A Formulators Guide to Process Selection for Plant-Based Beverages

This paper aims to provide insights into selecting processes for plant-based beverages and related fluid products like yogurts, ice creams, and sauces. Since these products are often used as a replacement for dairy products, they appear to have many of the same characteristics, such as flavors, nutritional benefits, viscosity, and others. Given this, why don't we process plant-based products the same way we process their dairy-based counterparts? To answer this, we need to look more deeply at the ingredients that make up these products and the processes used to produce them.

In many ways, plant-based products do parallel their dairy “equivalents ."However, they are pretty different in many ways that affect how they react to thermal processes. The reasons for these differences come down to their ingredients and the sources of these ingredients.

Of course, traditional dairy products use cow’s milk as their base. This is a single, consistent ingredient source. Additionally, dairy processing’s long history has resulted in a deep knowledge base about how these products react to thermal processes. It has also resulted in a wide range of refined, optimized processes.

Overall, milk is a pretty good formula. Its proteins are relatively heat stable. It maintains its white color well throughout the thermal process. It supports a variety of flavors and forms the base for many other foods (such as ice cream, protein shakes, meal replacements, cheeses, sauces, and fermented products like yogurt and sour cream). Additionally, it is abundant in many areas and provides good nutrition without being overly expensive to the consumer.

Comparatively, at this time, fluid plant-based products are quite new. They have not been researched to the same degree, and therefore we don’t know as much about how they react to thermal processes. This also means that there are not as many processing facilities optimized for them. Additionally, plant-based products use ingredients from many different sources. Along with the variation of sourcing also come variations in incoming bacterial loads and varying reactions to thermal processes that must be accommodated.

A key difference between dairy-based and plant-based products is definition. The types and amounts of minerals, proteins, vitamins, fats, and other components of cow's milk fall within known levels and are often standardized. It is a well-defined product and forms the basis for many other products. There are few, if any, such standards or definitions for plant-based products. Not only do plant-based products differ from dairy products, but they also differ significantly from one another! For example:

- Coconut milk is often lower in proteins but can be higher in fats
- Rice milk can be very low in protein but much higher in sugars and carbs
- Almond milk may be lower in proteins but also somewhat lower in fats and carbs
- Hemp milk is mid-range for protein but higher in fats and fiber
- Soymilk is more elevated in proteins and lower in fats

Next, not all ingredient sources are readily available in all regions, so seemingly similar products may have different formulas.

- Proteins from soy, nuts, legumes, chickpeas, hemp

- Fats and oils from soy, canola, palm, coconut
- Starches from grains or legumes
- Sugars and sweeteners from corn, cane, beets, maple, stevia
- Stabilizers from beans and seaweed
- Flavors, vitamins, colors, minerals, and other ingredients from a wide range of different sources

Additionally, consumer preferences vary from region to region; consumers in the USA like things sweeter than consumers in Asia and Europe.

As you can see, this all can complicate processing plant-based products. So, before we look at the actual processes, let's look at some trends in plant-based products (and how they differ from dairy-based products) that can help us choose the proper process:

1. Protein Denaturing and potential fouling: The proteins in plant-based products are generally less heat stable than the predominant proteins in milk. Thus, they will denature and foul more readily in plant-based products than in dairy-based products. This can be addressed by either using steam injection or indirect heat exchangers with added heat exchange area to reduce fouling and ensure long production runs.
2. Bacterial Loads: The bacterial loads in plant-based ingredients may be higher and less consistent than in dairy-based products. This may require more extreme thermal processes to ensure proper pasteurization, Extended Shelf Life, or aseptic processing. This can also compound the issue that these products may already be prone to fouling on the heat exchanger walls mentioned previously.
3. Homogenization: Depending on the type of plant-based product, you may be dealing with creaming, where fats and oils separate and rise to the top; sedimentation, where heavy solids gather and sink to the bottom; or even both. Thus, we see some homogenization being done upstream (between 2 heaters), but more often, it is done downstream between 2 coolers. We also see higher pressure homogenization pressures compared to dairy products.

Although there are many hurdles to processing plant-based products, they can offer the same benefits as dairy products. In addition, they can also provide other benefits such: as no animal-sourced ingredients, a clean label, and even avoiding allergens.

