

Abstract

SETTLE, DAVID WILLIAM. Thermal Processing of Sour Cream using Continuous Flow Microwave Heating - Feasibility Study. (Under the direction of Dr. Arthur P. Hansen and Dr. Josip Simunovic).

The purpose of this research was to develop a sour cream that could withstand the effect of UHT continuous microwave processing. The major benefit to the manufacturer of the UHT processing would be extended shelf-life, especially in conjunction with aseptic packaging. This would result in less spoilage, thus increased profits. This becomes increasingly important as sour cream increases in popularity and is sold and marketed at greater distances from the point of processing

One major problem with UHT processing of acidic dairy products is that high temperatures cause milk proteins to aggregate, especially at pH's around the pI (isoelectric point) of casein. Fouling (or burn-on) of the heat-exchanger tube walls is another factor that excludes the use of UHT processing to sterilize sour cream.

The proper formulation of sour cream with the use of stabilizers such as starch and gelatin can also minimize aggregation, reduce syneresis, and increase the viscosity of the final products. The addition of gelatin is often used in sour cream formulations as it increases water binding, whey retention, and adds to mouthfeel, and gives the final product sheen-like appearance.

In order to characterize the performance and functionality of sour cream under continuous flow microwave thermal processing conditions, seven sour cream formulations with different gelatin and starch content were produced and processed. Yield stress and viscosity tests were performed and compared to rheological tests performed on commercial brands to determine if they were within the upper and lower

commercially accepted limits. Viscosities were dynamically measured with the Stresstech. Dielectric properties of the sour cream samples were also analyzed. Dielectric measurements were taken at 5° C intervals. Microwave processing was performed using a 5 kw microwave system. Processing was performed at an output power of 3 kilowatts at 915 MHz at flow rate of 4 liters per minute to determine dielectric properties and estimate the need for formulation adjustments.

Rheological analysis of the seven NCSU sour cream formulations showed no correlations between stabilizer levels and yield stress or viscosity. Measurement of time and temperature data showed that variations were present and that processing conditions had an influence on the rheological behavior of the sour creams. Because of this, a single formulation could not be determined as optimal. All seven formulations were more viscous than the commercial brands tested but had lower yield stresses. Also, none of the seven formulations had visual casein aggregation. Rheological analysis of the seven formulations indicated that UHT continuous microwave processing was feasible using any of the formulations. This new process will allow sour cream to be aseptically packaged which had never been done. Aseptic packaging would allow manufactures to increase profit margins by reducing spoilage and eliminate refrigeration costs.

**Thermal Processing of Sour Cream using Continuous Flow
Microwave Heating - Feasibility Study**

by

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Biography

David was born on October 31, 1962. He was the second of three children. He grew up with a love of science, history, and food. He often cooked his own meals and sometimes cooked for the family. In High School he played football and basketball and soon became interested in nutrition and its effect on sports performance. After being accepted at Auburn University he entered the Chemical Engineering department. He then transferred to the University of Alabama in Huntsville where he earned a B.S. degree in Computer Science. After finishing school he was hired by Ford Aerospace's Western Development Laboratories in Palo Alto, CA. He worked there for the next 4 years as a systems analyst programming test equipment for the GOES (Geostationary Orbit Environmental Sattelite). In 1990 he married Sandra Curtis and also enrolled at the California Culinary Academy where he earned a culinary degree with high honors in 1991. In 1993, his wonderful daughter Sabrina Ivy Settle was born. He worked as a pastry chef for the next 7 years. The following 3 years were spent as the owner of HeavenScent Bakery in Raleigh NC. After that he started taking classes at N.C. State in hopes of being accepted into the Food Science Department.

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I owe special thanks to my parents and daughter for their support during this period of my life. My daughter was the person who kept me focused and if not for her my motivation would have dissapeared. Above everone else, she is the one who made the completion of this project possible. I also owe great thanks to Dr. Arthur P. Hansen, Dr. Josip Simunovic, Dr. Pablo Coronel, Sharon Ramsey, and Gary Cartwright for their professional and personal support for me during a very difficult time in my life. I would also like to recognize Dr. Jonathan Allen and Dr. Leon Boyd for their participation on this project as thesis committee members. I also thank Jimmy Buffett, Eric Clapton, Dire Straits, and other musicians that kept me company and in good spirits during those long nights and even longer days. I also need to thank all of the professors that I have had the privilege to be instructed by. Each one has shown interest in the sucessful completion of my research and offered any assistance that might be useful both in school and at a personal level.

Lastly, I would express my thanks to all my peers who have taken time out of their lives to help to me when I needed it.

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Introduction

UHT processing of milk has been a reality for many years, but some dairy products such as sour cream have not been successfully processed using UHT technology.

One problem with UHT processing of acidic dairy products is that high temperatures cause milk proteins to aggregate, especially in products that have pH's close to the pI (isoelectric point) of casein. The second problem with processing sour cream is that it is more viscous than milk. This may increase the fouling of the system walls resulting in a 'cooked' flavor.

Because of these restrictions the procedures for sour cream production and storage have changed little over the past 50 years. Storage of sour cream still relies on refrigeration. Since conventional sour cream is not pasturized after fermentation it contains active cultures and small amounts of bacteria which cause spoilage. This results in a self-life of 2 to 4 weeks.

The use of continuous microwave technology allows UHT processing to be used with minimal fouling of the system walls. The microwave energy is absorbed and converted into heat by the product. Because of this, the 'hot spot' is at the center of the flow profile (tube wall radius = 0) while the 'cold spot' is the inside of the tube.

UHT processing with continuous microwave technology in conjunction with aseptic packaging would be a boon to the sour cream industry. It would virtually eliminate financial losses due to spoilage and would eliminate refrigeration costs. This would result in higher profit margins.

Review of Literature

2.1 Fermented Dairy Products

2.1.1 The History of Fermented Dairy Products

The origin of fermented foods and cultured milk products predates recorded history. Most cultured foods start with milk, which people have been drinking since the dawn of agriculture. The first evidence of the domestication of cows occurred in 9,000 BC in Libya, and while there are no written records that prove these ancient people ate yogurt, the probability is high that they consumed cultured milk products of some sort (Wikipedia Encyclopedia, New Dairy Culture-Australia Dairy 2003). India's Ayurvedic writings, dating back to 6,000 BC, indicate that regular consumption of dairy products led to a long and healthy life. In India, the milk of almost every animal, from camels to yaks, continues to be made into cultured foods, including yogurt and cheese, of which there are more than 700 varieties.

Cultured foods first occurred naturally, probably from organisms present in the food itself or in the environment. Because these foods were pleasant tasting, it is likely that people soon learned to save a "starter culture" from a particularly good batch of yogurt or other cultured food. This starter was added to a bowl of fresh milk to induce fermentation.

Written records confirm that the conquering armies of Genghis Khan depended heavily on yogurt as a food source. History tells us that by the year 1206, Genghis Khan had conquered all of Mongolia and united the warring tribes under his banner. By 1215,

the Mongols held most of the Ch'in Empire and had vanquished Turkistan and Afghanistan. They even penetrated southeastern Europe.

Highly mobile, the Mongols rode small, swift horses that were bred to traverse the vast plains of the Mongolian empire. Every Mongol's wealth was measured by the number of horses he owned, and each soldier traveled with a large string of them. These hardy horses were what helped make this army invincible. Not only did they carry soldiers into battle, they also provided the rich milk that was fermented and enjoyed by every member of the conquering hordes—from the Great Khan to the lowliest slave. Known as kumiss, this is one of the earliest known fermented milk products. Highly nutritious, kumiss not only sustained the Mongols, it kept them healthy.

Kefir, another cultured milk product, originated in the Caucasus Mountains of Russia. It is variously cultured from the milk of goats, sheep, or cows. Its name translates loosely to "pleasure" or "good feeling." Due to its health-promoting properties, kefir was once considered a gift from the gods. Ever since the eighteenth century, kefir has been credited with healing powers. As early travelers to the Caucasus region came home with stories of its powerful healing properties, everyone wanted some of this medicinal miracle food. However, the necessary starter cultures, which were passed from generation to generation among the Mosley tribesmen of the Caucasus, were considered a very real source of family and tribal wealth. The tribes guarded the secret process jealously and protected it with their very lives. Microbial cultures used in a granular form were added to milk which caused lactic acid and alcohol to be produced. This process produces kefir. Kefir appears to be of great benefit

for old people, and in the U.S.S.R., it is one of the fermented milks used in the treatment of tuberculosis and other diseases.

In 1908, the health benefits of friendly bacteria first came to the attention of the general public, when Dr. Elie Metchnikoff, a Russian biologist, wrote “The Prolongation of Life”. Based on the research that earned him one of the world’s top honors, this book stunned the medical and scientific communities. In it, Dr. Metchnikoff recognized that certain white blood cells known as phagocytes ingest and destroy dangerous bacteria, a fact we now know to be true. Dr. Metchnikoff shared the 1908 Nobel Prize in Physiology and Medicine for identifying the process of phagocytosis, an important function of the immune system.

Concurrent with his work on the immune system, and perhaps closer to his heart, Dr. Metchnikoff devoted the last ten years of his life to the study of lactic acid-producing bacteria as a means of increasing life span. After much research, he was convinced that he had discovered why so many Bulgarians lived noticeably longer than other people. This phenomenon, he theorized, was due to their consumption of large quantities of cultured foods, especially yogurt, which he believed help maintain the benign (“friendly”) bacteria that live in the gastrointestinal tract. Today, we know his belief to be true.

Dr. Metchnikoff was among the first to recognize the relationship between disease and what he called the “poisons” produced in the bowel. He demonstrated how beneficial living bacteria normalize bowel habits and fight disease-carrying bacteria, thereby extending the normal life span. His book persuaded many that living longer is

the happy result of an intestinal tract that maintains a healthy daily supply of the cultured bacteria found in yogurt. It was Dr. Metchnikoff who named the primary yogurt-culturing bacteria *Lactobacillus bulgaricus*, in honor of the yogurt-loving Bulgarians (Trenev, 1998). Today, yogurt is enjoyed just about everywhere, with the exception of the Chinese, who prefer fermented soy products.

The friendly bacteria used to culture true yogurt are *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. When these bacteria are added to milk and allowed to ferment, the resulting culture is a naturally sweet, mildly tangy, smooth, fresh-tasting custard-like treat. And, thanks to the action of the bacteria, true yogurt is almost a “predigested” food. Within an hour after eating yogurt, 90 percent of it is digested. Compare this to a glass of milk, of which only 30 percent is digested in the same amount of time. More importantly, the friendly live bacteria present in true yogurt offer health benefit.

Sour Cream is a light cream (18% milk fat) with *Lactobacillus* and *Streptococcus lactis* bacteria added. Like yogurt, the lactose is used as a food source for the bacterial culture. Lactic acid is a by-product which causes protein gels to form due to a drop in pH. Real sour or cultured cream is the result of natural lactic acid fermentation, although rennet is sometimes added to create a thicker body. Sour cream has fewer calories than mayonnaise and is used in the same way. Sometimes cream is soured by chemicals and thickened with gums; then it is not a fermented product, but the packaging does not always state this clearly.

Sour cream has long been a traditional ingredient in Russian, Eastern European and German cooking, and has gained popularity in the rest of Europe, North America, and other parts of the world in the past 50 years or so. It was traditionally made by letting fresh cream sour naturally. The acids and bacteria present produced a generally consistent flavor and thick texture that went well with both sweet and savory dishes. These days, commercially produced sour cream is made by inoculating pasteurized light cream with bacteria cultures, letting the bacteria grow until the cream is both soured and thick and then refrigerating to stop the process.

Smetana (Czech and Slovenian: smetana, Slovak: smotana, Polish: śmietana, Russian: сметана) is an East European variety of sour cream. It is much heavier and sweeter than the West European variety and hard to get in the West. It is used very often in certain East European cuisines.

Another relative of sour cream is crème fraîche, which is also a soured cream. The taste is generally milder than that of sour cream and has a higher fat content. Crème fraîche is a slightly tangy, slightly nutty, and less thick than sour cream. Before the age of pasteurization crème fraîche made itself as the bacteria present in the cream fermented and thickened it naturally. It is widely available in Europe, but much less so in the US, where almost all cream is pasteurized, and therefore has to be inoculated with a bacterial culture. In general, crème fraîche and sour cream can be used interchangeably in most recipes, but crème fraîche has two advantages over sour cream: it can be whipped like whipping cream, and it will not curdle if boiled.

Buttermilk is another fermented milk product. Originally it was the liquids left after cream was churned into butter. Today, it is made commercially with lowfat milk with *Lactobacillus* and *Streptococcus lactis* bacteria added. Stabilizers are often added to buttermilk, usually carrageenan and guar gum, to increase viscosity, mouth-feel, and extend shelf-life by reducing protein aggregation.

