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Advances with intelligent on-line retort control and automation in thermal processing of canned foods

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Abstract

This paper presents a review of recent developments over the past 10 years that have further advanced the state of the art in improving food safety, quality and manufacturing efficiency in the canned food industry worldwide. The review focuses initially on retort control systems, and the various approaches that have been taken to help canned food processors accomplish on-line correction of unexpected process deviations, the major cause of lost productivity. Important features of each approach are discussed, along with suggested industry applications that would be appropriate for each method. The review also describes recent advances in industrial automation, including new retort systems for flexible and semi-rigid retortable packages, and automated materials handling systems for loading and unloading of batch retorts. The review concludes with a discussion of future trends to be expected in the industry.

Keywords: On-line control; Low acid foods; Batch retort; Process deviations

1. Introduction

Control of thermal process operations in food canning factories has traditionally consisted of maintaining specified operating conditions that have been predetermined from product and process heat penetration tests, such as the process calculations for the time and temperature of a batch cook. Sometimes unexpected changes can occur during the course of the process operation such that the prespecified processing conditions are no longer valid or appropriate, and off-specification product is produced that must be either reprocessed or destroyed at appreciable economic loss. These types of situations are known as process deviations. Because of the important emphasis placed on the public safety of canned foods, processors must operate in strict compliance with the US Food and Drug Administration's Low-Acid Canned Food (FDA/LACF) regulations. Among other things, these regulations require strict documentation and record-keeping of all critical control points in the processing of each retort load or batch of canned product. Particular emphasis is placed on product batches that experience an unscheduled process deviation, such as when a drop in retort temperature occurs during the course of the process, which may result from unexpected loss of steam pressure. In such a case, the product will not have received the established scheduled process, and must be either fully reprocessed, destroyed, or set aside for evaluation by a competent processing authority. If the product is judged to be safe then batch records must contain documentation showing how that judgment was reached. If judged unsafe, then the product must be fully reprocessed or destroyed. Such practices are costly.

Processors of low-acid canned foods make every effort to have effective and dependable control systems over the retort sterilization process to avoid unexpected process

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deviations that would leave the resulting process lethality in question. In spite of these efforts, unexpected process deviations continue to occur from time to time, and cannot be avoided. Processors are constantly in search of methods that would allow them to "correct" the process shortly after recovery from the deviation in order to compensate for the lost lethality caused by the deviation, while the process is still under way (on-line correction of process deviation). When this can be done precisely without unnecessary over processing, and automatically without operator intervention, it can be referred to as "intelligent on-line control".

Teixeira and Tucker (1997) presented a short review of the state-of-the-art in on-line control in thermal sterilization of canned foods at that time. They described proposed control systems based upon real-time data acquisition (Wojciechowski & Ryniecki, 1989), predetermined correction factors (NFPA, 1996), and mathematical models capable of simulating heat transfer into canned foods under various processing conditions (Bichier, Teixeira, & Balaban, 1995). Each of the systems described at that time had various limitations, problems or pitfalls associated with it. Considerable work has been undertaken since then to address many of these limitations and pitfalls, resulting in significant advances that have been reported in the literature. The purpose of this paper is to present a review of these advances, summarizing the important features of each, along with suggested industry applications that would be appropriate in each case. The first part of the review follows the format of Teixeira and Tucker (1997), in first addressing advances made in basic retort control with a new focus on strategies for validation computer-based control systems, followed by advances in each of the three general types of approaches to on-line correction of deviations:

- Real-time data acquisition.
- On-line correction factors.
- Mathematical heat-transfer models.

The second part of the review describes recent advances in industrial automation, including new retort systems for flexible and semi-rigid retortable packages, and automated materials handling systems for loading and unloading of batch retorts, along with a discussion of future trends to be expected in the industry.

2. Validation of computer-based control systems

In the earlier review by Teixeira and Tucker (1997), the state-of-the-art in retort control strategies at that time was aimed primarily at new and better ways to achieve and maintain constant the retort temperatures specified for a scheduled process time, in the hopes of minimizing the chance occurrence of unexpected process deviation. Focus was placed on replacing traditional hard-wire relay-logic systems with new electronic programmable controllers capable of communicating directly with new computer-based control systems. Since then, the food processing industry has begun to rely ever more increasingly on computer-based process control systems that rely heavily upon sophisticated software containing intricate programming codes developed by software engineers. The complexity and sophistication of these systems bring with them the potential for hidden errors and pitfalls "bugs", which could lead to serious problems if commissioned for use prior to proper validation.

Government regulatory agencies responsible for assuring food safety for the consuming public have quickly come to recognize to need for such validation, and have been addressing this issue aggressively by working closely with industry in developing and proposing methods and procedures for carrying out documented validation of new computer-based control systems. Leading scientists from the US Food and Drug Administration (FDA) have often been invited to speak on this topic at major conferences, and are an excellent source for information on the approach to validation (Larkin, 2004). Another useful source of information is the work of McGrath, O'Connor, and Cummins (1998), who described appropriate software and hardware tools that provide a powerful yet flexible platform from which to implement a process control strategy for the food processing industry.

At the heart of validating any process control system is the need to know precisely what needs to be controlled. This extends far beyond the simplistic view of controlling equipment operating parameters. For example, it does little good to assure the retort temperature was held constant at the level specified for the scheduled process, if something went wrong during product preparation that caused the product to heat differently from how it was expected to heat. Identifying all the factors that must be controlled in order for a scheduled process to be assured effective is an important part of the approach to Hazard Analysis and Critical Control Points (HACCP) studies. These, in turn, are an important component of process and control system validation. Approaches to validation of thermal process control involving verification by the HACCP system were described well by Leaper and Richardson (1999). In that work they placed due emphasis on new approaches aimed at assuring safety without undue over-processing, which would have a negative impact in the marketplace because of compromised product quality and manufacturing efficiency. Chen and Ramaswamy (2003) conducted an extensive analysis of critical control points affecting deviations in thermal processing using artificial neural networks. They conducted an analysis of different critical process and product variables with respect to their importance on accumulated lethality, process time, cooling time, and total cycle time under various process conditions; along with the combined effects of deviations happening to multiple variables at the same time.

These are only examples of the growing attention being paid to the need for process validation and its documentation in connection with the adoption of new computer-based control systems in the food process industry and the food canning industry, in particular. The importance of process validation cannot be overemphasized, and for this reason, it was chosen as the first topic to be addressed in this review paper. In the remaining sections of this review, focus will shift to each of the three general types of approaches to on-line correction of process deviations in thermal processing mentioned earlier (real-time data acquisition, on-line correction factors, and mathematical heat-transfer models).

