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Research Article

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Effects of Packaging Geometry on Heat Penetration Time in Retortable Semi-Rigid Plastic Trays

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Abstract Semi-rigid, retortable trays were filled with a food simulate and thermally processed in a water immersion automated batch retort system at rotational speeds of 6 RPM and 11 RPM. Triangle, rectangle, oval, and round trays were evaluated, each having approximately the same overflow capacity. During processing, trays were fixed in place with racks containing one shape per rack. Various rack location combinations were tested to provide processing data for each shape in each rack location. Heat penetration data was gathered using thermocouples located in the geometric center of each tray shape and this data was modeled to determine the slowest heating container. No differences were observed in rack location among tray geometries at either RPM level ($P>0.05$). The data generated during heat penetration runs was also used to model different retort temperatures and lethality values. A retort temperature of 215°F and a lethality value of 10 showed the highest average sterilization time ($P<0.05$) and these conditions were subsequently used for evaluation of tray geometry during thermal processing. At a rotational speed of 6 RPM, the average time to lethally was higher ($P<0.05$) for the triangle shaped tray than the rectangle and round shaped trays while the average process time to lethality for the oval tray was not different ($P>0.05$) than any other shape tray. At a rotational speed of 11 RPM, differences in average process time to reach lethality between tray geometries were insignificant ($P>0.05$).
Keywords *Retort Trays; Heat Transfer; Thermal Processing; Packaging*

1. Introduction

Thermal processing of prepackaged foods is one of the most widely used forms of food preservation (Teixeira and Tucker, 1997). A visit to any U.S. grocery store will find many different packaged food formats that have had some form of thermal process applied. The most familiar version of a retorted package is the metal can. Even with newer, more innovative packaging options available the metal can continues to be used in large quantities due to universal acceptance, low cost, and existing industrial infrastructure. However, there are multiple options available for shelf stable retort packaging including retort-able cartons, pouches, and semi-rigid trays, all which continue to grow in market penetration. A recent example of alternate package growth in the shelf stable marketplace is a new microwavable semi-rigid tray for the SpagettiOs® brand by the Campbell Soup Company (Campbell Soup Company, Camden, NJ). This offering, targeted at younger users, offers benefits beyond the traditional metal can such as microwave-ability and safe edges once opened.

The process of retorting delivers a packaged product that is commercially sterile. Commercial sterility is defined in 21 CFR Part 113.3 as "the condition achieved either by the application of heat which renders the food free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution and free of viable microorganisms (including spores) of public health significance, or by the control of water activity and the application of heat which renders the food free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution” (21 CFR 113.3).

The basic principle that governs the retort process is the transfer of heat from a heating medium into the packaged product (Rattan and Ramaswamy, 2014). Two specific modes of heat transfer are convection and conduction. Convection heating is observed in liquid based foods, such as broths, while conduction heating is observed in solid containing foods such a beans. Foods that contain both liquid and solid parts, such as soups and some sauces heat via a combination of effects (Rattan and Ramaswamy, 2014).

Consumer expectations have grown over the years to the point where higher quality levels at reasonable prices are expected. As process engineers and food scientists work to provide these types of products, balancing thermal processing for the destruction of microorganisms and the loss of nutrients is a critical consideration. For example, vitamin degradation is a first order reaction similar to microorganism destruction, only with a higher decimal reduction time associated with vitamins (Al-Baali and Farid, 2006). If a product was processed in a traditional retort process, nutrients could be degraded as microorganisms were eliminated to render the food commercially sterile. In this example, one possible alternate to maintain preserve some nutrient integrity would be to use higher temperatures at shorter processing times (Ramaswamy and Dwivedi, 2011). In an effort to further minimize quality impact on retorted foods, the thermal processing industry has continued to develop retorts and thermal processes which optimize sterilization times and retain the maximum amount of food quality (Singh et al., 2014)

Another possible strategy for delivering optimized heating to a food product could be the use of packaging type and geometry. Heat transfer could be designed at an optimum rate, retaining nutritional and organoleptic attributes that consumer’s desire. Ramaswamy and Grabowski (1998) showed a significant reduction in processing time for salmon packaged in semi-rigid plastic containers compared to product packaged in a metal can. Additionally, other research found shorter processing times which resulted in less browning of products such as pumpkin puree when processed in retort pouches versus cans (Snyder and Henderson, 1989).

By viewing packaging geometry as an impactful element in thermal processing, product developers would gain another tool to deliver consumer expectations of shelf stable food. This expanded approach to retort processing could give manufacturers an advantage in product cost, quality, and consistency.