2.1.2 Dairy Industry Trends

The year 2000 was challenging for most U.S. dairy producers, who experienced some of the lowest farm milk prices in decades. From July 2000 to July 2001, the number of dairy farms fell by 6,307. This represents 7.6% of dairy farms in business in 1999 and is the second largest percentage loss in 10 years. Losses occurred nationwide and varied substantially by region. The Midwest and Southeast incurred losses of 8.5% and 8.4% respectively, while the Northeast experienced a 6.2% drop. Western farms fell by 3.6%.

Nationwide, 42% of the dairy operations from 1992 are no longer milking cows. Although those involved and their communities were affected, the industry is dynamic and changing. While the U.S. lost almost 55,000 herds since 1992, the country lost only 6% of cows, and milk production has increased from 150.8 billion pounds in 1992 to 167.7 billion pounds in 2000. This current trend indicates a move toward larger herds but fewer farms.

As Table 2.1 indicates, change is occurring at varying rates across all regions. The West and the Northeast lost the smallest percentage of their herds (at 30 and 34% respectively). Herd size has increased most rapidly in the West and at the slowest rate in

the Northeast. Average Western herd size has nearly doubled in the past decade and is now more than three times greater than the next closest region, the Southeast. The West is also the only region where cow numbers have increased, with a gain of 782,000 cows or 37%. The nation, as a whole, lost 6% of its cows over this time period.

Table 2.1. Regional Changes from 1992 to 2001 in Herd size and herd numbers².

Region	1992			2001			Change (%)		
	Herds Cows ¹ (1,000's)	Cows /Herd	Herds	Herds Cows ¹ (1,000's)	Cows /Herd	Herds			
Southeast	14,165	1,628	115	7,485	1,244	166	-47	-24	45
West	7,450	2,140	288	5,218	2,922	560	-30	37	95
Northeast	29,785	1,824	61	19,658	1,650	84	-34	-10	37
Midwest	80,135	4,100	51	44,269	3,308	75	-45	-19	46
U.S.	131,535	9,692	74	76,630	9,124	119	-42	-6	62

¹ Cow numbers from NASS Milk Production Reports

² Surveys in prior years were conducted for the American Farm Bureau Federation. Herd numbers in this report from 1992 through 2000 are from those surveys

While the magnitude of herd and cow numbers differ, the Midwest and Southeast have lost herds and increased herd size at approximately the same rate. Milk prices, feed costs and other conditions vary between the two regions, but it appears that producers have been reacting in a similar manner. While we now see increased interest in large, new operations moving into the Midwest, over the past ten years the region has lost slightly more cows than the West gained.

Trends indicate the rapid rate of change that is occurring in the dairy industry. The changes affect not only producers, but also their communities, the industry infrastructure and business decisions made by the industry as a whole (Olson, 2001). One of the few dairy commodities that have seen positive changes occur is sour cream.

2.1.3 The Sour Cream Economic Market

In 2002, sour cream sales were up 5.4% to 685 million pounds, as compared to 2001. This increase is largely attributed to a growing hispanic community in the U.S. Hispanics are now the largest minority group in America, growing 67.5% between 1990 and 2002. At this rate, by 2012, nearly 1 in 5 people in the US will be hispanic (Anonymous, 2003). Also, Hispanic foods have gained popularity among non-hispanics. Sour cream consumption is also increasing because, according to the American Dairy Association, snacking and entertaining were the two overall hottest food trends for 2003. Dairy case dips, which use sour cream as the main ingredient, are perfect compliments to these trends (Anonymous, April 2003).

According to data from the USDA the average American in 2004 consumed 3.6 pounds more sour cream than in 1954. Figure 2.1 shows the growth in popularity of sour cream from 1954 to 2005.

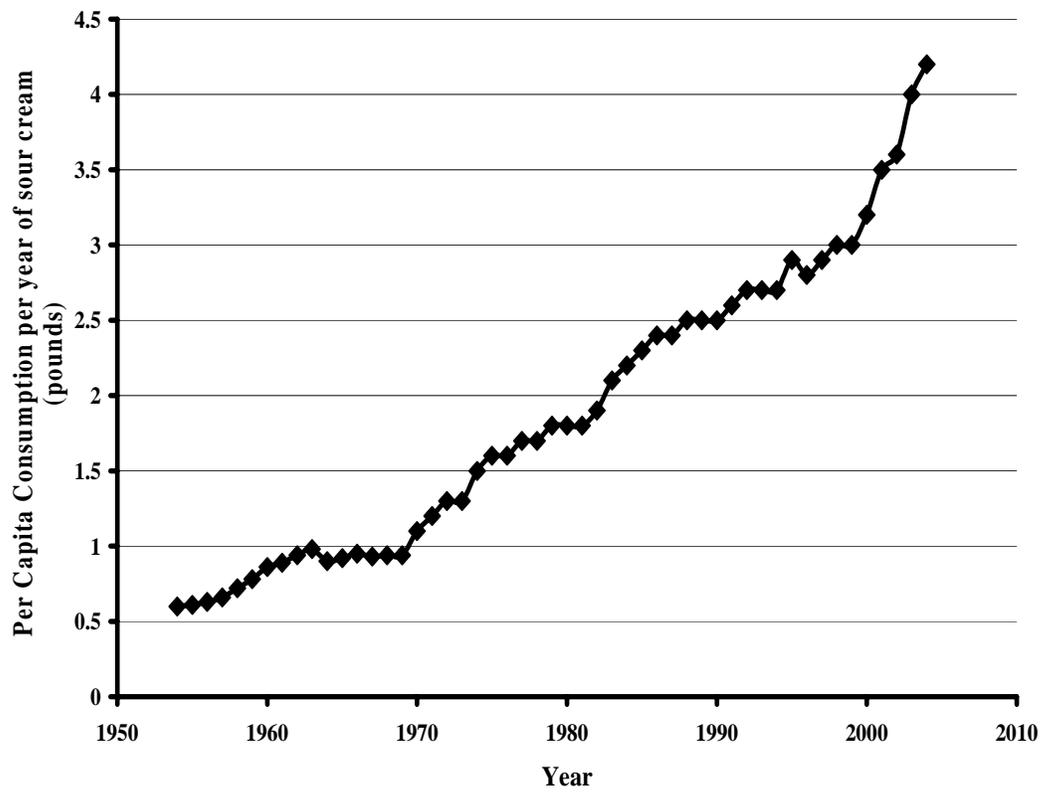


Figure 2.1: U.S. per capita consumption of sour cream¹

¹ Source: USDA/Economic Research Service. Last updated Dec. 21, 2005

2.2 Methods of Thermal Processing

2.2.1 Introduction

While pasteurization effectively eliminates potential pathogenic microorganisms, it also eliminates the probiotic benefits of cultured dairy products but it is not sufficient to inactivate the thermo-resistant spores in milk. Pasteurization is a method of destroying 95-99% of pathogenic bacteria in milk. This process increases shelf life of refrigerated milk. Combinations of heat and time minimize breakdown of vitamins and proteins. Several methods of Pasteurization exist. Batch pasteurization is performed at 145° F (63° C) for 30 minutes. High temperature short time (HTST) pasteurization is performed for 16 seconds at 161° F (72° C). HTST is currently the most popular method of pasteurization in the United States. Flash pasteurization is performed at 212° F (100° C) for 0.01 seconds. Ultra-pasteurization involves processing at 280° F (138° C) for 2 seconds. This provides a longer shelf life. Sterilization occurs at Ultra-high temperature (UHT) processing which is performed at 280° F (138° C) for 2-6 seconds. UHT processed milk is popular worldwide because it is sterile and shelf stable (Anonymous, 2003).

The term “sterilization” or “sterile” refers to the complete elimination of all microorganisms. The food industry uses the more realistic term “commercial sterilization”; a product is not necessarily free of all microorganisms, but those that survive the sterilization process are unlikely to grow during storage and cause product spoilage.

In retort canning processes it must be ensured that the “cold spot” has reached the desired temperature for the desired time. The “cold spot” is the thermal center of a food item and is the last area of an item to reach the desired temperature. With most canned products, there is a low rate of heat penetration to the thermal center. This leads to over-processing of some portions, and damage to nutritional and sensory characteristics, especially near the walls of the container. Longer processing times at lower temperatures often alleviates this problem.

Milk can be made commercially sterile by subjecting it to temperatures in excess of 100° C, and packaging it in air-tight containers. The milk may be packaged either before or after sterilization. The basis of ultra-high temperature (UHT) is the sterilization of food before packaging, then filling into pre-sterilized containers in a sterile atmosphere. Milk that is processed in this way using temperatures exceeding 135° C permits a decrease in the necessary holding time (2-6 sec) and enables the use of a continuous flow operation. Some examples of food products processed with UHT are liquid products such as milk, juices, cream, yogurt, wine, salad dressings. Foods with discrete particles (i.e. baby foods; tomato products; fruits and vegetables juices; soups, and larger particles such as the ones in stews) can also be good candidates for UHT processing.

2.2.2 Thermal Death Time (F)

In order to calculate appropriate time/temperature processes, thermal death time calculations are used. Thermal death time (F) is the total time required to accomplish a stated reduction in a population of vegetative cells or spores. F can be expressed as a multiple of D values (where D is the value for *Clostridium Botulinum*), as long as the survival curve is 1st order. The thermal death time (TDT) or F-value is calculated using the following equation:

$$F_0 = \int_0^t 10^{\frac{T(t)-T_0}{z}} dt$$

The subscript "0" is used to denote that the sterilization value has been normalized to a reference microorganism at a reference temperature (T_0). This method was proposed initially by Bigelow and others (1920) and has been used as a conservative approach to processing. The reference temperature used is 121.1 °C and the reference z value is that of *Clostridium Botulinum* (10 °C) at given reference temperature.

In food science literature for thermal processes, F is expressed with a subscript denoting the process temperature and a superscript denoting the z value for the organism being considered (Singh and Heldman, 2001). The z value is dependent on temperature, but the changes within a reasonable range of temperatures are small, and it can be considered constant. For sterilization processes, the reference temperature is 121.1 °C (250 °F), and the reference microorganism has a z value of *Clostridium Botulinum* (10 °C) Thus, F_T^z is the thermal death time for a temperature (T) and thermal

resistance (z). The common reference thermal time is for *Clostridium Botulinum* and is expressed as expressed as F_{121}^{10} or just F_0 , as stated above.

2.2.3 UHT Processing

Direct heating systems

As implied, the product is heated by direct contact with steam of culinary quality. Culinary steam is defined as steam that is suitable for direct injection into food products or direct contact with food products or surfaces that contact foods. The main advantage of direct heating is that the product is held at the elevated temperature for a shorter period of time. For a heat-sensitive product such as milk, this means less damage (Figure 2.2). There are two ways to achieve this. The first is steam injection. This procedure requires that high pressure steam is injected into pre-heated liquid by a steam injector leading to a rapid rise in temperature (Figure 2.3). After holding, the product is flash-cooled in a vacuum to remove an amount of water equivalent to amount of condensed steam added. This method allows fast heating and cooling, and volatile removal, but is only suitable for some products. It is energy intensive and because the product comes in contact with hot equipment, there is potential for flavor damage. The second method is steam infusion (Figure 2.4). This requires that a liquid product is pumped through a distributing nozzle into a chamber of high pressure steam. This system is characterized by a large steam volume and a small product volume, distributed in a large surface area of product. Product temperature is accurately controlled via pressure. Additional holding time may be accomplished through the use of plate or tubular heat exchangers, followed by flash cooling in vacuum chamber. This

method has the advantages of instantaneous heating and rapid cooling, no localized overheating or burn-on, it is suitable for low and higher viscosity products.

