12-2009

EFFECT OF OSCILLATING AND STATIC RETORT THERMAL PROCESSING TECHNOLOGY USING AN INSTITUTIONAL SIZE POUCH

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Recommended Citation

Trevino, Judith, "EFFECT OF OSCILLATING AND STATIC RETORT THERMAL PROCESSING TECHNOLOGY USING AN INSTITUTIONAL SIZE POUCH" (2009). *All Theses*. 696.
https://tigerprints.clemson.edu/all_theses/696

EFFECT OF OSCILLATING AND STATIC RETORT THERMAL PROCESSING TECHNOLOGY USING AN INSTITUTIONAL SIZE POUCH

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Food, Nutrition and Culinary Sciences

By
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December 2009

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ABSTRACT

The effects of oscillating and static retort thermal processing on heat penetration using an institutional size pouch were evaluated. A literature review of general information on retort thermal processing, process modes, processing mediums, retort pouches and starch was presented.

Frigex-W starch (National Starch Food Innovation) and water mixtures were prepared at three different concentrations (1%, 3% and 5%). Five replications of starch and water mixtures were processed using water spray as the processing medium in institutional size retort pouches (29.2 cm. x 38.1 cm.) using both oscillating and static processing modes.

Viscosity (by Brookfield viscometer and Bostwick consistometer), residual air (destructive technique), color (by Minolta L*a*b* colorimeter), processing time (slope of heat penetration curve) and process time to achieve 5 log reduction of *Clostridium botulinum* were determined for each starch and water mixture concentration level.

The mean slope values of the two processing modes (oscillating and static) were not different ($p>0.05$) for the 1% and 5% concentrations. The mean slope values of the processing modes (oscillating and static) were different ($p<0.05$) for the 3% concentration.

The results of this research were significant to the food industry because the oscillating technology may not be beneficial to companies processing low viscosity (1%) and/or high viscosity (5%) products since there was no difference between the two (oscillating and static) modes when evaluating processing time. Companies processing medium viscosity (3%) could benefit from investing in the oscillating technology because of the decreased processing time. The decreased processing time could result in increased production yields and retention of important nutrients.

However, companies processing low viscosity (1%) and/or high viscosity (5%) products may still benefit from investing in oscillating technology because of other benefits. Other potential benefits (for example: retention of important nutrients) need to be investigated to determine the effectiveness of the oscillating technology.

DEDICATION

I dedicate this thesis to my father, mother and two sisters.

ACKNOWLEDGMENTS

I would like to thank all of my committee members for their guidance and support: Dr. McGregor, Dr. Dawson, Dr. Rieck and Dr. Whiteside. I would like to thank Dr. McGregor for being a wonderful and inspiring mentor throughout my years at Clemson University. Working with Dr. Dawson on Creative Inquiry gave me the confidence to know that I could successfully complete a Masters degree. Dr. Rieck was an enormous help in designing this project and I thank him very much for that. I would like to thank Dr. Whiteside for teaching me so much about packaging science and thermal processing.

I would like to give a special thanks to all the students, staff and faculty in the Food Science & Human Nutrition Department especially Mrs. Collins and Dr. Han.

I would like to thank a number of people from the Packaging Science department including Rijosh Cheruvathur, Steffen Rau, Jerry Stoner and Jason Szymanski for their help loading and unloading the retort. I would like to thank Dr. Youngjae Byun from the Packaging Science department for his tremendous support and help throughout my research project. I would also like to thank Christopher “Shane” Hutchings from the Packaging Science department for all his help and work in the retort lab.

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Introduction

Thermally processed foods are a $134 billion industry in the United States each year (All Business, 2009). The canned vegetable market alone is 5 billion units. Other big categories in thermally processed foods are the 4 billion unit canned soup market and the 1.5 billion unit baby food market (Keith, 2001). There are many new technologies and packages revolving around the retort food industry. The new oscillating retort technology is similar to the rotary process in that it agitates the food product to help increase core heating rates; however, the oscillating technology could be used for retort pouches because the gentle rocking motion used will not damage the pouch (Collins, 2009). Retort pouches are increasing popularity in the United States. In 2005, Stan Sacharow (executive director of the Packaging Group Inc. in Princeton, NJ) reported that pouch sales in the U.S. were growing at a rate of 13-15% each year (Gazdziak, et. al. 2005).

There are a number of assumptions associated with oscillating technology. It is thought that, like rotary technology, the oscillating technology could result in shorter process times. A shorter process time could result in better flavor, better color and vitamin retention and could also lower energy costs and increase through put. Agitation from the oscillating technology could allow for higher temperatures to be used during the process which could reduce the process time even further (Parchomchuk, 1977). There is very little published work on the oscillating process and there are a number of questions to be answered before a company is to invest in the new technology. Is the technology going to result in faster process times? Is the quality of the product going to be the same; better? Is the nutritional content of the food product going to be the same; better? Is the new technology worth the capital investment of the new equipment? Which rocking movement (side to side or front to back) is more effective? Is the oscillating technology effective for all viscosity levels and food products? If not, which types should utilize the oscillating technology and which ones should not?

Retort Thermal Processing

Definition of Retort Thermal Processing

By definition, retort thermal processing is the procedure used to heat sealed cans or other retortable containers (example: retort pouch) in a chamber with steam valves that allow for precise temperature control in order to destroy bacteria and spores. The injection of steam under pressure allows the temperature to exceed the boiling point of water inside each can or pouch within the chamber (Murano, 2003). The introduction of a study performed by Shin et. al. in 1991 describes the objective of thermal processing of canned foods. The main goal of thermal processing is to produce a commercially sterile product (Shin et. al. 1991). Commercially sterile is the destruction of all viable microorganisms of public health significance and of those capable of reproducing under normal non-refrigerated conditions during storage and distribution (Galvin, et. Al., 1995). The target of thermal processing is to destroy *Clostridium botulinum* because it is the most heat resistant of the pathogenic bacteria. Sensory (color, texture and flavor) and nutritional aspects of the food must be considered and paid close attention to when evaluating thermal processing. The thermal process has to be optimal to prevent overcooking of the product (Shin et. al. 1991). Overcooking a product could result in loss of flavor intensity, an undesirable texture or loss of vitamin content.

The function of the retort process is to make microorganisms and spores inactive; however, this heat treatment may also cause the destruction of essential nutrients (i.e. lower quality). Maximizing quality retention in retorted products, while at the same time reaching the desired microbial reduction, is of high interest (Ali, et. al. 2006).

General Terms Related to Retort Thermal Processing

There are several important terms related to retort thermal processing. The decimal reduction time (D value) is the time required to kill 90% (or 1 log cycle) of organisms in the bacterial population. The Z value is the thermal resistance constant and it is the increase in temperature required to reduce the decimal reduction time (D value) by 90% or by one log cycle (Murano, 2003).

The microorganisms of concern for canned foods are anaerobic bacteria because they grow in the absence of oxygen (Galvin, et. Al., 1995). *Clostridium botulinum* is the most dangerous heat-resistant pathogen that is likely to be present in low acid foods (Abdul, et. al., 2006). Low acid foods are any foods (other than alcoholic beverages) with a finished equilibrium pH greater than 4.6 and a water activity greater than 0.85 (Galvin, et. Al., 1995). *Clostridium botulinum* produces a deadly toxin and can grow in anaerobic conditions inside a sealed container. The destruction of *C. botulinum* is a minimum requirement in the sterilization of foods. Other more heat resistant spoilage bacteria may be present in the food and therefore food products usually receive more than the minimum treatment (Abdul, et. al., 2006). The microorganism used to determine effectiveness of a heat processing time-temperature combination is the nonpathogenic bacterium, *Bacillus stearothermophilus. Bacillus stearothermophilus* is more heat resistant than the spores of *C. botulinum* (Murano, 2003).

The 12D Concept is the processing for a time-temperature combination that will result in a twelve log cycle reduction. A twelve log cycle reduction is required to establish a safety margin for thermally processed foods. The food product is considered "commercially sterile" when the probability of 1 spore of *Clostridium botulinum* surviving is 1 out of 10^{12} cans when the 12D treatment is applied. Commercially sterile means all pathogenic and toxin-producing organisms as well as spoilage organisms have been destroyed. Commercially sterile products contain a small number of heat-resistant bacterial spores, but these will not multiply under usual storage conditions within the food. If isolated from the food and given the correct (favorable) conditions, they may become viable (Murano, 2003).

Thermal death time (TDT) is a combination of heating time and temperature that kills various concentrations of spores. TDT is the time required to reduce a microbial population by a stated amount and it is also known as the time required to assure that there are no survivors. A TDT graph (on semilog paper) plots heating time in minutes on the y-axis and temperature (F or C) on the x-axis. The Fo value is the time required to reduce the microbial population by some stated amount with a temperature of 121°C and with a Z value of 10°C (Murano, 2003).

Heat Penetration Tests

Heat penetration tests are used to determine the heating (and cooling) rates of a specific food product in a given container under particular conditions (National Food Processors Association, 1985). They are performed to determine processing parameters for thermal processing. Thermocouples are inserted into the container at a defined length to reach the cold spot (point) within the container/package. The cold spot is the last spot in a can or other container to heat up. The cold spot is usually slightly below the center of the can or pouch for food products demonstrating convection heating and at the center of the container for conduction heated food products heating. The cold spot determines if heat has penetrated a container of food to heat up all the food particles to the correct temperature. The time it takes the cold point to heat up and reach the required temperature determines the overall processing parameters for a specific food product. Temperature and time readings are recorded at specific intervals for each container in the retort using a computer recording system. The intervals could be as short as 15 seconds. The data is analyzed using thermal processing software (Murano, 2003).

Retort Thermal Processing Procedure

The container (can or pouch) is filled with a specific quantity of the food product. A specific headspace (sometimes called residual air in pouches) is maintained in order to create a "stirring effect." The stirring effect is created by the amount of air in the container/package and the agitation of the container/package within the retort. The stirring effect is compared to using a spoon to stir a food product on a stovetop to help it heat up faster.

The can is hermetically sealed (airtight) with a lid (can seaming) and the pouches are heat sealed using seal jaws. The containers are placed in the chamber on stackable pallets or into specific size holes in the case of some rotary processes. The retort is set to reach a certain temperature and pressure for a specific amount of time. Steam and/or water are injected in to the retort. The come up time is the amount of time it takes the chamber to heat up to the cooking temperature. The cook time is the amount of time the product is cooked to render it commercially sterile. The cool time is the amount of time it takes the food product to cool down to ambient temperature (Murano, 2003).

Retort Thermal Processing Modes

There are three retort thermal processing modes: static, rotary and oscillating. During static retort processing, the product remains still inside the retort chamber. In rotary retort processing, the product rotates in a circle at different speeds to heat up the product faster. The oscillating process is a newer processing mode that moves the product from side to side or front to back in order to heat the product up faster. It is well known that the rotary process has more advantages than the static process (Hudson, 2009).

Advantages of Rotary Process versus Static Process

As the containers rotate inside a retort, the contents of the containers are agitated and this eliminates cold spots. The agitation also reduces processing time because the contents of the container are heated up faster and more evenly (Ali, et. al. 2006).

