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Identification and Control of Processing Variables That Affect the Quality and Safety of Fluid Milk

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ABSTRACT

The objective of this study was to increase quality and safety of fluid milk by eliminating postpasteurization contamination as measured by extended shelf life. Milk shelf life was defined as the number of days for standard plate count to reach 20,000 CFU/ml in milk stored at 7°C. Sequential analysis of the fluid milk processing system indicated filling machine and pasteurizer were significant sources of postpasteurization contamination. Aseptically sampled milk from the pasteurizer outlet indicated a maximum shelf life of more than 30 days could be achieved. The pasteurizer can be a source of contamination when inadequately cleaned or maintained. The filling machine was a significant source of contamination. Shelf life of milk in 236-ml containers was reduced 20 days compared with milk sampled before the filling machine. Carton-forming mandrels, filling heads, and airborne microorganisms were sources of contamination within the filling machine. Eliminating sources of postpasteurization contamination and proper cleaning followed by sanitizing with chlorine significantly increased milk shelf life in paperboard containers to 20.4 days from an initial shelf life of 9 days. Changing the sanitizing agent to peroxyacetic acid significantly increased milk shelf life to 33.9 days. Enclosing the filling chamber and adding sterile laminar flowing air significantly improved microbiological quality of air inside the chamber and reduced variance among milk shelf life samples.

There has been interest in recent years in expanding the shelf life of fluid milk because of potential advantages for both the processor and consumer. The dairy industry is in a state of change, which is driving it toward longer shelf life products without altered flavor or quality. Fluid milk processing plants are continuing to consolidate, resulting in larger product runs to maintain efficiencies and larger distribution areas, which will subject the milk to more temperature abuse. At the same time, the consumer is demanding a product that maintains flavor and microbial quality beyond the pull date. One of the principle factors associated with this concern about milk quality is its shelf life *(7, 12)*. Today, the consumer determines the acceptance of fluid milk by flavor and length of time before milk spoils in the refrigerator. Uniformly good flavor and acceptable keeping quality are essential in maintaining fluid milk sales.

Storage of pasteurized milk for long periods at refrigeration temperatures has provided time for microbial growth to produce quality problems. These problems are related to growth and metabolic activities of psychrotrophic microorganisms. Since gram-negative psychrotrophic microorganisms are destroyed by pasteurization, their presence is due to postpasteurization contamination. Even initial low levels of these microorganisms will grow to significant numbers at refrigeration temperatures and substantially reduce milk shelf life by producing off-flavors and physical defects.

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Five factors that limit the shelf life of refrigerated pasteurized milk are the microbiological quality of the raw milk, time and temperature of pasteurization, presence and activity of postpasteurization contaminants, types and activity of pasteurization resistant microorganisms, and the storage temperature of milk after pasteurization *(7, 15)*. The relationship between storage temperature and shelf life of pasteurized milk is well recognized. Low temperature retards bacteria growth and conversely increases shelf life *(3)*. It is often quoted that a 3°C rise in temperature decreases the shelf life of milk by one half *(1, 2, 10, 11, 15)*. Reducing postpasteurization contamination in this study extended milk shelf life.

The purpose of this research was to identify factors involved in postpasteurization contamination of fluid milk. Once these factors were identified, the processing and packaging systems were modified to extend fluid milk shelf life. Extended shelf life was used as an indicator of decreased postpasteurization contamination with psychrotrophic microorganisms.

Systematically studying the milk processing and packaging systems and correcting sources of contamination significantly increased the shelf life of milk. Two major areas were identified that caused postpasteurization contamination of fluid milk. The filling machine produced the most significant shelf life decrease, but the pasteurizer was also a source of contamination, especially after nonproduction days like weekends.

Many milk packaging machines used by the dairy industry were designed to minimally protect the milk during packaging and are similar to the filling machine used in this study. As a result, contamination with psychrotrophic mi-

croorganisms is widespread, resulting in reduced milk shelf life and increased consumer complaints. By studying the milk processing system and identifying factors contributing to postpasteurization contamination, it was possible to make relatively inexpensive changes that protected the product and resulted in extended shelf life and improved safety of fluid milk. No increase in pasteurization time and temperature was used to accomplish these objectives. Areas of concern in this study were raw milk quality, state of cleaning and sanitizing equipment, carton sanitary condition, air quality, and storage temperature.