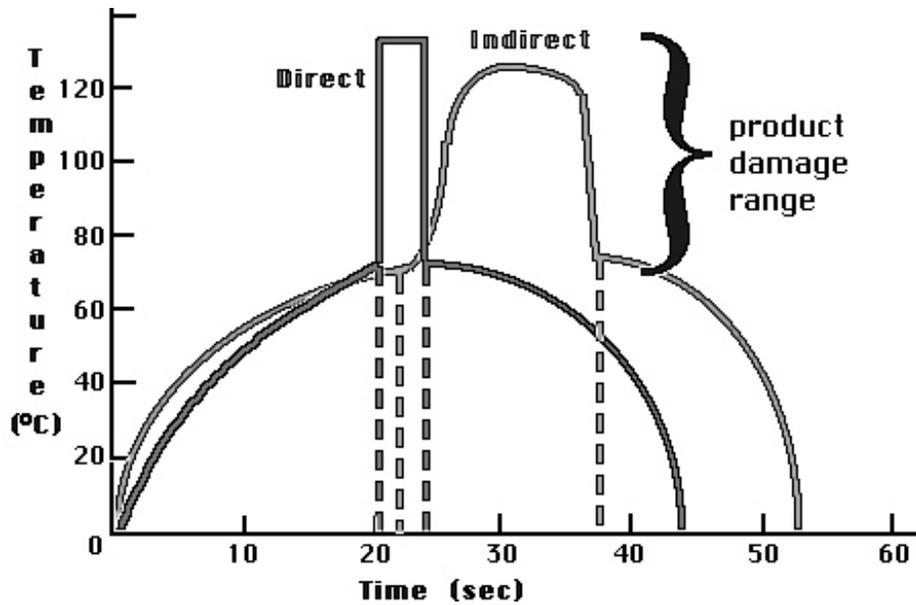


Figure 2.2: Time/Temperature curves for Direct and Indirect Continuous Sterilization Methods and product damage range

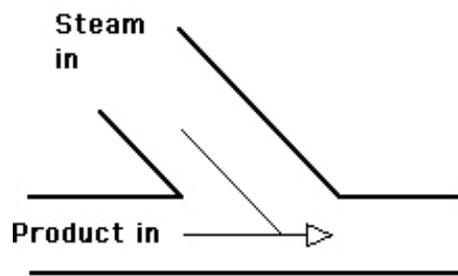


Figure 2.3: Diagram of a Steam Injection Valve

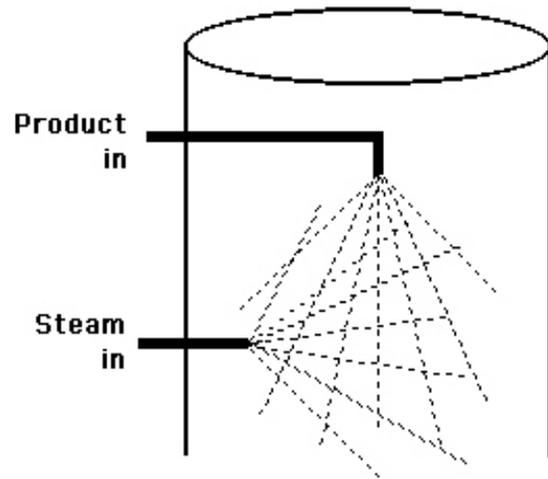


Figure 2.4 Diagram of a Steam Infusion Chamber

Indirect heating systems

In this method the heating medium and product are not in direct contact, but separated by equipment contact surfaces. Several types of heat exchangers are applicable and they include plate, tubular, scraped surface, and double-cone configurations.

Plate Heat Exchangers are similar to that used in HTST but operating pressures are limited by gaskets which results in lower liquid velocities. Low flow rates can lead to uneven heating and burn-on because of overexposure of the product to the plates and lack of turbulent flow rate which would result in more even heat distribution. This method is economical in floor space, easily inspected, and allows for potential energy conservation and regeneration. Products processed with this method should have low viscosities.

Tubular Heat Exchangers are available in several types which include shell and tube, shell and coil, double tube, and triple tube. All of these tubular heat exchangers have fewer seals involved than with plates. This allows for higher pressures, thus higher flow rates and higher temperatures. The heating is more uniform but difficult to inspect.

Scraped Surface Heat Exchangers work by pumping the product through a jacketed tube, which contains the heating medium, and is scraped from the sides with a rotating knife. This method is suitable for viscous products and particulates (< 1 cm) such as fruit sauces, peanut butter, tomato paste and other high viscosity materials. There is a problem with larger particulates; the long process time for particulates would

mean long holding sections which are impractical. This may lead to damaged solids and over processing of sauce (Singh, 2001).

Double-cone Heat Exchangers are suitable for large particulates because they involve separation of solids from the liquids and combine indirect heating in a double cone (batch) with direct heating of the liquid portion (may also be a scraped surface if the product is too viscous). The solid pieces are fed into a double-cone, rotated slowly on the horizontal axis with steam injection and heated surfaces. There is no burn-on because they are the same temperature. The liquid is directly heated with steam separately, and then added to the solids after pre-cooling. The double cone acts as a blender and coats solids. The product is then discharged to an aseptic filler by overpressure with sterile air. This method is useful for soups, stews, carrots, and vegetables. (www.dairyconsultant.co.uk/pages/UHT_process.htm, www.foodsci.uoguelph.ca)

Advantages of UHT

The reduction in process time due to higher temperature and the minimal come-up and cool-down time leads to a higher quality product, resulting in a shelf life of 6 months or greater, without refrigeration. Initially this process uses more energy, especially in conjunction with aseptic packaging. The increase in energy costs are recovered because spoilage is reduced and refrigeration is eliminated. UHT also allows for versatility when packaging the product. Processing conditions are independent of container size, thus allowing for the filling of large containers for food service or sale to food manufacturers.

Disadvantages of UHT

Complex equipment and processing plant design are needed to maintain sterile atmosphere between processing and packaging. This results in more highly skilled operators and larger payroll costs. Sterility must be maintained through aseptic packaging. Particle size can be a limiting factor. With larger particulates there is a danger of overcooking of surfaces and need to transport material, both of which limit particle size. There is also a lack of equipment for particulate sterilization, due especially to settling of solids and thus over processing.

Special heating and cooling requirements are also needed. The heating of a liquid food using UHT processing may require finite time for the product temperature to increase from the initial temperature to the holding tube temperature. Due to regulations, the lethality associated with the area under the lethal curve may not be considered. Only when the heating and cooling are instantaneous will the lethality of the process be equal to the lethality accumulated during the holding time. (Singh, Heldman, 2001., www.dairyconsultant.co.uk/pages/UHT_process.htm, www.foodsci.uoguelph.ca)

UHT processing extends shelf life and increases the initial quality of dairy products. Quality may decrease with time due to heat stable lipases and proteases produced by bacteria prior to sterilization. This can lead to flavor deterioration and age gelation of the product over time. UHT milk also has a more pronounced “cooked” flavor.

2.2.4 Microwave Thermal Processing

Introduction

Microwaves are a form of electromagnetic wave. The most familiar kind of electromagnetic wave is visible light. It takes energy to produce light and microwaves. A typical microwave oven needs several hundred watts of energy to make microwave energy powerful enough to heat a food product.

Like light, microwaves travel very fast, about 186,000 miles (300,000 kilometers) per second in air. In addition, both light and microwaves get weaker the further they travel from their source, and both can be focused into narrow beams by lenses (such as a magnifying lens) or concave mirrors called reflectors. This is because of the biggest difference between microwaves and light waves: their wavelengths. Light waves and microwaves are both electromagnetic waves and, therefore, part of the electromagnetic spectrum. The electromagnetic spectrum is the range of all electromagnetic waves. It includes everything from radio waves to microwaves, infrared and ultraviolet rays, and gamma rays.

Each of the different types of waves has a different wavelength. The length of a wave is not how far it travels, but how far it is from one peak of a wave to the next peak. Microwaves have much longer wavelengths than light, ranging from about 1 centimeter to 30 centimeters (about half an inch to a foot) and a frequency that range from 300 to 300,000 MHz. In the years since microwaves were discovered they have been used in many ways, including radar, telecommunications, television, and heating of food products (Ishii, 1995; Sadiku, 1995).

One of the most common non-military uses of microwaves is, of course, the microwave oven. Like many of today's great inventions, the microwave oven was a by-product of another technology. It was during a radar-related research project around 1946 that Dr. Percy Spencer was testing a new vacuum tube called a magnetron when he discovered that food placed near the magnetron increased in temperature. The logical scientific conclusion was that temperature increases were all attributable to exposure to low-density microwave energy. Dr. Spencer then fashioned a metal box with an opening into which he fed microwave power. The energy entering the box was unable to escape, thereby creating a higher density electromagnetic field. When food was placed in the box and microwave energy fed in, the temperature of the food rose very rapidly. Dr. Spencer had invented what was to revolutionize cooking, and formed the basis of a multimillion dollar industry, the microwave oven. (Patent # 2,495,429). (http://smecc.org/microwave_oven.htm)

Doctor Spencer continued at Raytheon as a senior consultant until he died at the age of 76. At the time of his death, Dr. Spencer held 150 patents and was considered one of the world's leading experts in the field of microwave energy, despite his lack of a high school education.

Engineers developed and refined Dr. Spencer's discovery for practical use. By late 1946, the Raytheon Company had filed a patent proposing that microwaves be used to cook food. An oven that heated food using microwave energy was then placed in a Boston restaurant for testing. At last, in 1947, the first commercial microwave oven hit the market. These primitive units were gigantic and enormously expensive, standing 5

½ feet tall, weighing over 750 pounds, and costing about \$5000 each. The magnetron tube had to be water-cooled, so plumbing installations were also required. In 1947, Raytheon demonstrated the world's first microwave oven and called it a "Radarange," the winning name in an employee contest. Housed in refrigerator-sized cabinets, the first microwave ovens cost between \$2,000 and \$3,000. Between 1952-55, Tappan introduced the first home model priced at \$1295. In 1965 Raytheon acquired Amana Refrigeration. Two years later, the first countertop, domestic oven was introduced. It was a 100-volt microwave oven, which cost just under \$500 and was smaller, safer and more reliable than previous models.

Technological advances and further developments led to a microwave oven that was priced for the consumer kitchen. However, there were many myths and fears surrounding these mysterious new electronic "radar ranges." By the seventies, more and more people were finding the benefits of microwave cooking to outweigh the possible risks, and none of them were dying of radiation poisoning, going blind, sterile, or becoming impotent. As fears faded, a swelling wave of acceptance began filtering into the kitchens of America and other countries. Myths were melting away, and doubt was turning into demand. By 1975, sales of microwave ovens would, for the first time, exceed that of gas ranges. The following year, a reported 17% of all homes in Japan were doing their cooking by microwaves, compared with 4% of the homes in the United States the same year. Before long, though, microwave ovens were adorning the kitchens in over nine million homes, or about 14%, of all the homes in the United States. In 1976, the microwave oven became a more commonly owned kitchen appliance than the

dishwasher, reaching nearly 60%, or about 52 million U.S. households. America's cooking habits were being drastically changed by the time and energy-saving convenience of the microwave oven. Once considered a luxury, the microwave oven had developed into a practical necessity for a fast-paced world. An expanding market has produced a style to suit every taste; a size, shape, and color to fit any kitchen, and a price to please almost every pocketbook. Options and features, such as the addition of convection heat, probe and sensor cooking, meet the needs of virtually every cooking, heating or drying application. Today, the magic of microwave cooking has radiated around the globe, becoming an international phenomenon.

The microwave oven had reached a new level of acceptance, particularly with regard to certain industrial applications. By having a microwave oven available, restaurants and vending companies could now keep products refrigerator-fresh up to the point of service, then heat to order. This results in fresher food, less waste, and money saved (Anonymous, 2006; Cowen, 1997).

As the food industry began to recognize the potential and versatility of the microwave oven, its usefulness was put to new tests. Industries began using microwaves to dry potato chips and roast coffee beans and peanuts. Meats could be defrosted, precooked and tempered. Even the shucking of oysters was made easier by microwaves. Other industries found the diverse applications of microwave heating quite advantageous. In time, microwaves were being used to dry cork, ceramics, paper, leather, tobacco, textiles, pencils, flowers, wet books and match heads. The microwave

oven has become a necessity in the commercial market and the possibilities seem endless.

Figure 2.5 shows a schematic diagram of the 5 kw system. The system consists of a microwave generator which contains the Magnetron. The Magnetron converts electrical energy to microwaves which are transmitted into the wave guide. The microwaves travel through the wave guide into the reactor. The waves reflect off the reactor walls. The waves are focused so that they converge at the center of the reactor where the product transport tube is located. The microwaves are converted into heat by the food product. The product is circulated through this system repeatedly until the desired temperature is reached. Temperature is monitored using thermocouples at the entrance and exit of the reactor. The temperature and time are recorded during the processing run. Once the desired temperature is reached the microwave generator is turned off. The product is then cooled by applying ice to the exterior of the transport tubes. Once the product is below 100° C the system is slowly depressurized by slightly loosening the sealed top of the product bin. Once the system is completely depressurized the product transport tube is disconnected and the product is pumped into storage containers.

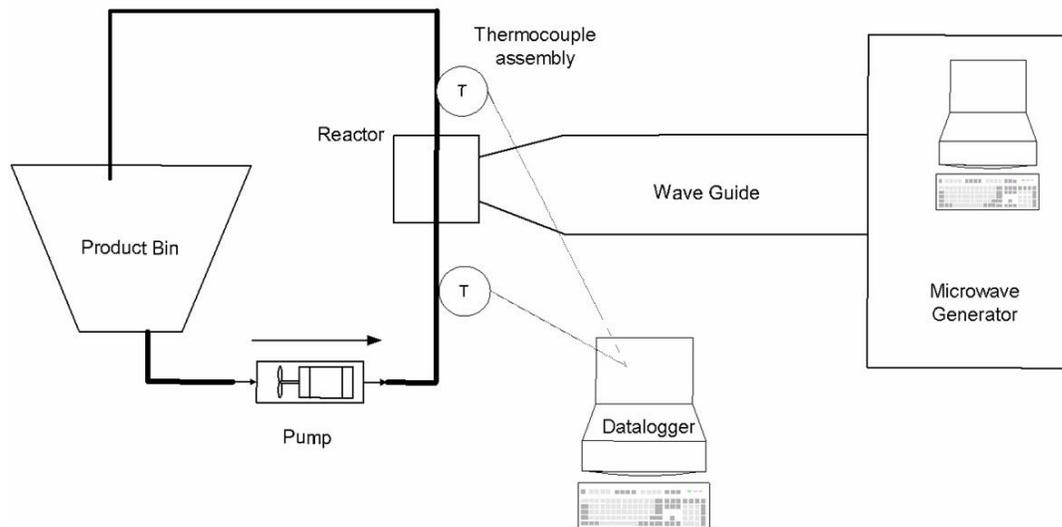


Figure 2.5: Schematic diagram of the 5-kilowatt system

Dairy Processing using Microwave Technology

One of the challenges processors face is being able to provide consumers with products that meet their expectations every time regardless of what point the product is in its life-cycle. Longer shelf life of products is essential for the dairy industry to remain prosperous because of the change in distribution practices. This is due to the decrease in the number of dairies and an increase in larger herds (Olson, 2001), which increases the average distance between processing locations and the consumer. Increased shelf life can increase the processing and distribution efficiency, reduce spoilage and insure the consumer receives higher quality dairy products.

