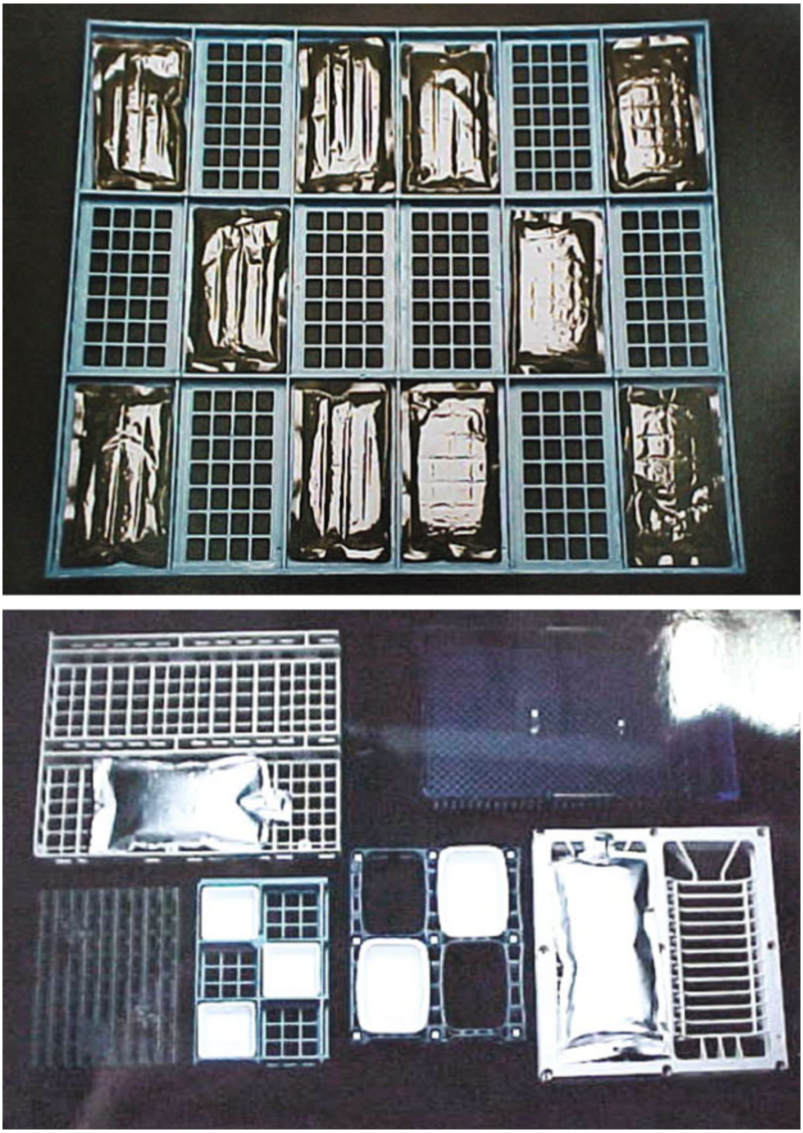

Fig. 11.9 Custom-designed racking systems for retortable flexible pouches (Courtesy of Allpax Products, Inc., Covington, LA)

glass jars. These novel packages were made possible by the development of food-grade polymer films with high oxygen-barrier properties capable of withstanding the high temperatures and pressures during the necessary heat sterilization process in pressurized retorts. The attractiveness of these packages and the fact that they are microwavable make them well suited for ready-to-eat dinner menu items. These packages have gained particular interest with those wishing to market

Fig. 11.10 Prototype of shelf-stable prepared meal ready-to-eat in retortable microwavable semi-rigid tray with transparent lid stock (Reproduced from Rich 2007 with permission)

shelf-stable prepared foods that can be featured as natural, organic, ethnic, vegetarian, or cultural such as "Ayurvedic." Ethnic food dishes typical of Latino, Mediterranean, Arabic, Indian, and Oriental cultures are becoming increasingly popular worldwide.

Research at the University of Florida has been underway to assist a small start-up company in developing a line of ethnic menu items in retortable semi-rigid trays (Rich 2007). The company has been operating restaurants featuring authentic cultural food dishes appropriate for strict vegetarian diets and the Ayurvedic life styles in India and Southeast Asia. It now wishes to distribute these menu items in retail markets as pre-packaged, shelf-stable, ready-to-eat meals so consumers can enjoy them conveniently in their homes (Fig. 11.10). This technology will enable manufacturers of shelf-stable food products to introduce into the marketplace a wider variety of fully-prepared ready-to-eat convenience food items.

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