MATERIALS AND METHODS

The fluid milk processing system of a small-volume dairy plant was used as a system that could be easily modified and monitored to identify important parameters that affect milk shelf life. Raw whole milk (<5°C) was standardized with raw skim milk (<5°C) to 2.1 ± 0.1% milk fat and stored in 1,135-liter tanks until pasteurized.

Pasteurization was achieved using an APV-Crepaco (Chicago, Ill.) plate pasteurizer with processing conditions of 75°C for 18 s. The State of Wisconsin, Department of Agriculture, Trade and Consumer Protection timed and sealed the pasteurizer *(14).*

An elevated 1,135-liter pasteurized milk storage tank was used to supply a LiquiPak Model 800 LH (Tetra Pak, Chicago, Ill.) paperboard filling machine equipped with an internal sanitation cycle. The filling mechanism was a four-head piston arrangement equipped with antifoam screens. Filled paperboard cartons (Tetra Pak) were removed from the filling machine manually, placed in wire milk cases, and placed in cold storage below 5°C. Milk temperature at filling was <5°C and did not exceed 9°C in the filled carton before storage.

The pasteurizer and homogenizer were cleaned in the same CIP loop with manually added chemicals. Cleaning cycle was a standard commercial cycle developed and monitored by the chemical supplier (H. B. Fuller, Minneapolis, Minn.). At the conclusion of milk processing, the system was switched to 15°C water and rinsed for 10 min. A 1% caustic solution was prepared using BW-90 chelated caustic detergent (H. B. Fuller) and circulated at 88°C for 20 min followed by a 10-min rinse with 55°C water. Monarch MP-2 (H. B. Fuller) acid was added at the level of 10.5 ml per liter of water and circulated 20 min at 71°C. The acid cleaner was discharged to the drain and the system rinsed with 15°C water for 10 min. Standard procedure was to leave rinse water in the pasteurizer surge tank at the conclusion of the final rinse after CIP.

The complete system was sanitized at the start of production with chlorine sanitizer (Monoklor, H. B. Fuller) at a concentration of 100 to 200 mg/liter as solution was discharged to the floor. Dichloroisocyanurate sanitizer (chlorine) was added as a source of chlorine when the pasteurizer reached operating temperatures and was in forward flow. This chlorine solution was pumped through the pasteurizer, to the pasteurized milk storage tank, through the filling nozzles of the filling machine, and onto the floor. In addition, the pasteurized milk storage tank and filler surge tank were fogged with a 150-mg/liter chlorine solution.

Sampling procedure. QMI Tru-Test aseptic sampling valves (QMI Food and Dairy Quality Management, Inc., St. Paul, Minn.) were used to divide milk processing system into sections to determine the source of microbial contamination. A minimum of 24 samples of milk per location per day were collected aseptically directly from milk lines using two-sided needles (Vacutainer 7215, Becton Dickinson, Rutherford, N.J.) with a needle holder (Vacutainer 364893, Becton Dickinson). Milk samples of approximately 10 ml were collected directly into sterile, partially evacuated 20-ml Vacutainer glass tubes (6433, Becton Dickinson). Air sterilized by indirect electrical heating to 330°C and cooled to 21°C in an air sterilization unit (E. C. Merrill Inc., Oshkosh, Wis.) was injected into the sample tubes with a sterile syringe (9633, Becton Dickinson) to ensure adequate oxygen for growth of aerobic psychrotrophic microorganisms. Sterility was confirmed by injecting 50 cm^3 of air onto covered petri dishes containing Trypticase glucose extract agar (BBL 11760, Becton Dickinson, Cockeysville, Md.). Incubation was at 32 ± 1°C for 48 ± 3 h. The lid of the Petri dish was raised 5 cm and air was injected at a 45° angle over the surface of the agar. Bulk samples of milk after raw milk storage and the pasteurizer surge tank were collected with a sterile, 60-ml, long-handled, stainless steel cup and transferred to sterile plastic sampling bags (Whirl Pak, Nasco, Fort Atkinson, Wis.).