In a research study by Ali et. al. (2007), the total process time at a given temperature and Fo value decreased with increasing rotation. A rotational speed of 6 r.p.m (revolutions per minute) caused a reduction of as much as 6 minutes compared to stationary retort processes (Ali et. al., 2007).

A study by Tucker et. al. (2006) described rotary processing. The movement of the headspace bubble or residual air in a packaged food provides agitation which helps in maximum heat transfer. There are two types of rotations used for thermal processing, end-over-end (EOE) and axial rotation. EOE involves the containers being loaded vertically and a crate rotating around a central horizontal axis. During axial rotation cans are rotated individually in the horizontal plane (Tucker et. al, 2006).

One of the first studies involving rotary processing was performed by Clifcorn et al. in 1950. This study investigated agitating cans during both methods of rotation (EOE and axial). High rotation speeds and high temperatures provided an improvement in overall product quality, especially for viscous and heat sensitive products. Many studies have shown that mixing the product by agitating the headspace bubble can accelerate the heat transfer within a product (Tucker et. al, 2006).

An article by Collins (2009) examined which retort process was best for specific container types. Gentle motion processing was discussed in the article. The cylindrical containers were placed in baskets or in the case of pouches and trays, placed in racks that were stacked to form a basket. A reciprocating forward and backward motion was applied. This processing induced convection in the product. Gentle motion processing works at 0-60 “strokes” per minutes. A stroke is one complete forward and return movement of the retort load. Gentle motion processing usually is used with saturated steam, steam/water spray or water cascade process modes. Retort pouches and low-profile trays are best for gentle motion processing because this process mode is less abusive to the containers and the low-profile geometry requires less vigorous agitation to force convective heating inside the containers (Collins, 2009).

Retort Sterilization Processes

There are four types of retort sterilization processes:

- Saturated steam
- Water immersion
- Water spray
- Steam-air

Overpressure Sterilization

An article by Hudson (2009) described overpressure sterilization. Pouches and most retortable plastic containers require overpressure sterilization processes. Overpressure sterilization means that air is introduced into the retort during sterilization. The overpressure adds pressure around the outside of the containers to prevent container deformation. The pouches have thin walls and when they begin to heat and mix with the gases inside the container, the internal container pressure increases at an increasing rate. If the external pressure is not great enough, the container will deform or rupture (Hudson, 2009).

Saturated steam

Some advantages of the saturated steam process include low capital investment, easy to operate manually and they can process most canned products. Some disadvantages are; uses a lot of energy (steam) in the venting step, can usually only process “heavy sidewall containers” like cans and it can’t process fragile containers (pouches, plastic bottles, plastic jars, etc.). Saturating the retort with steam is a requirement because air is considered an insulator. There is no overpressure during this process (since air is not allowed to enter the vessel at any time). However, there is sometimes air-overpressure used during the cooling steps to prevent container deformation (Hudson, 2009).

The process steps for saturated steam sterilization retorts are as follows: come up vent open, come up vent closed, cook, pressure cool fill, pressure cool, atmospheric cool and drain (Hudson, 2009).

The purpose of the come up vent open is to saturate the retort with steam and to remove all air that was inside the retort chamber. The vent valve must be open for the entire vent step. At the end of the step, the temperature of the retort must be at or above the vent temperature (Hudson, 2009).

During the come up vent closed step, the temperature is controlled and brought up to cook temperature. At the end of the come up vent closed step, the temperature must be at or above the scheduled cook temperature (Hudson, 2009).

The purpose of the cook step is to maintain the process temperature for the time required by the process. The temperature and time defined in the process must be met during this step. The following recordings are required during the cook step: MIG (mercury in glass) reading, chart reading and bleeder valve check (Hudson, 2009).

The pressure cool fill step begins the cooling process. During this step, cooling water enters the retort at the same time that overriding pressure control is started. The pressure cool fill step ends when the water level reaches a certain level (defined in the recipe or formula) (Hudson, 2009).

The pressure cool step continues the cooling process and cooling water continues to flow in the retort and then it flows out through the drain valve (controlling the level). Pressure is also maintained during the pressure cool step (Hudson, 2009).

During the atmospheric cool step cooling continues and pressure is released. The last step is the drain step and it is where water is drained from the retort (Hudson, 2009).

Water Immersion

Water immersion uses an overpressure process. The product is isolated from any cooling air (because it is immersed in water) but air can be introduced into the vessel during the process. The overpressure is created by introducing air or steam on top of the water. Sometimes the air is added to the steam which in turn heats up the air. Because this process is an overpressure process, it can handle most fragile containers. Water immersion retorts sometimes have two vessels. The upper vessel is a "hot water reservoir that is preheated for the next process and is used to capture the sterile water from the previous process." The lower vessel (process vessel) is where the product is placed (Hudson, 2009).

Some advantages of this system are it can use carbon steel vessels, can handle most container types, good for rotary (buoyancy of the load), partial immersion process for rotary, very good for rotary with r.p.m of 10 and above and energy savings because the storage tank allows the water to be captured after the process.

Some disadvantages of water immersion include high capital investment (with double tank system), nearly impossible to operate manually and more maintenance time and increased cost (with retorts with rotary processes) (Hudson, 2009).

The process steps for water immersion retorts are as follows: prepare tank, come up fill, come up, cook, pressure cool, pressure cool fill, atmospheric cool and drain (Hudson, 2009).

The purpose of the prepare tank step is to heat (superheat) the water in the storage vessel (the hot water reservoir). The temperature, pressure and water level are all brought to the setpoints defined in the recipe or formula. This step is not finished until the water temperature in the storage vessel is greater than the product initial temperature (which was entered into the system by the operator) (Hudson, 2009).

The come up fill step is also known as vent process vessel or sterilization 1. The purpose of this step is to drop the superheated water stored in the storage vessel onto the product in the process vessel (lower vessel). When the water drops, it forces most of the air to exit. The exiting of this step happens when the water level reaches a defined point (usually enough to cover the baskets) (Hudson, 2009).

The come up step is also known as sterilization 2. During this step, the pump remains on, rotation continues (if a rotary process) and the temperature and pressure continues to be controlled to a set point. To exit this step, time and temperature conditions must be met at the same time. At the end of this step, the retort must be at or above the cook temperature (Hudson, 2009).

The cook step is also known as sterilization 3. During this step, the retort must be at or above cook temperature and at or above the water level for the entire step. If a rotary process, the flow must be within acceptable range for the entire step and at acceptable r.p.m. The operator must make the following checks and entries: MIG reading, chart reading and sigh glass level check (Hudson, 2009).

The pressure cool fill step begins the cooling process. During this step, the storage tank is filled. Cooling water enters the process vessel while the warmer water is forced out into the storage tank. When the storage tank is filled to the "recapture level", the step ends (Hudson, 2009).

During the pressure cool step cooling water enters the process vessel and flows through the pressure relief valve and then leaves the retort. The step ends when the pressure cool time is completed and an established temperature set point in the process vessel is reached (Hudson, 2009).

The atmospheric cool step continues the cooling process. When the time is completed and an established temperature set point is reached the step ends (Hudson, 2009).

During the drain step, water is drained from the retort and the process is complete (Hudson, 2009).

Water Spray

Water spray is an overpressure process. The overpressure is provided by introducing air or steam into the retort. Water spray sterilization can handle most containers. Some advantages of this system include lower capital investment, energy efficient (water can be reused without chemical treatment for the next process), it allows for energy savings when it has a storage tank (because of recapturing of process water), relatively simple in design, good for static and good for low r.p.m rotary processes. Some disadvantages of water spray are it is not good for high (10 or above) rotary processes, more maintenance time and money (with the rotary option), longer come up times for high r.p.m. and longer cooling times (Hudson, 2009).

The process for water spray retorts involve the following steps: prepare tank, come up fill, come up, cook, pressure cool, atmospheric cool and drain (Hudson, 2009).

The prepare tank step is optional (only if there is a preheat tank on the retort). The purpose of the prepare tank step is to heat (superheat) the water in the storage vessel. To complete the step, temperature, pressure and water level are all brought to set points defined in the recipe or formula. An internal temperature (I.T.) check of the product is also performed during this step and the water temperature has to be greater than the I.T. (Hudson, 2009).

The purpose of the come up fill step is to fill the bottom of the retort with water and preheat the water. The water at the bottom is used for recirculation through the heat exchanger. The step is completed when the desired preheat water temperature and level are reached. The preheat temperature must be greater than the I.T. For rotary process, the rotation may begin in this step (Hudson, 2009).

During the come up step, the pump is turned on and rotation starts (if not started already in previous step). At the end of the scheduled come up time, the retort must be at, or above, scheduled cook temperature (Hudson, 2009).

During the cook time, the retort must be at, or above, scheduled cook temperature, at or above, a safe water level to prevent cavitations of the pump and have acceptable r.p.m (if rotary process). During the cook step, the operator makes the following entries: MIG reading, chart reading and sight glass level check (Hudson, 2009).

The pressure cool step begins the indirect cooling process in the process vessel. The process water is run through the heat exchanger and back into the vessel. External cooling water is run on the outside of the heat exchanger to cool the water inside the process vessel. The step ends when the pressure cool time is completed and an established temperature set point is reached (Hudson, 2009).

The atmospheric cool step continues the cooling process in the process vessel. Pressure has been reduced to nearly no overpressure during atmospheric cooling. The step ends when the atmospheric cool time is completed and the established temperature set point is reached (Hudson, 2009).

During the drain step, water is drained from the retort and the process is complete (Hudson, 2009).

Steam-Air

Steam-air is an overpressure process but the product is exposed to the overpressure air. A large fan is used to mix the steam and air to prevent cold spots in the retort. Some steam-air sterilization processes have rotary options. Steam-air sterilization can handle most container types. Advantages of this process include moderate capital investment, energy efficient (fan), simple design and easy process to administer. Disadvantages of steam-air are it is not good for rotary (especially r.p.m. of 15 and above), rotary option requires more maintenance time and money and the fan adds to the complexity of the retort (Hudson, 2009).

The steps for a steam-air process include the following: come up vent open, come up vent closed, cook, pressure cool/atmospheric cool and drain (Hudson, 2009).

The come up vent open step is optional. The purpose of this step is to introduce steam into the vessel and to minimize the air that is already in the retort (Hudson, 2009).

During the come up vent closed step the vent valve is closed and the temperature is controlled and brought up to cook temperature. At the end of the come up time, the retort must be at or above the scheduled cook temperature (Hudson, 2009).

The purpose of the cook step is to maintain the recipe or formula temperature for the time required by the recipe or formula. During this step, the temperature is checked at least once. The MIG reading, chart reading and the bleeder valve check are checked and recorded during the cook step. The fan remains on during the cook step (Hudson, 2009).

During the pressure cool and atmospheric cool step, the fan is turned off and not used for the remainder of the process (Hudson, 2009).

During the drain step, water is drained from the retort and the process is complete (Hudson, 2009).

Retort Pouches

General Information on Retort Pouches

The retort pouch is a flexible three-ply laminate that is processed like a can and is shelf-stable (Lopez, 1981). Retort pouches are not a new idea. In the 1960s, the military switched from canned C-rations to Meals Ready to Eat (MRE's) using pouches. The development of the retort pouch dates back to World War II. During WWII, Dr. Rudolf Heiss was the head of the Fraunhofer-ILU, a leading food research institute based in Munich, Germany. The German high command requested a convenient package to supply the Wehrmacht with "tasty, nutritious, ready-to-eat meals." Heiss and his coworkers developed a thin-profile package with a high surface area to volume (Sacharow, 2003).