Existing literature is unclear with regard to the effect of packaging geometry on overall processing time and heat penetration in packages of like construction and identical internal volumes. The goal of this study was to understand what impact geometry plays in overall processing by studying semi-rigid plastic trays of the same construction, same internal volume, but different geometries. Oval, triangle, rectangle, and round trays were produced via flatbed thermoforming and used for the evaluation. A water immersion rotary retort process was employed at two rotational speeds (6RPM and 11RPM) to study the influence of rotation on heating rates.

2. Materials and Methods

Trays used for this experiment were constructed of polypropylene (PP) / ethylene vinyl alcohol (EVOH) / polypropylene (PP) while the heat sealable lid-stock used to seal the tray consisted of cast polypropylene (CPP) / adhesive / Nylon / adhesive / EVOH / polyethylene terephthalate (PET). Four different shapes (Figure 1) were used in this experiment, including, rectangle, oval, round, and triangle (Sonoco Products Company, Hartsville, SC).

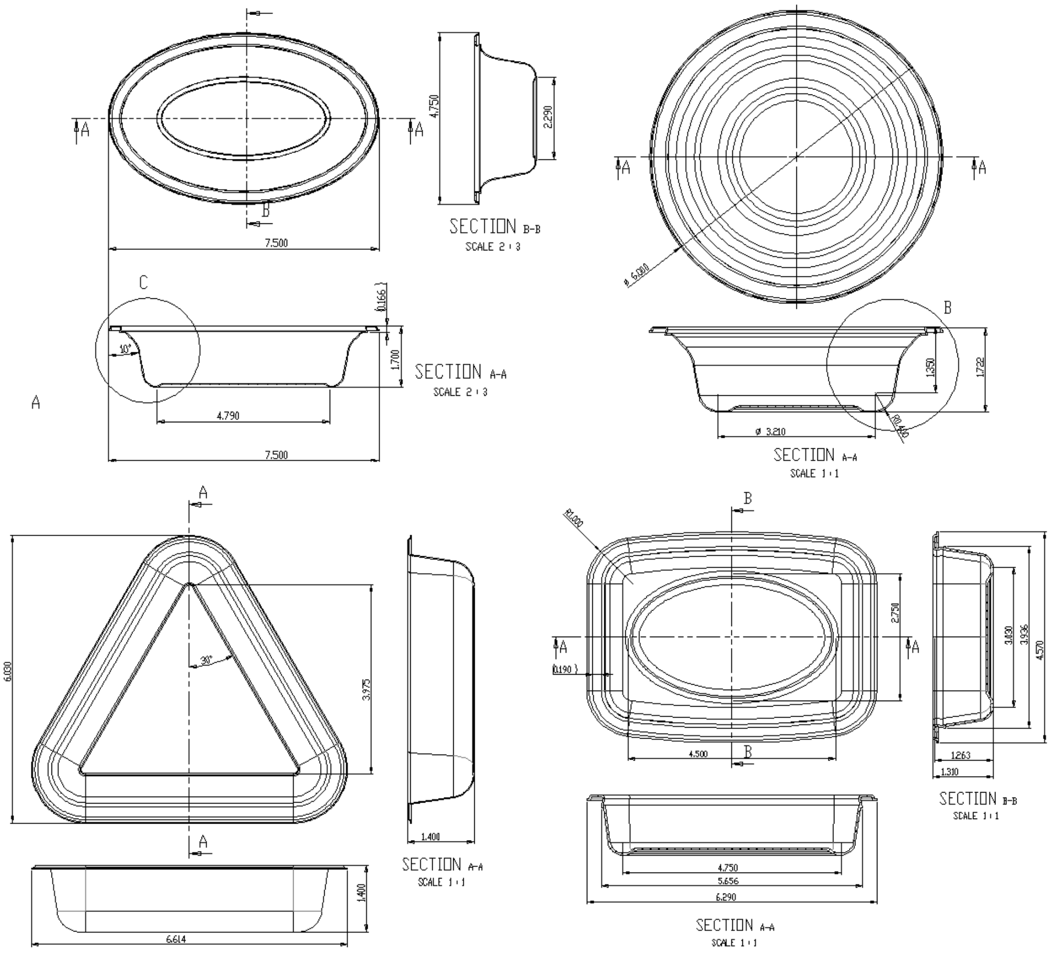

***Figure 1**: Retort tray shapes evaluated*

A model food system was designed to allow for easier quantification of the heat exposure impacts. This model system consisted of tomato paste (36 brix, ConAgra Foods, Omaha, NE), soybean oil (ConAgra Foods, Omaha, NE), water, ascorbic acid (Graham Chemical Corp., Barrington IL), and Panodan® 150 emulsifier (Danisco, Madison, WI) per Table 1. The model system was prepared in a steam-jacketed kettle with minimal heat applied during blending (not greater than 90°F). Manual mixing with a whisk and a direct drive pressure batch mixer (SPX, Rochester, New York) was used for thorough mixing of all components.