The filling machine was isolated from the processing system by modifying one of the four milk supply lines from the filler surge bowl to one of the four filling heads on this machine. A portion of milk in all cartons passed through this line. A stainless steel elbow equipped with a Tru-Test sampling valve was installed to aseptically collect milk immediately before the filling head.

The carton-forming mandrels that contact the inside of the paperboard carton and hold it in place while the carton bottom is heat sealed are a potential source of contamination. The mandrels, filling heads, and other sections of the filling machine were swabbed with sterile swabs (Precision Bioport 5, 5201, San Fernando, Calif.) in tubes containing neutralizing buffer (Difco Buffer 0362-15-5, Difco Laboratories, Detroit, Mich.) to determine cleanliness using the swab contact method *(8).* Milk was collected after the pasteurizer to determine the quality of milk being supplied to the filling machine. These samples were compared with milk packaged in paperboard cartons.

Forty-eight samples of milk in paperboard cartons were randomly collected in duplicate and numbered consecutively during each day of milk processing. Sample order of testing was determined using random-number tables. An average production run of 2% milk-fat milk was 1.5 to 1.75 h. Samples were packed in ice for transport to the laboratory. All milk samples were stored at 7 ± 0.5°C. Standard plate counts (SPCs) *(9)* were determined on different sealed samples from approximately 2 days after collection until 10^7 CFU/ml were exceeded.

Experimental design. The experimental design consisted of a sequential analysis of the complete processing system using randomized, complete block, split-plot analysis or a two-sample *t* test to compare variables once potential sources of contamination were identified. Different sealed representative milk samples were evaluated periodically for SPCs and discarded. Shelf life was defined as the number of days for the SPC to reach 20,000 CFU/ml at 7°C. This was based on the legal limit for pasteurized milk *(14).*

SPCs plotted against days of storage at 7°C exhibited typical exponential growth. When the same data were plotted using semilog paper, a straight line resulted. The equation of the line of best fit was determined using the method of least squares and number of days to 20,000 CFU/ml was calculated.

Evaluation of the processing system. Paperboard cartons were shipped from the supplier to Isomedix Operations, Inc. (Libertyville, Ill.) for sterilization by cobalt-60 irradiation to reduce bacterial counts to <1 CFU per 236-ml carton. Minimum delivered dose was 12.5 kGy during an exposure time of 100 min for 115 cases (115,000 cartons). Sterile and nonsterile cartons were formed on the filling machine and sealed empty before milk was

passed through the system. The residual bacteria count (RBC) was determined *(8).*

Two chemical sanitizing agents were compared for their effect on the shelf life of fluid milk packaged in paperboard containers. Chlorine (Monochlor ''B,'' Monarch Chemical Division, H. B. Fuller) was used during initial work to optimize the shelf life of packaged milk. Chlorine concentration was monitored daily to ensure that the minimum recommended concentration of 100 mg/liter was maintained as solution was discharged to drain. After milk shelf life was determined using chlorine, the sanitizer was switched to peroxyacetic acid (P-3 Oxonia Active, Klenzade Division, Ecolab, St. Paul, Minn.) at a minimum concentration of 2,000 mg/liter. Chemical levels were monitored with test kits supplied by the chemical supply companies.

The LiquiPak 800 LH filling machine was equipped with plastic side panels along the filling chamber. However, the top of the filling machine over the filling chamber was open directly to the processing plant. To determine whether this was affecting fluid milk shelf life, plastic panels were fabricated (Acme Equipment, Madison, Wis.) and installed as a top cover to enclose the filling chamber. In addition, laminar flowing sterile air was introduced within the filling chamber. Air was sterilized with the Merrill air sterilization unit and Tygon tubing used to deliver the air to a manifold constructed of rigid polyvinyl chloride tubing that distributed the sterile air evenly over the carton filling area.

