Process Monitoring

to Ensure Dairy Quality and Safety

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QUALITRU SAMPLING SYSTEMS

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Abstract

The impact of quality failures in dairy processing can have far-reaching consequences leading to high financial losses, operational challenges, and loss of reputation. Strategies must be developed to control the introduction of gram-positive, psychrotolerant organisms from the raw milk supply and to detect, monitor, and eliminate gram-negative post-pasteurization contaminants before biofilms can develop. In this vein, Quality standards must be developed that encompass all aspects of plant operation that may impact product quality, including equipment failures, sanitation and plant hygiene, and raw material quality. The implementation of a Hazard Analysis and Critical Control Point (HACCP) quality management system is paramount, with Critical Control Points established to incorporate elements critical to both food safety and product shelf stability. Recommendations for establishing Critical Control Points for fluid milk process are provided.

Introduction

No one can accurately predict the economic or reputational impact of a quality failure in dairy processing, but the costs can be dramatic. Analysts estimate, for example, the much-reported 2022 recall of Abbott powdered dairy-based infant formula had an economic cost of $325 million and additionally caused a crisis in global infant formula availability[1,2]. Similarly, a 2015 Fortune Magazine article[3] reported a *Listeria* outbreak in Blue Bell ice cream that forced the company to lay off 1,450 of its 3,900 employees and furlough 1,400 more. Only a $125 million loan commitment from a private investor saved the company from going under. These are not isolated examples. In 2022 alone, the U.S. Food and Drug Administration (FDA) reported 24 cases of dairy-related quality failures resulting in product recalls[4].

While such dramatic examples are uncommon, the impacts of quality failures—whether foodborne disease or shelf life related—can have far-reaching effects leading to high financial losses and operational challenges. Conversely, maintaining consistently high quality can have several positive effects on milk processors, which include the following of particular note:[5-9]

- **Increased market demand and price premiums.** Higher dairy quality, as measured by bacterial content and other means, leads to improved sensory properties and longer shelf life. In turn, better taste, texture, or appearance may increase market demand, stabilize distribution, and allow price premiums. Consumers are loyal to and are willing to pay more for products they perceive to be higher quality.
- **Lower processing costs.** Higher milk quality with fewer impurities or bacterial contaminants reduces the need for additional processing steps to meet product safety and quality standards. Fewer impurities and lower contamination can result in cost savings for milk processors.
- **Improved yield and higher efficiency.** Better dairy quality can enhance yield and improve efficiency. For example, higher-quality milk may augment cheese curd formation and enable easier, faster processing that increases efficiency, improves production, and results in higher yields for processors.
- **Reduced waste and losses.** Milk processors may experience reduced waste and losses due to improved dairy quality. Lower bacterial content and better handling practices can help extend dairy product shelf life, leading to fewer unsaleable or returned products and greater consumer acceptance.
- **Increased market access and export opportunities.** Consistently high-quality products augment a milk processor's reputation, potentially opening up or expanding new market access and export opportunities. Many countries have stringent regulations for dairy imports based on product quality. Maintaining high product quality standards helps ensure compliance with such regulations.

Overall, maintaining high quality is essential for milk processors to remain competitive, improve profitability, and establish or maintain a strong foothold in domestic and international markets. Conversely, failure to maintain dairy quality can lead to economic losses, reduced competitiveness, and potential damage to a company's reputation.

Gram-negative Bacteria Are Common Post-pasteurization Contaminants

In a symposium review paper published in 2018, Martin, et al.[10] noted that four primary groups of psychrotolerant bacteria in pasteurized fluid milk are notable in post-pasteurization contamination that can lead to failures in milk quality. These include (1) *Pseudomonas spp*; (2) coliforms; (3) non-*Pseudomonas*, non-coliform gram-negative bacteria; and (4) gram-positive endospore-forming bacteria. Of these, *Pseudomonas spp* is most commonly reported as responsible for post-pasteurization contamination.

High-temperature, short-time (HTST) pasteurization delivers at least a 6-log reduction in psychrotolerant gram-negative bacteria concentrations. Therefore, the presence of gram-negative psychrotrophic organisms in pasteurized milk indicates contamination occurring during or after pasteurization.[11] Gram-negative psychrotrophs can grow rapidly at refrigerator temperatures, producing enzymes that

negatively affect milk flavor, texture, and appearance. Even if introduced in small numbers, these post-pasteurization contaminants can cause milk spoilage in a very short time, easily on the order of seven to 14 days.