Table 1: *Food model system formula*

Ingredient	% of Total
Water	49.1%
Tomato Paste, 36 Brix	32.7%
Oil, Soybean	16.3%
Ascorbic Acid	1.0%
Emulsifier, Panodan 150	0.8%
Total	100.0%

Trays of each geometry were filled with approximately 12 net ounces of model system and sealed via a platen heat sealer (Pack Line PLB-15, New York, NY) with the appropriate seal platen and carrier system for each geometry. Once sealed, the lid-stock on each tray was manually trimmed and all units were stored at refrigerated temperatures for 12 hours prior to processing. Additionally, three (3) trays of each geometry were prepared with a needle style thermocouple (CNS, Ecklund Harrison, Fort Myers, FL) located through the sidewall of each tray with the end of the thermocouple located in the geometric center of the model food product. These trays were also filled with 12 ounces net weight of product prior to heat sealing and storage. After the rest period, trays were loaded into the appropriate retort racks based on the layout described in Figure 2. Thermocouples were then attached via 22-gauge type T copper-constantan wires (Ecklund Harrison, Fort Myers, FL) to a rotary CALplex™ data logger (TechniCAL, Metairie, LA). Two free leads were used, one placed next to the mercury in glass (MIG) temperature gauge probe and the other in the center of the process basket. Data was recorded from each thermocouple in 15-second intervals. Trays filled with water were used as ballast in each run to reduce the amount of food model system and trays needed for each run as indicated in Figure 2.

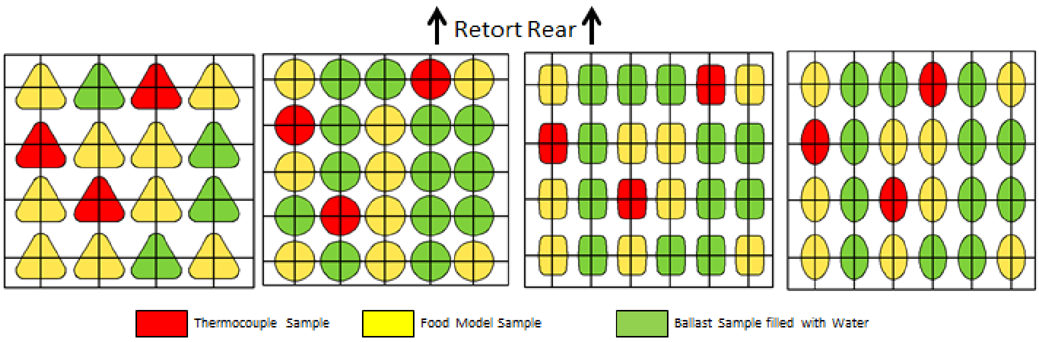

Figure 2: *Retort rack layout with sample type*

With four different tray geometries and corresponding racks, a total combination of six different rack to rack configurations were evaluated to determine if rack position inside the retort would have any effect on heating profiles. Figure 3 details the configurations used for each processing run.

		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Top	1	Rectangle	Round	Oval	Triangle	Rectangle	Oval
	2	Triangle	Rectangle	Round	Oval	Oval	Rectangle
	3	Oval	Triangle	Rectangle	Round	Triangle	Round
Bottom	4	Round	Oval	Triangle	Rectangle	Round	Triangle

Figure 3: *Rack location matrix for heat penetration runs*

An Allpax 5202 multimode pilot retort (Allpax, Covington, LA) was used in water immersion mode for each processing run with a maximum over pressure of 30 pounds per inch gauge (psig) used during processing to prevent tray deformation and protect seal integrity. Each rack position, as described in Figure 3, was processed at both 6 revolutions per minute (RPM) and 11 RPM. This retort vessel had come-up time (CUT) of 12 minutes and the slowest in-package heating zone was quantified with CALsoft™ modeling software (TechniCAL, Metairie, LA) at a processing temperature of 220°F. Once all runs were completed, CALsoft™ was used to establish average processing times given the slowest heating zones for each container.