Each dairy product has its own processing procedures and problems. Two major issues related to the processing performance of sour cream are fouling of the smoothing valve and the stability to syneresis during freezing and thawing. To render the texture of

an acidified gel commercially acceptable as sour cream, the process of smoothing is introduced after the gel network is broken. Although several techniques have been used to smooth the texture, one of the most popular is the use of a single service homogenization valve. This valve can be described as a tightly woven stainless steel plug that creates a mild shear force by flow diversion when the product is pumped through it (Hunt and Maynes, 1997).

One of the new methods of extending shelf life of dairy products is microwave heating. Currently available industrial methods of heating (indirect heating using plate or tubular heat exchangers and direct heating using steam injection or infusion) cause undesirable quality changes in dairy products such as 'cooked' flavors, especially in viscous thermo-sensitive products. Increased fouling of the heat exchanger walls can also occur which can raise processing costs due to cleaning and maintenance. To achieve the UHT pasteurization of sour cream without these negative effects, the use of rapid continuous non-contact heating using cylindrical microwave heaters was implemented. Cylindrical microwave heaters/reactors are patented devices providing a focused, uniform high powered microwave energy field across a cylindrical exposure region containing a microwave transparent tube made of Teflon[®] through which the processed material is pumped. This will enable heating the product to 135°C to 145°C for 2 seconds to produce a commercially sterile sour cream. This new patented technology enables rapid continuous and uniform heat delivery to pumpable products which results in a reduction of heat induced flavor compounds and a reduction of the degradation of nutritional components, and reduced fouling of the pipe walls.

Very little is known about microwave heating of sour cream for extended shelf life (ESL) products. J.J. Tuchy et al 1987 demonstrated that cream and sour cream shelf life could be extended by using a hot fill system where the product is heated to 73-80°C, then taken directly from the pasteurizer and filled into plastic pouches on a Jencopack FFS machine. Pouches were then cooled to 10° C in 15-20 minutes by immersion in a water bath cooled to 3° C. In the second system, which was an ultra clean cold-filling system, product from the chilled section of the pasteurizer was filled into form fill-seal pouches that had been sterilized in a unit utilizing H₂O₂ high intensity UV light, hot sterile air and bacterial filters. Product contact surfaces down stream of the pasteurizer were cleaned at 88° C. Both systems improved keeping quality of product held at 4-7° C compared with the commercially pasteurized controls. Products filled on the ultra-clean system had longer shelf life than those filled on the hot fill system (e.g. shelf life of low acid products were extended by approximately 10 days). The hot fill system was an effective method for high acid dairy products such as sour cream. Microwave heating coupled with thermal properties of food materials and variation of thermal delivery as a result of processed material property variation have been provided by the following researchers; Saltiel and Datta 1998, Zhong and Datta 1999, Datta 2000, H. Zang and Datta 2000, Lau et al. 1998, 1999a, 1999b.

Over the years, numerous attempts have been reported to evaluate the potential of milk pasteurization using microwaves (Hamid et al, 1969., Sall, 1976., Chiu et al, 1984, Knutson et al, 1988, Thompson et al, 1990, Kudra et al, 1991). Most of these researchers provided valuable information using microwave ovens, but they did not

attempt to address the key issues of microwave processing in an industrial environment, such as thorough and even heating of the product. Despite more than a 30-year history of research and development, continuous microwave pasteurization and sterilization of foods is still considered an alternative and emerging technology. As such, it is subject to special scrutiny by the government regulatory agencies to insure that the products marketed to the public using this technology are safe. A report by Fleishman and Larken 2000 presented the U.S. Food and Drug Administration perspectives on microwave pasteurization and sterilization processes. Compared to other alternative and emerging technologies for food processing, continuous processing of homogeneous fluid foods using microwave energy appears to be in a very favorable position for rapid commercialization and is facing the lowest level of regulatory concern.

2.3 Protein Gelation, Aggregation, and Stabilization

Aggregation and gelation of proteins can occur as the pH approaches the pI for that protein. By lowering the pH through fermentation, a gel network is formed from the two main proteins in cow's milk, Casein (80%) and Whey (20%). The gel network gives firmness to the finished product. Aggregation of the proteins occurs when heat processing is combined with agitation, which produces a clotted texture. Denaturation of whey proteins during pasteurization of milk results in the formation of whey protein aggregates and whey protein-coated casein micelles. After cooling a substantial number of thiol groups remains exposed. Formation of larger disulfide-linked protein structures during acidification at ambient temperature was demonstrated by SDS-agarose gel electrophoresis and dynamic light scattering (Vasbinder et al, 2003).

Historically, acidification of heated milk was applied as a preservation technique. Now, acidified products like yogurt are highly appreciated for their texture, taste and health properties. During yogurt and sour cream preparation, the milk is subjected to a heat treatment before acidification. Therefore, production of yogurt (and sour cream) can be seen as a two-step process (Vasbinder et al, 2003).

On heat treatment at temperatures higher than 70°C the major whey proteins, i.e. β -lactoglobulin (β -lg) and α -lactalbumin (α -lac), denature. The temperature-induced conformational change of β -lg results in the exposure of both hydrophobic parts of the polypeptide and reactive thiol groups. These reactive thiol groups can form disulfide links with other reactive thiol groups or disulfide bridges as present in α -lac, β -lg, BSA, k-and as β -casein through thiol group/disulfide bond interchange reactions. During the heating of milk, mainly β -lg interacts covalently with k-casein present at the exterior of the casein micelles (Corredig & Dalgleish, 1996; Jang & Swaisgood, 1990; Singh, 1993). However, significant quantities of α -lactalbumin and the minor whey proteins also can interact with the casein micelles (Corredig & Dalgleish, 1996; Oldfield et al, 2000). Additionally, soluble disulfide-linked whey protein aggregates are formed (Oldfield et al., 2000; Anema & Klostermeyer, 1997). So, heated milk is a complex mixture of native and denatured whey proteins and casein micelles in which the denatured whey proteins occur either as whey protein aggregates or as whey protein aggregates bound to casein micelles. A significant amount of thiol groups will remain active after cooling the milk to ambient temperature (Hashizume & Sato, 1988; Guincamp, Humbert et al, 1993).

Acidification of milk towards the pI of casein, i.e. pH 4.6, lowers the stability of the k-casein on the surface of the casein micelles (Tuinier & De Kruif, 2002). The casein micelles lose their steric stabilization and Van der Waals attraction causes flocculation. Heat treatment of milk prior to acidification of milk at temperatures ranging from 201°C to 401°C changes the gelation properties markedly compared to those of unheated milk. Heat treatment has caused a shift in gelation pH towards higher pH values (Heertje et al, 1985; Horne & Davidson, 1993; Lucey et al, 1997; Vasbinder, et al, 2001). The final gel formed has an increased gel hardness, higher storage modulus(G') (Lucey et al., 1997; Lucey et al, 1998; Parnell-Clunies, et al, 1988; van Vliet & Keetels, 1995) and shows less susceptibility to syneresis. These effects are related to whey protein denaturation and the whey protein coating of the casein micelles, causing an increase of the gelation pH from 4.6 (pI casein micelles) to 5.2 (pI whey proteins) (Vasbinder et al., 2001). Electron microscopy revealed that heat treatment of milk changed casein micelles into micelles with appendages composed of whey proteins on the surface. These whey protein coated micelles are thought to cause the increased gel hardness and decreased syneresis as they prevent coalescence of the micelles and increase the number of contact points between the micelles (Davies, Shankar, Brooker, & Hobbs, 1978; Heertje et al., 1985; Mottar & Bassier, 1989).

High temperature does not denature casein but can cause it to irreversibly aggregate. Also, depending primarily on pH (generally below pH 6.2), the large aggregates, bonded by covalent crosslinking, coagulate and a gel may be formed (Fox and McSweeney, 1998; Walstra et al., 1999). Other reactions and conditions, such as

those involving calcium bridging or the depletion of k-casein from the micelles, may play a role in the heat coagulation. Although this aggregation of casein and possible subsequent coagulation may affect the viscosity of the milk more than the denaturation of the serum proteins, very high temperatures and other specific conditions must be met (Fox and McSweeney, 1998; Walstra et al., 1999).

Addition of different proteins causes increased firmness and less syneresis. Gelatin behaved differently from milk proteins by binding large amounts of water without increasing the firmness as much as the added milk proteins. Gelatin was also superior for smoothness and appearance (Rash, 1990).

Gelatin is a high-molecular-weight polypeptide, gelatin consists of chains of 300 to 4,000 amino acids (primarily glycine and proline/hydroxyproline). It is derived from animal collagen, mainly pork or beef, but other sources are available, most notably fish. Boiling hydrolyzes the collagen, and converts it into gelatin. Two processes are used: an acid process gives type A gelatin and an alkaline process gives type B gelatin. Their properties are similar, but type A can negatively interact with other anionic polymers, such as carrageenan. A thermoreversible gel starts to form when a hot gelatin solution is cooled to below 30° to 35 °C; at refrigeration temperatures (5°C), it takes 5 to 8 hours to reach maximum gel strength (measured in Bloom). Because the gels dissolve at low lower temperatures, they “melt in the mouth” with good flavor release. It also stabilizes a wide range of dairy products and provides emulsification in products such as whipped cream (Kuntz, 2002).

Gelatin is also a desirable dairy stabilizer because it adds a sheen-like appearance to dairy products. It is commonly used in conjunction with modified food starch or pectin in order to prevent a jelly-like texture which occurs when gelatin is used alone (Chandan, 2006).

Experiment I - Analysis of Commercial sour creams

3.1 Introduction

To produce a UHT stable sour cream acceptable rheological limits needed to be determined. This was accomplished by analyzing the rheological properties of four different commercial sour creams (Kroger[®] Natural, Kroger[®] Original, Breakstone[®], and Westover[®]). The upper and lower viscosities and yield stresses were used as limits for viscosity and yield stress of the UHT stable sour cream formulation.

Yield stress is defined as the force necessary to initiate the flow of a product and is an important attribute in many foods. High yield stress is necessary in sour cream to keep it from flowing off of a baked potato or other foods. Yield stress has significant correlation ($p < 0.001$) with the sensory firmness as perceived by panelists in laboratory-made ($r = 0.99$) and retail ($r > 0.97$) yogurts, independently of other physical or sensory properties. The apparent residual stress was significantly correlated with sensory viscosity ($r > 0.90$). Several advantages exist for assessing firmness using the yield stress including (1) less time to run the samples, (2) more power to detect differences, (3) less damage associated with sample handling, (4) avoid use of relative scales or anchors, (5) simple data analysis (homogeneous variances), (6) avoid costs associated with training and managing panelists, and (7) potential to design products based on a target yield and apparent residual stress (Harte et al, 2003).

Viscosity of a material such as sour cream can be calculated by dividing shear stress by shear rate. A shear rate range of 5 to 100 was used because this range is

representative of mastication and swallowing. Shear stress can be viewed as the resistance of a material to deformation and is measured as Force (F) and is usually measured in Pascals (Pa). The generation of a power law equation can be derived from the graph of these two data arrays. The power law equation assigns a numeric value to the shear-thinning behavior exhibited. Power law modeling will also assign a numeric value to identify the level of viscous behavior in the shear rate range used.

3.2 Materials and Methods

Four different brand names (Kroger[®] Natural, Kroger[®] Original, Breakstone[®], and Westover[®]) were purchased from a local retail grocery chain. Ingredient lists of these brands are shown in table 3.1. Three individual containers were purchased for each brand. Viscosity data was collected in triplicate on the StressTech (ATS RheoSystems[®], 52 Georgetown Rd., Bordentown NJ 08505) using a serrated bob and cup. StressTech program information is in Appendix B. Yield stress was measured on the V1.0 Brookfield Viscometer HP (Brookfield Engineering Laboratories, Inc., 11 Commerce Boulevard, Middleboro, MA) using the vane method. Appendix C contains programming information for the Brookfield.