The primary goal of a dairy process monitoring program is to detect, monitor, and, if found, develop strategies to eliminate gram-negative post-pasteurization contaminants.

Corrosion, cracking, and pitting in 316 stainless steel pipe that has been etched with acid. Pits, cracks, and fissures may become attachment sites for biofilms.

Raw Milk Quality Plays an Important Role

From a bacteriological perspective, dairy process monitoring must begin with raw milk quality. This is true for several reasons. First, while the Pasteurized Milk Ordinance (PMO) limits the total bacterial count of commingled grade A milk to 300,000 colony-forming units per milliliter (CFU/ml),[12] certain conditions may elevate the bacterial levels to a point where a 6-log reduction during pasteurization is insufficient to inactivate all contaminating organisms. Such conditions may include holding raw milk for an extended time or under inadequately refrigerated conditions; cleaning or hygiene failures in raw milk holding vessels or transfer lines; or equipment failures, such as contaminant-harboring pits or cracks in stainless steel silos, tanks, pumps, or milk transfer lines. While rare in countries such as the U.S. with effective on-farm, distribution, and in-plant cooling capabilities coupled with clean-in-place (CIP) technology, this situation may be more prevalent in countries with less sophisticated practices or available technology.

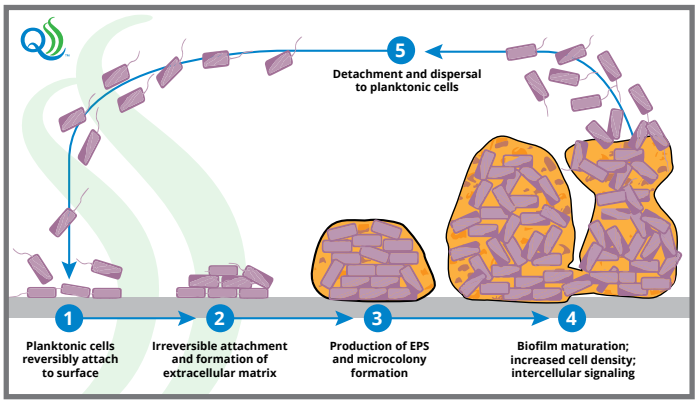
Of greater importance in the U.S. is the presence of gram-positive, psychrotolerant, endospore-forming bacteria in the raw milk supply, notably *Bacillus* and *Paenibacillus spp*, that enter the raw milk from soil, bedding, or other environmental conditions on the farm. Endospores of these bacteria can survive pasteurization and then germinate and grow under refrigeration conditions.[13] While slower growing than true psychrophilic or psychrotrophic organisms, such as *Pseudomonas spp*, spore-forming contaminants can grow quickly enough at refrigerator temperatures to produce proteolytic and lipolytic enzymes that can contribute to quality failures in pasteurized milk products with shelf lives greater than approximately two weeks. In milk processing facilities where gram-negative post-pasteurization contaminants are well controlled, the presence of gram-positive spore-formers should be considered as a potential detriment to extended shelf stability.

Effective monitoring for raw milk bacterial contamination must include aseptic sampling as the product is leaving the transport tank, as it is entering the raw milk storage silo, and as it is leaving the silo on its path to the pasteurizer. Only in this way can trouble spots be isolated and contaminants controlled.

Biofilms Present a Risk of Persistent Contamination

All organisms important in dairy food safety and quality management are capable of forming biofilms on dairy processing equipment. Biofilms are immobile aggregations of microcolonies of microorganisms attached to surfaces. The organisms within a biofilm are embedded in and protected by an organic polymer matrix consisting of extracellular polymeric substances (EPS) that are formed and secreted by the bacteria comprising the biofilm. This protective EPS coating makes biofilms particularly difficult to control and eradicate.[14-16]

Biofilms form when individual cells (or groups of cells) weakly adhere to a surface and begin to secrete EPS. This is the first in a series of five phases of biofilm formation that include (i) the reversible attachment phase; (ii) the irreversible attachment phase, where interactions between the surface and the bacteria form tight ionic attachments; (iii) production of EPS and envelopment of cells forming the biofilm; (iv) biofilm maturation and increasing cell density; and (v) dispersal or detachment, where cells are released in large numbers to establish additional biofilms or contaminate their environment. Although varying by species and environmental conditions, maturation of a biofilm typically occurs within 72 to 144 hours following initial attachment. While most detachment occurs following maturation, cells may detach and contaminate their environment at any stage of biofilm development, making biofilms a persistent contamination risk immediately upon initiation.