Analysis of variance (ANOVA) was used to interpret the impact of rack position in the retort relative to racks containing other shapes for both 6 RPM and 11 RPM runs. All analyses were conducted with SAS® (SAS Institute, Cary, NC) software, using a significance level of 0.05 for hypothesis testing.

Additionally, the heat penetration data collected was used to model additional process conditions via CALsoft™, as described in Table 2. These model conditions used an initial temperature (IT) of 75°F and varied with different retort temperatures (RT) of 220°F and 215°F respectively as well as lethality (F value) values of one (1) and ten (10). Once average time to process temperature for each variable was determined via the process modeling functionality of CALsoft™, ANOVA was used to interpret the impact of changing lethality and RT. All analyses were conducted with SAS® (SAS Institute, Cary, NC) software, using a significance level of 0.05 for hypothesis testing.

Table 2: *CALsoft™ modeling inputs for average time to process temperature*

CALsoft Input Variables for Modeling		
Retort Temperature (RT)	Lethality (F value)	Initial Temperature (IT)
220°F	1	75° F
220°F	10	75° F
215°F	1	75° F
215°F	10	75° F

3. Results and Discussion

3.1. Retort Rack Location

The analysis showed there was no significant difference (P>0.05) among rack locations for any of the tray shapes (round, oval, triangle, rectangle) with regards to time to maximum temperature (Table 3 and Figure 4).

Table 3: *Average time to maximum temperature by retort rack location for each tray shape*

Shape	Rack Positon	Average time to maximum temperature (seconds)	Standard Deviation
Oval	Rack 1	1856.25	405.33
Oval	Rack 2	1464.55	228.30
Oval	Rack 3	1494.00	73.94
Oval	Rack 4	1590.00	317.49
Rectangle	Rack 1	1278.75	286.98
Rectangle	Rack 2	1425.00	604.34
Rectangle	Rack 3	1735.00	415.11
Rectangle	Rack 4	1440.00	161.55
Round	Rack 1	1685.00	601.77
Round	Rack 2	1787.50	200.22
Round	Rack 3	1482.00	168.20
Round	Rack 4	1376.25	180.81
Triangle	Rack 1	1592.50	193.36
Triangle	Rack 2	1530.00	156.17
Triangle	Rack 3	1523.18	332.94
Triangle	Rack 4	1746.25	295.08

	F Value	P>F
Rack Location	0.31	0.8209

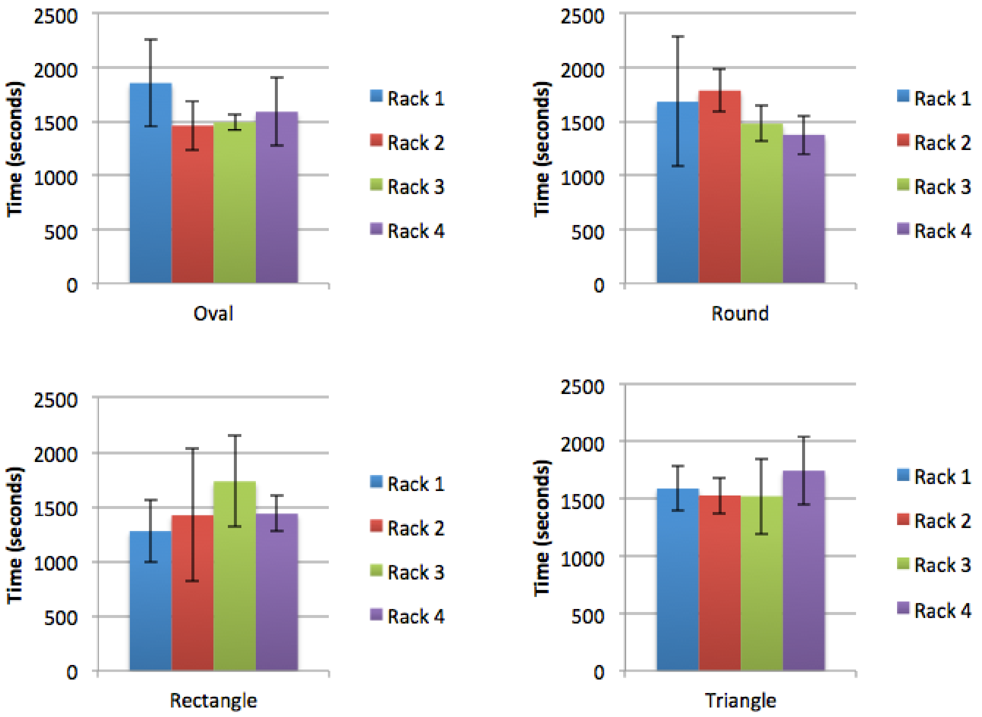

Figure 4: *Retort Rack Location – Average time to maximum temperature*

However, the analysis did show a difference (P<0.05) in average time to maximum temperature regarding the rotation speed of the retort basket used. There was longer time to maximum temperature (P<0.05) at 6 RPM versus 11 RPM across all tray geometries as seen in Figure 5.