Common Processes

Plant-based products can take many forms, such as drinks, shakes/smoothies, yogurts, desserts, sauces, puddings, and more. The most common processes used to produce these products include:

- Pasteurization
- High-acid aseptic processing
- Low acid aseptic processing (with direct or indirect heating)
- And extended shelf-life processing

They form the product's characteristics, such as flavor, color, texture, viscosity, and nutrient content. They also determine the product’s shelf-life (and distribution method). As you can see, selecting the right processing style is a critical step in developing products.

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Pasteurization

Pasteurization is the gentlest of these processes. It preserves freshness, is commonly available, and can work for a wide range of products. Many products are pasteurized, including:

- Plant-based milks
- meal replacements
- flavored drinks
- protein shakes and smoothies

These products may be very high quality, but they must be refrigerated. They also have a limited shelf life which often limits their distribution.

The goal of pasteurization of high-acid foods (pH<4.6), such as juices and many smoothies, is to reduce spoilage organisms such as yeasts and mold and to inactivate enzymes that would degrade the product. For low-acid foods (those with a pH>4.6), such as plant-based milks, the goal is to reduce pathogens and spoilage organisms. These processes must have a minimum of a 5-log reduction of bacteria. However, commercial operations typically have a higher kill rate to ensure longer functional shelf-lives for their products. Since not all organisms are destroyed in this process, the products must be refrigerated.

Pasteurization processes use temperatures of 72°-90° C and relatively long hold times of 15 to 45 seconds (lower temperatures use longer hold times). The products are then filled at refrigerated temperatures.

As shown below, this process uses indirect heating and, for many products, an upstream homogenizer to create stable emulsions for products with fats and oils. This flow diagram shows a complete laboratory pasteurization process. It includes a product pump, pre-heater, in-line homogenizer, final heater, hold-tubes, and coolers.

Figure 1. Laboratory Pasteurization Process

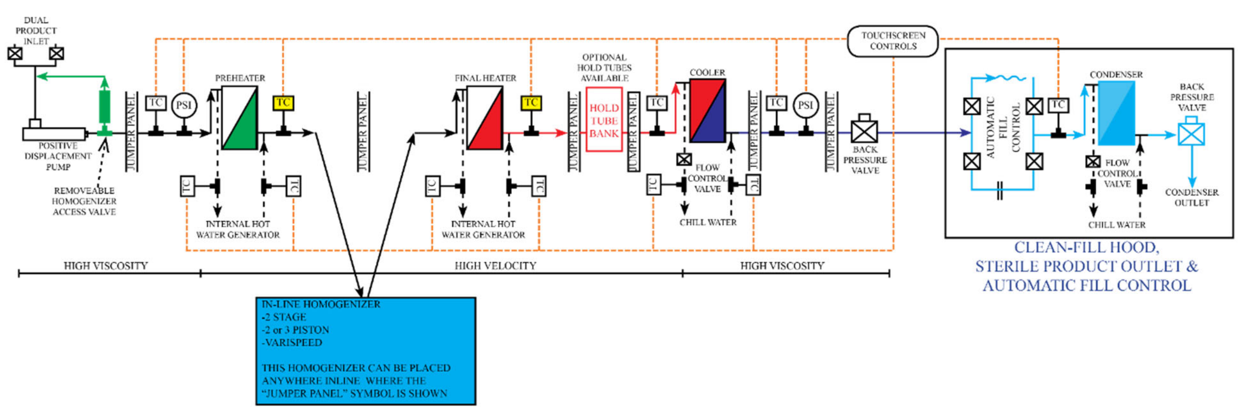

Figure courtesy of MicroThermics, Inc.

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High Acid Aseptic Processing

High acid aseptic processing is also an all-indirect process. As the name suggests, it can only be used for products with a pH<4.6. Aseptic processing creates products that have long, unrefrigerated shelf lives. It can also generate high-quality products for many products. The most common products are juices, but plant-based and protein smoothies are becoming more popular.

High acid aseptic processes must also have a minimum 5-log reduction of bacteria. Depending on what provides the best product quality (within the 5-log requirement), this process uses temperatures of 86°-110° C & typically hold-times between 10 and 20 seconds. Because this can be a gentler sterilization process, formulators can sometimes acidify their beverages below 4.6. If the pH changes do not adversely affect their product, they can create a higher quality plant-based aseptic beverage than if they used a low acid aseptic process.