The Five Main Phases of Biofilm Development

Photo: QualiTru Sampling Systems.

Bacterial biofilms attach to environmental surfaces and grow into dense mats that persistently contaminate raw or pasteurized products. Once established, biofilms are difficult to eradicate. Continual process monitoring is critical to isolate biofilms in the early stages of development before they can become fully established.

Biofilms are of great importance to the dairy industry. They can form on the surface of virtually all materials used in dairy processing, including stainless steel, Teflon, rubber, glass, polypropylene, ceramic or other tiles, and more. They can become established on environmental surfaces, such as walls, floors, and drains; surfaces of stainless steel equipment, such as milk storage tanks, pasteurizers, and piping; gaskets; valves; filling equipment; milk handling devices; and more.[17,18]

Importantly, biofilms can form even in the absence of a sanitation or hygiene failure. Stainless steel surfaces with roughness exceeding 0.8 microns; scratches, cracks, or pits on valve bodies, filler hoses, or gaskets; or pinholes or pressure cracks in tanks or tank doors can all harbor biofilms, even when standard cleaning-in-place programs are performing as designed. Aggressive cleaning procedures may be required to eliminate an established biofilm once identified, and plant engineers may be called upon to repair or replace equipment contributing to persistent biofilm formation.

Often Overlooked

Heat exchangers, sweet water, and glycol coolants are often overlooked as potential sources of product contamination. A 1989 study by Strantz, et al.[19] showed the frequent presence of psychrotrophs in glycol and sweet water from 17 dairy processing plants in Minnesota and South Dakota, with populations of psychrotrophs in coolant media ranging from <0.3/100ml (most probable number or MPN) to >240/100ml. The time of year had no influence on the population range. *Staphylococcus spp* was found in 29.6% of sweet water and 4.5% of glycol samples. Coliforms were less present, and *Salmonella spp* was found in one sample. A second survey involving 51 plants across the United States showed similar results.

This study is noteworthy because cooling water and glycol can serve as a source of bacterial contamination in pasteurized dairy products. Such contamination can occur if the barrier (generally stainless steel) between the pasteurized product and the cooling media is cracked or contains pinholes, and the pressure differential permits the flow of cooling media into the pasteurized product. In the Strantz, et al. study, four of 14 plants that responded to survey questions on HTST pressures reported