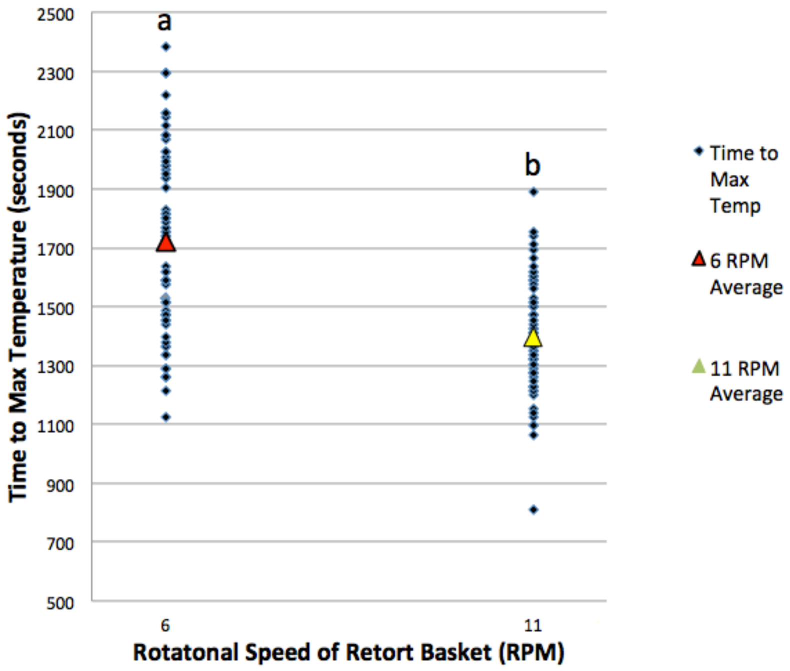

Figure 5: *Average time to maximum temperature versus rotational speed; letters denote statistical difference*

The impact of container position in the processing vessel on heat penetration was a foundational goal of this study. The use of rotation in a water immersion process intuitively leads to a conclusion of minimal localized heating due to the constant container movement within the vessel and maximum contact with the heating medium. Anecdotal information regarding temperature distribution tests using this process vessel supported this direction; however, basic data regarding this racking system did not exist. Without knowledge that location in this particular processing unit was not significant, subsequent data could be correlated by location. Since the data collected indicated there was no significance ($P>0.05$) in retort rack or thereby semi-rigid tray location inside the processing vessel (see Figure 2 & 3), further experimentation became possible using this loading methodology. Previous research around rotational effects on the slowest heating zone of a retort vessel supports these findings. Smout et al. (1998) studied effects of rotation on the slowest heating zone of retort in water cascading mode, finding that rotation caused the slowest heating zone to occur in the center of the retort basket, where as in static mode the slowest heating zone was located near the base of the basket. The authors concluded this was likely caused by the location of heating medium introduction from the top of the process vessel down, which is inherent to the water cascade design (Williams, 2012).

Furthermore, data collected showed there was no significance in rack position at either rotational speed. There was, however, a difference ($P<0.05$) for average time to maximum temperature for 6 RPM versus 11 RPM, with the higher rotational speed resulting in a shorter average time (Figure 5). This effect was observed in other published research where an increase in speed of rotation led to an overall reduction in total process time for a product that had broken heating characteristics (Bindu and Srinivasa Gopal, 2008; Ansar Ali et al., 2008). Additionally, Rattan and Ramaswamy (2014) also found a significant relationship between lethality level, rotational speed, color, and texture differences.

3.2. Average Time to Lethality by Process at 6 RPM

The average time to lethality at 6 RPM was found to be higher ($P<0.05$) for the process using a RT of 215°F and a lethality value (F) of 10 versus any of the other processes tested (Figure 6). For the process with a RT of 220°F, F=10, the average time to lethality was higher ($P<0.05$) than the RT of 215°F, F=1 process or the RT of 220°F, F=1 process. The average time to lethality for RT of 215°F, F=1 process and RT of 220°F, F=1 process were not different ($P>0.05$).