Table 3.1: Commercial Brand Ingredient lists

Brand	Ingredient List
Breakstone [®]	Cultured pasteurized grade A milk and cream, enzymes
Kroger [®] Natural	Cultured cream, nonfat milk and enzymes
Westover [®]	Cultured cream, skim milk, whey, modified corn starch, gelatin, sodium phosphate, guar gum, carrageenan, sodium citrate, calcium sulfate, and locust bean gum.
Kroger [®] Original	Cultured cream, skim milk, whey, modified corn starch, gelatin, sodium phosphate, guar gum, carrageenan, sodium citrate, calcium sulfate, and locust bean gum.

A pre-shear of each sample was performed on the StressTech to eliminate anomalies caused by yield stresses due to the presence of stabilizers and protein gel networks. Each sample was then dynamically tested using shear rates from zero to 1000 1/s. Corresponding shear stress and viscosity data were collected in this range. Data in the range between 10 and 100 were analyzed using Microsoft Excel. Trend lines, R^2 values, and trend line equations were calculated using power law modeling. From the equations, consistency coefficients (K) and flow behavior indexes (n) values were determined (Table 3.2 and Figure 3.1). The range between 10 and 100 was used because this is the normal shear rate range for mastication, spooning or scooping, and stirring.

3.3 Results and discussion

No significant differences in yield stress were seen between Breakstone[®], Kroger[®] original, and Westover[®]. Kroger[®] natural was significantly different in yield stress from the other brands. When viscosity was tested on the StressTech, there were significant differences between all the commercial brands. It was noted that the sour creams with stabilizers had higher K values and lower n values (i.e. more shear thinning behavior). The all natural varieties had higher n values, showing that they are more Newtonian in nature.

Table 3.2 Power Law Modeling of Commercial Sour Creams (x = shear stress, y = shear rate)

Sample	Power law model	K	n	R ²
Kroger [®] original	$y = 26.092x^{0.3038}$	26.092	0.3038	0.9734
Westover [®]	$y = 29.385x^{0.254}$	29.385	0.2540	0.9390
Breakstone [®]	$y = 16.953x^{0.4345}$	16.953	0.4345	0.9946
Kroger [®] natural	$y = 8.0636x^{0.4296}$	8.0636	0.4296	0.9754

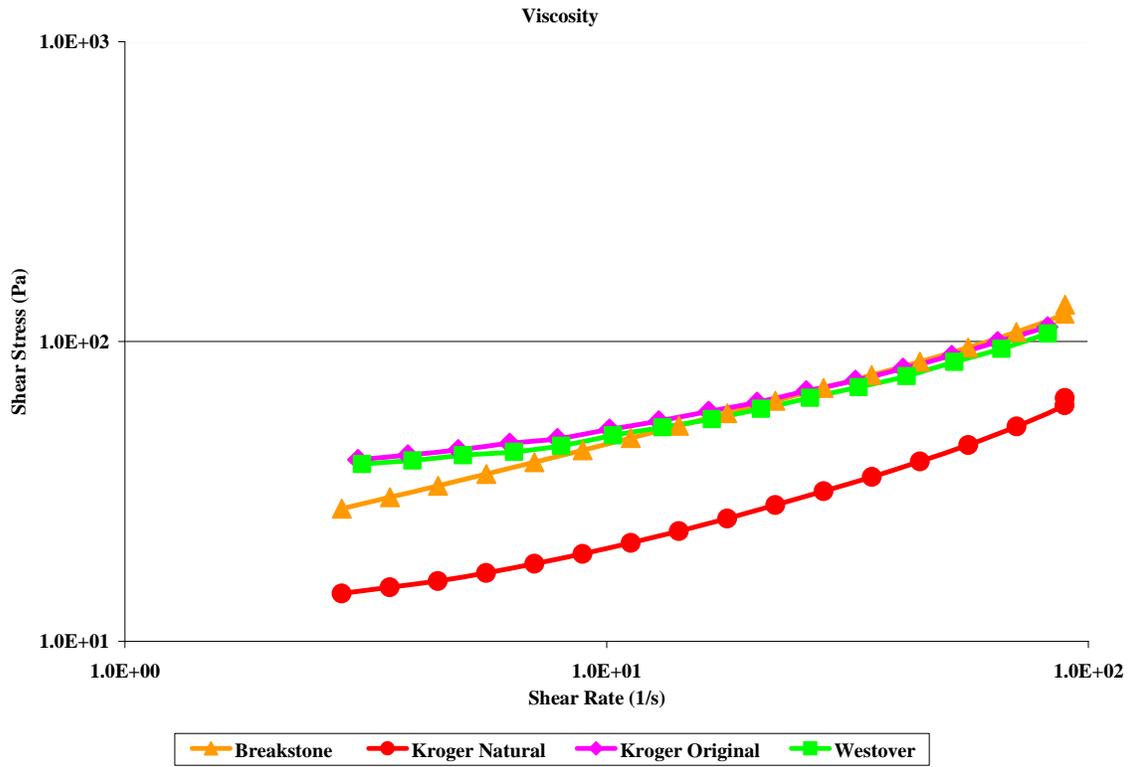


Figure 3.1: Breakstone[®], Kroger Natural[®], Kroger Original[®], Westover[®] Shear Stress vs. Shear Rate

There were significant differences in the behavior index and consistency coefficient between all the commercial brands. The natural brands had more Newtonian behavior while the brands with stabilizers exhibited more shear-thinning behavior.

Analysis of the yield stress data shows that there was no statistical difference between Breakstone[®], Kroger[®] original, and Westover[®]. Kroger[®] natural had a yield stress significantly different from Breakstone[®], Kroger original[®], and Westover[®]. The data are Table 3.3 and Figure 3.2.

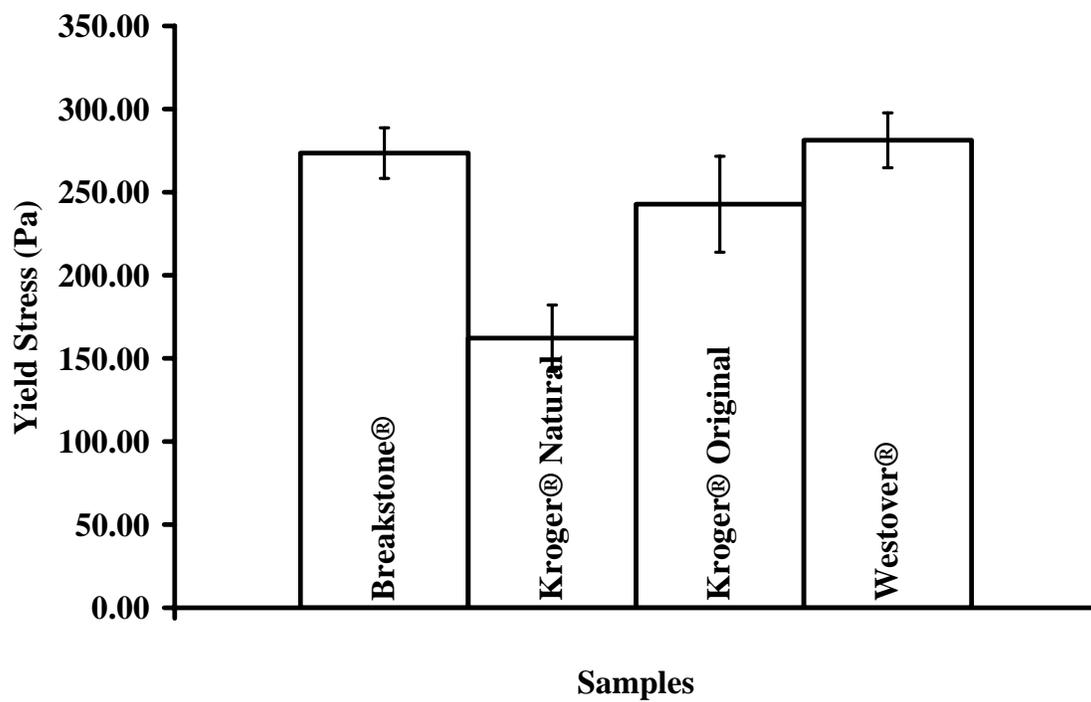


Figure 3.2: Breakstone®, Kroger Natural®, Kroger Original®, Westover® Yield Stress using the HP Brookfield YR-1

Table 3.3: Breakstone[®], Kroger Natural[®], Kroger Original[®], Westover[®] Yield Stress data using HP Brookfield Viscometer

Sample	Yield Stress				
	Test 1	Test 2	Test 3	Average	Std. Dev.
Breakstone [®]	289.97	260.06	270.39	273.47	15.19
Kroger Natural [®]	156.44	145.86	184.37	162.22	19.90
Kroger Original [®]	245.93	269.97	212.46	242.79	28.88
Westover [®]	279.10	298.68	265.96	281.25	16.47

Experiment II - Formulation determination

4.1 Introduction

A sour cream formulation that could withstand UHT treatment needed to be developed that had rheological properties between the upper and lower limits determined in the experiment I. Seven different formulations were developed to characterize the behavior of the stabilization system which would determine the optimal combination of stabilizers. The seven formulations were rheologically analyzed using modeling techniques. A single formulation was then chosen and retested for consistency in experiment III.

4.2 Materials and Methods

Thermtex® starch (National Starch and Chemical, Food Products division, 10 FINDERNE Avenue, P.O. Box 6500, Bridgewater, New Jersey 08807-0500, 908-685-5000) was chosen for this product because it is resistant to high shear, high temperatures, low pH, and has excellent cold storage stability. It also allows excellent heat penetration, possibly due to the gradual viscosity development during heating (Figure 4.1). A technical service bulletin for Thermtex® can be found in Appendix A.

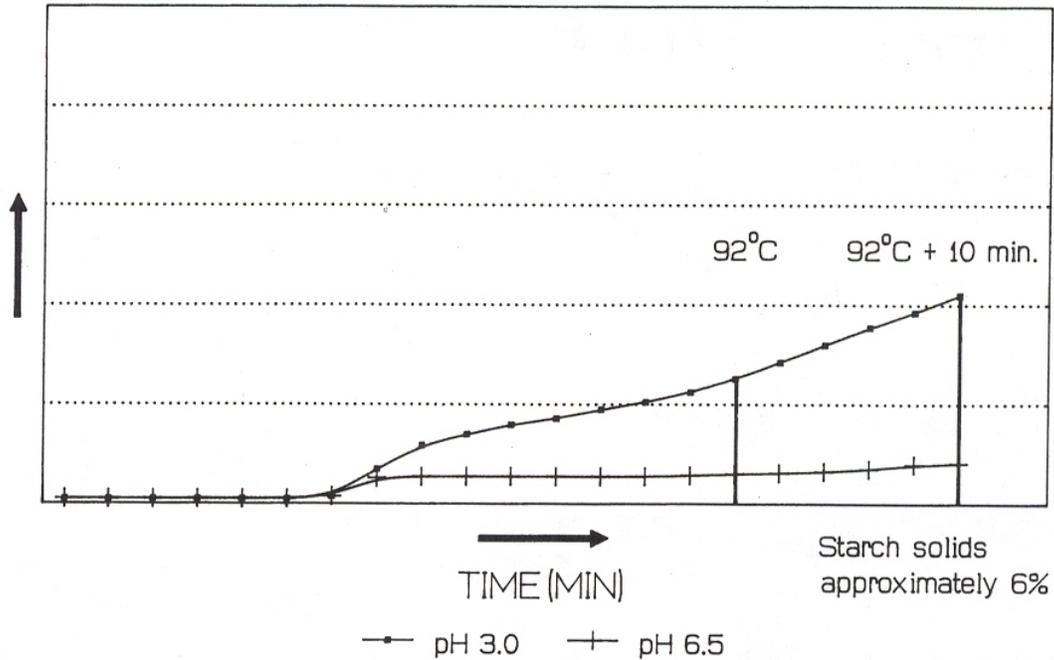


Figure 4.1: Thermotex® Amylograph

The 250 Bloom, type B Gelatin was supplied by Vyse Gelatin Company, Inc. 5010 North Rose Street, Schiller Park, IL 60176-1023. Cream (approximately 38 % milk fat) and milk (approximately 4% milk fat) were supplied by the North Carolina State Dairy pilot plant (Raleigh, NC). Eighty pounds (36.28 kg) of a standardized cream and milk (18% milkfat) was heated to 165° F (73.8° C) for 30 minutes in a pasteurization vat, Micro Process Design, D & F Equipment Co., 5301 Burlington Road, McLeansville, NC 27301. Model MPD1050. The mixture was then separated into seven 24-pound (10.89 kg) portions. Eight pounds (3.63 kg) were taken from each

portion and stabilizers were incorporated using a single speed 1 quart Waring blender. The 8 pounds of mixture containing the stabilizers was then reincorporated into the remaining 16 pounds (7.26 kg). Table 4.1 shows the corresponding formulations.

Table 4.1: Formulation Matrix. Starch and gelatin by percent total weight.

		Gelatin		
%		0.47	0.50	0.53
Starch	2.83	1	2	*
	3.00	3	4	5
	3.15	*	6	7

* denotes formulations that were not implemented.