Retort pouches are very common in Asia and Europe and high-speed lines have been developed in both geographic regions. Huston Keith (principal for Keymark Associates in Marietta, GA) states that there were about 800 million to 1 billion pouches (mostly pet food) sold in the U.S. and Canada in 2005. In 2005, Stan Sacharow (executive director of the Packaging Group Inc. in Princeton, NJ) reported that pouch sales in the U.S. were growing at a rate of 13-15% each year (Gazdziak, et. al. 2005).

A number of different food products utilize retort pouches including pet food, meat, poultry, seafood, rice and soups. Many companies have recently introduced food products in retort pouches: Star-Kist, Chicken of the Sea, Bumble Bee, Tyson (white-meat chicken), Sara Lee (Sweet Sue Kitchens, chicken, ham, turkey and other products in retort pouches) and Masterfoods Inc. (Ready Rice, cooked, shelf-stable rice in pouches) (Demetrakakes, 2004).

Advantages of Retort Pouches

There are several advantages of retort pouches. Retort pouches reduce the processing time of the food product. They have a shorter cook time because of the high ratio of surface area to volume (Mykytiuk, 2002). The shorter cook time results in better taste, improved nutritional value and less moisture loss (Gazdziak, et. al. 2005).

Retort pouches improve safety for both consumers and employees. There are no sharp edges which eliminate cuts for both employees in the food plants and for consumers at home when they open the package. It is easier for the consumer to open the package as opposed to cans because pouches do not require a can opener. Some pouches even have re-closable features (Mykytiuk, 2002). Pouches also allow for easy dispensing without utensils (Gazdziak, et. al. 2005).

Pouches take up less space and weigh less which means increased utilization of warehouse/storage space. The reduced weight and space also saves money because more unfilled pouches can be delivered at once to the processing facilities as opposed to unfilled cans (Mykytiuk, 2002).

The package differentiation and larger package facing of pouches is eye-catching compared to cans. The material of the pouch allows for better graphics and pictures of the product and for more room for other items (example: recipes, company information, etc.). Some pouches are pre-labeled which means there is one less step required during the production process and thus preventing the opportunity for mislabeling (Mykytiuk, 2002).

Disadvantages of Retort Pouches

Despite the many advantages of pouches, there are a few disadvantages. Improper pouch handling could result in damage to the pouch that could weaken the seal or compromise the pouch hermeticity. Examples of improper handling are manual handling and overlapping or touching of pouches in the retort. Examples of proper handling of retort pouches include drying the pouches and enclosing them as fast as possible in a protective outer wrap. It is very important to correctly dry the pouch to avoid recontamination of the seal (Canadian Food Inspection Agency, 2002). Pouches are also susceptible to cuts, punctures and pinholes (Mykytiuk, 2002).

There has been some resistance adopting retort pouches in the United States because of the need for large capital investment in equipment. U.S. companies already maintain high efficiency canning lines. The canning companies would have to invest large amounts of money for the new pouch filling and sealing equipment. Also, the inexperience of employees related to equipment and procedure plays a factor in developing and producing products processed in retort pouches (Mykytiuk, 2002).

Research Studies Involving Retort Pouches

There are several research studies that examine the effectiveness of retort pouches. In a study conducted in India in 2005 by Ali Et. Al, sardines in oil were canned in aluminum cans and retort pouches at three different lethality values and processed in a stationary retort. Sardines processed in retort pouches had a shorter process time compared with aluminum cans. The sardines in the retort pouch samples were harder compared with sardines processed in aluminum cans. Chewiness, cohesiveness, and springiness were higher in retort pouch samples compared with samples processed in aluminum cans (Ali Et. Al, 2005).

Another example illustrating the benefits of retort pouches was a study involving mushrooms in brine processed in retort pouches conducted in 2004 in India by

Chandrasekar. No deformity, leakage or spoilage was observed in the retort pouches. The product remained sterile and acceptable even after 12 months of storage. The product had high acceptability (7.9 on a 10 point scale) and only reduced slightly (to 7.5) after 12 months of storage (Chandrasekar, 2004).

In a study performed by Mohan, et. al. (2005), products processed in retort pouches were found to be superior to canned products. The products in the pouches had better sensory and texture attributes (firmness, hardness and chewiness) as well as overall acceptability. The study cited a number of research articles that have shown the advantages of pouches over cans: Chia et al. (1983) processed trout, pollock and shrimp in pouches and found processing time reductions of 34%, 32%, and 37% respectively compared to cans. Another study by Durance and Collins (1991) showed a 48% reduction in process time for chum salmon in pouches compared to cans (Mohan, et. al. in 2005).

A study conducted by Dymit (1973) showed that shrimp processed in retort pouches were superior in flavor and color compared to canned products. This study demonstrated that there is a significant reduction in processing time for pouches compared to cans (with equal weights). The products were processed to an equal lethality. The process time was reduced by 35.67% for 16 x 20 cm pouches when compared to 301 x 206 cans when processed for equivalent lethality. Process time was reduced by 56.56% for 17 x 30 cm pouches when compared to 401 x 411 cans. The products processed in the pouches were lighter in color, firmer, had higher scores for overall acceptability, higher in hardness, chewiness and springiness compared to products processed in the cans. Overall, the study demonstrated that the products processed in pouches were of better quality compared to the products processed in cans (Mohen, 2005).

In a study performed by Bindu et. al. (2008), heat penetration characteristics of smoked tuna in oil and brine in retort pouches at different rotational speeds were examined. This study showed that heat penetration was faster in brine-packed tuna compared to oil-packed tuna. The high viscosity of the oil prevents rapid convection movement within the pouches. The rotation reduces process time which in turn can save fuel and energy and produce higher quality products (better nutrition, color, taste and flavor) (Bindu et. al, 2008).

In an article authored by Ramaswamy (1997), two types of container were evaluated for heating behavior of thermally processed Pacific salmon in steam-air and water immersion still retorts. The containers of interest were semi-rigid containers (SPC). They reported that the salmon processed in the SPC only needed about half the time to process compared to the product processed in the cylindrical metal can (CMC). The process that provided reduced overcooking (better quality) and reduced processing time (energy savings) for the salmon in tomato sauce was the high-temperature, short-time processing in the SPC (Ramaswamy, 1997).

A paper by Williams et. al. (1981) compared the cost of cans and retort pouches. The study focused on processed fruit and vegetable products. The study found that the retort pouch packaging system was the least expensive compared to the other two systems examined, which were an existing canning line and a new canning line. A number of different factors were examined in the study. The costs of the acquisition and maintenance of the pouch system were significantly higher than the can (existing or new) but other expense factors were lower for the pouch system. The pouch system had lower freight costs because of the lighter weight and smaller volume of the pouches. This study also stated that the purchase price of the pouch is lower than that of the can. The pouch system also saved on energy (transportation and container manufacture). The type of pouch the study was investigating was a multilayer flexible pouch consisting of polypropylene, aluminum foil and polyester (Williams et. al., 1981).

Starch

General Terms Related to Starch

By definition, starch is a polysaccharide derived from plant sources (corn, potato, rice and wheat). It is a polymer of 200 or more glucose units containing amylopectin (branched) and amylose (unbranded) regions. Starch granules are cytoplasmic plant structures storing starch polysaccharides. Gelatinization is the irreversible disruption of the molecular organization of starch granules due to heat and water. During gelatinization, the starch granules swell in size. A starch paste is a viscoelastic starch and water system that possesses both thick liquid-like (viscous) and solid-like (elastic) properties. The pasting process follows gelatinization. Gelation follows pasting and it is the formation of a gel from a cooled paste. A starch gel is a rigid, thickened starch and water mixture that has the properties of a solid. Retrogradation is the result of heating and cooling of starch in water, with reassociation of especially amylase polymers into an ordered structure (Murano, 2003).

Types of Starches

Starches are often modified in order to help their functionality in food processing. Most modifications involve the alcohol groups on the starch polymer or glycosidic bond cleavage. Modified starches have a variety of functions including film formation, exhibiting freeze-thaw stability, pasting and gelling, enhanced solubility and promoting viscosity (Murano, 2003).

Pregelatinized starches are common chemically modified starches used in food manufacturing. This type of starch increases product thickness with minimal thermal processing (Murano, 2003). They are precooked starches that are able to swell instantly in cold water (Fennema, 1996).

Starch Considerations for Research Study

There were a number starches considered for this research study. Purity-W, Thermflo and National Frigex from National Starch Food Innovation considered but Frigex-W (National Starch Food Innovation) was chosen for the experiment.

Purity-W is a modified food starch derived from waxy maize. It is characterized by high viscosity, a smooth, short texture and excellent cold temperature storage stability. The viscosity obtained by using Purity-W is higher compared to those of conventional starches. Purity-W does not set to form a gel when cooled. The product works well in neutral and some acid systems. It is used in a number of food products including canned, retorted high pH systems (for example: gravies, stews and soups), puddings and other desserts. Purity-W has a bland taste and therefore will not mask the flavor of food products with delicate flavor profiles. National Starch Food Innovation recommends the use of Purity-W in cream style corn because it helps provide excellent color, brightness, sheen and decreased tendency to curdle (National Starch Food Innovation, 2009).

Thermflo is a modified food starch derived from waxy maize that imparts a smooth, heavy mouthfeel to food products. It is applicable in high and low pH food systems and has very good cold temperature storage stability (recommended for frozen foods). Thermflo is used in a variety of food systems (retorted foods, aseptically canned foods and frozen foods) and food products (fruit fillings, glazes, puddings, custards, cream pie fillings, gravies and sauces).

National Frigex is a modified food starch derived from tapioca. It imparts a smooth, clear, heavy bodied and short-textured appearance to food products. National Frigex is very stable in low temperature storage conditions and has excellent resistance to heat and acid conditions. It can be used in a variety of food processing systems including high temperature-short time, ultra high temperature and conventional batch cooking systems. It is recommended for use in bland products (for example: puddings and cream fillings) (National Starch Food Innovation, 2009).

Frigex-W is a modified food starch derived from waxy maize. It is used as a thickener in aseptically canned products and frozen foods. When used in food products, Frigex-W gives the food a heavy-bodied, smooth, short texture when fully cooked in an aqueous system. Frigex-W has excellent resistance to heat, acid and shear conditions. It is also very stable in cold temperature storage. Frigex-W has been used in a variety of food products including puddings and cream fillings. Because of its resistance to acid, it has also been used in some fruit products and acid containing sauces (National Starch Food Innovation, 2009).

Literature Cited

Abdul Ghani Al-Baali, A.G. and Farid, M.M. 2006. Sterilization of Food in Retort Pouches. Springer Science+Business Media, LLC. 25-27 p.

All Business. 2009. Canned Food Processing. www.allbusiness.com

Ali, A., Sudhir, B. and Gopal, T.K.S. 2005. Effect of Heat Processing on the Texture Profile of Canned and Retort Pouch Packed Oil Sardine (*Sardinella longiceps*) in Oil Medium. Journal of Food Science 70 (5).