As shown below, the basic high acid aseptic flow diagram is very similar to pasteurization; however, the conditions are more extreme, and no homogenizer is needed for many products.

Figure 2. Laboratory High-Acid Aseptic Process

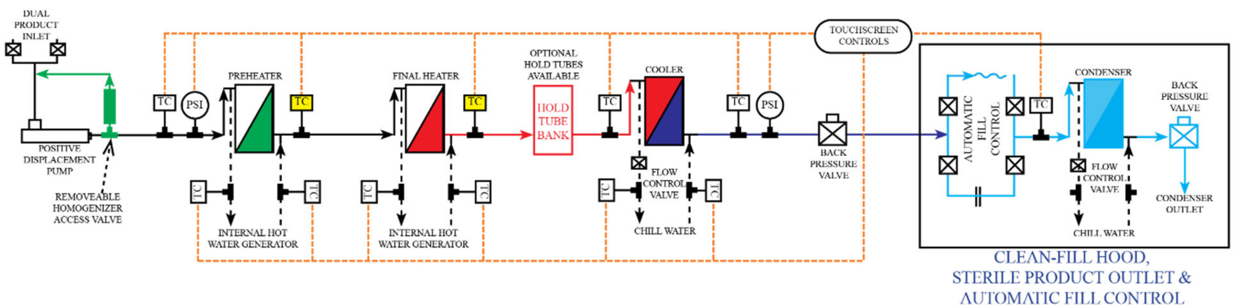

Figure courtesy of MicroThermics, Inc.

Low Acid Aseptic Processing

Low-acid aseptic processing is the most extreme of the thermal processes. It is used for products with a pH>4.6. These processes must have a minimum of 12-log reduction of the bacteria, C, botulinum.

Low-acid foods present a risk for botulism poisoning. Therefore, ensuring the product's sterility is paramount. These processes use temperatures of 136°-150° C and comparatively short hold times of only 2-10 seconds (longer for viscous or unique products). These conditions are required to ensure that all heat-resistant spores of the organism, C. botulinum, and all vegetative cells are killed. Please note that C. botulinum does not reproduce in products with a pH<4.6; thus, the high acid aseptic processes are less extreme.

Low-acid aseptic products can be produced without preservatives and are sterile. Therefore, they do not require refrigeration until they are opened. This enables these products to be shipped, sold, and stored easily. While these products may not be considered "premium," they are still high quality and very convenient, making them quite popular. This process and these products are widespread in the USA but are even more popular in Europe, Asia, and South America. These regions have a smaller refrigerated infrastructure, so products that do not require refrigeration are very popular.

Examples of low-acid aseptic plant-based products include:

- Milks or
- Flavored or unflavored milk replacements
- Protein drinks
- Meal replacements
- Savory sauces
- Cheese sauces
- Puddings

There are two main types of conventional low-acid aseptic processes: Indirectly heated and Directly Heated.

Indirectly Heated Low Acid Aseptic Process

Indirectly heated processes heat products using a heating medium (i.e., steam or hot water) to heat the product through the wall of a heat exchanger. They usually also integrate a homogenizer either upstream from the hold tube (between two heaters) or downstream from the hold tube (between two coolers). These are very common processes; however, they often cannot be used with plant-based products because the proteins in many of these products tend to burn on and foul the heaters.