Each formulation was then homogenized in Gaulin Homogenizer (model #: 300CDG, serial number: 722 48 484699, Manton-Gaulin Mfg. Co. Everett, MA) using 500 psi 2nd phase and 2000 psi 1st phase. Besides thoroughly mixing the stabilizers and other ingredients, homogenization also prevents creaming and wheying off during incubation and storage, thus stability, consistency and body are enhanced. The mixtures were cooled to 73°F using a 4° C water bath before being inoculated with 0.1 g of Vivolac® Dry-set Buttermilk/sour cream premium freeze dried Lactic culture ((product: ssk26, code: 089523). Vivolac Cultures Corp. Indianapolis, IN).

The formulations were then allowed to ferment overnight for 18 hours in 10-gallon stainless steel dairy containers. It was tested for titratable acidity before processing, which was 0.79. Approximately 8 pound of each formulation was then

thermally processed in the 5-kilowatt microwave (Industrial Microwave Systems, LLC, 3000 Perimeter Park Drive, Building One, Morrisville NC 27560) at a power of 3-kilowatts and a flow rate of 4.0 L/minutes until a temperature of 130° C was reached. Dielectric data were collected at 5° C increments during the processing. It was then cooled to 80° C by covering the processing pipes with ice. The sour cream was placed into 5-pound containers and stored for 2 months at 4° C. The samples were then tested on the Brookfield HP to determine yield stress values. Each sample was then analyzed using the StressTech. Rheological data were analyzed and graphed to determine significant differences.

4.3 Results and Discussion

Because of variations in heat treatment times, pumping times, and cool down times using the 5-kilowatt unit no correlation could be found between stabilizer amounts and yield stress and viscosities. Because these problems are inherent due to the design of the system, no improvements could be made that might better standardize the processing procedure. Figure 4.2 shows the time and temperature processing variations that occurred. Another issue is that Thermtex has delayed gelation properties. This means that longer heat treatment time is needed to maximize the gelation of the starch (Figure 4.1). At some unknown point the starch will start to break down. It should be noted that a 10% increase in Thermtex[®] did not always increase the cold gel strength but a 10% increase caused anywhere from a 25% increase in hot viscosity to 200% increase. Table 4.2 shows how formulation may cause inconsistencies.

Underprocessing will result in less viscosity due to lack of full gelation of the starch. It is also possible that starch/gelatin interaction may interfere with increased viscosities and yield stresses in some of the formulations. These issues are worthy of further research. Because of these issues it was inconclusive which of the formulations was optimal. Several different formulations could prove to be optimal depending on the processing parameters. Because of this, the initial formulation was chosen because it had shown to be successful in past processing runs on the 5-kilowatt microwave unit.

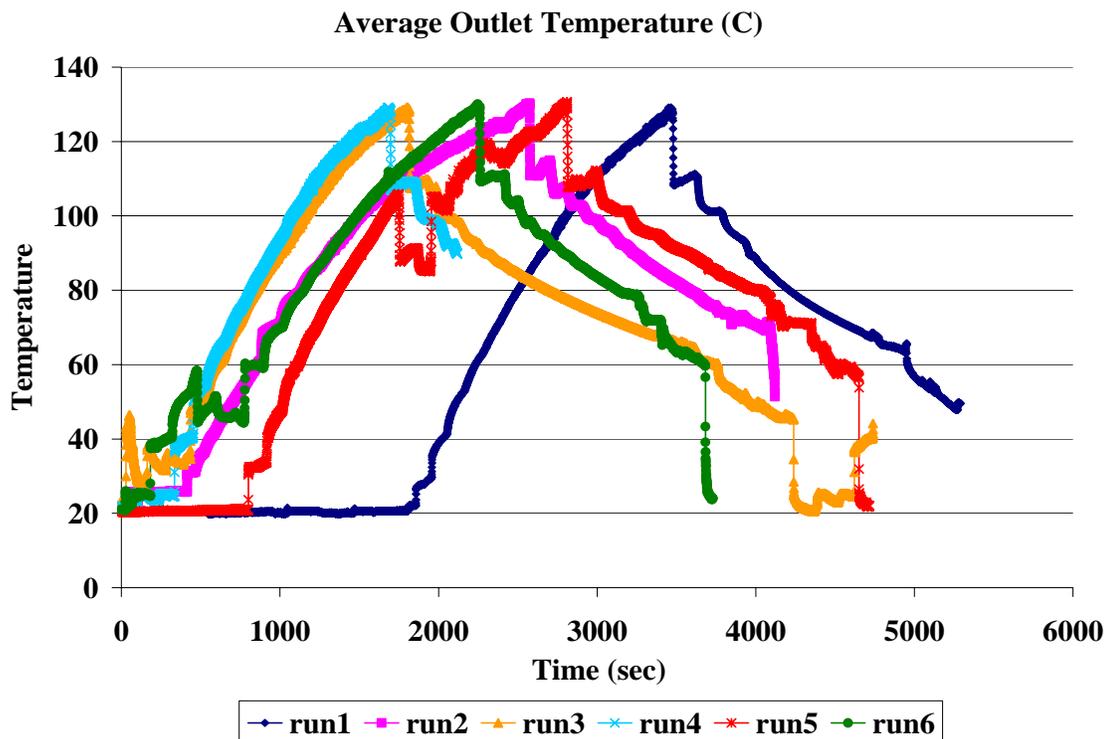


Figure 4.2: Time and temperature processing variations

Table 4.2: Combinations of modified waxy maize starch and modified tapioca maltodextrin (10% aqueous solutions) after heating to 82° C , followed by homogenization at 10.3 MPa and cooling to 65° C and gel strength after cooling to 4° C (Hunt, Maynes, 1997).

Starch Type ¹		Hot viscosity	Cold gel strength
Thermtex [®]	N-lite D [®]		
	(%)	(cP)	(mm)
0	100	3	110
10	90	4	114
20	80	6	112
30	70	10	110
40	60	39	90
50	50	282	74
60	40	515	90
70	30	6510	70
80	20	9,600	84
90	10	37,750	110

¹Thermtex[®], a modified waxy maize starch and N-Lite D[®], modified tapioca maltodextrin, were obtained from National Starch and Chemical Company.

Statistical analysis of yield stress of the NCSU and commercial brands (figure 4.3 and table 4.3) show that yield stress median values could be categorized into 3 distinct groups that were significantly different. Significant differences did not always correspond to increases or decreases in stabilizers. This supports the hypothesis that processing conditions cause variations in the sour cream texture which is independent of the amount of stabilizers present.

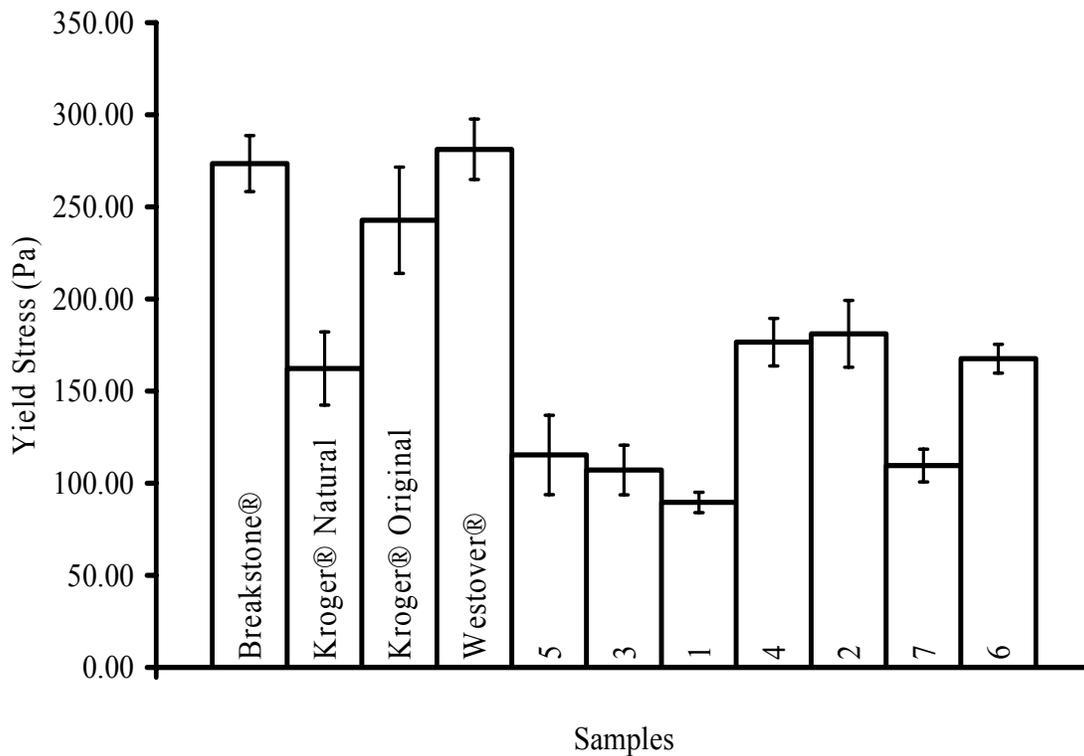


Figure 4.3: North Carolina State University sour cream formulation yield stress and commercial brand yield stresses

Table 4.3 Significant differences between sour cream yield stresses using 1-way ANOVA statistical analysis.

Sample
Sample 1 ^a
Sample 3 ^{a,b}
Sample 7 ^b
Sample 5 ^{a,b}
Kroger Natural ^{® c}
Sample 6 ^c
Sample 4 ^c
Sample 2 ^c
Kroger Original ^{® d}
Breakstone ^{® d}
Westover ^{® d}

Figures 4.4 and 4.5 graph the relationships between the NCSU sour cream formulations, Breakstone and Kroger Original respectively. As the graphs depict, all the NCSU sour creams had higher viscosities than the commercial brands. Table 4.5 contains the power law equations for the seven NCSU sour cream formulations. Statistical analysis using 1-way ANOVA statistical analysis of K and n values showed significant differences between all the samples (commercial and NCSU sour creams).

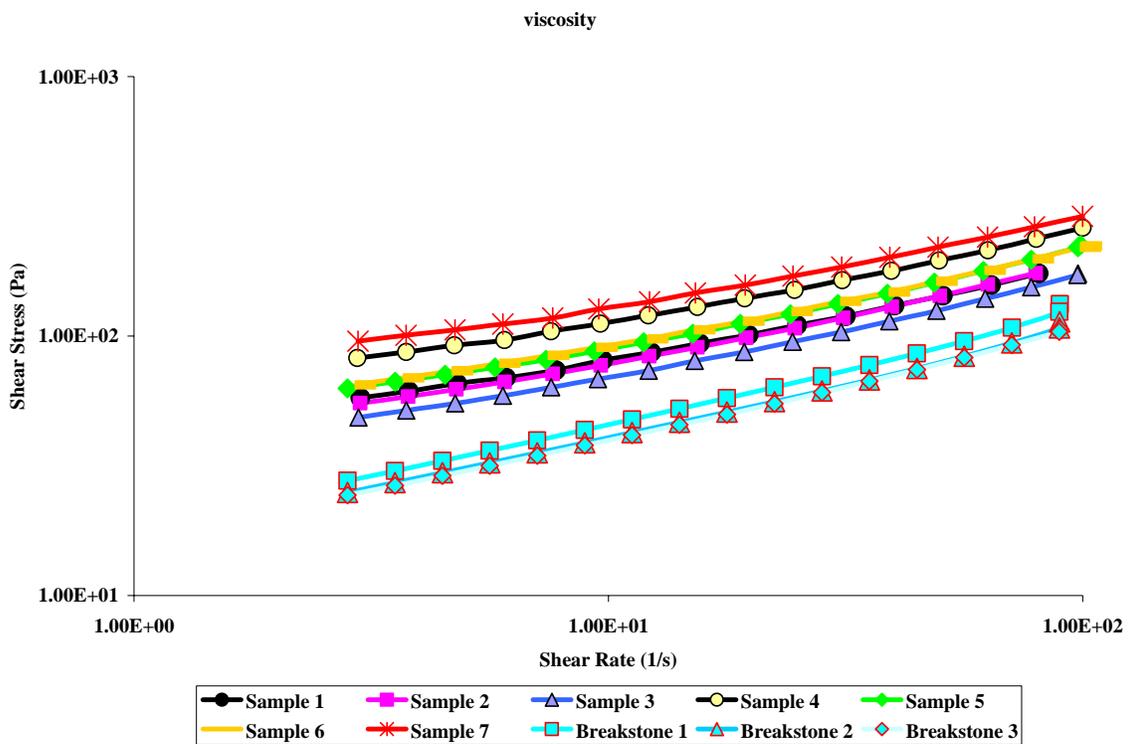


Figure 4.4: Shear Stress vs. Shear Rate for NCSU Sour Cream formulations and Breakstone