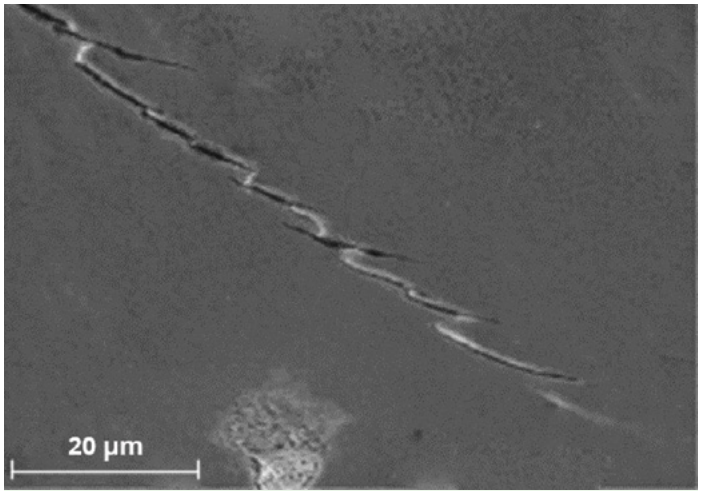
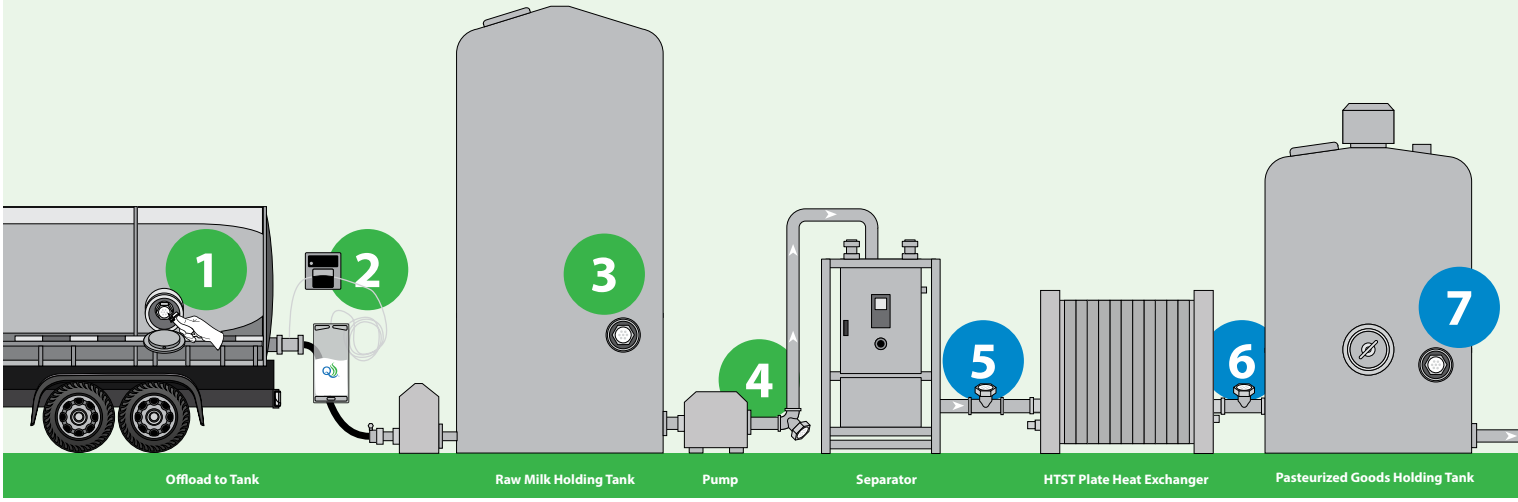


Photo: ScienceDirect, Corrosion Science, Volume 53, Issue 11, November 2011

Hairline cracks in pasteurizer plates may allow contaminating microorganisms to enter pasteurized milk.

Figure 1: Example of Process Monitoring Sampling Sites



that coolant pressure was greater than the pressure of the milk. While this condition runs contrary to the PMO, it is not uncommon in practice. Similarly, tanks cooled with sweet water or glycol may develop cracks or leaks that open when the tank is filled with milk, allowing contaminants to flow into the pasteurized milk product.

Systems in which glycol concentration exceeds 30% showed fewer contaminants. In addition, the study suggested that microorganisms in sweet water can be controlled by adding halogen or quaternary ammonium sanitizers if the addition of sanitizer is carefully monitored. Occasional or indiscriminate addition of sanitizer had little effect in controlling microbial levels. One point of caution, however, is that adding high levels of halogen compounds may contribute to cooling system corrosion.

Isolating Contamination Through Process Monitoring

Contamination by spoilage or disease-causing bacteria is difficult to isolate and is often transient. The only sure way to find and control bacterial contaminants in a dairy processing environment is to isolate contamination hotspots and uncover contamination as it occurs. This requires careful monitoring of each step in the production process.