Ali, A.A., Sudhir, B., and Gopal, T.K.S. 2006. Effect of Rotation on the Heat Penetration Characteristics of Thermally Processed Tuna in Oil in Retort Pouches. International Journal of Food and Technology 41: 215-219.

Ali, A., Sudhir, B., Mallick, A.K. and Gopal, T.K.S. 2007. Effect of Rotation on Process Time of Thermally Processed Mackerel in Oil in Aluminum Cans. Journal of Food Process Engineering 31: 139-154.

Bindu, J. and Gopal, T.K.S. 2008. Heat Penetration Characteristics of Smoked Tuna in Oil and Brine in Retort Pouches at Different Rotational Speeds. Journal of Food Processing and Preservation 32: 231-246.

Chandrasekar, V., Gopal, T.K.S. and Rai, R.D. 2004. Heat Penetration Characteristics and Shelf-life Studies of Mushrooms in Brine Processed in Retort Pouches. Packaging Technology and Science 17:213-217.

Collins, K. Director of Process Services, Allpax Products, Inc. Which Retort is Best for Your Container. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Demetrakakes, P. 2004. Retort Pouches Build Up Steam: Big Food Companies are Taking Advantage of Technical Advances to Bring out Retorted Products in Flexible Material - Technology: Retort Packaging. Food and Drug Packaging.

Fennema, O.R. 1996. Food Chemistry. Marcel Dekker, Inc. 191-204 p.

Galvin, A. and Weddig, L. M. 1995. Canned Foods: Principles of Thermal Process Control, Acidification and Container Closure Evaluation. Sixth Edition. The Food Processors Institute. 1, 4-5 and 12 p.

Gazdziak, S. May 2005. Packaging Technology: Retort Pouches Heating Up. The National Provisioner Magazine.

Hudson, S.B. President, Allpax Products, Inc. The Best Retort Sterilization Process: How to Make the Best Choice. Retorts.com. Accessed February 3, 2009 at 1:25PM.

Hudson, S.B. President, Allpax Products, Inc. Retorts and Retortable Containers. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Hudson, S.B. President, Allpax Products, Inc. Saturated Steam Retorts: Understand the Retort Sterilization Process. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Hudson, S.B. President, Allpax Products, Inc. Steam Air Reports: Understanding the Retort Sterilization Process. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Hudson, S.B. President, Allpax Products, Inc. Water Immersion Retorts: Understand the Retort Sterilization Process. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Hudson, S.B. President, Allpax Products, Inc. Water Spray Retorts: Understand the Retort Sterilization Process. Retorts.com. Accessed February 4, 2009 at 2:17PM.

Keith, H. November 2001. Retort Pouches. Flexible Packaging.

Lopez, A. 1981. A Complete Course in Canning: Book 1 – Basic Information on Canning. Canning Trade, Inc. 368 p.

Mohan, C.O., Ravishankar, C.N., Gopal, T.K.S. and Bindu, J. 2005. Thermal Processing of Prawn “kuruma” in Retortable Pouches and Aluminium Cans. International Journal of Food Science and Technology 43: 200-207.

Murano, Peter S. 2003. Understanding Food Science and Technology. Thomson Wadsworth. 130-132, 215-222 p.

Mykytiuk, A. 2002. Retort Flexible Packaging: The Revolution Has Begun. Flexible Packaging. P 18-25.

National Food Processors Association. 1985. Guidelines for Thermal Process Development for Foods Packaged in Flexible Containers. 5 p.

National Starch Food Innovation. 2009. Frigex-W. www.foodinnovation.com.

Parchomchuk, P. 1977. A Simplified Method for Agitation Processing of Canned Foods. Journal of Food Science 42: 265-268.

Ramaswamy, H.S. and Grabowski, S. 1997. Thermal Processing of Pacific Salmon in Steam Air and Water-Immersion Still Retorts: Influence of Container Type Shape on Heating Behavior. 32: 12-18.

Sacharow, S. 2003. Is the Retort Pouch Really Ready to Replace the Metal Can? Paper, Film and Foil Converter.

Shin, S. and Bhowmik, S. 1991. Thermal Kinetics of Color Changes in Pea Puree. Journal of Food Engineering 24: 77-86.

Tucker, G.S., Emond, S.P., Hughes, J.P., Jones, T.E.R. and James, P.W. 2006. Maximizing the Headspace Bubble Action in Rotary Thermal Processing of Packaged Foods. Food Manufacturing Efficiency 1: 25-33.

Williams, J.R., Steffe, J.F. and Black, J.R. 1981. Economic Comparison of Canning and Retort Pouch Systems. Journal of Food Science 47: 284-290.

EFFECTS OF OSCILLATING AND STATIC RETORT THERMAL PROCESSING TECHNOLOGY USING AN INSTITUTIONAL SIZE POUCH

Abstract

The effects of oscillating and static retort thermal processing on heat penetration using an institutional size pouch were evaluated. Frigex-W starch (National Starch Food Innovation) and water mixtures were prepared at three different concentrations (1%, 3% and 5%). Five replications of starch and water mixtures were processed using water spray as the processing medium in institutional size retort pouches (29.2 cm. x 38.1 cm.) using both oscillating and static processing modes.

Viscosity (by Brookfield viscometer and Bostwick consistometer), residual air (destructive technique), color (by Minolta L*a*b* colorimeter), processing time (slope of heat penetration curve) and process time to achieve 5 log reduction of *Clostridium botulinum* were determined for each starch and water mixture concentration level..

The mean slope values of the two processing modes (oscillating and static) are not different ($p>0.05$) for the 1% and 5% concentrations. The mean slope values of the processing modes (oscillating and static) are different ($p<0.05$) for the 3% concentration.

The results of this research are significant to the food industry because the oscillating technology may not be beneficial to companies processing low viscosity (1%) and/or high viscosity (5%) products since there is no significant difference between the two (oscillating and static) modes when evaluating processing time. Companies processing medium viscosity (3%) could benefit from investing in the oscillating

technology because of the decreased processing time. The decreased processing time could result in increased production yields and retention of important nutrients.

However, companies processing low viscosity (1%) and/or high viscosity (5%) products may still benefit from investing in oscillating technology because of other benefits. Other potential benefits (for example: retention of important nutrients) need to be investigated to determine the effectiveness of the oscillating technology.

Introduction

Thermally processed foods are a $134 billion industry in the United States each year (All Business, 2009). The canned vegetable market alone is 5 billion units. Other big categories in thermally processed foods are the 4 billion unit canned soup market and the 1.5 billion unit baby food market (Keith, 2001). There are many new technologies and packages revolving around the retort food industry. The new oscillating retort technology is similar to the rotary process in that it agitates the food product to help increase core heating rates; however, the oscillating technology could be used for retort pouches because the gentle rocking motion used will not damage the pouch (Collins, 2009). Retort pouches are becoming more and more popular in the United States. In 2005, Stan Sacharow (executive director of the Packaging Group Inc. in Princeton, NJ) reported that pouch sales in the U.S. were growing at a rate of 13-15% each year (Gazdziak, et. al. 2005).

There are a number of assumptions associated with oscillating technology. It is thought that, like rotary technology, the oscillating technology could result in a faster processing time. A shorter process time could result in better flavor, better color and vitamin retention and could also lower energy costs and increase through put. Agitation from the oscillating technology could allow for higher temperatures to be used during the process which could reduce the process time even further (Parchomchuk, 1977). In the literature review, no research studies were found involving the oscillating technology and there are a number of questions to be answered before a company is to invest in the new technology. Is the technology going to result in faster process times? Is the quality of the product going to be the same; better? Is the nutritional content of the food product going to be the same; better? Is the new technology worth the capital investment in new equipment? Which rocking movement (side to side or front to back) is more effective? Is the oscillating technology effective for all viscosity levels and food products? If not, which types should utilize the oscillating technology and which ones should not?

The objective of this research is to determine the effects of oscillating and static retort technology on heat penetration using an institutional size retort pouch at three viscosity levels.

Materials & Methods

Frigex-W Starch (National Starch Food Innovation) and Water Mixture Preparation

The Frigex-W starch (National Starch Food Innovation) and water mixtures were prepared at three concentrations (1%, 3% and 5%). The appropriate amount of water for each concentration was heated in a steam jacketed kettle to 85°C. The two kettles used in this experiment were a 132-liter kettle and a 756-liter kettle. The appropriate amount of starch was gradually added to the 85°C water while stirring. After all the starch was added, the mixture was heated to 100°C and held for 10 minutes while stirring. The starch and water mixture was then allowed to hydrate for 72 hours. After 72 hours, the starch and water mixture was put into pouches and processed in a retort with a cook time of 60 minutes at 123°C in static mode in order to stabilize the viscosity. The pouches were then stored in a refrigerator at 5.5°C until needed.

The day before processing, the starch and water mixture was removed from refrigeration and held for 24 hours to equilibrate at room temperature (around 21°C). 13.2 kilograms of the starch and water mixture was then used to fill the thermocouple containing pouches. Those pouches were then used in the actual experiment to simulate a food product at three different viscosity levels.

Pouch Preparation

There were a total of 90 pouches used in the experiment. Clear institutional size retort pouches (29.2 cm. x 38.1 cm.) were used in this experiment. The pouch size was equivalent to a #10 can. In order to connect the thermocouples to the pouches, a hole was punched into the pouch on the edge half way up the pouch. After the hole was punched, the packing gland and thermocouple were inserted. 12.7 cm. thermocouples were used in the experiment. In order to keep the thermocouples in place inside the retort pouches, nylon cylinders (1.9 cm. by 3.8 cm.) with a hole in the middle were attached to the pouch. The thermocouple was placed inside the hole in the nylon cylinder. The cylinders were placed 4.4 centimeters from the temperature recording end of the thermocouple (**Figures 1 and 2**).