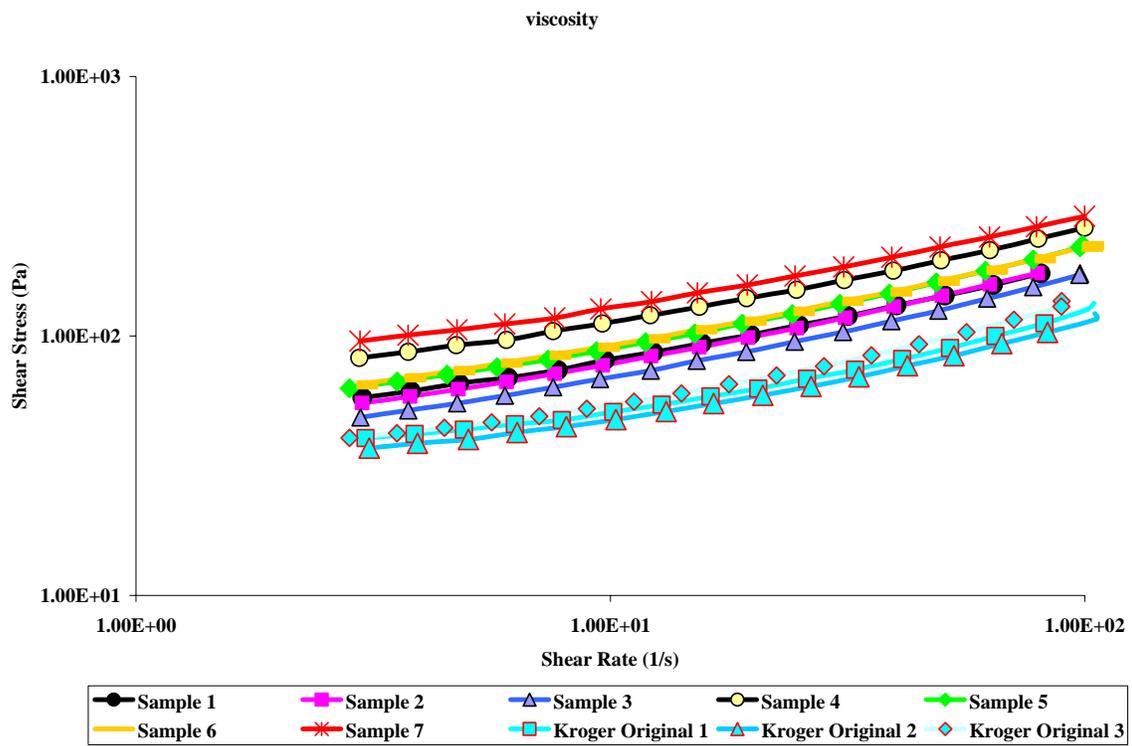


Figure 4.5: Shear Stress vs. Shear Rate for NCSU Sour Cream formulations and Kroger Original

Table 4.4: NCSU sour cream sample yield stress data from Brookfield HB

Sample	Test 1	Test 2	Test 3	Average	Std. Dev.
5	128.41	90.48	127.07	115.32	21.52
3	117.87	111.59	92.04	107.17	13.47
1	95.09	89.52	84.04	89.55	5.525
4	182.57	161.80	185.45	176.61	12.90
2	191.20	160.15	191.83	181.06	18.11
7	113.65	115.69	99.43	109.59	8.858
6	159.79	167.69	175.27	167.58	7.741

Table 4.5 Power law equations for North Carolina State University sour cream formulations

Sample	Power law model	K	n	R ²
5	$y = 63.431x^{0.3179}$	63.431	0.3179	0.9913
3	$y = 54.305x^{0.3283}$	54.305	0.3283	0.9925
1	$y = 42.035x^{0.3502}$	42.035	0.3502	0.9935
4	$y = 38.216x^{0.3344}$	38.216	0.3344	0.9945
2	$y = 40.385x^{0.3584}$	40.385	0.3584	0.9910
7	$y = 35.508x^{0.3528}$	35.508	0.3528	0.9941
6	$y = 30.573x^{0.366}$	30.573	0.3660	0.9928

Because of the inconsistencies between formulations and expected viscosities dielectric data were also analyzed. Dielectric data were collected for MWS1-7 in the range 30° C to 130° C. The two dielectric properties are important. Dielectric loss (ϵ'') is the ability of a material to convert microwave energy into heat. The dielectric constant (ϵ') is the ability of the material to absorb microwave energy.

Dielectric data was analyzed to detect behavior changes caused by changes in the level of stabilizers used. MWS1-7 were all similar which implies that the variations in stabilizer levels were not large enough or that stabilizers do not affect dielectric properties (Figures 4.6, 4.7).

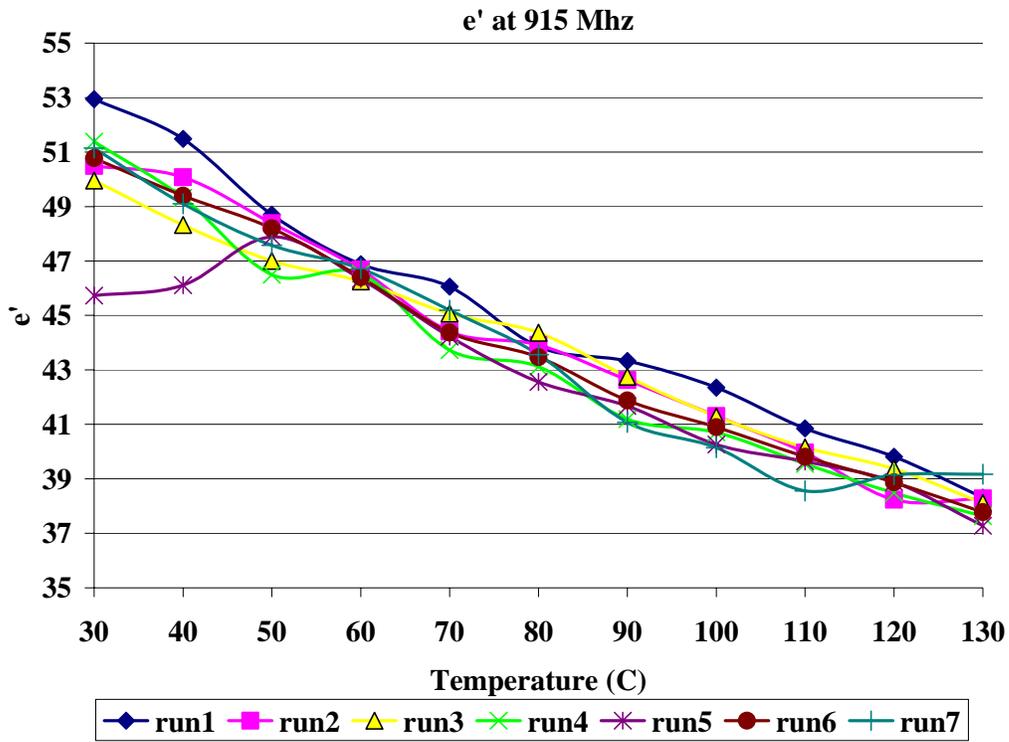


Figure 4.6: Effect of temperature on the dielectric constant (ϵ') of the seven NCSU formulations

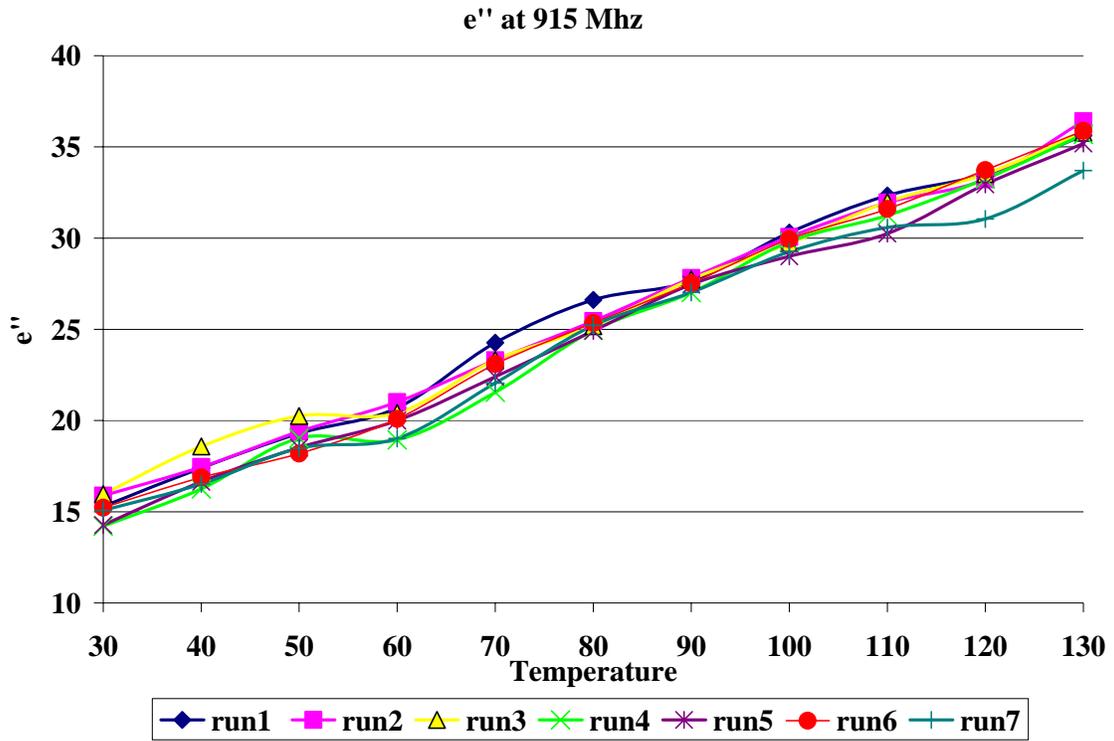


Figure 4.7 Effect of temperature on the dielectric loss factor (ϵ'') of the seven NCSU formulations

Experiment III -Validation of Formulation

5.1 Introduction

Formulation MWS4 needed to be validated before moving from bench production to commercial production using the 60 kw unit. To confirm the results from experiment II, formulation MWS4 was used to produce a final batch of sour cream to be tested rheologically in triplicate. Validation of the results from this experiment were then compared to results from Experiment II.

5.2 Materials and Methods

Thermtex® starch (National Starch and Chemical, Bridgewater, New Jersey) was chosen for this product because it is resistant to high shear, high temperatures, low pH, and has excellent cold storage stability. It also allows excellent heat penetration, possibly due to the gradual viscosity development during heating. A technical service bulletin can be found in Appendix A. The 250 Bloom, type B Gelatin was supplied by Vyse Gelatin Company, Inc., Schiller Park, IL. Cream (approximately 36 % milk fat) and milk (approximately 3.6% milk fat) were supplied by the North Carolina State University Dairy pilot plant (Raleigh, NC). Twenty-seven pounds (12.25 kg) of cream and milk standardized to 18% milkfat were pasteurized in a stainless steel dairy container for 30 minutes at 165° F. The starch and gelatin were added using a single speed 1 quart Waring blender as described in chapter 4. The mixture was homogenized using a Gaulin homogenizer (Manton-Gaulin Mfg. Co. Everett, MA) and cooled to 73° F using a 4° C water bath before inoculating with Vivolac® Dry-set Buttermilk/sour

cream premium freeze dried Lactic culture (product: ssk26, code: 089523,. Vivolac Cultures Corp. Indianapolis, IN). Fermentation was allowed to proceed for the next 18 hours. It was tested for titratable acidity before processing, which was 0.77. It was then separated into three one-8 pound (3.63 kg) portions. The three portions were named sample 8, 9, and 10. Each portion was processed with the 5kw microwave system (Industrial Microwave Systems, LLC, Morrisville NC) to a temperature of 130° C and then cooled to 80° C by covering the systems pipes with ice. It was placed in containers and stored at 4 °C for 1 month. MWS8-10 were analyzed using the StressTech as described in chapter 4.

5.3 Results and discussion

Since variations were present between all the samples from the same batch of sour cream it appears that lack of consistent processing parameters was a factor in the viscosity of the final product. Variations in processing may amplify or reduce viscosities in relation to changes in formulation. Table 5.1 shows the power law equations and Figure 5.1, 5.2, 5.3 shows the graphed data. The graphs show that the final formulation was more viscous that either Breakstone or Kroger Original. The final processing run of Sample 4 was slightly less viscous that the original processing run of Sample 4.

Table 5.1: Power law modeling equations comparing the final runs, previous formulation from chapter 4 (Sample 4) and Kroger original.

