Received: 29 June 2021

Revised: 21 October 2021

Accepted: 2 November 2021

A Case-study: Temperature Distribution and Heat Penetration in Steam-air Retort, Using Glass Jars and Retort Pouches

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Abstract. Retort thermal sterilization of canned food is a technology, which allows preserving food products by applying heat on packaged food in retorts (autoclaves) at temperatures up to 121 °C. The thermodynamics of the processes in the retort are influenced by the product stacking method in the basket and packaging material. The aims of this study were: 1) to analyse and compare temperature distribution (TD) and the slowest to heat location in the steam-air retort stacked with glass jars and with retort pouches; 2) to analyse and compare commercial product heat penetration (HP) characteristics in glass jars and retort pouches. Temperature measurements were performed with wireless thermocouples. The come-up time (heating phase) required to achieve in the retort temperature uniformity criteria of ± 0.5 °C, is 28 min when the retort is stacked with glass jars, and 24 min when the retort is stacked with retort pouches. Total calculated process time (holding phase), necessary to achieve the sterilization value (F_0 of 3 min), for sample in glass jars was 67 min, but in retort pouches – 62 min. The overall sterilization process time difference between two considered packaging types was 9 min, which is significant amount of time in the context of commercial processing. The study clearly shows the necessity to perform the Temperature Distribution and Heat Penetration study, as each packaging material, stacking method and product will affect sterilization process thermodynamics and, therefore, the overall process time and consequently - the safety of food product.

Key words: Process evaluation; process determination; CUT; holding time; autoclave processing.

Introduction

The main conditions for successfully produced food products include not only high quality goods and affordable prices, but also reliable, safe and aesthetically pleasing packaging. Various packaging materials are currently used for storing and identifying products, from traditional glass to innovative polypropylene with a barrier layer (Han, 2005). Food packaging contributes to extending the shelf life and maintaining the quality and safety of the food products (Kelsey, 1989).

Glass jars are widely used for packing foods and beverages. These have the advantages of very low interaction with the contents and visibility of the product. However, they require more careful processing and handling, as well as inner pre-treatment with steam.

Flexible retort pouches are a unique alternative packaging for sterile shelf-stable products that can withstand common thermal processing temperatures in canning industry, i.e. 120 °C. Pouches are made of laminated materials that provide oxygen and moisture barrier (Simpson *et al.*, 2019).

Retort packaging have numerous advantages in food

processing industry in comparison with glass packaging – easier logistics, lower weight, and more convenient handling in general. From the food production point of view, according to Brody *et al.*, (2008), products packaged in pouches need less heat energy amount to achieve the 'commercial sterility'.

In the canning industry, thermal preservation processes are designed based on product pH to contain the production of the botulin toxin by *Clostridium botulinum*, as the toxin is not produced at pH < 4.6. Therefore, low-acid canned foods should receive increased attention in the prevention of *Clostridium botulinum* (Noronha, 1996). Therefore, it is necessary to give a scientific justification for such sterilization regime, which would preserve the culinary qualities of canned food, at the same time, would ensure the destruction of microorganisms that cause spoilage, i.e. achieved sterilization value (F_0) ≥ 3 min (Rawat, 2015).

Thermodynamics of the processes in retort are influenced by product stacking method in the basket, packaging material and product properties (Holdsworth & Simpson, 2016). In liquid products, heat is transferred mainly by convection, and the temperature in the can rises faster due to the constant movement of product particles; therefore, the temperature

difference inside the can is negligible. Products with a dense consistency are warmed up due to thermal conductivity; heating proceeds slowly due to the absence of transition of the product particles from heated to cold areas. As temperature difference between the retort and the packaging decreases – heat transfer rate decreases accordingly (Al-Baali & Farid, 2006).

Retort steam-air sterilization method consists of the following steps: basket with the packaged product loading, full basket placement into the retort, deaeration phase, heating the retort with steam (coming-up phase) until the set temperature, holding the set temperature in retort (holding phase) and application of cold water (cooling phase). The coming-up time is the time necessary to achieve uniform temperature in the retort. The process time (holding phase) for a commercial operation (sterilization process) is measured from the moment when retort reaches processing temperature, till the time when steam is discharged from the retort and cooling water is applied, i.e. the cooling phase has

started. Duration of the sterilization process time is determined by the rate of heat transfer into the containers (Al-Baali & Farid, 2006).