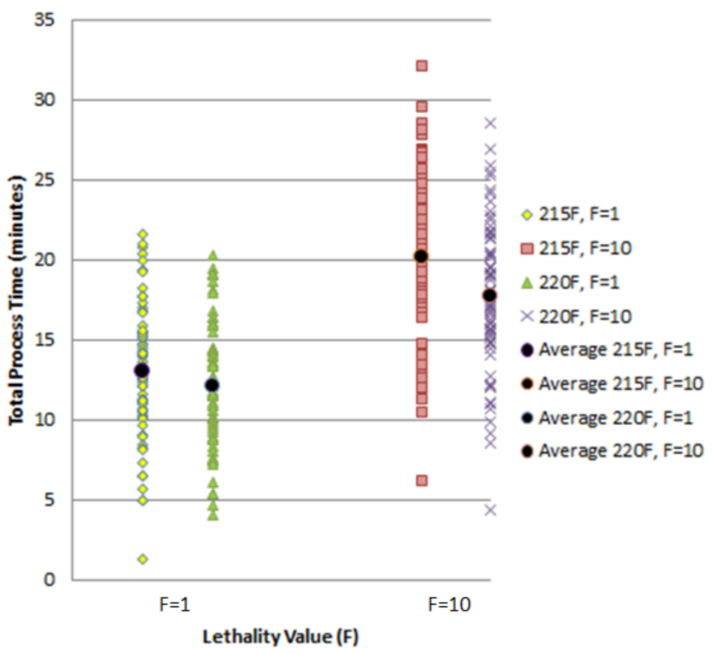

Figure 6: *Average time to lethality by process condition at 6 RPM with standard deviation*

3.3. Average Time to Lethality by Process at 11 RPM

The average time to lethality at 11 RPM was found to be higher ($P<0.05$) for the process using a RT of 215°F and a lethality value (F) of 10 versus any of the other processes tested (Figure 7). For the RT of 220°F, F=10 process, the average time to lethality was higher ($P<0.05$) than the RT of 215°F, F=1 process or the RT of 220°F, F=1 process. The average time to lethality for the RT of 215°F, F=1 process and the RT of 220°F, F=1 process was not different ($P>0.05$).

The average process time to lethality was found to be dependent on both retort temperature and the lethality value desired at both rotational speeds tested. A retort temperature (RT) of 215°F at a lethality value (F) of 10 was shown to have a longer ($P<0.05$) average time to lethality than any of the other processes analyzed (see Table 2). Since the average of the Ball process time was used, an understanding of how the Ball process time is calculated in CALsoft™ is needed to fully understand the logical effects of RT and lethality needs on the total process time.

$$B_b = f_h[\log(j_{ch}(T_{RT} - T_{IT})) - \log g] \qquad (1)$$

The Ball formula method, as defined in Equation 1, determines the total process time (B_b) by using factors such as the heating lag factor (j_{ch}) and the heating rate index (f_h), as well as the retort temperature (T_{RT}), the initial product temperature (T_{IT}) and the number of degrees the slowest heating point in the container is below the retort temperature at the end of the heating process (Awuah et al., 2006; Awuah et al., 2007). As Equation 1 shows, a change in retort temperature has a direct impact on processing time. Heating factors also play a critical role in determining the Ball process time, however, each rotational speed was compared independently. This analysis showed the longest average processing time was achieved by the same process conditions (RT215°F, F=10) at both rotational speeds.