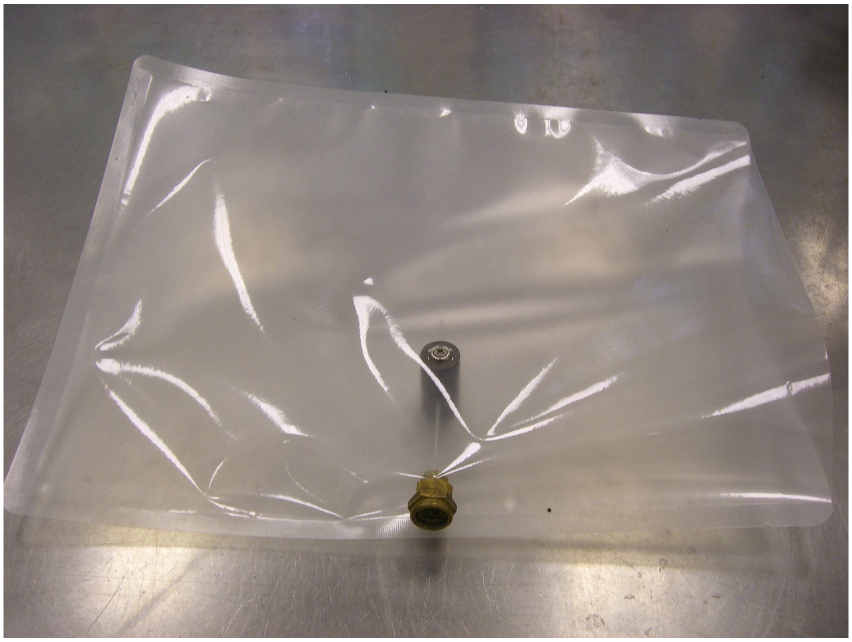

Figure 1: Unfilled Clear Institutional Size Retort Pouch (29.2 cm. x 38.1 cm.) with Thermocouple Inserted

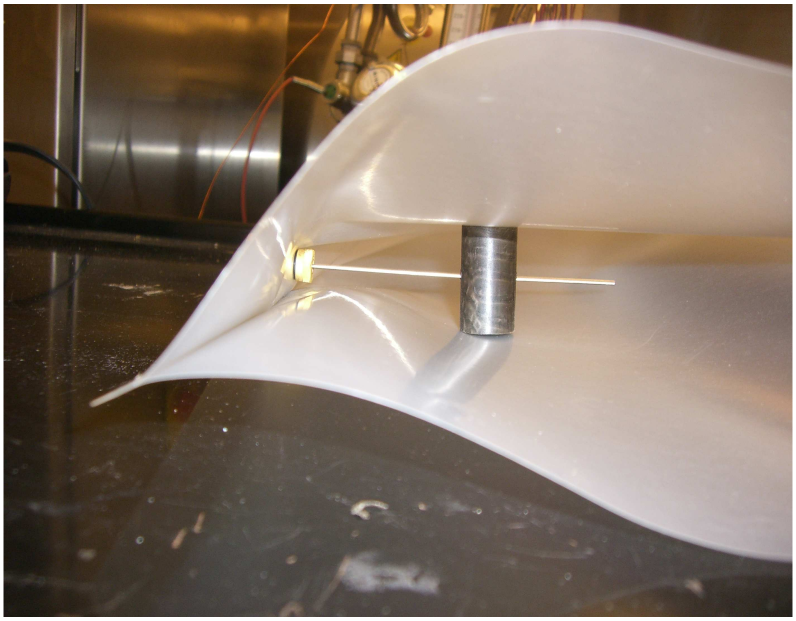

Figure 2: Close-up View of Unfilled Clear Institutional Size Retort Pouch (29.2 cm. x 38.1 cm.) with Thermocouple Inserted

The pouches was sealed using a Toyo Jidoki heat sealer with the following settings: temperature 125°C, heating time 0.7 seconds and cooling time 3.0 seconds. Once filled, the pouches were 3.8 centimeters thick. Each pouch was labeled 1 through 9. Pouches 1 through 3 were for the low viscosity (1% concentration), 4 through 6 were for the medium viscosity (3% concentration) and 7 through 9 were for the high viscosity (5% concentration).

Position of Pouches inside Retort

The pouches were loaded into the retort where each thermocouple was attached to a cord inside the retort chamber that was then connected to the computer which recorded the time and temperature. The data collection software used was CALSoft.

Nine pouches were processed per run. The positions in the retort were labeled 1 through 9. The starch and water mixture pouches were on trays 7, 8 and 9; there was a total of 14 trays in a basket (2 baskets inside the retort). Positions 1, 2 and 3 were on tray 7. Positions 4, 5 and 6 were on tray 8. Positions 7, 8 and 9 were on tray 9. The remaining spaces in the retort were filled with pouches containing water to create even heat distribution. Pouch location was randomized as outlined in the experimental design.

Retort Process

A Surdry 2 basket retort (model number AO142) was used to conduct the experiment using the thermal process outlined in **Table 1**. As stated above, each basket holds 14 trays. The processing medium used in this experiment was water spray. The speed for the oscillating mode was 10.5 r.p.m. The angle for the oscillating mode was 10 degrees. The oscillating mode used rocked side to side. One revolution was when the basket rocked to the left and to the right and then returned to its original position.

Table 1: Thermal Process for Retort Pouches Filled with Frigex-W Starch and Water Mixtures

Step	**Pressure (psi)**	**Temperature (°C)**	**Time (minutes)**	**Pressure Vessel (PV) Level**
Fill	N/A	N/A	N/A	54
Come up	18	93.3	7	48
Come up	32	93.3	6	45
Hold/cook	32	121	N/A	45
Microcool	18	93.3	6	70
Cooling	15	29.4	8	70
Cooling	15	29.4	30	70
Drain	N/A	N/A	2.5	N/A

The pouches were heated until all pouches reached 121°C. The experimental design required 5 processing runs of the oscillating mode and 5 processing runs of the static mode.

Sample Analysis (Color by Minolta L*a*b* Colorimeter and Viscosity by Brookfield Viscometer and Bostwick Consistometer)

The color of the starch and water mixture was measured both before and after processing using a Minolta L*a*b* colorimeter. The sample was put into a petri dish and placed on top of a white slab to ensure an accurate reading.

The viscosity was measured before and after processing in the retort to make sure the viscosity was stable. The viscosity was measured using a Brookfield viscometer and a Bostwick consistometer. The samples were measured at room temperature (21°C).

For analysis using the Brookfield viscometer, the samples were placed in a 250mL beaker. The sample was placed under a spindle attached to the viscometer. The spindle was inserted in the sample until the notch marked on the spindle was completely immersed. The sample spun for 5 minutes at a speed of 12 r.p.m. The spindle number used with the Brookfield measurement varied depending on the viscosity. The 1% concentration samples used spindle number 1, the 3% concentration samples used spindle numbers 1, 2 and 3 and the 5% concentration samples used spindle number 4.

For analysis using the Bostwick consistometer, the holding chamber was filled to the top with sample while the gate was down. Using the backside of a knife, the sample was smoothed out. The gate was released and the sample was allowed to flow for 30 seconds. At the end of 30 seconds, the distance the sample traveled was measured in centimeters.

Residual Air (Pouch Headspace)

A residual air (headspace) test was performed within an hour after processing. The test was performed by filling the sink with water. A ring stand was used to hold an upside down graduated cylinder so that the top of the cylinder was just under the surface of the water. The pouch was held under water under a funnel attached to the graduated cylinder filled with water. A corner of the pouch was cut open under the funnel and the air was squeezed out. The amount of residual air in the pouch was measured (millimeters) as the amount of water displacement in the cylinder (Canadian Food Inspection Agency, 2002).

Experimental Design

A split-plot design with retort method as the whole plot factor and viscosity as the sub-plot factor was used. SAS proc plan was used to generate randomization. The specific randomization plan for pouch location in the retort is outlined in **Tables 2** and **3**.

The retort factor randomization was designed as follows:

1. Assign the numbers 1 through 5 to the static method and numbers 6 through 10 to the oscillating method.
2. Use the random sequence in **Table 2** to assign the order the different retort methods are to be conducted.

The randomization plan for retort factor is outlined below in **Table 2.**

Table 2: Randomization Plan for Retort Factor

Order	1	2	3	4	5	6	7	8	9	10
Method	S	S	O	O	O	O	S	O	S	S

S = static, O = oscillating

The viscosity factor randomization was designed as follows:

1. Label the positions in the retort machine from A to I.
2. Label the nine pouches from 1 to 9. (Pouches 1 through 3 for the low viscosity (1% concentration), 4 through 6 for the medium viscosity (3% concentration), and 7 through 9 for the high viscosity (5% concentration)).
3. Use the random sequences in **Table 3** to place the pouches in the positions of the retort.

The randomization plan for viscosity factor is outlined below in **Table 3.**

Table 3: Randomization Plan for Viscosity Factor

	Position in Retort								
Run	A	B	C	D	E	F	G	G	I
1	3	2	5	6	1	9	8	7	4
2	7	9	4	3	5	6	8	2	1
3	9	8	5	2	4	6	1	7	3
4	9	8	3	1	7	6	4	2	5
5	6	7	2	4	1	8	5	9	3
6	3	4	1	8	9	2	5	6	7
7	8	7	5	6	4	1	2	3	9
8	3	9	6	1	4	2	5	8	7
9	2	7	3	4	1	5	8	9	6
10	3	2	5	9	1	6	8	4	7

Statistical Analysis

Means, standard errors and significance levels of 5% were found for viscosity, residual air, L* values and slope values through statistical analysis using SAS.

Results & Discussion

Viscosity

The starch and water mixtures were chosen because in pretrial tests, the viscosity did not change during the retort process. Bentonite and water mixtures were also evaluated for use in the experiment but did not produce a stable viscosity during pretrial testing (**Appendix A**). The mean square root viscosity values for the 1%, 3% and 5% starch and water concentrations are not different ($p>0.05$) from before the retort process to after the retort process for both the oscillating and static processing modes (**Table 4**), thus viscosity did not affect the heating rates. Square roots were calculated because of outlying values during the statistical analysis.

The viscosity results for the Bostwick consistometer were not reported because the 1% concentration sample results and some of the 3% concentration samples results exceeded the instrument's capability. The Bostwick measurements for the 1% concentration samples were greater than 24 centimeters. The Bostwick measurements ranged from 12.25 centimeters to greater than 24 centimeters in the 3% concentration samples to a range of 4.0 to 6.0 centimeters for the 5% concentration samples.

Table 4: Mean Square Root of Viscosity Values (cP) of Retort Processed Frigex-W Starch and Water Mixtures Measured by Brookfield Viscometer

Concentration (%)	**Mean Viscosity (cP) Before Process**	**Mean Viscosity (cP) Oscillating**	**Mean Viscosity (cP) Static**
1	2.24^{aA} (2.2)	2.10^{aA} (1.0)	2.33^{aA} (1.0)
3	16.26^{aB} (2.2)	39.65^{aB} (10.9)	29.31^{aB} (8.1)
5	168.4^{aC} (2.2)	170.7^{aC} (3.6)	172.5^{aC} (4.0)

Mean square root of viscosity value (standard error). a,b,c values that share the same lowercase letters within the same row are not different as determined by least squares means ($p>0.05$). A, B, C values that share the same uppercase letters within the same column are not different as determined by least squares means ($p>0.05$).

Residual Air (Pouch Headspace)

Residual air is important in retort processing because of its effect on heating rate. If there is not enough residual air in the package, there will be no stirring effect to help agitate the food product to heat faster. Excessive residual air can act as an insulator and slow down the heating rate (Campbell, et. al. 1992).

The mean log residual air values for oscillating versus static in the 1% and 5% concentrations are not different ($p>0.05$) while the mean log residual air value for oscillating versus static in the 3% concentration is different ($p<0.05$) (**Table 5**). Logs were calculated because of outlying values during the statistical analysis.

There are a number of possible reasons why the mean log residual air values were different. The different mean residual air values could have resulted from human error during filling the pouches. Although every effort was made to obtain a consistent fill, pouches were hand filled and sealed and therefore some inconsistencies may have resulted from entrapped air. The destructive technique used to measure residual air was limited by the precision and accuracy of the person performing the test and the equipment setup used in the test. One of the reasons the mean residual air values for all the concentrations are lower for the oscillating process compared to the static process could be due to air entrapment in the starch and water mixtures because of the agitation of the products during the oscillating process. Therefore, more residual air could actually have been in the samples than were reported. The residual air values were measured immediately after processing. If the residual air measurements were taken after the samples were allowed to sit for 24 hours or 48 hours, the results for the oscillating mode might have been more consistent with those of the static mode because any air bubbles as a result of the agitation during the oscillating process could have settled during that time.