Air quality was measured using a sedimentation test *(8).* Petri dishes (100 mm diameter × 15 mm, Baxter D1906, Baxter Health Care Corp., McGaw Park, Ill.) containing Trypticase glucose extract agar (BBL 11760, Becton Dickinson) were exposed for 30 min at five locations within the filling chamber. Each day the five locations were averaged and reported as average daily sedimentation rate. Two locations outside the filling machine were used to measure air quality in the processing plant. One dish was placed on top of the filling machine and the other 10 ft away from the filler, 8 ft above the floor. These external locations were also averaged each day. Therefore, two values were reported for each day. Exposure plates were used to measure air quality before and after the cover was installed and sterile air was distributed in the filler. Temperatures within the filling chamber were monitored.

RESULTS AND DISCUSSION

Initial evaluation of the milk processing system. Random interval sampling of 48 cartons containing milk throughout the first 90 min of production was used to collect base data during an 85-day period. Samples of milk were used to determine the average shelf life of milk produced in this dairy, and no attempt was made to intervene or correct potential sources of contamination. The average milk shelf life was 9 days ($n = 26$ days, SE = 0.51) before intervention. Researchers *(4–6)* have reported that gram-negative psychrotrophic organisms grow rapidly in milk at refrigeration temperatures but are destroyed during pasteurization. Therefore, these results indicated postpasteurization contamination may be occurring in the system. This short milk shelf life indicated that there might be problems with the cleaning and sanitizing procedures.

To identify the sources of postpasteurization contamination, the fluid milk processing system was systematically studied by components. Initially, the system was divided into the pasteurizer and homogenizer section, pasteurized milk storage section, and filled cartons. A randomized complete block design was used to compare the three treatments, which were the sections of the processing system blocked by day sampled. These results (Table 1) indicated that a maximum milk shelf life of more than 30 days was achieved directly from the pasteurizer, but there was a wide range in results of 9.9 to 60 days. SPC testing was discontinued for milk samples from the pasteurizer and pasteurized milk storage that did not show microbial growth after 60 days. A shelf life of 9.9 days suggested contamination was occurring in the pasteurization process before the milk was pumped to the storage tank.

TABLE 1. *Shelf life of milk sampled from three sections of the fluid milk processing system*[a]

	Average shelf life (days at 7°C)	Standard error	Range (days)
Pasteurizer	40.3 A	5.3	9.9–60.0
Pasteurized milk storage	36.8 A	5.3	8.2–60.0
Milk in cartons	15.5 B	2.2	4.6–37.0

[a] Fourteen processing days were observed per section. Results with the same letter are not different at the 5% significance level. Shelf life is defined as number of days for standard plate counts of milk to reach 20,000 CFU/ml at 7°C.

Milk samples aseptically collected with Tru-Test sampling valves after the cooling section of the pasteurizer were representative of the maximum shelf life possible for this milk. Contamination at this point would indicate inadequately cleaned or maintained equipment. Milk was sampled on 14 processing days randomly selected during a 42-day period. Of these, 64% of the milk samples had a shelf life of more than 30 days when sampled immediately after pasteurization. Sixty percent of the milk samples that had an SPC greater than 20,000 CFU/ml before 30 days of storage were packaged on Mondays. This suggested that the pasteurizer section was not being cleaned. Residual microorganisms were able to multiply during nonproduction days at ambient temperature and achieve populations sufficient to contaminate subsequent production even with circulation of chlorine sanitizer before start-up.

Packaged milk shelf life was significantly ($P < 0.001$) shorter than shelf life of milk samples collected either after the pasteurizer or pasteurized milk storage. Minimum shelf life was 4.6 days. The average shelf life decreased 21.3 days for milk in cartons after the filling operation compared with milk sampled after the pasteurized milk storage tank. This suggested that the filling machine was a major source of postpasteurization contamination that significantly shortened the shelf life of milk.

Monitoring the milk processing system more closely might have increased employee awareness of equipment cleaning, and correcting potential problems significantly ($P < 0.05$) increased the packaged milk shelf life to 15.5 days ($n = 14$ days, SE = 2.2) in this part of the study from 9 days initially ($n = 26$ days, SE = 0.51).