Figure 3. Laboratory Indirect Low Acid Aseptic Process-Upstream Homogenization

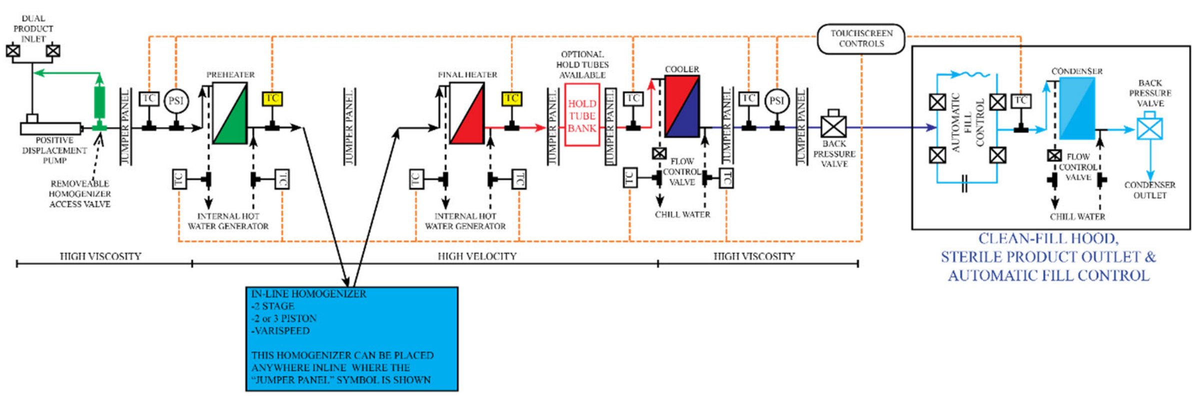

Figure courtesy of MicroThermics, Inc.

Upstream homogenization is used when trying to create a stable emulsion of fats/oils, minerals, and other ingredients with water.

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Figure 4.0 Laboratory Indirect Low-Acid Aseptic Process-Downstream homogenization

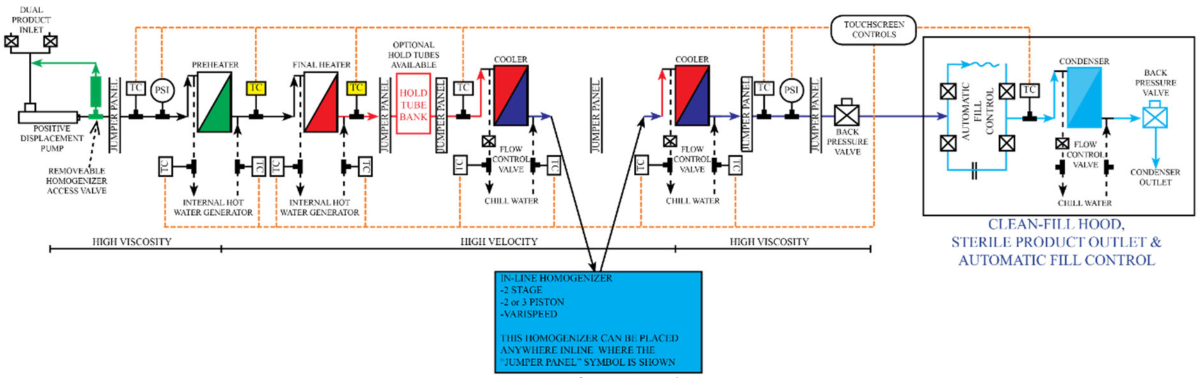

Figure courtesy of MicroThermics, Inc.

Downstream homogenization addresses issues in the thermal process, such as a gritty texture or separating products created by proteins that denature in the heaters.

Directly Heated Low Acid Aseptic Process

Directly heated processes use an indirect regenerative heater (pre-heater) and then inject steam directly into the product in the final heating stage. This raises the temperature of the product very quickly, without any hot surfaces for the product to burn on. These processes also typically integrate a homogenizer. The homogenizer may be located upstream of the hold tube. However, it is most frequently located downstream from the hold tube between a vacuum cooler (which also removes the water vapor from injecting steam into the product) and an indirect cooling heat exchanger.

Figure 5.0 Laboratory Direct Steam Injection Process with Upstream Homogenization