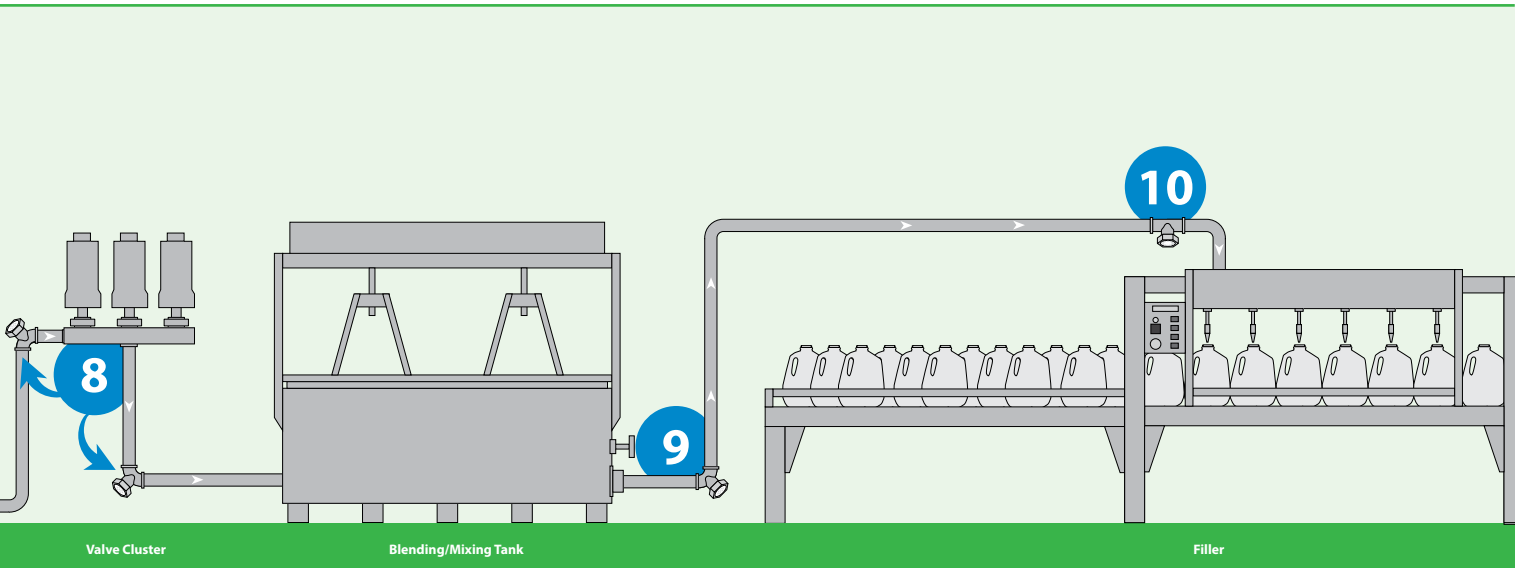
Figure 1 below provides an example of what a process monitoring plan might look like. Ideally, a contamination control plan should consider all the critical control points (CCP) or processes that represent potential sources of contamination in the process and then establish a sampling plan to isolate each source. For example, as noted earlier, contamination of raw milk could occur on the farm; in the transport tank; in the milk transfer lines and pumps going to and from the storage silo (including gaskets); and the storage silo itself. Therefore, samples for microbial testing should be taken from the delivery tanker as it is unloaded, the raw milk storage silo, and upon exit from the silo as it leaves the raw milk storage bay. This sampling method allows each critical location to be isolated.

On the pasteurized side, possible points of contamination include the HTST pasteurizer; transfer lines and pumps (including gaskets); pasteurized milk storage tanks; blending and mixing tanks; valve clusters; filling machines; and other processing equipment that could harbor biofilms, cross-contaminate from cooling media, or become contaminated by exposure to the air, dust, or condensate that could enter an open vessel. Therefore, each potential source of contamination should be identified as a CCP and aseptic samples should be taken immediately before and closely downstream from each potential contamination point. Collected samples should be immediately removed to the lab and tested using appropriate microbiological techniques. In the case of HTST sampling (points 5 and 6 in Figure 1), samples should be tested for gram-negative psychrotrophic contaminants to uncover potential contamination issues within the pasteurizer and for gram-positive organisms that may indicate spore-former contaminant carryover from the raw supply.

This sampling procedure will help to isolate sources of contamination that may impact the safety or shelf stability of the finished product. The procedure will not, however, pinpoint the exact foci of contamination. Once contamination is isolated, additional procedures will be required to find the exact source. These procedures may involve visual observation, use of ultraviolet lights to fluoresce contamination hotspots, surface swabbing and microbial testing, adenosine triphosphate (ATP) measurement, or other techniques.

Conclusion

Lengthening distribution lines, expanding export opportunities, increasing competition from plant-based dairy substitutes, and mounting consumer pressure all speak to a demand for high-quality dairy products with extended shelf stability. This presents a need for vigilant process monitoring in the dairy industry. Remember that extremely low levels of psychrotrophic or psychrotolerant contamination are enough to create biofilms or directly contaminate dairy products and lead to quality failures. In refrigerated milk, psychrotrophic contamination at levels as low as <1 CFU per gallon of milk will destroy sensory quality in seven to 14 days. With psychrotolerant spore-formers, shelf stability will deteriorate within 21 days. Constant, vigilant process monitoring is the only sure way to control these quality-degrading contaminants and maintain high product purity levels.