Pasteurization and filling process evaluation. This study identified two areas of the milk processing system that were causing postpasteurization contamination of milk

TABLE 2. *Shelf life of milk collected after various sections of the milk processing system compared to milk in 236-ml cartons*[a]

	Average shelf life (days at 7°C)	Standard error	Range (days)
Raw milk	2.5 A	0.22	2.0–3.2
Pasteurizer surge tank	2.5 A	0.14	2.1–2.8
After homogenization	9.1 B	0.82	6.2–10.7
After pasteurizer	51.5	8.48	17.6–60.0[b]
Milk in cartons	13.4 B	2.65	7.9–20.0

[a] Five processing days were observed per treatment. Numbers with same letter are not different at the 5% significance level; logarithmic transformation of data was used.

[b] Milk evaluated from 4 of 5 days exceeded 60-day shelf life; shelf life is defined as the number of days for standard plate counts of milk to reach 20,000 CFU/ml at 7°C.

TABLE 3. *Comparison of milk sampled before passing through the head of the filling machine with milk in cartons sampled after passing through the filling machine*[a]

	Average shelf life (days at 7°C)	Standard error	Range (days)
Milk sampled before passing through the filling machine head	35.4	5.2	6.9–60.0
Milk in cartons	15.4	1.6	6.1–30.9

[a] Seventeen processing days were observed per location. Results are significantly different at $P = 0.001$. Shelf life is defined as number of days for standard plate counts of milk to reach 20,000 CFU/ml at 7°C.

and shortening shelf life. The filling machine produced the most significant shelf life decrease, but the pasteurizer section was also a source of contamination, especially after nonproduction days like weekends. To lengthen milk shelf life, it was necessary to identify the sources of contamination occurring during pasteurization.

The pasteurization section of the processing system was evaluated by moving the Tru-Test sampling valves to allow aseptic collection of 10-ml samples after the homogenizer and pasteurizer. Also, bulk samples of standardized raw milk and raw milk from the pasteurizer surge vat were collected in sterile plastic sample bags. Filled cartons were evaluated for shelf life to monitor the filling machine. A randomized, complete block, experimental design was used to study the effect of the following treatments on milk shelf life: the raw milk, pasteurizer surge tank, homogenizer, pasteurizer, and cartons. The treatments were blocked by days sampled. Results are shown in Table 2. Logarithmic and square root transformations of all data were used to detect differences between treatments.

Raw milk quality can influence the final shelf life of packaged milk. During an 18-month period, the SPC of raw milk averaged 7,200 CFU/ml ($n = 58$, SE = 2,300) on periodic evaluations. The poorest raw milk sample contained 125,000 CFU/ml. The maximum requirement for commingled milk is 300,000 CFU/ml *(14)*.

The heat treatment in the regeneration section of the pasteurizer lengthened milk shelf life after homogenization even though the milk was not pasteurized. Even though the average shelf life of milk sampled after the pasteurizer was 51.5 days, it had a large SE of 8.48 ($n = 5$ days). The shortest shelf life of milk collected after the pasteurizer was 17.6 days. Milk from 4 of the 5 days evaluated did not have significant microbiological growth at 60 days when testing was discontinued. This is reflected in the standard error. To accomplish this, close monitoring of cleaning cycle times and temperatures and that the proper cleaning chemicals were added at the correct time was required. The equipment must be disassembled routinely for inspection and swabbing to determine cleanliness. We did not find equipment design errors that could be modified to improve this section of the milk processing system.

Cartons of milk in this portion of the study indicated that a high level of contamination was occurring after the pasteurizer. Packaged milk had a significantly ($P < 0.001$) shorter shelf life than milk samples collected after the pasteurizer. This supported the conclusion that the filling machine is a significant source of contamination.