Since there are no specific requirements in Latvia Republic legislation for canning facilities regarding the sterilization process designed for autoclaves, the aims of this study were:

- 1) to analyze and compare temperature distribution (TD) and the slowest to heat location in the steam-air retort OP-Panini SN4280 stacked with glass jars and with retort pouches.
- 2) to analyze and compare commercial product heat penetration (HP) characteristics in glass jars and retort pouches in the steam-air retort OP-Panini SN4280.

Materials and Methods

Packaging

In this study, glass (Table 1) and retort pouch packaging (Table 2) were used. Glass jars were manufactured by LLC Krasnoye Echo (Gus-Khrustalny, Russia).

Table 1

Physical properties of the glass jars	
Property	Values
Nominal capacity, ml	500
Full capacity, ml	540 ± 10
Height, mm:	115 ± 1; O88 ± 1.5
Diameter, mm	88 ± 1.5
wall thickness, not less than, mm	1.2
bottom thickness, not less than, mm	2.0

Retort pouches were manufactured by C. L. P Industries Ltd. “Tadbik” (Kibbutz Negba, Israel). Pouch material composition: lacquer 10 µm, polyethylene terephthalate 12 µm, aluminium 9 µm, biaxially oriented nylon 15 µm, polypropylene 80 µm.

Table 2

Physical properties of the retort pouches	
Property	Values
Thickness, µm	126
Weight, g/m ²	147±11
Width size, mm	160±2
Length size, mm	210±2
Gusset height, mm	43±1
Side seal width, mm	8±1

Bottom seal width, mm	8±1
Tear notch location, mm	25±1

Processing

Experiments were performed at Kronis Ltd. (Bauska, Latvia), in the production-scale, horizontal steam – air retort OP-Panini SN4280 (Maranello MO, Italy). Steam inlet pipe was located lengthwise on the bottom of the retort with inlet points between the baskets, and fan that is meant to distribute steam and ensure steam-air mixing – at the far end of the retort, near the 1st basket (Fig. 2). Air inlet was located on the top of the retort, between the 2nd and the 3rd basket. Resistance thermometer (Pt100), which is used by the retort to control the process setpoints, was located on the top - between the 3rd and the 4th basket. Throughout the experiment, the following retort program setpoints were set the same for the jars and the pouches during the TD study:

1. preliminary step: steam inlet and outlet are open until the references Pt100), which controls the process, indicates 80 °C;
2. come-up (CUT) phase: 15 min to 120 °C;
3. overshoot: 5 min at 120 °C;
4. holding phase: 20 min at 118 °C;

5. cooling phase: 25 min, or until the references packaging would achieve 50 °C.

HP study was performed with the same setpoints, except the holding phase – 60 min at 118 °C.

Thermocouple fastening

For this study, 20 T-type thermocouples with 10 cm long probes, and 1 pressure sensor combined with thermocouple were used (Tecnosoft, Mezzate MI, Italy). Temperature accuracy of the selected thermocouples was ± 0.2 °C.

During the TD study, temperature measuring devices (TMD) were located inside of the packaging, with temperature sensor located outside of the packaging, protruding through the divider sheets into the layer above, to measure the ambient temperature. For both glass (Figure 1a) and flexible packaging (Figure 1b), locking bolts (Tecnosoft, Mezzate MI, Italy) were used to fix and adjust the position of sensor. During the HP study, TMD sensor was located in the expected coldest zone of the packaging.

A

B

Figure 1. Thermocouple fastening in glass jars case (a) and retort pouch case (b).

Products

For TD study, packages were filled with water and used as a ballast during the sterilization, to ensure steam distribution flow in the retort similar to production conditions. For HP study, commercial product “Rassolnik” soup (pH = 5.1) was used. The product was a thick soup concentrate, a mixture of fresh, pickled or salted vegetables with the addition of oil, tomato paste, salt, sugar, flour and spices. Retort pouches were filled with 530 g, and the glass jars were filled with 470 g of the product.

Temperature distribution (TD) studies

TD studies were conducted in a retort using distributed TMDs to establish venting procedures, venting schedules, come-up requirements, temperature stability and uniformity, all of which are necessary to establish reproducible and reliable heating and cooling performance throughout the

retort.

TD study was performed in three stages for both types of packaging:

1. During the first stage (Figure 2a), 18 temperature measurement devices (TMDs) were distributed in one basket from the top to the bottom. Four process cycles were performed. During each cycle the basket with TMDs was moved to the next position, starting at first position – the farthest from the door of the retort, which allows us to analyze temperature distribution through each basket in each position in the retort.