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References

1. Forbes N. How the Infant Formula Recall Will Impact Abbott's Revenue. The Motley Fool, May 17, 2022. https://www.fool.com/investing/2022/05/17/how-the-infant-formula-recall-will-impact-abbotts/
2. Jung J, N Olynk Widmar, B Ellison. 2023. The Curious Case of Baby Formula in the United States in 2022: Cries for Urgent Action Months after Silence in the Midst of Alarm Bells. Food Ethics, 2023; 8(1):4.
3. Fortune Magazine. http://fortune.com/2015/09/25/blue-bell-listeria-recall/ How ice cream maker Blue Bell blew it.
4. FDA. Recalls, Market Withdrawals, & Safety Alerts. https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts.
5. VanLeeuwen, JA, GP Keefe, R Tremblay, C Power, JJ Wichtel, D Waltner-Toews. Estimation of the on-farm impact of clinical mastitis in dairy cows. J Dairy Sci, 2004; 87(4), 1299-1307.
6. Stewart S, E Goddard, Z Mohamed. Assessing the impact of individual milk quality on processing efficiencies and profitability in the Australian dairy industry. J Dairy Sci, 2017; 100(6): 4430-4441.
7. Moschini G, P Sckokai. Production choices with milk quota restrictions. Euro Rev Ag Econ, 2002; 29(2): 157-179.
8. Di Cagno R, M De Angelis, M Calasso, M Gobbetti, PF Fox, TM Cogan. Use of small peptides from breakdown of casein by a proteinase of Lactococcus lactis subsp. cremoris MM19 to stimulate the growth of Lactococcus lactis subsp. lactis MM17. Int Dairy J, 2004; 14(6): 513-517.
9. Li T, J Luo, S Shen, J Wang, Y Cao, T Zhang. Determinants of Chinese dairy imports. China Ag Econ Rev, 2020; 12(3): 469-487.
10. Martin NH, KJ Boor, M Wiedmann. Symposium review: Effect of post-pasteurization contamination on fluid milk quality. J Dairy Sci, 2018; 101:861-870.
11. Villamiel M, P de Jong. Inactivation of Pseudomonas fluorescens and Streptococcus thermophilus in Trypticase® Soy Broth and total bacteria in milk by continuous-flow ultrasonic treatments and conventional heating. J Food Eng, 2000; 45:171-179.
12. FDA. 2015. Standards for grade "A" milk and milk products. Pages 34-35 in Grade "A" Pasteurized Milk Ordinance. Standards for grade "A" milk and milk products. U.S. Department of Health and Human Services, Washington, DC.
13. Ranieri ML, KJ Boor. Short communication: Bacterial ecology of high-temperature, short-time pasteurized milk in the United States. J Dairy Sci, 2009; 92:4833-4840.
14. Stadnyk I, T Hushtan, G Sabadosh, Y Yevchuk. Formation of microbial biofilms on stainless steel with different surface roughness. Potrav Slovak J Food Sci. 2019; 13(1)915-924.
15. Fysun O, H Kern, B Wilke, H-C Langowski. Evaluation of factors influencing dairy biofilm formation in filling hoses of food-processing equipment. Food Bioprod Processing, 2019; 113:39-48.
16. Hilbert LR, D Bagge-Ravn, J Kold, L Gram. Influence of surface roughness of stainless steel on microbial adhesion and corrosion resistance. Int Biodeterior & Biodegrad, 2003;52:175-185.
17. Austin JW, G Bergeron. Development of bacterial biofilms in dairy processing lines. J Dairy Res. 1995; 62:509-519.
18. Bhosale S, P Brahmane, A Kubade, RJ Desale. Biofilm in the dairy industry: Detection and common process for control biofilms. Pharma Innovation J. 2021; SP-10(8):809-817.
19. Stantz AA, EA Zottola, RL Petran, BJ Overdahl, LB Smith. The Microbiology of Sweet Water and Glycol Cooling Systems Used in HTST Pasteurizers in Fluid Milk Processing Plants in the United States. J Food Prot, 1989; 52(11):799-804.