Sample	Power law model	K	n	R ²
8	$y = 34.618x^{0.3866}$	34.618	0.3866	0.9899
9	$y = 36.337x^{0.3628}$	36.337	0.3628	0.9827
10	$y = 27.902x^{0.4396}$	27.902	0.4396	0.9909
4	$y = 38.216x^{0.3344}$	38.216	0.3344	0.9945
Kroger original	$y = 26.092x^{0.3038}$	26.092	0.3038	0.9734

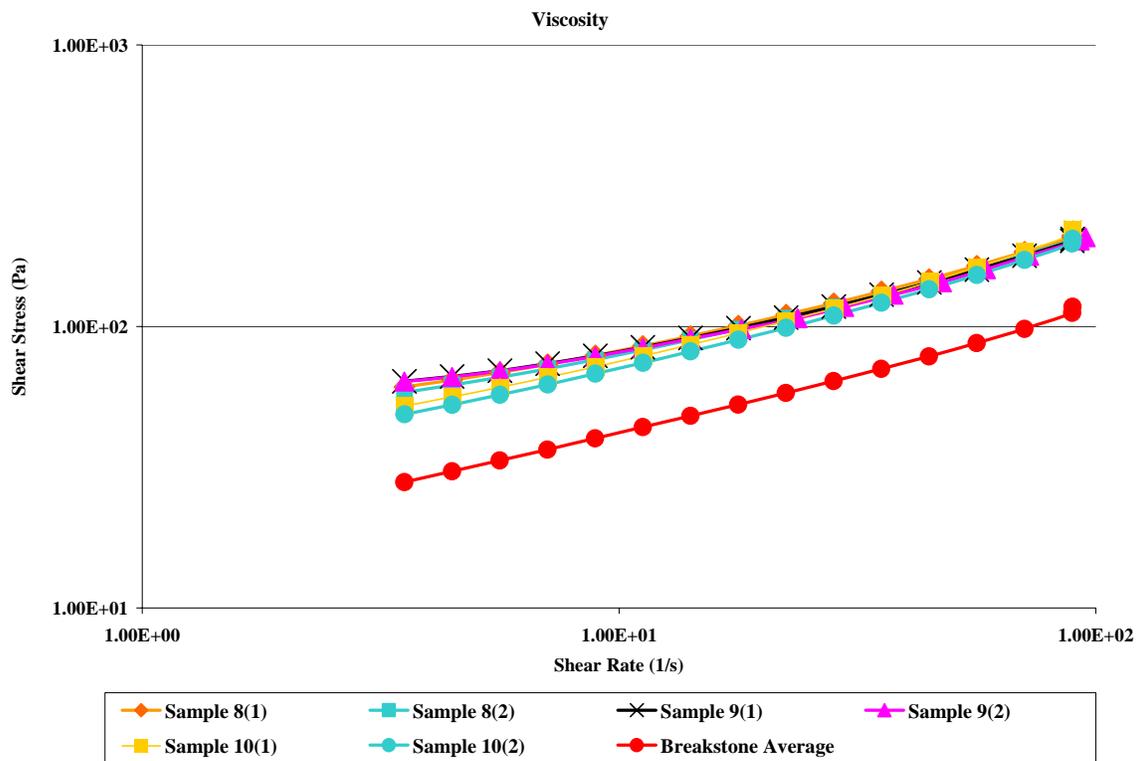


Figure 5.1: Shear Stress vs. Shear Rate for Final NCSU formulations and Breakstone®

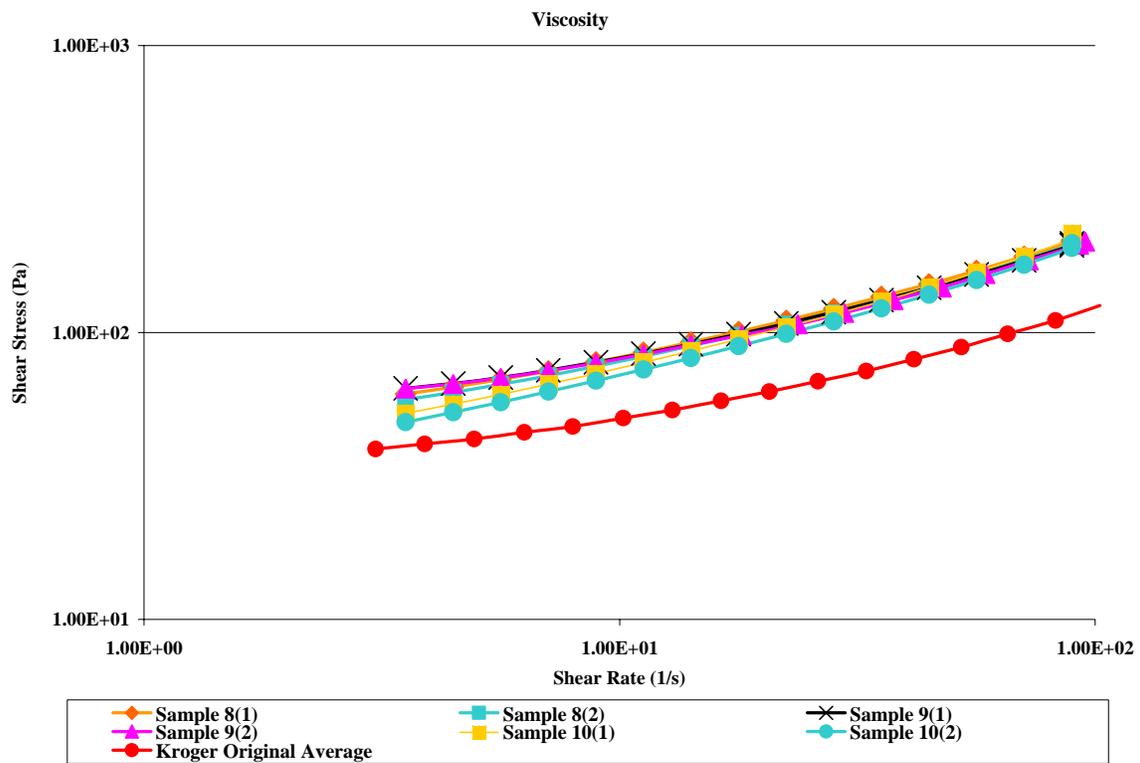


Figure 5.2: Shear Stress vs. Shear Rate for Final NCSU formulations and Kroger® Original

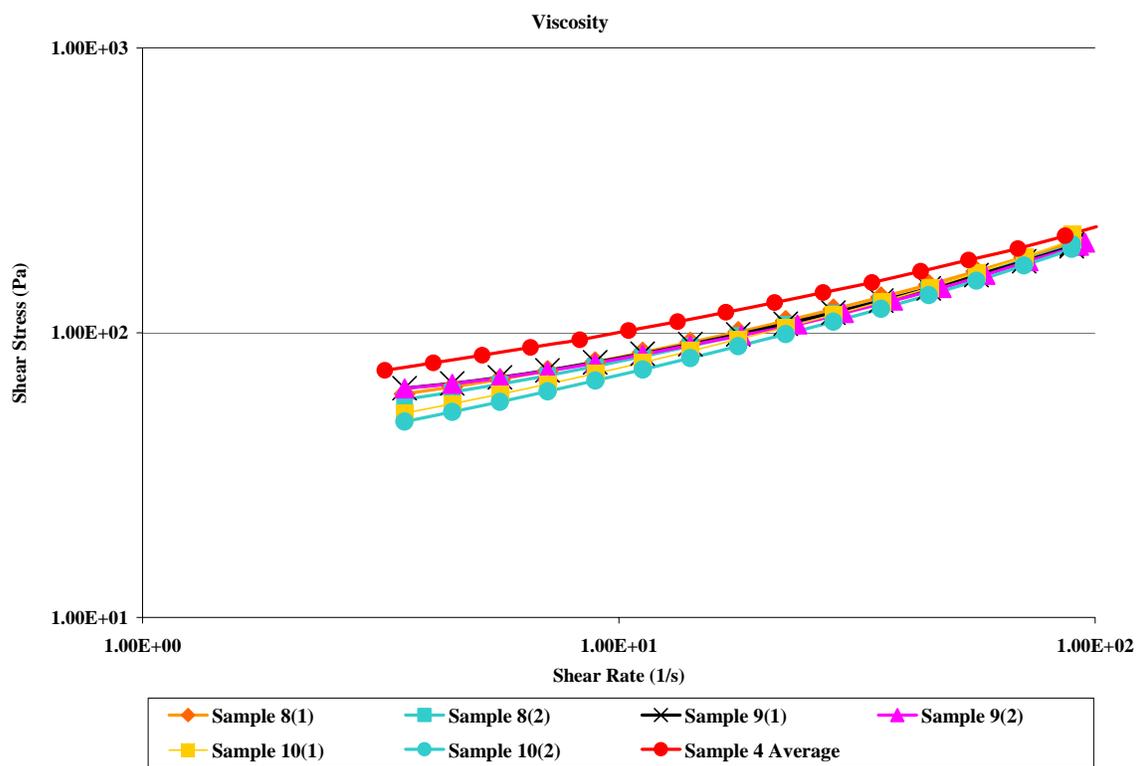


Figure 5.3: Shear Stress vs. Shear Rate for Final NCSU formulations and Sample 4

Conclusions

Designing a successful stabilization system for a product with a dairy gel depends on the quality of the raw ingredients, use of customized ingredients for increased performance, and how the product is processed. Processing may be done with methods that are established or with emerging new technologies, such as microwaves. In order for these products to be successful at a food service level they must be consistent, functional, and have an extended product shelf life.

Although inconsistencies were present due to variations in heating, cooling, and pre-heating pumping times which are inherent variables in the normal operation of the 5kw microwave unit, all the formulations performed well. And although an optimal formulation could not be determined, the basic formulation using starch and gelatin is robust enough to handle variations in heating and cooling times during UHT processing.

The final formulation (Sample 4) proved to produce a sour cream that had less yield stress but higher viscosity than any of the commercial brands. Sample 4 also had no visible protein aggregation. The results of this research indicate that properly formulated sour cream can be UHT processed with continuous microwave technology to produce an acceptable product.

Future optimization should also include processing the sour cream at different acidity levels for both sensory and starch functionality. This is important since excessive acidity is often considered a sensory defect by consumers. Also, acidity

affects the functionality of Thermtex®. Future formulation should include freeze/thaw acceptability for use in frozen foods, such as gourmet frozen entrees.

Future research should continue with a scaled up batch of sour cream that is UHT processed on the 60-kilowatt commercial unit and packaged aseptically. After packaging, sensory, rheological, and shelf-life analysis should be performed monthly over a 6-month period.

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Appendices

Appendix A: Thermtex Technical Bulletin



Food Products Division
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P.O. Box 6500
Bridgewater, New Jersey 08807-0500
908-685-5000

TECHNICAL SERVICE BULLETIN

THERMTEX®

THERMTEX is a modified food starch derived from waxy maize. This product finds use in many canned food systems where optimum heat penetration and high final viscosity are required.

Physical Properties:

Color	White to off-white
Form	Powder
Moisture	Approximately 11%
pH	Approximately 6

Features and Benefits:

THERMTEX is resistant to high temperature, low pH, and shear. It also has excellent cold temperature storage stability. Products prepared with THERMTEX have a smooth short texture which remains consistent even after prolonged storage. A unique feature of this product is its ability to allow excellent heat penetration during retorting. This quality is possible due to the gradual viscosity development during heating.

Applications:

THERMTEX has application in retorted food systems, in particular, cook-in-can fruit fillings and aseptically processed canned foods. When preparing fruit fillings with THERMTEX, the time required to reach 200°F is reduced significantly while end viscosity remains approximately the same. The specific parameters for each system have to be determined by each processor.

THERMTEX is also recommended for some UHT systems as a result of its excellent resistance to viscosity breakdown under extreme processing conditions. THERMTEX also finds application in high shear systems such as emulsion meats.

THERMTEX meets National Food Processors Association standards for thermophilic spores.

Label Declaration:

"Food Starch-Modified"

MFB098

The information given and the recommendations made herein are based on our research and are believed to be accurate but no guarantee of their accuracy is made. In every case we urge and recommend that purchasers before using any product in full scale production make their own tests to determine to their own satisfaction whether the product is of acceptable quality and is suitable for their particular purposes under their own operating conditions. No representatives of our firm are authorized to accept or change the foregoing provisions but, subject to such provisions, our engineers are available to assist purchasers in adapting our products to their needs and to the circumstances prevailing in their business. Nothing contained herein shall be construed to imply the manufacturer of any relevant patents or to constitute a prediction, inducement or recommendation to practice any invention covered by any patent, without authority from the owner of the patent. We also expect purchasers to use our products in accordance with the guiding principles of the Chemical Manufacturers Association's Responsible Care® program.

Appendix B: StressTech program information

FlowCurve C25 Sample vol 15.9cc

Serrated Bob

Sample loading method: To gap

Maximum loading force 2.000E+1 N Proceed when force is below 1.000E+1 N or when waiting more then 1.000E+3 s

Limit loading speed below 10.000 mm to 0.300 mm/s

Set temperature 4.0 °C Equilibrium time 60.0 s

Prompt for rotor release

Manual control Number of measurements 2 Measurement interval 6.000E+1 s

Shear rate table Shear rate 1.000E-1 - 1.000E+2 1/s Time 600.0 s No. of Measurements 60

Regulator strength 100.0 %

Appendix C: V1.0 Brookfield Viscometer Model: HB program parameters

V1.0 Brookfield Viscometer
Model: HB
Spindle No.: 72

Program: EZ-Yield

Test Parameters:

Pre-shear(rpm): 0
Auto-zero speed(rpm): 0
Run speed(rpm): 0.03

Base Increment Calibration(%): 0.9

Immersion mark: Secondary

Pre-shear time (sec): 0
Wait time (sec): 0
Base Increment (msec): 0.03
Torque Reduction (%): 100