2. During the second stage (Figure 2b), 20 TMDs were divided between 4 baskets, located in the slowest part of the baskets, i.e. the lower part, which allows us to identify the slowest heated zone of the retort.

3. During the third stage (Figure 2c), 4 TMDs were located in the slowest heated zone of the basket, located in

slowest heated position of the retort.

One TMD combined with pressure sensor was always

located near the reference Pt100. Time-temperature data was gathered twice, but only the “worst case” data was considered in this work.

Figure 2. Thermocouple locations during the three stages of Temperature Distribution study for retort stacked with glass jars.

Heat penetration (HP) studies

HP studies were performed with the same ballast, as TD study. Time-temperature data were obtained by measuring temperature inside of the thermal center of the packaging filled with commercial product. Packages with TMDs were located in the slowest heated zone of the retort, defined during the TD study. Further heat penetration factors were calculated by Ball method (Ball, 1923), and consequently holding phase was defined by Stumbo method (Stumbo, 1973) with implemented apparent position numerical solution (APNS) method (Noronha, 1996). Time-temperature data was gathered twice, but only the “worst case” data was considered in this work.

Data processing

Data obtained during the experiments was collected and analyzed with a computer using Ball 2.2 and Stumbo 2.2. Average values and standard deviation were obtained using Microsoft Excel v16. The heat penetration data was plotted using Ball 2.2 against time on a semi-log graph. The temperature difference (retort temperature minus core temperature of the product) was plotted on the log scale. The lag factor for heating (j_h), slope of the heating curve (f_h), lag factor for cooling (j_c), slope of the heating curve (f_c) - were

determined from semi-log graph.

Results

Temperature distribution study in retort stacked with glass jars

Data analysis from the first stage of the experiment (Table 3) showed that the lower part of the basket was heated the slowest, which were the layers No. 2 to 6. Comparing TMD readings in the right side of the basket (i.e. considering point of view from the door) with the data from the left side, we can conclude that the right side of the basket was heated slower.

The second stage showed that the slowest heated TMDs were located in the layer No. 4 for the 1st, 3rd and 4th basket, but in the 2nd basket the slowest TMD was located in the layer No. 2. To achieve ± 0.5 °C temperature difference between the highest and the lowest temperature measurements, the change was made to prolong CUT for 5 min for the coldest TMD in 1st basket, 9 min for the TMD in the 2nd basket, and 11 min for the TMDs in the 2nd and 3rd basket. At the start of the holding phase, the TMD No. 6, which is located in the 2nd basket, had similar value as the TMD No. 12 in 3rd basket. It was noted that after 1, 3 and 5 min of the holding stage, the difference between the retort temperature and the coldest point (ΔT) was higher for the thermocouples in the 3rd basket. In spite of the fact that the same amount of time is necessary to

heat the foregoing TMDs in the 2nd and 3rd basket, it is considered that the slowest heated zone is in the 3rd basket, between the layers 2 and 4, due to worse heating dynamic.

Table 3

Temperature data analysis for temperature distribution study in retort stacked with glass packaging

Stage	Basket position	¹ T _{std dev} , °C	² T _{mean} , °C	³ T _{min} , °C	⁴ ΔT, °C	ΔT+1 min, °C	ΔT+3 min, °C	ΔT+5 min, °C	±0.5°C, min
a	1	1.9	118.3	113.5	6.5	4.3	2.7	1.5	10
	2	1.3	118.7	115.2	3.9	3.0	2.2	1.5	10
	3	1.9	118.5	113.9	5.9	4.4	3.2	2.2	12
	4	0.6	119.4	118.2	2.4	2.3	1.8	0.5	-
b	1	0.3	119.1	118.5	1.1	0.9	0.8	0.5	5
	2	1.4	116.8	114.4	5.1	3.8	2.6	1.7	11
	3	1.3	115.8	114.6	5.0	4.1	3.1	2.0	11
	4	1.4	116.9	115.6	4.0	3.5	2.3	1.3	9
c	3	1.5	117.6	116.1	3.5	1.7	1.1	1.0	13

¹Standard deviation in temperature readings at the end of the coming-up time (CUT) phase; ²Mean between thermocouple readings at the end of the CUT; ³The lowest thermocouple reading at the end of the CUT; ⁴Temperature difference between reference thermocouple and the lowest reading in the retort;

The third stage of the experiment showed that despite the lower T_{min} and ΔT temperatures at the start of the overshoot, as well as after 1, 3 and 5 min, it still needed 13 more minutes to achieve ±0.5 °C difference between the highest and the lowest readings of the thermocouples in the retort.