3. Real-time heat penetration data acquisition

The use of real-time heat penetration data acquisition is unquestionably the most effective and most certainly the very safest approach to achieving on-line correction of process deviations. It was the first control strategy discussed in the earlier review by Teixeira and Tucker (1997), and deserves primary attention and careful consideration whenever it can be economically justified. As the name implies, this type of control strategy relies upon real-time acquisition of heat penetration data while processing is under way with a production batch of product in a commercial retort operation. This means that prior to each batch, a small number of product containers are instrumented with temperature probes prior to filling and seaming, and connected to a data logger by lead wires passing through a retort packing gland. The data logger is connected to a computer with software capable of reading and performing calculations with the data. In this way, the critical cold spot temperature is measured by the data logger and read by the computer as input for calculating the accumulating lethality (F_0) as the process proceeds. This results in a very accurate calculation of process lethality as it accumulates over time. In following the control strategy, this calculated lethality is continually compared with the target value required at the end of heating, so as not to begin the cooling phase until target lethality has been met. Thus, if an unexpected deviation were to occur, it would simply slow down the rate at which lethality accumulates, and the start of cooling would be delayed until target lethality was achieved. In this way, on-line correction occurs automatically without operator intervention, and without any unnecessary degree of over-processing.

Teixeira and Tucker (1997) also described further refinement of this approach by Rynieckie and Jayas (1993), who showed how the real-time cold spot temperature could be further analyzed to obtain the heat penetration parameters from which the cooling lethality could be predicted and accounted for in the decision of when to begin cooling.

An early commercial application of this control strategy was reported by Wojciechowski and Ryniecki (1989), and mentioned in Teixeira and Tucker (1997). That application involved the retort processing of large canned Polish hams and whole chickens. More recently, work reported by Kumar, Ramesh, and Nagaraja Rao (2001) described the retrofitting of a vertical retort for on-line control by real-time data acquisition. They provided detailed flow diagrams in describing the control logic for the system, and

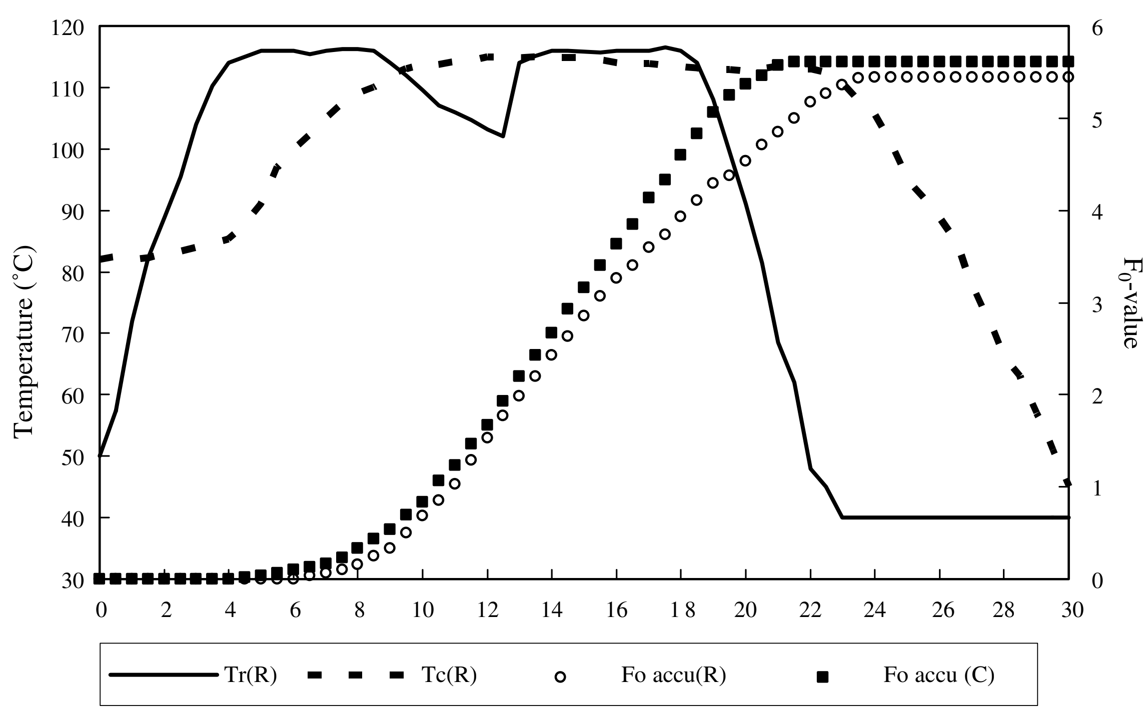


Fig. 1. Effect of control system response to perpetrated process deviation on the lethality value (F_0) during thermal process of canned green beans (Kumar et al., 2001).

carried out heat penetration tests with deliberately perpetrated deviations to demonstrate system performance (Fig. 1).

Perhaps the most valuable feature of control strategies based on real-time acquisition of heat penetration data is that they are nearly foolproof. Because the heating behaviour of the product in the retort is being observed in real-time, as the process is under way, anything that might have gone wrong earlier in product preparation that might have changed the product heating characteristics (critical control points) is revealed and accounted for.

The obvious disadvantage is that in most industrial applications, this type of control strategy would be cost prohibitive. In the case of the very large canned Polish hams and whole chickens, the product value was very high, and the process times were very long (one batch per day), with sufficient time to prepare instrumented sacrificial test cans prior to each batch. This is the rare type of situation in which this approach can be economically justified.

4. Control by on-line correction factors

Commercial systems most commonly in use for on-line retort control fall into this category, and were also described in Teixeira and Tucker (1997). They accomplish on-line correction of process deviations by extending process time to that which would be needed had the entire process been carried out at the lower retort temperature reached at the lowest point in the deviation. These alternative retort temperature–time combinations are predetermined for each product from heat penetration tests, and stored in a file for immediate access when needed. This method of correction often results in significant unnecessary over-processing with concomitant deterioration in product quality. Further, the extended process time that is given can cause a costly interruption to the retort loading/unloading rotation schedule in large cook room operations, with negative impact on manufacturing efficiency (Simpson, Almonacid, & Teixeira, 2002). Nonetheless, these commercial systems are versatile because they are applicable to any kind of food under any size, type or shape of container, as well as mode of heat transfer (Larkin, 2002). They also require no mathematical heat transfer models (nor computers nor software).