Table 5: Mean Log Residual Air Values (mL) of Retort Processed Frigex-W Starch and Water Mixtures Measured by Destructive Technique

Concentration (%)	**Mean Residual Air (mL)** **Oscillating**	**Mean Residual Air (mL)** **Static**
1	1.1^{aA} (0.19)	1.6^{aA} (0.19)
3	1.1^{aA} (0.19)	1.8^{bA} (0.19)

5	1.8^{aB} (0.19)	1.6^{aA} (0.19)

Mean log residual air value (standard error). a,b, c values that share the same lowercase letters within the same row are not different as determined by least squares means (p>0.05). A, B, C values that share the same uppercase letters within the same column are not different as determined by least squares means (p>0.05).

Color

L* represents lightness where 0 represents black and 100 represents white. The mean L* values for the 1%, 3% and 5% concentration samples not were different ($p > 0.05$) for both the oscillating and static processes compared to before the process (**Table 6**).

Table 6: Mean L* Values of Retort Processed Frigex-W Starch and Water Mixtures Measured by Minolta L*a*b* Colorimeter

Concentration (%)	**Mean L* Before Process**	**Mean L* Oscillating**	**Mean L* Static**
1	55.62^{aA} (4.9)	50.41^{aA} (2.2)	49.53^{aA} (2.2)
3	48.46^{aB} (4.9)	45.69^{aB} (2.2)	49.53^{aA} (2.2)
5	37.67^{aC} (4.9)	38.58^{aC} (2.2)	43.48^{aB} (2.2)

Mean L* value (standard error). a,b,c values that share the same lowercase letters within the same row are not different as determined by least squares means (p>0.05). A, B, C values that share the same uppercase letters within the same column are not different as determined by least squares means (p>0.05).

In general, there was very little color change observed in the starch and water mixtures comparing before processing, static and oscillating. This supports the recommendation of Frigex-W as a suitable starch for use in retort processed foods.

The 1% and 3% concentration starch and water mixtures were darker after both processes (oscillating and static). The darkening could be a result of caramelization.

Slope (Heating Curve)

The slope value represents the slope on a temperature versus time graph (heating curve). The larger the slope value, the faster it took the product to heat to a temperature of 121°C. The smaller the slope value, the longer it took the product to heat to a temperature of 121°C. As the process time becomes longer, the production yields decrease. A longer process time could also result in an overcooked product leading to unwanted changes in color, texture or nutrient content.

The mean slopes values of the two processing modes (oscillating and static) were not different ($p>0.05$) for the 1% and 5% concentrations (**Table 7**). The slope values of the processing modes (oscillating and static) were different ($p<0.05$) for the 3% concentration. The 1% concentration was similar to water or chicken broth in viscosity. These results do not coincide with a study performed by Parchomchuk (1977) where it was stated that agitation was most effective for liquid products that heat by conduction (Parchomchuk, 1977). In this experiment, the convection currents in the low viscosity products could have been disrupted by the agitation of the oscillating process and therefore could have actually slowed the heating process.

Bindu et. al. (2008) evaluated heat penetration characteristics of smoked tuna in oil and brine in retort pouches at different rotational speeds. The study by Bindu et. al. showed that heat penetration was faster in brine-packed tuna compared to oil-packed tuna. The high viscosity of the oil prevented rapid convection movement within the pouches (Bindu et. al, 2008). Ali et. al. (2006) stated that heat transfer in liquid foods can be significantly increased by agitation during the processing of the food (Ali et. al, 2006). The findings of the studies by Bindu et. al. (2008) and Ali et. al. (2006), in addition to that of Parchomchuk (1977) also do not support the results of this research study.

As explained in the research study by Parchomchuk (1977), agitation was not advantageous for solid food products, for example meat and fish (Parchomchuk, 1977). The high viscosity samples (5% concentration) used in this research study were not as viscous as meat or fish; however, the results of this study agree with that of Parchomchuk's because the processing time was not affected by agitation during the oscillating mode for the 5% concentration samples.

Ortiz, et. al. (1995) stated that rotary thermal processing was more effective than stationary thermal processing for high viscosity products because it reduced sterilization time by approximately 50% (Ortiz, et. al, 1995). The research by Ortiz, et. al. (1995) may seem to contradict the findings of this study; however, what they consider their high viscosity (10,000 cP) is in the range for the medium viscosity (3% concentration) after retort processing in this study. Therefore, the results by Ortiz, et. al. (1995) support the findings of this study because the mean values for the 3% concentration samples are different ($p>0.05$) between the oscillating and static processing modes**.** **Figures 3**, **4** and **5** illustrate the results shown in **Table 7**.

The results of this research are significant to the food industry because companies processing low viscosity (1%) and/or high viscosity (5%) products do not need to invest in new capital for the oscillating processing mode since there is no significant difference between the two (oscillating and static) modes when evaluating processing time. Companies processing medium viscosity (3%) could benefit from investing in the oscillating technology because of the decreased processing time. The decreased processing time could result in increased production yields and retention of important nutrients.

Companies processing low viscosity (1%) and/or high viscosity (5%) products may still benefit from investing in oscillating technology because of other reasons. The other reasons (for example: retention of important nutrients) need to be studied further to determine the effectiveness of the oscillating technology.

Table 7: Mean Slope Values of Heating Curve of Retort Processed Frigex-W Starch and Water Mixtures

Concentration (%)	**Mean Slope Oscillating**	**Mean Slope Static**
1	6.6^{aA} (0.13)	6.5^{aA} (0.10)
3	6.7^{aA} (0.10)	5.9^{bB} (0.10)
5	1.9^{aB} (0.13)	1.89^{aC} (0.10)

Mean slope value (standard error). a,b,c values that share the same lowercase letters within the same row are not different as determined by least squares means ($p>0.05$). A, B, C values that share the same uppercase letters within the same column are not different as determined by least squares means ($p>0.05$).

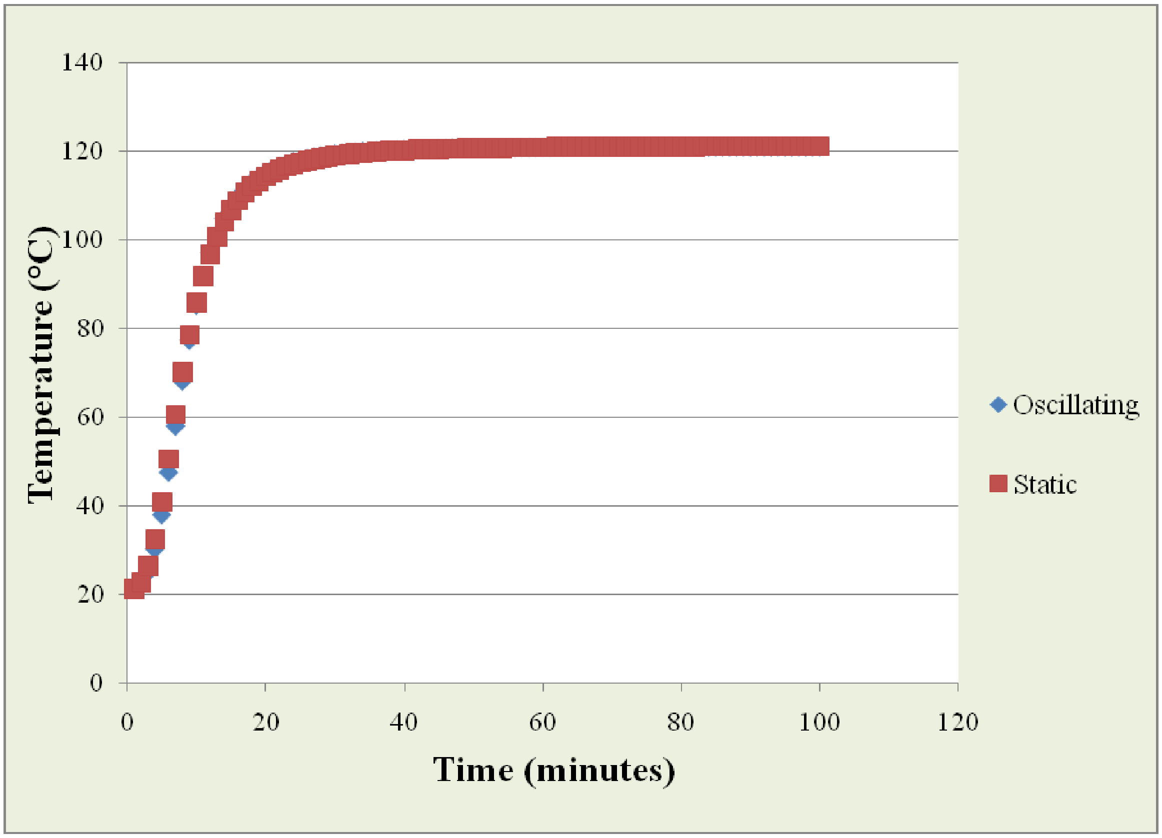

Figure 3: Heating Curve of Oscillating and Static Processes for 1% Concentration Samples of Retort Processed Frigex-W Starch and Water Mixtures

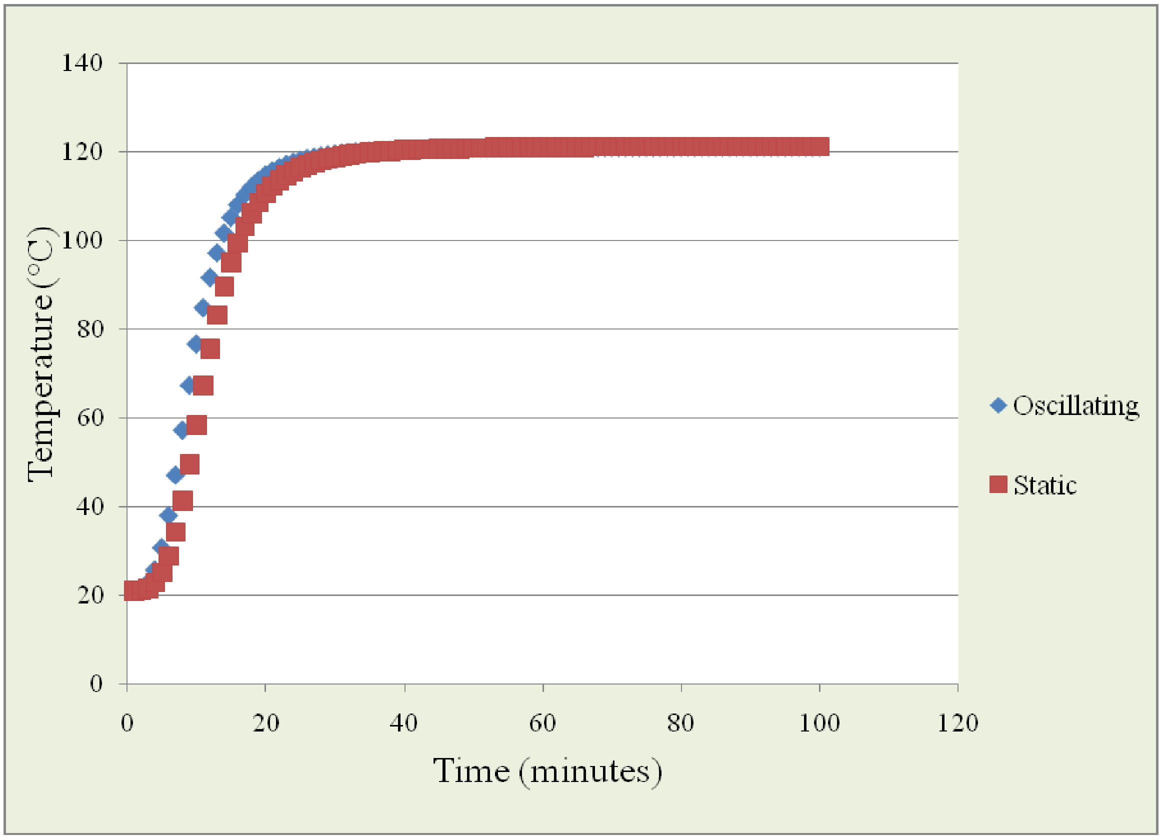

Figure 4: Heating Curve of Oscillating and Static Processes for 3% Concentration Samples of Retort Processed Frigex-W Starch and Water Mixtures