Milk filling machine evaluation. To study the filling machine more closely, a Tru-Test sampling valve was installed between the filler surge tank and one filling head of the filling machine. All cartons received milk through this filling head. Milk samples were aseptically collected immediately before the filling head to isolate the filling machine after the surge bowl from the milk supply system. These samples were compared with milk in cartons (Table 3). Milk samples were also collected after the pasteurizer to determine if the milk was contaminated before it reached the filling machine.

A randomized, complete block design with treatments of milk before the filler head and milk in cartons was blocked by day sampled. Milk from 17 days was collected during a 62-day period. Average shelf life of milk before the filling head was significantly ($P < 0.001$) longer than the average shelf life of milk in cartons. However, there was a wide range in shelf life of 6.9 to 60 days for milk sampled before the filler head. Milk collected before the filling head had a shelf life greater than 20 days for 12 observations (70.6%). The other 5 days had high levels of contamination that severely shortened the shelf life of milk collected before the filling head. This suggested uncleaned equipment. The shelf life of milk sampled before the filling head suggested that a shelf life of more than 30 days could be achieved if postpasteurization contamination were eliminated and equipment were clean. To reduce the effect of the filling machine on milk shelf life, a study was made to determine where the contamination was originating. The CIP cycle times were monitored and lengthened from 3.5 to 20 min to provide improved cleaning. CIP solutions were monitored to ensure correct chemicals were added at the proper time. Cycling of valves and filling pistons in the filling machine were adjusted during CIP to increase flow of cleaning chemicals. Modifi-

cations were done after consultation with a representative from Monarch Chemicals (H. B. Fuller), which had established the recommended cleaning procedures and supplied chemicals for this processing plant.

Carton-forming mandrels. The LiquiPak 800 LH filler was equipped with eight aluminum carton-forming mandrels. The flat paperboard carton was opened and slipped onto a mandrel to form finished cartons. A microbiological examination of the mandrels was conducted using the swab contact method *(8)* at room temperature. Approximately 50 cm^2 on each mandrel was swabbed. Microbial counts ranged from 36 to 2,700 CFU/mandrel with an average of 304 CFU/mandrel ($n = 24$, SE = 165.3).

The cleaning regimen was modified to have the operator manually clean the forming mandrels daily with a mild alkaline cleaner recommended by the chemical supplier (Monarch Antisoil 301, H. B. Fuller) at 60°C followed by rinsing with 45°C water. Effectiveness of the cleaning routine was monitored with the RBC for empty cartons formed on the machine *(8)*. The RBC was measured by forming and sealing cartons on the machine without milk. The initial nine cartons were sampled and the RBC for each day was the average of these cartons. The average RBC of sterilized cartons was 13.9 CFU per 236-ml container ($n = 9$ days, SE = 5), and nonsterilized cartons averaged 10.3 CFU per 236-ml container ($n = 10$ days, SE = 7.1). They were not significantly ($P < 0.05$) different. This indicated that standard packaging material that was handled and stored properly will not shorten shelf life.

Woven wire screens in filling head. The LiquiPak 800 LH filler uses a series of five woven wire screens in the filling head to minimize foam in the carton. If foam were produced during the filling operation, it would interfere with forming the top seal and leaking cartons would result. This would also allow microorganisms to enter the carton and increase the rate of spoilage. The filling head is the only area where woven wire is allowed for a product contact surface in a Grade A fluid milk plant. Unfortunately, woven wire is impossible to clean. Hand cleaning the screens and installing them before sanitizing was not adequate. Swabbing the top and bottom of the four assembled filling heads gave a microbial count of 1,200 CFU after hand cleaning without sanitizer. Placing the screens in a clean-out-of-place tank for cleaning did not improved the microorganism loading. If the screens are not clean, they would be an excellent source of contamination since all milk must pass through these screens located in the filler nozzles. Therefore, the screens were autoclaved between uses to eliminate microbial contamination.