Perhaps some of the most exciting new advances in on-line correction of process deviations over the past few years fall into this category of control strategy, and are reported in Simpson, Figueroa, and Teixeira (in press), Simpson, Figueroa, Llanos, and Teixeira (submitted for publication), and Akterian (1996, 1999). The Simpson papers describe novel control strategies that take into account the duration of the deviation in addition to the magnitude of the temperature drop. In one strategy a ‘‘proportional’’ extended process time at the recovered retort temperature is calculated that will deliver the final specified lethality with very little, if any, over processing. A second strategy corrects a deviation with an alternative higher retort temperature process that still delivers the specified final process lethality, but within the same original process time as was pre-scheduled. This second approach has important implications in assuring smooth uninterrupted operation of a retort battery system in large cook rooms, where loading/unloading and venting schedules must be carefully synchronized, as described in Simpson et al. (2002).

Results from use of the first strategy, ‘‘proportional corrected process time’’, in response to unexpected process deviations occurring relatively early and late in a process on both conduction and convection-heated food products are summarized in Table 1. The term ‘‘exact correction’’ is the correction determined by use of the appropriate mathematical heat transfer model (conduction or convection), ‘‘proportional correction’’ refers to the correction determined by the Simpson method, and ‘‘commercial correction’’ refers to the commonly used method of extending process time to that which would be needed had the entire process been carried out at the lower retort temperature reached at the lowest point in the deviation, described earlier. Note that use of the Simpson ‘‘proportional correction’’ method results in a correction nearly identical to that predicted by the heat transfer model, and with substantially less over processing (in terms of both process time and quality retention) than the commonly used method of extending process time to that which would be needed had the entire process been carried out at the lower retort temperature of the deviation.

Results from use of the second Simpson strategy, that accomplishes the on-line correction without extending the original process time, are shown in Fig. 2.

In both control strategies, the correction factors needed are quickly calculated from the anatomy of the recovered process deviation and original process, along with a set of predetermined ‘‘equivalent retort temperature–time

Table 1
Outcomes of each corrected process deviation described in Simpson et al. (in press) in terms of final process time, lethality and quality retention for three different alternative correction methods

	Early deviation			Late deviation		
	Time (min)	F_0 (min)	Nutrient retention (%)	Time (min)	F_0 (min)	Nutrient retention (%)
Pure conduction						
Scheduled process	64.1	6.0	72.7	64.1	6.0	72.7
Exact correction	66.3	6.0	72.9	66.8	6.0	72.7
Proportional correction	67.5	6.5	72.2	67.5	6.2	72.3
Commercial correction	86.2	16.3	62.3	86.2	14.4	62.8
Forced convection						
Scheduled process	15.6	6.0	92.4	15.6	6.0	92.4
Exact correction	18.4	6.1	91.5	19.6	6.0	90.9
Proportional correction	20.8	8.0	89.7	20.8	7.0	89.9
Commercial correction	25.6	11.8	86.2	30.6	14.7	82.8

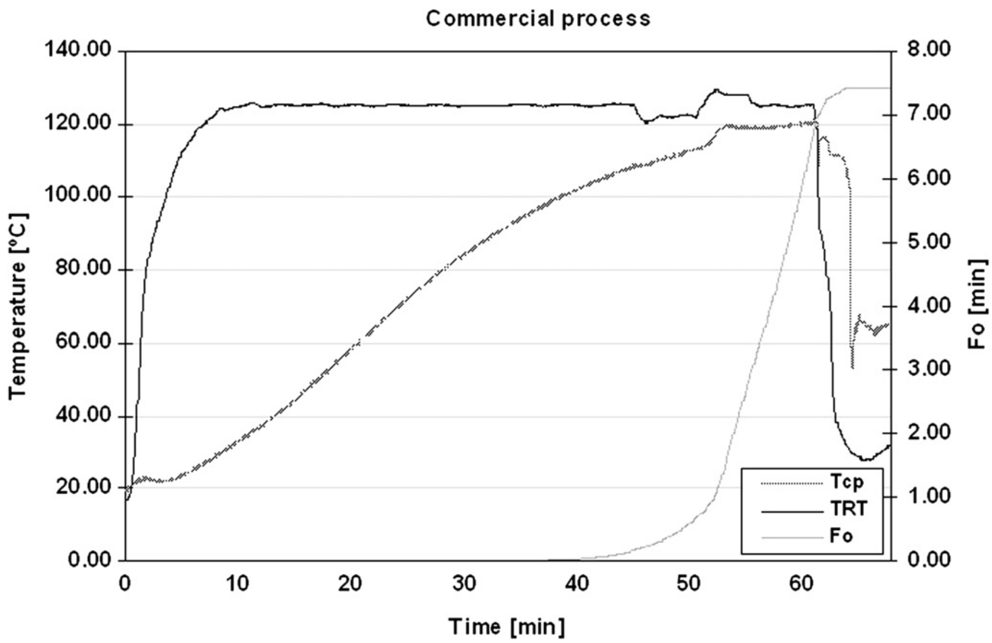


Fig. 2. Profiles of retort (TRT) and internal product cold spot temperatures (T_{cp}) over time (left scale), along with profile of accumulated lethality over time (right scale) from heat penetration test with ravioli in cans (0.075 m diameter, 0.113 m height) experiencing perpetrated process deviation immediately followed by temporary high retort temperature correction (from Simpson et al., submitted for publication).

combinations'' that deliver the same lethality for each product, stored in a file for immediate access when needed, just as with the method commonly used by industry until now. These methods are intended for easy implementation in any cannery (large or small), with no need for on-site access to computer-based control systems and/or computer software of any kind, and at very little cost to implement.

The work of Akterian (1996, 1999) also falls into this category of on-line correction of process deviations, but the correction factors are calculated using mathematical sensitivity functions. The computations are also quite simple, and can be handled by standard micro-controllers suitable for process control.

A more mathematically elegant approach to optimizing control strategies for the thermal sterilization of canned foods was reported by Chabli, van Willigenburg, and van Straten (1999). Optimal retort temperature profiles were sought after and found that would ensure the required degree of sterilization was met, while minimizing costs defined in terms of process time and nutrient retention. Using this approach, they designed a closed loop ''receding horizon'' optimal controller that was shown to be exceptionally robust with respect to uncertainty in the thermal diffusivity parameter.

Note that all these approaches involving calculation of correction factors or execution of optimization search routines require some type of on-line operator intervention. In view of the approaches discussed thus far, it would seem that the ideal approach to intelligent on-line control would be based upon accurate prediction of the product cold spot temperature profile and associated accumulating process lethality in response to any dynamic retort temperature variation, without the need for experimentally measuring internal product temperature, or operator intervention of any kind. The following section on development and application of heat transfer models will show how such an approach is possible, and ever more practicable today.