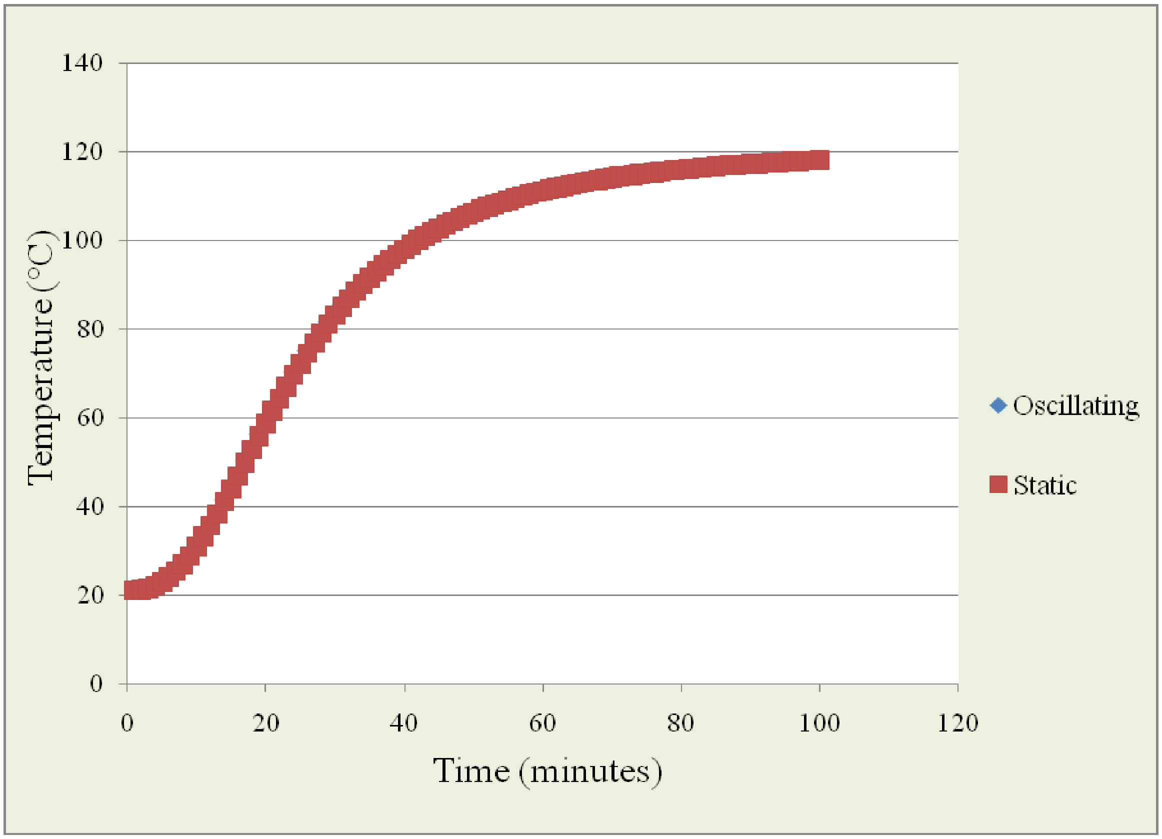

Figure 5: Heating Curve of Oscillating and Static Processes for 5% Concentration Samples of Retort Processed Frigex-W Starch and Water Mixtures

Process Time to Achieve 5 log reduction of *Clostridium botulinum*

The process time to achieve 5 log reduction of *Clostridium botulinum* for the 1% concentration was the same for both processes. The process time to achieve 5 log reduction of *Clostridium botulinum* for the 3% concentration was almost 3 minutes faster for the oscillating mode compared to the static mode. The process time to achieve 5 log reduction of *Clostridium botulinum* for the 5% concentration using the oscillating process was .25 minutes faster than the static process.

Table 8: Process Time to Achieve 5 log Reduction of *Clostridium botulinum* of Retort Processed Frigex-W Starch and Water Mixtures

Concentration (%)	**Lethal Rate (min.) Oscillating**	**Lethal Rate (min.) Static**
1	16	16
3	16.75	19.25
5	40.75	41

Conclusions

Based on the conditions used in our study:

1. Frigex-W starch and water mixtures produce a stable viscosity for use in model studies for evaluating retort processing systems.
2. Frigex-W starch and water mixtures undergo minimal color change during retort processing.
3. The oscillating process is effective at reducing the processing time for 3% concentration starch and water mixtures when compared to the static process.
4. The oscillating process is not effective at reducing the processing time for 1% concentration and 5% concentration starch and water mixtures when compared to the static process.

There is very little published work on the use of oscillating retort technologies. Future work should focus on the impact of this technology on the nutritional components of foods (for example: vitamin retention), effect on specific food attributes (flavor, color and texture) and comparisons of various oscillating methods. The oscillating process used in this study utilized a side to side rocking motion. A back and forth rocking motion may provide additional applications and improved processing times in other products or systems.

Acknowledgements

I would like to thank Lisa Godkin from National Starch Food Innovation for her help with picking the correct starch for my research. I would like to thank Richie Burke from Cryovac Sealed Air for his help with filling the retort pouches. I would like to thank Greg Rowhouse from Minolta for his help with the color analysis of the starch and water mixture.

Literature Cited

All Business. 2009. Canned Food Processing. www.allbusiness.com

Ali, A.A., Sudhir, B., and Gopal, T.K.S. 2006. Effect of Rotation on the Heat Penetration Characteristics of Thermally Processed Tuna in Oil in Retort Pouches. International Journal of Food and Technology 41: 215-219.

Bindu, J. and Gopal, T.K.S. 2008. Heat Penetration Characteristics of Smoked Tuna in Oil and Brine in Retort Pouches at Different Rotational Speeds. Journal of Food Processing and Preservation 32: 231-246.

Campbell, S. and Ramaswamy, H.S. 1992. Heating Rate, Lethality and Cold Spot Location in Air-entrapped Retort Pouches during Over-pressure Processing. Journal of Food Science. 57 (2):485-489.

Canadian Food Inspection Agency. 2002. Flexible Retort Pouch Defects: Identification and Classification.

Gazdziak, S. May 2005. Packaging Technology: Retort Pouches Heating Up. The National Provisioner Magazine.

Keith, H. November 2001. Retort Pouches. Flexible Packaging.

Ortiz, A.S., Alves, V.R.M., Oliveira, M.L., Anjos, D.V. and Goncalves, J.R. (1995). Performance of Aluminum Trays for Sterilized Products. Packaging Technology and Science 8: 55-72.

Parchomchuk, P. 1977. A Simplified Method for Agitation Processing of Canned Foods. Journal of Food Science 42: 265-268.

APPENDICES

Appendix A

Food Simulate Trial Tests and Viscosity Results

Bentonite and Water Mixture

At the beginning of the research project, a bentonite (a type of clay) and water mixture was considered for use as the food simulate for processing. Ten concentrations were prepared to determine the viscosity values before processing. The ten samples were allowed to hydrate for 48 hours before the viscosity reading by Brookfield viscometer was taken (**Table 9**). The samples were not processed in a retort.

Table 9: Viscosity Values (cP) for Non-Retort Processed Bentonite and Water Mixtures after 48 Hours of Hydration Measured by Brookfield Viscometer

% Concentration	**Viscosity (cP)**
1	5
2	2.5
3	10
4	42.5
5	125
6	1050
7	4100
8	9500
9	30,500
10	68,500

An 8% concentration of the bentonite and water mixture was prepared and processed in a retort with a cook time of 60 minutes at 121°C. The stability of the mixture was not consistent and therefore was not used. **Table 10** shows the results both before and after processing.

Table 10: Viscosity Values (cP) for 8% Concentration of Bentonite and Water Mixture Before and After Retort Processing Measured by Brookfield Viscometer

Sample	**Viscosity (cP)**
Before processing	11,300
Before processing	18,000
After processing	35, 500
After processing	37,000

Starch and Water Mixtures

A variety of starches were considered for use. Purity-W (National Starch Food Innovation) was considered but a technical representative at National Starch Food Innovation suggested two other starches (National Frigex and Thermflo). After a discussion with Lisa Godkin of National Starch Food Innovation, Frigex-W was chosen. Lisa Godkin suggested using concentrations no higher than 5-6% which represents pudding. She said 2-3% is similar to gravy. She gave instructions to heat the starch and water mixture to at least 85°C and hold for 10 minutes. After the retort process, the viscosity values were measured by Brookfield viscometer (**Table 11**).

Table 11: Viscosity Values (cP) for 5% Concentration of Retort Processed Frigex-W Starch and Water Mixture without Stabilizing Consistency Measured by Brookfield Viscometer

Sample	**Viscosity (cP)**
Before retort processing	2800
30 min. cook time	3700
60 min. cook time	6800
90 min. cook time	7300
120 min. cook time	8300
150 min. cook time	9200

After the first trial test, a 48 hour period of hydration was suggested. The starch was prepared the same way as before but it was allowed to hydrate at room temperature (21°C) for 48 hours before being processed in the retort. After the retort process, the viscosity values were measured by Brookfield viscometer (**Table 12**).

Table 12: Viscosity Values (cP) for 48 Hour Hydrated 5% Concentration of Retort Processed Frigex-W Starch and Water Mixture Measured by Brookfield Viscometer

Sample	**Viscosity (cP)**
Before Retort	17,000
30 minutes cook time	22,500
60 minutes cook time	27,500
90 minutes cook time	26,500
120 minutes cook time	27,000
150 minutes cook time	32,000

After reviewing the results of the second trial test, it was concluded that the starch and water mixture should be retort processed with a cook time of 60 minutes before being used in the research in order to stabilize the viscosity of the mixture.

Appendix B

Raw Data from Research Experiment

Raw data including viscosity values, residual air and color data from the research experiment is presented (**Tables 13-22**).