Chlorine and peroxyacetic acid sanitizers. A significant lengthening of milk shelf life was achieved in this study by cleaning equipment and correcting sources of contamination. The shelf life of fluid milk packaged in 236-ml paperboard containers and stored at 7°C is shown in Table 4. Chlorine at a concentration of 100 to 200 mg/liter was used exclusively in this project to sanitize all milk contact surfaces before processing was started. Correcting sources of postpasteurization contamination identified in this study followed by cleaning and sanitizing the milk processing and packaging system with chlorine significantly ($P < 0.01$) increased milk shelf life. Shelf life of milk in paperboard cartons increased to an average 20.4 days. This was an excellent shelf life for milk packaged in paperboard cartons. The difference in standard error suggested that the assumption of equal variance in the *t* test may not be valid. An *F* test for homogeneity of variance was highly significant, indicating variances were different. Use of the Satterthwaite adjustment to allow for unequal variance did not alter conclusions *(13)*. The days with shorter shelf life probably were due to failure in the cleaning regimen and not related to the chlorine sanitizer.

TABLE 4. *Prestudy and final shelf life of milk packaged in 236-ml paperboard containers using chlorine and peroxyacetic acid as sanitizing agents*[a]

	Average shelf life (days at 7°C)	Standard error	Range (days)
Prestudy shelf life (chlorine) ($n = 26$ days)	9.0	0.51	5.9–16.6
Final shelf life (chlorine) ($n = 8$ days)	20.4	2.98	7.3–30.6
Final shelf life (peroxyacetic acid) ($n = 8$ days)	33.9	4.12	21.3–53.0

[a] All comparisons are different at the 5% significance level. Shelf life is defined as number of days for standard plate counts of milk to reach 20,000 CFU/ml at 7°C.

The sanitizing agent was changed to peroxyacetic acid after the shelf life of milk was optimized using chlorine. A significant ($P < 0.05$) increase in shelf life was obtained by sanitizing with peroxyacetic acid at a minimum concentration of 2,000 mg/liter. Average milk shelf life increased to 33.9 days. Shelf life of this length can be obtained only by careful monitoring of the complete fluid milk processing system and following correct cleaning and sanitizing procedures daily. Peroxyacetic acid was a more effective sanitizer than chlorine under conditions of this test.

Enclosing the filling chamber and introducing sterile air. Plastic panels were installed to cover the filling chamber of the LiquiPak 800 LH filler, and sterile laminar flowing air was introduced within this chamber to minimize contamination. Enclosing the filling chamber did not result in a significant change in milk shelf life. Milk averaged 26.9 days ($n = 7$ days, SE = 0.71) to reach 20,000 CFU/ml at 7°C, which was not significantly different at the 5% level than the 33.9 days ($n = 8$ days, SE = 4.1) achieved before enclosing the machine. However, enclosing the filling chamber reduced the variance among observations. The standard deviation of the observations before enclosing the filling chamber was six times larger than the standard deviation of samples after enclosing the chamber. An *F* test for homogeneity of variance between the two groups suggested that variances of the two groups were different (*P*

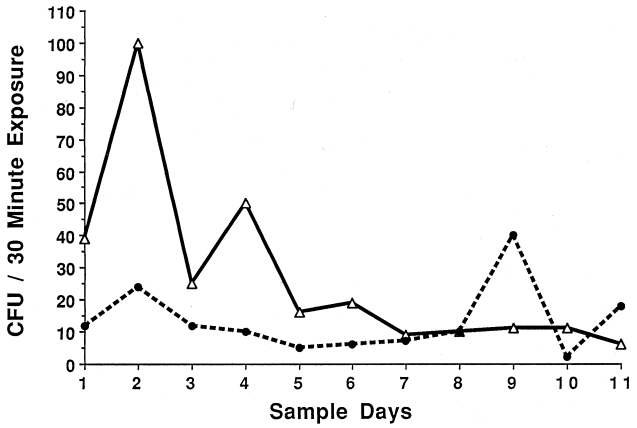

FIGURE 1. *Comparison of microbiological air quality inside the filling chamber (△) before and after enclosing the area versus processing plant air (●). Days 1 to 6 are before the filling chamber was enclosed.*

< 0.001). Use of the Satterthwaite adjustment *(13)* in the two-sample *t* test to allow for unequal variance did not alter conclusions. An improvement in microbiological quality of the air within the filling chamber was measured using the sedimentation test *(8)*.