5. Mathematical heat transfer models

In recent years food engineers knowledgeable in the use of engineering mathematics and scientific principles of heat transfer have developed computer models capable of simulating thermal processing of conduction-heated canned foods such as described in Teixeira and Tucker (1997). These models make use of numerical solutions to mathematical heat transfer equations capable of predicting accurately the internal product cold spot temperature in response to any dynamic temperature experienced by the retort during the process. As such, they are very useful in the rapid evaluation of deviations that may occur unexpectedly. Accuracy of such models is of paramount importance, and the models must work equally as well for any mode of heat transfer or size and shape container. The models described earlier by Teixeira and Manson (1982), and Datta, Teixeira, and Manson (1986) were derived for the case of pure conduction heat transfer in a solid body of finite cylinder shape. Additional work at that time and reported in Teixeira and Tucker (1997), described modification of these models to overcome those limitations (Bichier et al., 1995; Kim & Teixeira, 1997). These reports confirmed that food containers need not be of the same shape as the solid body assumed by the heat transfer model, nor need they heat by the same mode of heat transfer (conduction, convection or mixtures of both). They could be of any shape so long as temperature predictions were required only at the single cold spot location within the container from which heat penetration data were determined. However, a serious limitation to applications for real-time on-line control of process deviations was that the occurrence of a deviation had to be anticipated in advance in order to enter a command into the computer to implement the necessary change in software code that was needed to obtain an accurate response to the deviation. Since, by nature, deviations occur unexpectedly, these modifications had limited practical application.

These limitations quickly became well understood by others working in the field of thermal processing, who soon proposed a greatly improved model (Noronha, Hendrickx, Van Loey, & Tobback, 1995). The Noronha model assumed the product was still a pure conduction-heating solid, but in the form of a sphere. An "apparent" thermal diffusivity was obtained for the solid sphere that would produce the same heating rate as that experienced by the product cold spot. Similarly, the precise radial location where the heating lag factor (j_h) was the same as that at the product cold spot, would be used as the location at which temperature was calculated by the model (Figs. 3 and 4). Thus, for any product with empirical parameters (f_h and j_h) known from heat pen-

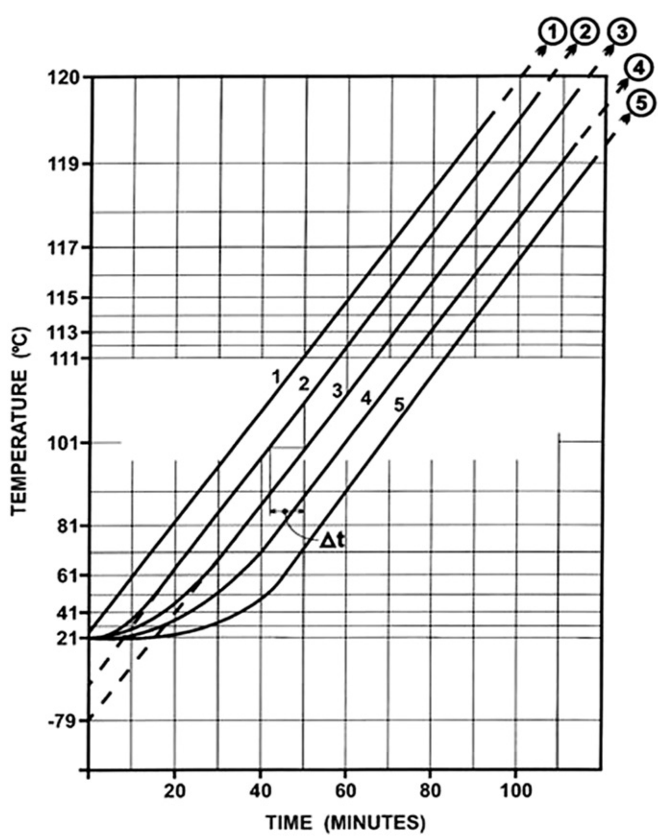


Fig. 3. Heat penetration curves for five different locations along the radius on the mid plane of a cylindrical container (see Fig. 4), illustrating relationship between location and heating lag factor (j_h).

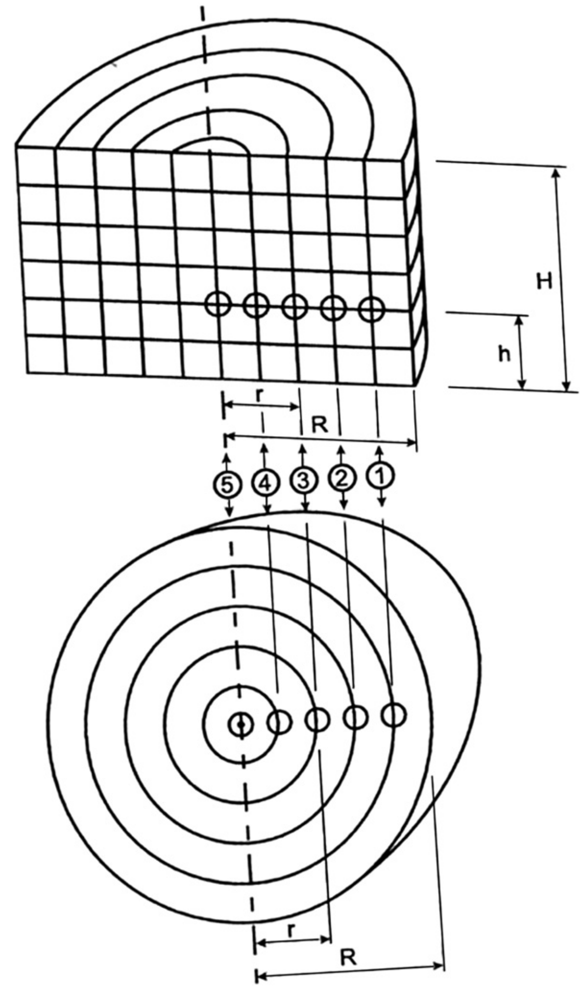


Fig. 4. Replacement of solid body shape from finite cylinder to perfect sphere for simplification of numerical heat transfer model with choice of radial location based upon heating lag factor from heat penetration tests.

etration tests, it would be possible to simulate the thermal response at the product cold spot to any dynamic boundary condition (time varying retort temperature) regardless of shape, mode of heat transfer or process conditions.

