



Non-Thermal Technologies for Milk Preservation: Keeping Milk Fresh Without the Heat

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Emerging technologies that aim to improve milk safety while preserving its fresh-like quality. Milk is one of the most nutritious and widely consumed foods, but it is also highly perishable. Its rich combination of water, proteins, fats, lactose, minerals and vitamins provides an excellent environment for microbial growth. Pasteurization and refrigeration have therefore become essential tools for ensuring milk safety and extending shelf life. However, heat treatment can cause changes in some milk components, including protein structure, flavour and heat-sensitive nutrients. This has encouraged researchers to explore non-thermal preservation technologies that can reduce microorganisms while producing fewer heat-related changes in milk.

What are non-thermal technologies?

Non-thermal processing refers to preservation methods that achieve microbial control using physical forces or energy other than conventional heating as the primary mechanism. Technologies being investigated for milk include high-pressure processing (HPP), pulsed electric fields (PEF), ultraviolet (UV-C) treatment, cold plasma, ultrasound and membrane filtration. The basic idea is simple: make milk safer and last longer while keeping it closer to its original fresh characteristics.

High-Pressure Processing – Preserving Milk Under Pressure

High-pressure processing, commonly called HPP, uses very high hydrostatic pressure to damage microorganisms without relying mainly on heat. Milk is placed in a pressure vessel and subjected to intense pressure for a defined period. HPP can effectively reduce many vegetative microorganisms while producing relatively limited heat-related changes. It has therefore attracted considerable interest for producing “cold-pasteurized” or minimally processed dairy products. Among emerging non-thermal technologies, HPP currently has the strongest practical position as a standalone alternative for some drinking-milk applications. The major attraction of HPP is its ability to improve microbial safety while maintaining many of the sensory and nutritional characteristics associated with fresh milk.

Pulsed Electric Field – Using Electricity Against Microbes

Pulsed electric field (PEF) technology uses very short, high-voltage electrical pulses. When microorganisms are exposed to the electric field, their cell membranes can develop pores—a phenomenon known as electroporation. At sufficient treatment intensity, this damage can lead to microbial inactivation. PEF is particularly interesting for liquid foods because milk can flow continuously through a treatment chamber. Research indicates that PEF can reduce microorganisms in milk while limiting changes to nutrients, colour and sensory properties. However, PEF alone has limitations, particularly against bacterial spores, and may therefore need to be combined with other preservation hurdles.

Ultrasound – Tiny Waves with Powerful Effects

Ultrasound uses high-frequency sound waves to generate microscopic bubbles in the liquid. The formation and collapse of these bubbles, known as cavitation, can produce physical effects capable of damaging microorganisms and modifying the milk matrix. Ultrasound has attracted interest not only for microbial control but also for homogenization and improvement of certain functional properties of dairy products. Recent research considers ultrasound a promising technology for safer and more sustainable dairy processing, although optimization of treatment intensity and energy consumption remains important.

UV-C and Cold Plasma – New-Age Surface and Liquid Treatments

Ultraviolet-C (UV-C) uses short-wavelength ultraviolet radiation to damage microbial DNA and prevent microorganisms from reproducing. It has potential for milk and dairy applications, although the turbidity and opacity of milk can limit light penetration. Cold plasma, on the other hand, contains highly reactive species capable of damaging microbial cells. It can operate with limited heat generation and has therefore attracted interest as a promising emerging preservation technology. However, treatment uniformity, equipment design and industrial scale-up remain important challenges.

The Future: Combining Technologies

The future of milk preservation may not depend on finding one “perfect” technology. Instead, researchers are increasingly interested in hurdle technology, where two or more mild preservation methods are combined. For example, HPP, PEF, UV, filtration or ultrasound could potentially be integrated with refrigeration or mild thermal treatment. Such combinations may improve microbial control while reducing the intensity required from any single process. Recent research particularly highlights multi-hurdle approaches as an important direction for improving safety and consistency.

Bottom Line

Non-thermal technologies are changing the way scientists think about milk preservation. HPP, PEF, ultrasound, UV-C, cold plasma and membrane filtration offer promising possibilities for producing safe milk while retaining more of its fresh-like characteristics. However, these technologies should not yet be viewed as universal replacements for pasteurization. Their success will depend on scientific validation, regulatory acceptance, cost-effective equipment and reliable industrial-scale operation. The future of milk preservation may therefore be a combination of science, technology and smart processing—keeping milk safe, nutritious and closer to the quality consumers expect from fresh milk.