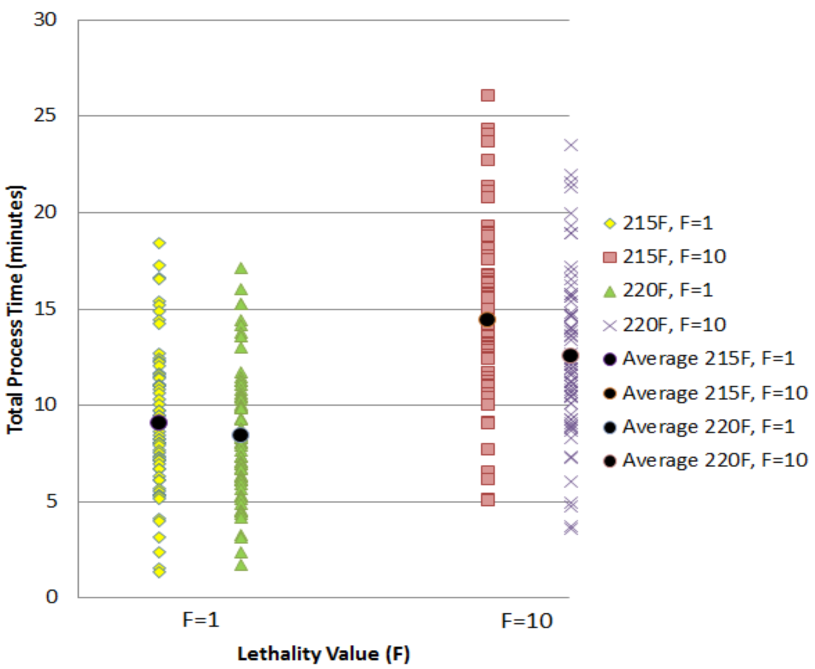

Figure 7: *Average time to lethality by process condition at 11 RPM with standard deviation*

3.4. Heat Penetration by Shape at 6 RPM

Since the RT of 215°F, F=10 process was shown to be significantly longer than the other processes evaluated, the heat penetration data was further evaluated by shape at these process conditions (heating factors for this process are shown in Table 4). At 6 RPM, the average time to lethality was higher ($P<0.05$) for the triangle shaped tray than for the rectangle and round shaped tray (Figure 8). The average time to lethality for the oval tray was not different ($P>0.05$) than any other shape tray.

Table 4: *Heating factors for trays at 6 RPM, for RT215°F, F=10 process*

Shape	Average heating rate index (f_h)	Average Lag Factor (J_{hc})
Triangle	23.81	0.94
Oval	22.48	0.79
Rectangle	20.69	0.66
Round	18.38	0.99

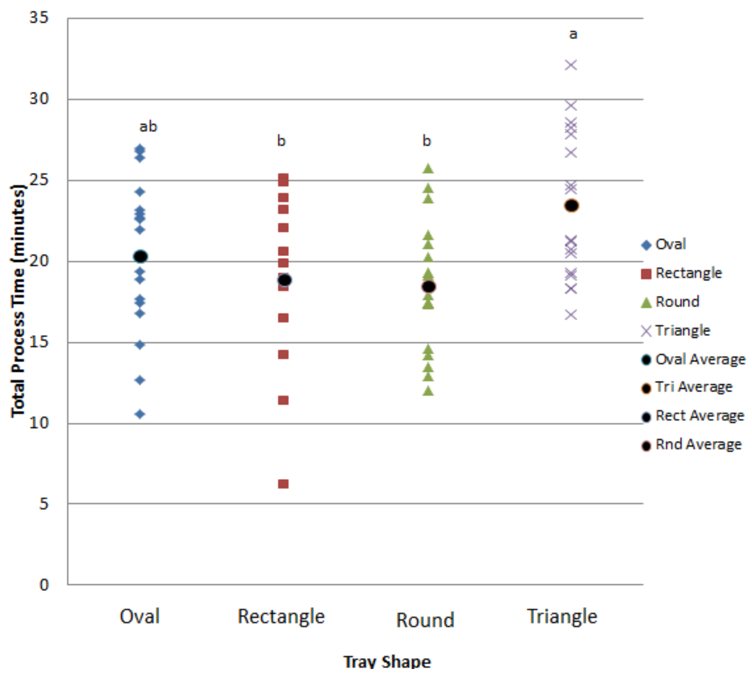

Figure 8: *Average time to lethality by tray shape at 6 RPM for RT215°F, F=10 process. Letters denote statistical difference*

3.5. Heat Penetration by Shape at 11 RPM

Using the process with a RT of 215°F and F value of 10, heat penetration data was evaluated by shape for 11 RPM runs (heating factors for this process are shown in Table 5). There was not a difference ($P>0.05$) in the average time to lethality among tray shapes for this process at 11RPM (Figure 9).

Table 5*: Heating factors for trays at 11 RPM, for RT215°F, F=10 process*

Shape	Average heating rate index (f_h)	Average Lag Factor (J_{hc})
Oval	15.92	0.79
Triangle	13.53	0.95
Round	14.38	0.76
Rectangle	13.64	0.60

At the 6 RPM rotational speed, the triangular shaped trays were found to heat more slowly than either the rectangular or round shaped trays. Initially, it was thought that a correlation between total surface area differences of each shape could explain the difference in heating rates. However, when the surface areas were calculated there was no dramatic difference between shapes (triangle = 90.25in^2, round = 91.66in^2, rectangle = 92.93in^2, & oval = 94.85in^2; includes surface area of lidstock). The data generated at 11 RPM provides further insight into the heat penetration mechanism. At 11 RPM, there was no difference ($P>0.05$) in the average time to lethality for each tray shape, indicating the increase in rotational speed nullified any heating impact of geometry. This data suggests that geometry does play a part in heating, to a critical level of movement (rotation). More aggressive agitation provided at a higher rotational speed could reduce temperature gradients faster. Therefore, at a lower rotation speed the geometry effect becomes more of a factor impacting heating than at higher rotational / agitation levels. Table 4 and Table 5 show the heating lag factors for each tray at both rotational speeds.