Recall that heat penetration test data normally produce straight-line semi-log heat penetration curves from which the empirical heat penetration parameters (f_h and j_h) can be determined. Incorporation of the parameters into the heat transfer model is accomplished by the relationship between thermal diffusivity (α) and heating rate factor (f_h) for a sphere (Eq. (1)); and the relationship between heating lag factor (j_h) and radial location (r) within the sphere (Eq. (2)). These and similar relationships for other regular solid body shapes can be found in Ball and Olson (1957).

$$f_h = 0.233(R^2/\alpha) \quad (1)$$

$$j(r) = 0.637(R^2/r)\sin(\pi r/R) \quad (2)$$

Noronha's model was incorporated into a commercial computer software package by Balaban (1996) and Teixeira et al. (1999) used it to carry out an extensive testing protocol to demonstrate performance of the model under a host of challenging process conditions, including model response to multiple deviations occurring unexpectedly during a single process with solid and liquid products under still and agitated cooks. Results from heat penetration tests on five products from Teixeira et al. (1999) are presented in Table 2. All products exhibited straight-line (log-linear) heat penetration curves on semi-logarithmic plots of unaccomplished temperature differences versus time. Can-to-can variation in heating rate factor (f_h) and lag factors derived from direct analysis of the heat penetration curve (j_h analyze) were determined by the maximum and minimum values found over all six cans from two replicate tests. The true heating lag factor found by trial and error simulation (j_h simulate) was also compared. This was the value chosen for use in the heat transfer model along with the maximum f_h values (slowest heating) for conservative routine simulation of each product. The range of lethality values, calculated from the temperatures measured by thermocouples in each can (F_0 actual), were also compared. Lethality was calculated from the simulated temperature profile (F_0 simulated) predicted by the heat transfer model in response to the retort temperature data file from each heat penetration test as input. Similar models for this same purpose have also been developed, tested and challenged by others with similar performance results (Wang, 2006).

Fig. 5 from Teixeira et al. (1999) compares internal cold spot temperatures predicted by model simulation with profiles measured by thermocouples in response to multiple retort temperature deviations that were deliberately perpetrated during a heat penetration test by shutting off the main steam supply valve, and reopening it after a few minutes. The simulated profiles follow the measured profiles quite closely in response to relatively severe (and twice repeated) deviations.

The final test of model performance in the simulation and evaluation of process deviations was a comparison of lethality accomplished by actual and simulated temperature profiles (Table 3). Recall that the accomplished lethality (F_0) for any thermal process is easily calculated by numerical integration of the measured or predicted cold spot temperature over time by the General Method (Simpson, Almonacid, Acevedo, & Teixeira, 2003). Thus, if the cold spot temperature can be accurately predicted over time, so can the accumulated process lethality. In all cases the simulated lethality predicted agreed most closely with

Table 2
Heat penetration results on products using two replicated heat penetration tests with six instrumented cans for each product (from Teixeira et al., 1999)

Product and process	f_h (min) (range)	j_h analyze (range)	j_h simulate	F_0 – actual (range)	F_0 – simulated
5% Bentonite 1 kg cans (98 × 110 mm), static cook	70.4–73.0	1.9–2.0	2.0	6.0–7.0	6.2
5% Bentonite tuna cans (86 × 45 mm), static cook	20.0–22.0	1.4–1.6	1.4	7.5–9.8	7.4
Water 1 kg cans (98 × 110 mm), static cook	3.0–3.1	1.8–2.3	1.0	9.8–10.8	9.9
Water tuna cans (86 × 45 mm), static cook	1.7–1.9	2.5–3.9	1.0	7.9–10.6	7.7
Peas in brine 1/2 kg cans (74 × 88 mm), agitated cook	2.5–3.0	2.6–3.4	1.0	10.8–12.0	11.0

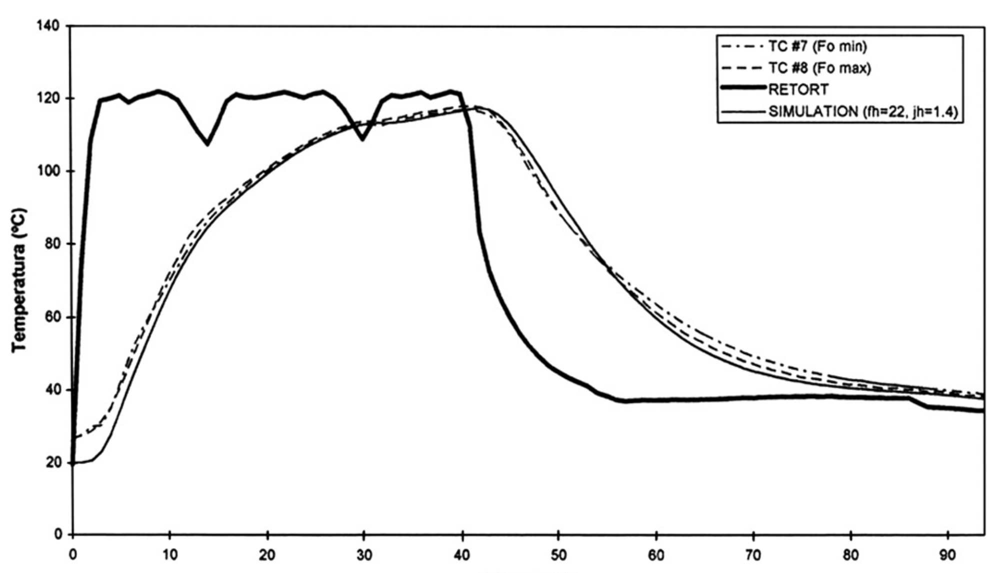


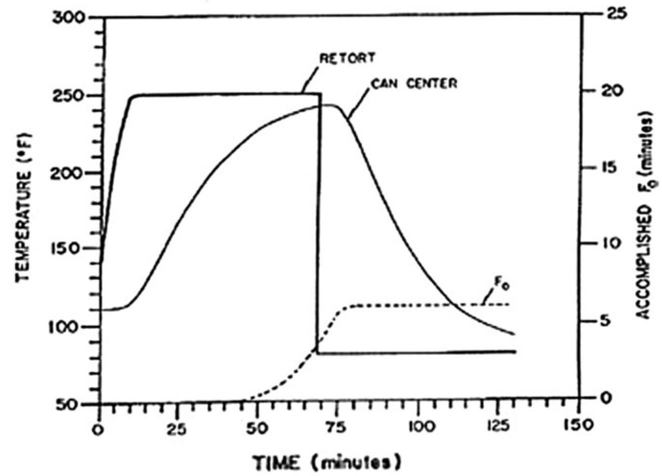
Fig. 5. Comparison of internal cold spot temperatures predicted by model simulation with those measured by thermocouples in response to multiple retort temperature deviations during a heat penetration test with 5% bentonite suspension in 6-ounce tuna can (from Teixeira et al., 1999).