Table 13: Raw Data for 1% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Brookfield Viscometer

Run	**Spindle #**	**RPM**	**Reading**	**Viscosity (cP)**	**Temp. (°C)**
Before Process	1	12	1	5	20.6
Before Process	1	12	1	5	20.6
Before Process	1	12	1	5	20.7
Before Process	1	12	1	5	20.7
1	1	12	1	5	21.1
1	1	12	1	5	21.1
1	1	12	0.5	2.5	20.3
1	1	12	1.5	7.5	20.3
2	1	12	0.5	2.5	20.3
2	1	12	2	10	20.3
2	1	12	1	5	20.5
2	1	12	1	5	20.5
3	1	12	0.5	2.5	22.6
3	1	12	0.5	2.5	22.8
3	1	12	1	5	22.3
3	1	12	0.5	2.5	22.4
4	1	12	0.5	2.5	21.8
4	1	12	0.5	2.5	21.7
4	1	12	1	5	21.6
4	1	12	0.5	2.5	21.6
5	1	12	0.5	2.5	21.3
5	1	12	2	10	21.3
5	1	12	0.5	2.5	21.2
5	1	12	1	5	21.2
6	1	12	0.5	2.5	21.2
6	1	12	0.5	2.5	21.3
6	1	12	2	10	20.8
6	1	12	1	5	21.2
7	1	12	1.5	7.5	20.0
7	1	12	0.5	2.5	20.1
7	1	12	2	10	20.2
7	1	12	2.5	12.5	20.4
8	1	12	0.5	2.5	21.8
8	1	12	1	5	22.1
8	1	12	2	10	21.8
8	1	12	3	15	22.1
9	1	12	1	5	20.2
9	1	12	1.5	7.5	20.3
9	1	12	1.5	7.5	19.9
9	1	12	0.5	2.5	19.8
10	1	12	1	5	20.3
10	1	12	0.5	2.5	19.8
10	1	12	1	5	19.8
10	1	12	1	5	20.0

Table 14: Raw Data for 3% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Brookfield Viscometer

Run	**Spindle #**	**RPM**	**Reading**	**Viscosity (cP)**	**Temp. (°C)**
Before Process	1	12	49	245	20.6
Before Process	1	12	46	230	20.6
Before Process	2	12	13	325	20.5
Before Process	2	12	10.5	262.5	20.4
1	2	12	67	1675	20.7
1	2	12	71	1775	20.7
1	3	12	18	1800	20.6
1	3	12	14.5	1450	20.6
2	3	12	20	2000	20.7
2	3	12	21	2100	20.7
2	3	12	19	1900	20.4
2	3	12	20	2000	20.4
3	2	12	45.5	1137.5	22.4
3	2	12	45	1125	22.6
3	2	12	44	1100	22.2
3	2	12	44.5	1112.5	22.4
4	2	12	5	125	22.2
4	2	12	10.5	262.5	22.1
4	2	12	11	275	21.8
4	2	12	10.5	262.5	21.8
5	2	12	48	1200	21.4
5	2	12	39.5	987.5	21.3
5	2	12	53	1325	20.9
5	2	12	51	1275	20.8
6	3	12	65	6500	21.7
6	3	12	66	6600	21.4
6	3	12	65	6500	20.9
6	3	12	65.5	6550	20.5
7	1	12	1.5	7.5	19.7
7	1	12	1.5	7.5	20.3
7	1	12	2.5	12.5	19.8
7	1	12	1.5	7.5	20.2
8	2	12	45.5	1137.5	21.9
8	2	12	47	1175	21.3
8	2	12	48	1200	21.4
8	2	12	48.5	1212.5	21.3
9	2	12	3	75	20.8
9	2	12	16.5	412.5	20.6
9	2	12	17	425	20.3
9	2	12	18	450	20.1
10	3	12	16.5	1650	20.1
10	3	12	16.5	1650	20.7
10	3	12	16	1600	19.6
10	3	12	16	1600	19.6

Table 15: Raw Data for 5% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Brookfield Viscometer

Run	**Spindle #**	**RPM**	**Reading**	**Viscosity (cP)**	**Temp. (°C)**
Before Process	4	12	55	27,500	20.0
Before Process	4	12	62	31,000	20.0
Before Process	4	12	55	27,500	20.4
Before Process	4	12	55	27,500	20.3
1	4	12	60	30,000	21.7
1	4	12	67	33,500	21.6
1	4	12	56.5	28,250	20.4
1	4	12	65	32,500	20.4
2	4	12	50.5	25,250	20.5
2	4	12	53.5	26,750	20.4
2	4	12	48.5	24,250	20.3
2	4	12	58.5	29,250	20.3
3	4	12	54	27,000	23.2
3	4	12	51	25,500	22.7
3	4	12	51	25,500	22.8
3	4	12	51.5	25,700	22.7
4	4	12	80.5	40,250	21.8
4	4	12	59	29,500	21.7
4	4	12	53	26,500	21.6
4	4	12	73	36,500	21.7
5	4	12	53	26,500	21.8
5	4	12	59	29,500	21.4
5	4	12	59	29,500	21.7
5	4	12	54	27,000	21.2
6	4	12	58	29,000	21.6
6	4	12	53	26,500	21.3
6	4	12	61.5	30,750	21.3
6	4	12	53	26,500	21.1
7	4	12	64	32,000	19.4
7	4	12	69.5	34,750	19.2
7	4	12	72	36,000	19.3
7	4	12	67	33,500	19.7
8	4	12	58	29,000	21.1
8	4	12	57	28,500	21.2
8	4	12	70	35000	21.3
8	4	12	62	31000	21.3
9	4	12	54.5	27250	20.2
9	4	12	62	31000	20.3
9	4	12	68.5	34250	20.1
9	4	12	58	29000	20.1
10	4	12	53	26500	20.2
10	4	12	53.5	26750	20.1
10	4	12	58.5	29250	19.4
10	4	12	53.5	26750	19.9

Table 16: Raw Data for 1% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Bostwick Consistometer

Run	**Distance (cm)**	**Temp. (°C)**
Before Process	> 24	20.6
Before Process	> 24	20.6
Before Process	> 24	20.7
Before Process	> 24	20.7
1	> 24	21.1
1	> 24	20.7
1	> 24	20.3
1	> 24	20.3
2	> 24	20.7
2	> 24	20.7
2	> 24	20.5
2	> 24	20.5
3	> 24	22.8
3	> 24	22.8
3	> 24	22.8
3	> 24	22.8
4	> 24	21.7
4	> 24	21.6
4	> 24	21.7
4	> 24	21.7
5	> 24	20.3
5	> 24	20.3
5	> 24	20.3
5	> 24	20.3
6	> 24	20.6
6	> 24	20.6
6	> 24	20.6
6	> 24	20.6
7	> 24	20.6
7	> 24	20.6
7	> 24	20.6
7	> 24	20.6
8	> 24	21.3
8	> 24	21.3
8	> 24	21.3
8	> 24	21.3
9	> 24	20.1
9	> 24	20.1
9	> 24	20.1
9	> 24	20.1
10	> 24	20.2
10	> 24	20.2
10	> 24	20.2
10	> 24	20.2

Table 17: Raw Data for 3% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Bostwick Consistometer

Run	**Distance (cm)**	**Temp. (°C)**
Before Process	> 24	20.6
Before Process	> 24	20.6
Before Process	> 24	20.5
Before Process	> 24	20.1
1	21.50	20.7
1	20.50	20.7
1	21.50	20.6
1	20.50	20.6
2	20.00	20.7
2	19.75	20.6
2	20.00	20.4
2	20.00	20.4
3	> 24	22.5
3	> 24	22.5
3	> 24	22.5
3	> 24	22.5
4	> 24	21.6
4	23.50	21.4
4	23.50	21.6
4	> 24	21.6
5	> 24	20.0
5	> 24	20.0
5	> 24	20.0
5	> 24	20.0
6	12.25	21.3
6	12.5	20.8
6	12.5	20.4
6	12.25	21.0
7	> 24	21.0
7	> 24	21.0
7	> 24	21.0
7	> 24	21.0
8	> 24	21.3
8	> 24	21.3
8	> 24	21.3
8	> 24	21.3
9	> 24	20.8
9	> 24	20.8
9	> 24	20.8
9	> 24	20.8
10	19.5	20.6
10	16.5	19.9
10	20	19.7
10	20.25	19.8

Table 18: Raw Data for 5% Concentration of Retort Processed Frigex-W Starch and Water Mixtures Measured by Bostwick Consistometer

Run	**Distance (cm)**	**Temp. (°C)**
Before Process	4.50	20.0
Before Process	4.50	20.0
Before Process	5.00	20.4
Before Process	5.00	20.3
1	5.00	21.6
1	5.25	21.6
1	5.00	20.4
1	5.00	20.4
2	5.00	20.6
2	5.50	20.4
2	5.50	20.3
2	6.00	20.3
3	5.00	22.7
3	5.00	22.8
3	5.25	22.6
3	5.50	22.6
4	5.00	21.8
4	5.00	21.6
4	5.25	21.4
4	5.00	21.4
5	5.00	20.4
5	5.50	20.1
5	5.25	20.7
5	5.25	20.3
6	5.5	21.6
6	5.5	21.0
6	5.5	21.3
6	5.5	20.7
7	5.5	19.7
7	5.5	20.2
7	5.75	20.6
7	5.5	21.1
8	5.25	20.9
8	5.25	20.9
8	5	20.9
8	5.25	20.8
9	5.25	20.3
9	4	19.7
9	4.5	19.8
9	4.5	19.7
10	5	19.9
10	5.25	19.9
10	5.25	19.7
10	5.25	20.1

Table 19: Raw Data for Residual Air Values (mL) for 1%, 3% and 5% Concentrations of Retort Processed Frigex-W Starch and Water Mixtures

Concentration (%)	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**	**Run 10**
1	60	325	25	75	20	5	25	5	25	75
1	175	N/A	N/A	10	5	5	40	10	5	5
3	65	150	80	25	5	5	5	25	15	50
3	80	105	15	15	10	5	20	15	500	260
5	205	240	175	55	80	30	10	40	10	25
5	75	255	80	50	70	45	30	45	10	25

Table 20: Raw Data for L* Values for 1% Concentrations of Retort Processed Frigex-W Starch and Water Mixtures

Run	**L* Value**
Before Process	55.7
Before Process	55.54
1	50.56
1	50.68
2	48.75
2	47
3	50.06
3	51.64
4	50.77
4	50.71
5	50.73
5	50.7
6	50.51
6	50.46
7	49.7
7	49.92
8	49.3
8	49.25
9	49.89
9	49.8
10	49.52
10	49.5

Table 21: Raw Data for L* Values for 3% Concentrations of Retort Processed Frigex-W Starch and Water Mixtures

Run	**L* Value**
Before Process	50.32
Before Process	46.6
1	62.34
1	62.17
2	46.27
2	46.86
3	43.08
3	43.05
4	51.56
4	50.87
5	47.67
5	47.53
6	40.08
6	40.27
7	46.87
7	46.99
8	46.78
8	45.98
9	39.09
9	38.98
10	39.42
10	39.37

Table 22: Raw Data for L* Values for 5% Concentrations of Retort Processed Frigex-W Starch and Water Mixtures

Run	**L* Value**
Before Process	37.61
Before Process	37.72
1	58.53
1	59.15
2	39.64
2	39.63
3	38.93
3	39.83
4	40.21
4	40.87
5	39.26
5	30.34
6	39.07
6	39.26
7	39.12
7	39.35
8	38.94
8	39.11
9	41.45
9	41.19
10	38.44
10	38.3