Figure 1 compares the microbiological loading of the air inside the filling chamber before and after enclosing the area versus the processing plant air. The initial 6 sample days were obtained when there was no cover on the filling machine. The microbiological quality of the air was substantially poorer inside the filling chamber than in the processing plant. This may be due to mechanical motion that increased air movement; thus, more microorganisms would impinge onto the exposed petri dishes. The average microbial sedimentation rate was 41.6 CFU per 30-min exposure ($n = 6$ days, SE = 12.8) inside the filling chamber, with a range of 16.2 to 100 CFU per 30 min, compared with a processing room air average rate of 11.7 CFU per 30 min ($n = 6$ days, SE = 3) and a range of 3 to 24 CFU per 30 min. After the filling chamber was enclosed and sterile laminar airflow installed, the microbiological air quality within the filling chamber improved significantly ($P = 0.05$) and was more uniform, averaging 9.5 CFU per 30 min ($n = 5$ days, SE = 1.0), with a range of 5.6 to 11.4 CFU per 30 min. Reduced variance of the observations after enclosing the filling chamber required use of the Satterthwaite adjustment *(13)* in the two-sample *t* test due to unequal variances of the two groups. Processing plant air averaged 14.1 CFU per 30 min ($n = 5$ days, SE = 7.0) and ranged from 2 to 40.5 CFU per 30 min. Generally, after installing the cover, air quality inside the filling chamber was better than the air in the processing room around the filling machine. This points out the value of keeping all doors closed on a filling machine not only for safety, but also for improved packaged milk quality.

Large-volume dairy plant. The original milk processing system studied was in a relatively small dairy. This more easily allowed monitoring and modification of the system to study variables. Average production runs were 1.5 h compared with larger commercial dairies processing milk for more than 15 h per day. A large commercial dairy was evaluated for comparison with the smaller system. The objective was to determine whether the milk shelf life in a larger plant was similar to milk shelf life in the smaller dairy. If they were similar, it would indicate the need for careful monitoring of the milk processing system and possible need for modifications to extend the shelf life of milk. The information derived in the small dairy should be applicable to any size dairy.

Dairy A packaged 236-ml paperboard containers with a LiquiPak 222 dual line filler. Packaging rate was 222 cartons per minute. Cleaning cycles and chemicals were supplied by Klenzade (Ecolab), with peroxyacetic acid used as a sanitizer at the start of production and to sanitize the filling chamber during production. The LiquiPak 222 is designed with stainless steel carton-forming mandrels, which could be easily cleaned, and a bellows-type filling mechanism instead of a piston, which eliminated the use of woven wire screens. No attempt was made to alter this system. Cartons filled with milk were collected and stored at 7°C to determine shelf life. Average milk shelf life was 13.1 days ($n = 6$ days, SE = 1.4), with a range of 10.8 to 19.7 days. This processing plant produced an adequate quality product to meet current code date of 14 days.

The onset of off-flavor development would be expected when the SPCs of these milk samples reached 10^6 CFU/ml *(4, 5)*, which averaged 20.6 days at 7°C. The shortest shelf life milk sample reached this level in 16.8 days. This would only give 2.8 days beyond the code date using a 7°C incubation temperature. Generally, it is desirable to provide 4 to 5 days beyond the code date to avoid customer complaints. Shelf life was longer when the milk was stored at less than 4°C.

Milk shelf life. It was possible to achieve a shelf life of more than 30 days for milk in paperboard cartons if the equipment were cleaned and sanitized and the milk were protected from postpasteurization contamination after the pasteurizer. As raw milk bacteria continue to decrease, it is possible to pasteurize milk to approach a microorganism-free status. When this occurs, downstream milk handling procedures become much more critical in assessing shelf life and fluid milk safety. There are many fillers used in the fluid milk industry similar to the LiquiPak 800 LH in this study. By studying the milk processing system and identifying factors of postpasteurization contamination, it was possible to make relatively inexpensive changes that protected the product and resulted in an extended shelf life and improved safety of fluid milk.

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