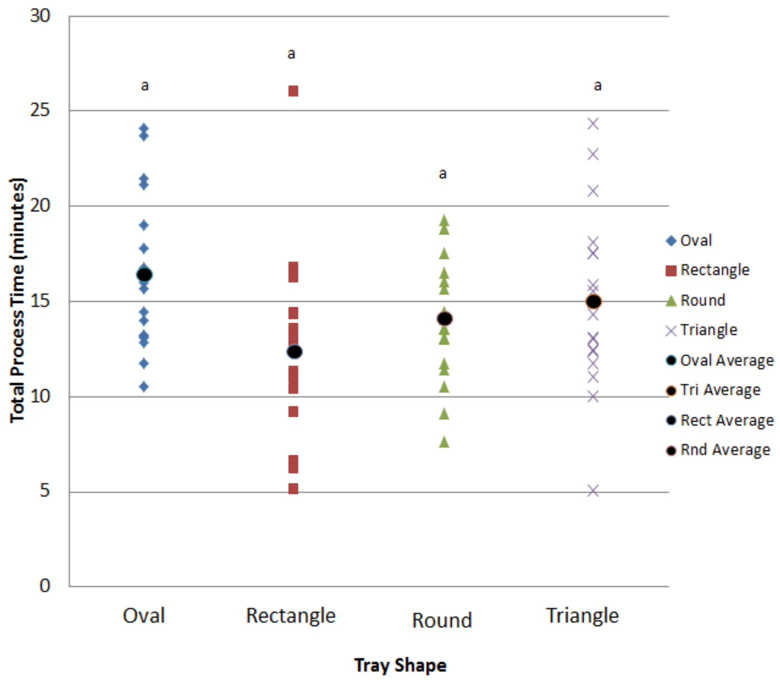

Figure 9: *Average time to lethality by tray shape at 11 RPM for RT215°F, F=10 process. Letters denote a statistical difference*

The impact of geometry change is demonstrated in the case of 6 RPM and the effect of increased agitation seen from rotational speed increases as 6 RPM values are compared to 11 RPM values for the same food system and same tray geometries. The geometry benefit seen at 6 RPM is negatively impacted as rotational speed is increased with a tip over point somewhere between 6 and 11 RPM. Ramaswamy and Dwivedi (2011) showed that rotation speed has a significant impact on the overall heat transfer coefficient in a retort environment, further confirming these results.

4. Conclusions

The impact of geometry on heat penetration was studied with the use of differently shaped semi-rigid trays of PP/EVOH/PP construction and similar internal volumes. A model food system or simulant, consisting of water, tomato paste, oil, ascorbic acid, and an emulsifier was used to fill the packages, which were subsequently sealed with a heat sealable lid stock. A thermal process was applied using a water immersion heating mode at two rotational speeds (6 and 11 RPM) in a pilot sized retort vessel. Trays were held in place during retorting with the use of racks which fit inside the retort basket of the processing unit and were designed specifically for each shape.

Previous research had indicated differences in product processed in different packages, such as metal cans versus flexible retort pouches or semi-rigid trays, but there was a lack of information available regarding the effects of geometry change as an independent variable only, excluding packaging construction and internal volumetrics as variables of possible influence to the study.

Results from this study showed there was no significant difference in average time to maximum temperature related to shape or rack location in the retort basket during processing ($P>0.05$) (Table 4). There was a significant difference in the average process time at 6 and 11 RPM, with 11 RPM resulting in significantly faster heating times ($P<0.05$). A retort temperature of 215°F and a lethality value of 10 showed the highest average sterilization time (P<0.05). At a rotational speed of 6 RPM, the average time to lethally was higher (P<0.05) for the triangle tray than the rectangle and round tray, which was likely due to uneven heating gradients within the triangle shape. The average time to lethality for the oval tray was not different (P>0.05) than any other tray shape. At 11 RPM differences it average time to lethality between tray shapes was insignificant (P>0.05).

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