Temperature distribution study in retort stacked with retort pouches

During the first stage of the TD study, basket-per-basket approach showed (Table 4) that the lowest mean temperature readings were achieved in the 2nd and 3rd basket. The slowest heated TMDs in these baskets were located in the front part of

the 6th and 8th layers, while in the 4th basket, the lowest temperature was achieved in the back side of the basket, in the 6th layer. The lowest temperature of the basket in 1st position was achieved in the 8th layer. Despite the fact that the coldest thermocouple in the 3rd basket at the start of the holding phase, have had higher temperature, than the thermocouple in the 2nd basket - it took 3 min to achieve ±0.5 °C uniformity in the retort for the 3rd basket, while for the 2nd basket it took 2 min.

During the second stage of the experiment, TMDs (n=18) were divided between the 2nd and the 3rd baskets, and located in the layers 6 and 8. Four of the lowest temperature readings were achieved in the 3rd basket 8th and 6th layers.

Table 4

Temperature data analysis for temperature distribution study in retort stacked with flexible packaging

Stage	Basket position	¹ T _{std dev} , °C	² T _{mean} , °C	³ T _{min} , °C	⁴ ΔT, °C	ΔT+1 min, °C	ΔT+3 min, °C	ΔT+5 min, °C	±0.5 °C, min
a	1	0.1	118.6	118.4	0.4	0.4	0.2	0.1	-
	2	0.2	118.1	117.8	0.9	0.6	0.4	0.3	2
	3	0.3	118.9	118.2	1.3	0.8	0.5	0.3	3
	4	0.2	119.1	118.6	0.9	0.6	0.4	0.2	1
b	2, 3	0.4	119.1	118.5	1.4	0.8	0.6	0.6	8
c	3	1.5	117.6	116.1	3.5	1.7	1.1	1.0	13

¹ Standard deviation in temperature readings at the end of the coming-up time (CUT) phase; ² Mean between thermocouple readings at the end of the CUT; ³ The lowest thermocouple reading at the end of the CUT; ⁴ Temperature difference between reference thermocouple and the lowest reading in the retort;

During the third stage of the experiment, it was decided to compare temperature readings (n=18) between the layers No. 6 to 9 of the 3rd basket. The lowest temperature readings were achieved in the middle-left part of the layer No. 8, followed by the middle-front part of the layer No. 9, and middle-left part of the layer No. 7. To achieve temperature uniformity in the retort, it was necessary to prolong the CUT phase of the sterilization cycle for 9 min.

Heat penetration study

The purpose of heat penetration studies is to determine heating and cooling behavior of a product/package

combination in a specific retort system for the establishment of safe thermal processes to deliver commercially sterile products and to assist in evaluating process deviations.

One of the most precise and generally adapted method for sterilization process time (holding time) evaluation is the Stumbo formula method (Stumbo, 1973), which assumes that CUT contribution in total lethal effect is 42%, which have been determined by Ball (Ball, 1923). A number of 42% is a “conservative estimate” (Holdsworth & Simpson, 2016), and is only applicable to the cases with linear heating profile, which often do not correspond to the reality. Numerous studies have found different effectiveness coefficients, affected by the packaging material, reporting the contribution up to almost 80% (Ramaswamy & Tung, 1986; Ramaswamy *et al.*, 1993; Spinak & Wiley, 1982).

For the product in each packaging type, heating rate index (f_h), heating lag factor (j_h), cooling rate index (f_c) and cooling lag factor (j_c) are presented (Table 5).

Table 5

Heat penetration data and calculated process times for thick soup concentrate “Rassolnik”

Packaging	¹ f_h , min	² j_h	³ f_c , min	⁴ j_c	⁵ CUT contribution, %	T, °C	Holding time, min
Glass jar	59.7	2	75.7	2.08	57%	118	67
Retort pouch	71.6	1.18	70.4	2.18	61%	118	62

¹ Heating rate index; ² Heating lag factor; ³ Cooling rate index; ⁴ Cooling lag factor; ⁵ Coming-up time.