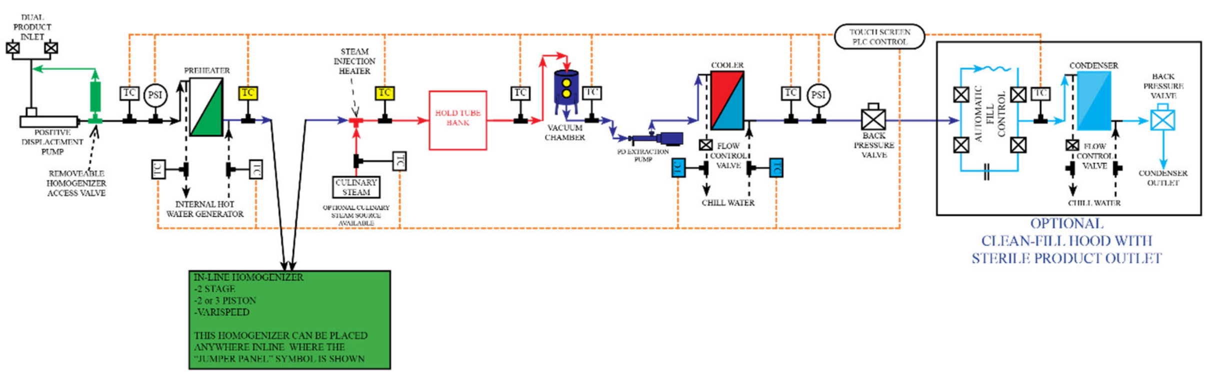

Figure courtesy of MicroThermics, Inc.

This low-acid direct Aseptic process has an upstream homogenizer to create a stable emulsion for products of fats and oils with water.

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Figure 6.0 Laboratory Direct Steam Injection Process with Downstream Homogenization

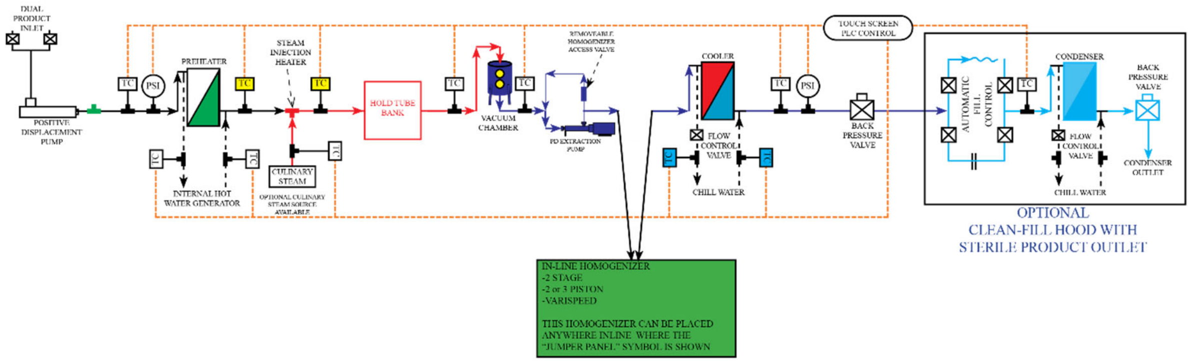

Figure courtesy of MicroThermics, Inc.

Downstream homogenization addresses issues in the thermal process, such as a gritty texture or separating products made by proteins that denature in the heaters.

Extended Shelf Life (ESL) Processing

ESL Process takes the best qualities of pasteurization and aseptic processing. There are both high-acid and low-acid ESL products. They are processed close to sterilization conditions, then filled at refrigerated temperatures into non-sterile containers. This results in extremely high-quality products with long (3-6 month) refrigerated shelf lives. Examples of ESL Products include

- Plant-based milks and milk replacements
- Plant-based protein drinks
- Smoothies with or without added proteins
- And many others that are currently in development

These products have an image of being fresh and very good for you. As a result, they have become quite popular.

The flow diagrams used for these processes resemble the aseptic process flow diagrams previously displayed, but the processing conditions may be slightly lower than the actual aseptic process. This enables them to reduce the bacterial count well below the pasteurization requirement and maximize product quality. In addition, it also allows these products to enjoy a very long shelf life in the refrigerator.

Processing in Research and Product Development

The marriage between process and formula is critical to developing products that can go into production and be successful in the market. Sterilization and pasteurization processes inherently change products. This means your new formula strawberry, plant-based, protein-enriched shake may be great until it goes through a commercial-style process. Then it's burned, the wrong color, gritty, or has other quality issues.

Product development aims to generate formulas that yield the product identities your consumers want after the commercial pasteurization or sterilization process. This is why processing in R&D is so necessary.

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While selecting the proper process (pasteurization, Aseptic, ESL) is critical, choosing the actual process conditions within that process is just as important. Therefore, efficiently and accurately simulating commercial-style processes in your lab must be part of your product development.

MicroThermics offers a full range of easy-to-use laboratory UHT/HTST processing equipment. Our laboratory processing lines and processing services are unequaled in their ability to accurately simulate commercial:

- Pasteurization
- Extended shelf-life
- Aseptic
- Hot fill
- And custom processes

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