Table 3
Process deviation test results showing lethalities calculated from temperatures predicted by model simulation (F_0 – simulated), and those calculated from actual measured temperatures (F_0 – actual) in slowest and fastest heating cans in response to different types of retort temperature deviations during processing (from Teixeira et al., 1999)

Product and process	Deviation (A, B, C)	F_0 – simulated	F_0 – actual	
			min	max
5% Bentonite 1 kg, static	A	5.5	5.5	6.4
	B	3.0	3.3	5.3
	C	1.7	1.6	2.4
5% Bentonite tuna, static	A	6.5	6.6	7.6
	B	5.6	5.7	7.0
	C	4.8	4.7	5.7
Water 1 kg, static	A	7.4	7.4	8.2
	B	7.8	8.8	10.3
	C	7.1	7.4	8.8
Water tuna, static	A	4.4	5.4	6.2
	B	6.0	6.6	7.7
	C	5.5	6.7	8.0
Peas in brine 1/2 kg, agitated	C	9.1	9.2	10.0

the minimum actual lethality calculated from measured temperature profiles. Model predictions that tend toward the minimum side of the range are always desirable for conservative decision-making.

Computer-based intelligent on-line control systems can make use of these models as part of the decision-making software in a computer-based on-line control system. Instead of specifying the retort temperature as a constant boundary condition, the actual retort temperature is read directly from sensors located in the retort, and is continually updated with each iteration of the numerical solution. Using only the measured retort temperature as input to the control system, the model operates as a subroutine calculating the internal product cold spot temperature after small time intervals in carrying out the numerical solution to the heat conduction equation by finite differences. At the same time, the model also calculates the accomplishing process lethality associated with increasing cold spot temperature in real time as the process is under way. At each time step, the subroutine simulates the additional lethality that will be contributed by the cooling phase if cooling were to begin at that time. In this way, the decision of when to end heating and begin cooling is withheld until the model has determined that final target process lethality will be reached at the end of cooling. By programming the control logic to continue heating until the accumulated lethality has reached some designated target value, the process will always end with the desired level of lethality (F_0), regardless of an unscheduled process temperature deviation. At the end of the process, complete documentation of measured retort temperature history, calculated center temperature history, and accomplished lethality (F_0) can be generated in compliance with regulatory record-keeping requirements. Such documents are shown in Fig. 6, taken from Datta, Teixeira, and Manson (1986), for a simulated



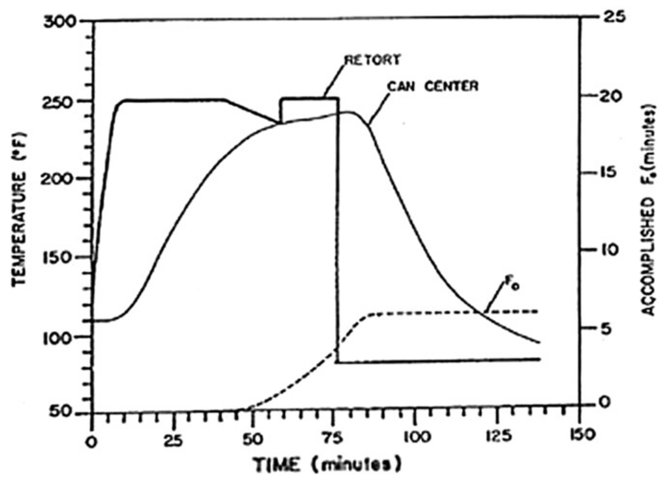


Fig. 6. Output documentation of computer-based on-line control system showing scheduled heating time of 68 min for normal process (above), and heating time extended automatically to 76 min in compensation for unscheduled temporary process deviation (below) (from Datta et al., 1986).

normal process (above), and for the same intended process with a simulated unexpected deviation (below). Wang (2006) also proposed this same approach to on-line control of batch retorts with the use of similar heat transfer models, and went one step further to show how they could be applied to continuous retort systems (hydrostatic sterilizers and rotary reel and spiral cookers) to accurately identify under processed containers experiencing temperature deviations, and divert them when exiting the retorts without stopping the chain, reel or belt.

6. Industrial automation of batch retorts

Many of the most recent advances made in the design of industrial batch retorts has come about in response to the increasing popularity of flexible retort pouches and retortable semi-rigid microwavable plastic dinner trays and lunch bowls. These flexible and semi-rigid containers lack the strength of traditional metal cans and glass jars to withstand the large pressure differences experienced across the container during normal retort operations. To safely process these types of flexible packages, careful control of overriding air pressure is needed during retort processing, and pure saturated steam, alone, cannot be used as the heat exchange medium. Instead, new retorts designed to be used with pressure-controlled steam–air mixtures, water spray, or water cascade have been recently developed for this purpose (Blattner, 2004). Examples of some of these new retort designs are given in Fig. 7. A close-up view of some of the specially designed racking configurations used to hold flexible retortable packages in place during retorting is shown in Fig. 8.

Perhaps the most significant advances made in the food canning industry to-date have been in the area of automated materials handling systems for loading and unloading batch retorts. Traditionally, the loading and unloading of batch retorts has been the most labor-intensive component in food canning factories. Unprocessed sealed containers would be manually stacked into baskets, crates or carts. Then, the baskets or crates would be loaded into empty vertical retorts with the aid of chain hoist, or wheeled carts would be loaded into horizontal retorts with the aid of track rails for this purpose. In recent years leading manufacturers of retort systems have been hard at work designing and offering a host of new automated materials handling systems to automate this retort loading and unloading operation.

Most of the new automated systems available to date are based on the use of either automated guided vehicles (Heyliger, 2004), or orthogonal direction shuttle systems (Blattner, 2004; Heyliger, 2004). Both types of systems are designed for use with horizontal retorts. The automated guided vehicles (AGV) work like robots. They carry the