Samples of the retort pouches showed higher heating rate index (f_h) than product in the glass packaging, but lower heating lag factor (j_h). Such difference in heating rate index is influenced by packaging material physical properties (thickness and thermal conductivity), as well as its practical usage.

Discussion

The slowest to heat zone of the retort in both cases was observed in the 3rd basket. Such occurrence could be described by the retort principle of operation. Steam inlet pipe is located on the bottom of the retort, and fan that is meant to distribute steam – at the far end of the retort, near the 1st basket. Since basket located in the 1st position blocks the flow produced by the fan, and the basket in 4th position is located where the flows meet, consequently receiving the best convection - the 2nd and the 3rd basket positions are expected to be slowest to heat.

It is logical to expect better steam flow on the outer side of the baskets than in the inner. It is also expected the upper part of the retort to be warmer than the bottom, because of natural convection of ambience, but the steam pipe location should level the differences. In case of the glass jars, the 3rd – 4th layers were the slowest to heat in terms of the basket, while in the pouch case it was the 8th layer. Such occurrence could be described by the density of the stacking method. In conductive heated materials, the “cold spot” is shifted lower from the center, while convective heated materials tend to have the cold spot in the geometric center (Campbell & Ramaswamy, 1992; Joseph, Speers & Pillay, 1996). It is fair

to assume that retort pouch stacking method allows steam to penetrate the basket faster, thus shifting the “cold zone” upwards from the geometric center.

In comparison, retort stacked with flexible packaging showed the lower T_{stddev} in temperature readings <0.5 °C at the end of the CUT, while the T_{stddev} in the retort stacked with glass jars showed <2.0 °C. Such a fact was observed mainly because of the density of how the packaging was stacked in the basket. Glass jars were placed one on top of the other without any shift, divided with plastic divider plates with large holes, while retort pouches were placed horizontally on the shelves, forming ~0.5 cm of headspace between the retort pouches and the shelf above. Such stacking method improves steam flow through the basket, therefore, enhancing the heat distribution throughout the retort. Nevertheless, the overall time required to achieve the temperature uniformity criteria of ±0.5 °C for the retort stacked with glass jars was 28 min, while retort stacked with the retort pouches was 24 min, which could be considered as small difference.

Since retort pouches are flexible, they form thinner layer of product that needs to be penetrated by heat, when placed horizontally in the autoclave basket, while glass jars diameter is constant, and has thicker layer of product that heat should penetrate. Total calculated process time (holding phase), necessary to achieve $F_0 = 3$ min, for product in glass jars was 67 min, but in retort packaging – 62 min. Despite the larger heating rate index f_h (time, necessary to elevate temperature for 1 log₁₀) and lower f_c (time, necessary to lower temperature for 1 log₁₀), lower heating lag factor j_h considerably affects total process time, resulting in lower necessary time to achieve $F_0 = 3$ min. It is clearly seen that even retort pouches

were filled with 530 g of product, while glass jars contained 470 g of product, nonetheless retort pouches showed 5 min faster result than glass packaging.

This study has certain limitations. Since heat transfer agent in steam-air retort is a mixture of air and steam – the mechanisms of heat transfer are mainly convection and condensation (Ramaswamy, 1983), the heating rate may be dependent on steam concentration in the heat transfer agent. Consequently, final achieved sterilization values may vary among expected, hence require heating rate distribution research in chosen retort.

Conclusions

The CUT required to achieve ± 0.5 °C temperature uniformity in the steam-air retort stacked with glass jars and retort packaging is 28 and 24 min, respectively. The holding phase time (process time) necessary to achieve $F_0 = 3$ min for the product in glass jars was 67 min and for the retort pouch was 62 min. The overall sterilization process difference between two packaging types was 9 min, which is considerable amount of time in the context of commercial processing.

The study clearly shows step-by-step process performing the Temperature Distribution and Heat Penetration study, as well as shows the necessity for them, as each packaging material, stacking method and product will affect sterilization process thermodynamics and, therefore, the overall process time and consequently - the safety of food product.

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Acknowledgements

The authors would like to thank Mr. Frits Eckenhausen for training, comprehensive consultations during the study and provided software for calculations.

Present research leading to these results in accordance with the contract No. 1.2.1.1/18/A/002 between Latvian Food Competence Centre Ltd. and the Central Finance and Contracting Agency (08.05.2019) has been conducted by Kronis Ltd. with the support from the European Regional Development Fund (ERDF) within the framework of the project Latvian Food Industry Competence Centre.