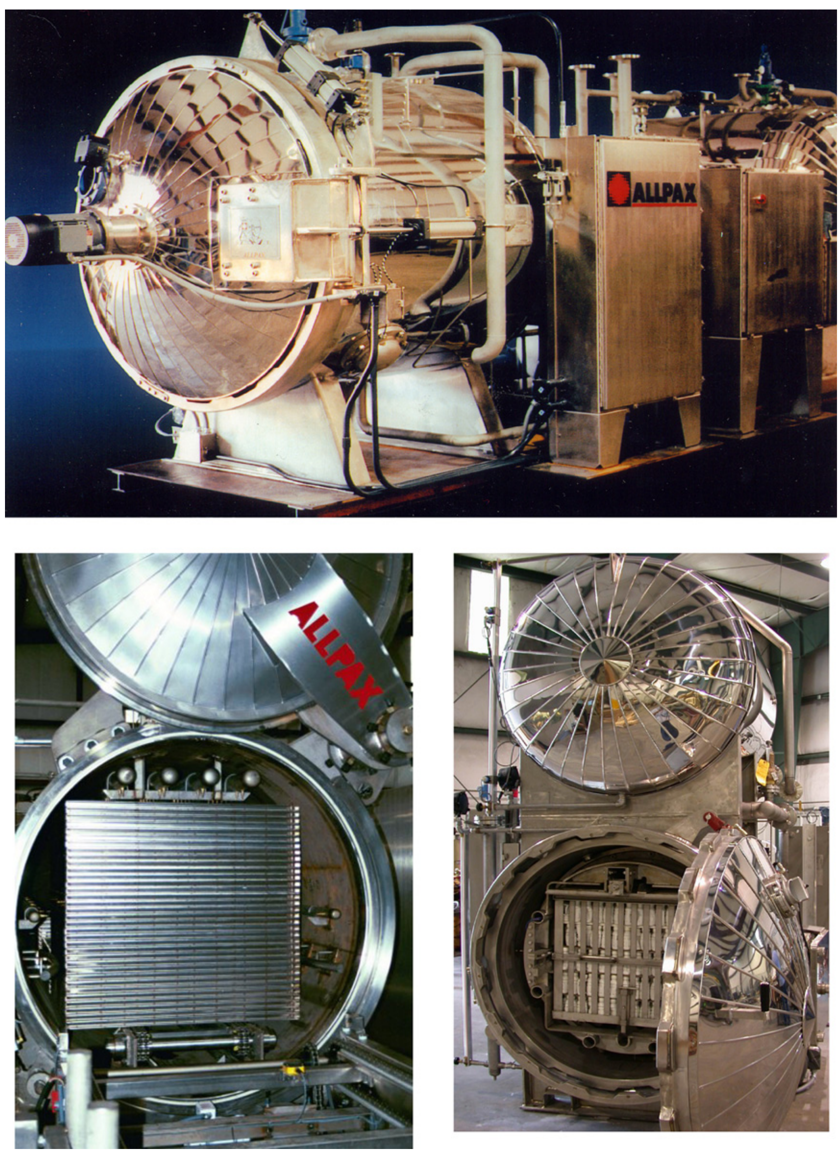


Fig. 7. New retort systems (rotating and still-cook) with specially designed racking configurations for processing flexible and semi-rigid packages (Courtesy of ALLPAX, Covington, LA).

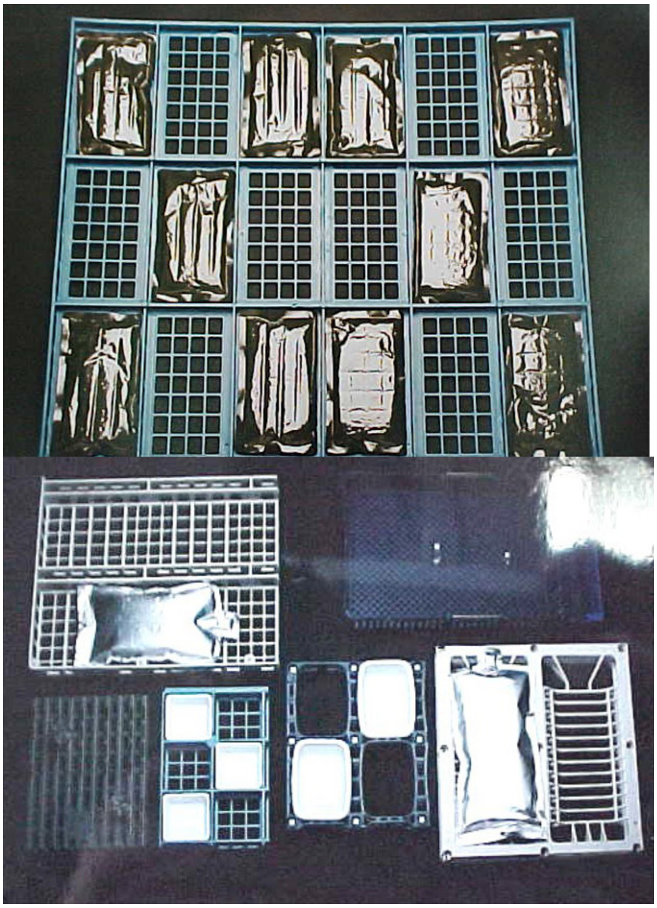


Fig. 8. Rack designs for flexible and semi-rigid retortable packaging systems (Courtesy, ALLPAX, Covington, LA).

loaded crates of unprocessed product from the loading station to any designated retort on the cook room floor that is ready to be loaded. They also carry the loaded crates of finished processed product from the unloaded retort to the unloading station for discharge as out-going product exiting the cook room to the case packing operations. These robotic AGVs are designed to integrate with the loading station in such a way that sealed product containers arriving on a conveyor automatically stack into the crate carried by the AGV, which later inserts the entire crate into the designated retort. Unloading at the unloading station for finished product discharge is likewise accomplished in a similar automated way, but in reverse. The AGVs are guided by an underground wire tracking system buried beneath the cook room floor. This leaves the cook room floor space open and free of any rail tracks or guide rails that would otherwise impede the safe movement of factory workers in their normal work flow operations. A panoramic view of a large cook room operation using an automated batch retort system with automated guided vehicles is shown in Fig. 9 (Heyliger, 2004), and a close-up view of an automated guided vehicle in the process of loading or unloading a horizontal retort is shown in Fig. 10.

An alternative to the automated guided vehicle (AGV) system is the shuttle system offered by several retort manufactures. Unlike the AGV system, the shuttle system relies upon a set of tracks or rails that are fixed in place on the cook room floor. These rails span the length of the cook room along the row of horizontal retorts, allowing a shuttle carrying loaded crates to slide along these rails until it has aligned itself in front of the designated retort waiting to be loaded. In a similar fashion, when a retort is ready for unloading, an empty shuttle slides along these rails until it has aligned itself with that retort to receive the loaded crates of processed product. Then the shuttle slides along the rails to far end of the cook room where unloading of

Fig. 9. Automated batch retort system with use of automated guided vehicles in large cook room operation (Courtesy, FMC Food Tech., Madera, CA).

Fig. 10. Automated guided vehicle for batch retort loading/unloading (Courtesy, FMC Food Tech., Madera, CA).

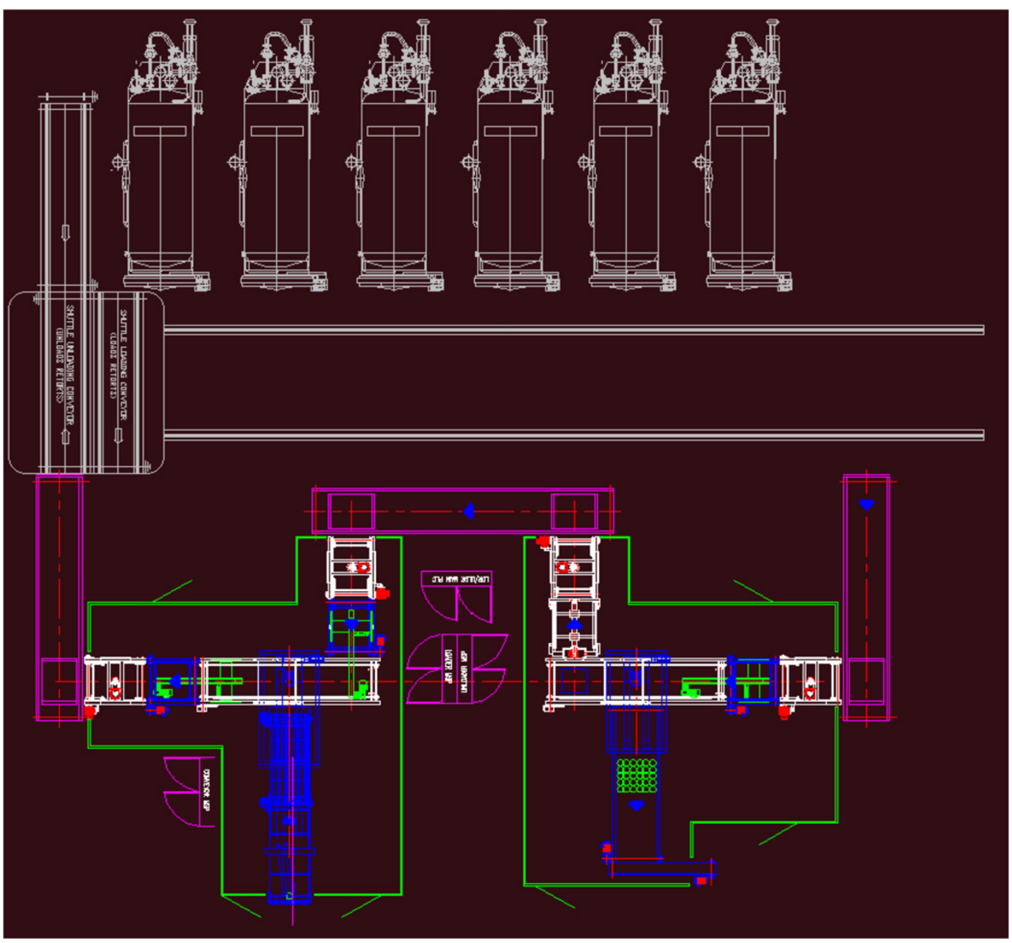


Fig. 11. Automated shuttle-based batch retort control system (Courtesy, ALLPAX, Covington, LA).

processed product takes place for discharge out of the cook room. Normally, the unprocessed product loading station and the processed product unloading stations are located at opposite ends of the cook room (Fig. 11). Figs. 12 and 13 illustrate the shuttle systems offered by ALLPAX and FMC, respectively.

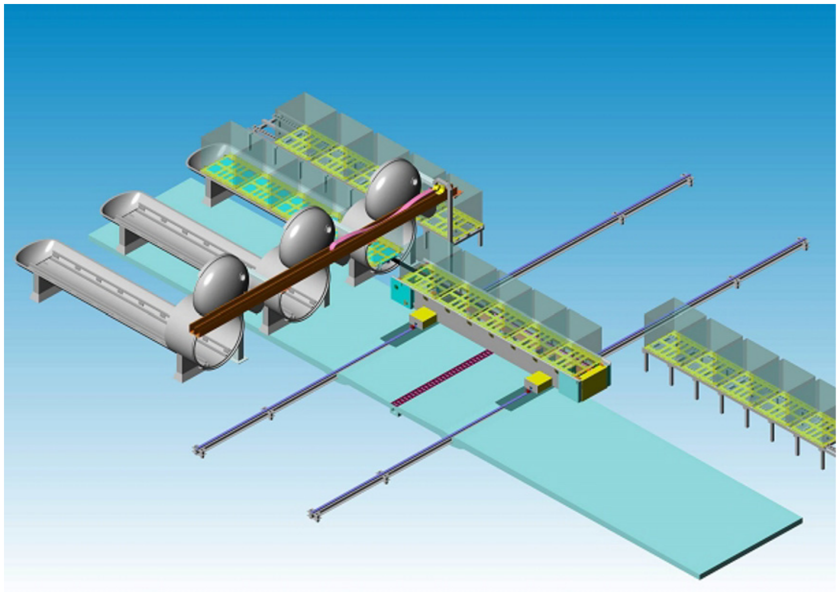


Fig. 12. Automated shuttle batch retort system (Courtesy of ALLPAX, Covington, LA).

Fig. 13. FMC shuttle system for automated batch retort loading/unloading (Courtesy, FMC Food Tech., Madera, CA).

7. Future trends

As the food canning industry continues to remain competitive in an ever expanding global market, the need for technological advances that lead to increasing productivity, better product quality with enhanced safety assurance, and all at lower and lower cost, advances in automation and intelligent on-line control will inevitably continue at a rapid pace. New developments that are likely to occur soonest will be the application of computer-based retort control systems for on-line correction of process deviations. These developments are likely to occur first in relatively small canneries with labor-intensive batch retort operations located in developing countries. These are the companies with the greatest need and most receptive to adopting new technology appropriate to their level of processing operations.

Very simple systems are now under development intended for this market. These systems will consist only of a lap top computer equipped with software containing the mathematical heat transfer models described in this review paper. These lap top computers will communicate with commercially available data acquisition modules (data loggers), and serve as traditional data acquisition systems, but with a twist. The data logger will be continuously reading retort temperature, and sending this information to the lap top computer. From these data and with the mathematical heat transfer model, the computer will be continuously calculating the increasing internal cold spot temperature and associated accomplished lethality, and comparing this accomplished lethality with the specified target value for the process. When calculated accomplished lethality reaches the specified target value, the lap top computer will signal the operator to take the necessary action to end heating, and commence cooling. These systems will involve no computer-controlled actuators to automatically shut off or turn on valves. Instead the operator will be expected to be watching the monitor as the process is under way, and operate the retort as always ("opto-digital" control). The operator will simply wait until the computer indicates when to turn off the steam, rather than do so when indicated by a stop watch.

In the area of materials handling automation, the industry may witness a move to more and more sophisticated robotics that may ultimately replace the shuttle systems and automated guided vehicles that have become the state-of-the-art today.

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