This literature review was prepared in response to questions from State Regulatory Agencies in the US regarding the efficacy of teat cleaning and sanitation in automatic milking systems (AMS). The literature review is presented in reverse chronological order and includes the author’s abstracts. The main focus of the review is the efficacy of teat and udder cleaning, although several notable studies on milk quality, residue avoidance and udder stimulation have also been included. A report on the pilot project authorized by the NCIMS on milk quality from AMS farms in the US is also attached. It is worthy to note that the bacterial quality of milk from AMS farms was better and the Somatic Cell Count was no different than a randomly selected cohort of diary farms in Wisconsin.


Abstract: In order to evaluate the efficiency of the cleaning system of a milking robot (Fullwood-Merlin) installed in an Italian farm, field tests have been run in order to evaluate milk TBC of different cow groups using various set ups of the automatic teat cleaning system. Results showed that the automatic teat cleaning system guarantees better results than no teat cleaning ($4,42\pm 0,54 \log_{10} \text{CFU/ml}$), as observed by Schuiling (1992), although the results do now show statistically significant differences, and one cleaning cycle ($4,419\pm 0,75 \log_{10} \text{CFU/ml}$). Other results show statistically significant differences in groups subjected to no teats cleaning and to a double teats cleaning cycle, emphasizing a total bacterial count of the milk higher than the reference group subjected to a manual cleaning of each teat by a disposable disinfectant towel. In both phases of the experiment we have observed that a single teats cleaning cycle is more efficient in the removal of organic residues from the teats surface than a double one. The most likely hypothesis is that an extended action of the cleaning rollers of the robot do not increase the removal of organic residues from the teats but, on the contrary, favor its redistribution on the teats surface. **Overall, and as regard the test carried out, the teats cleaning unit of tested automatic milking system, guarantees a satisfactory cleaning of the teats surface.**


Abstract: The aim of this study was 1) to develop a protocol for the evaluation of teat cleaning systems with regard to risk of milk contamination in automatic milking systems, and 2) to estimate the level of residues in milk after teat cleaning making use of a cobalt solution treated brush or teat cup. Results were as follows: 1) The effect of teat and udder cleaning via cobalt levels in the milk could not be determined because no significant difference was found between samples from Co-manure treated cows with and without teat cleaning. The amount of cobalt added to the manure (5g/kg) was probably not high enough, 2) Disinfection of teat cleaning systems showed Co-Residues in milk, but the levels were rather low (4-80 µg/kg). **Differences between AM-systems were not significant, but only two farms per brand were studied.**

Slaghuis, BA, RT Ferwerda-Van Zonneveld, and A Mooiweer. 2004. Cleaning Effects of Teat Cleaning
in Robotic Milking Systems by Use of Poppy Seed as Tracer. 118.

Abstract: The aim of this study was to assess the cleaning effects of different types of cleaning devices in robotic milking systems. Two farms per brand were selected by the producer/suppliers. Six brands and two conventional farms were tested, so results of 14 farms were obtained. Results showed significant effects of teat cleaning and brands. Differences between brands in teat cleaning efficiency could be concluded; from three brands teat cleaning was more effective (85-99% reduction in poppy seed in milk) than from three other brands (50-70% reduction in poppy seed in milk). Conventional teat cleaning gave a reduction of 99%. **Teat cleaning determined by the poppy seed method showed to be effective for all brands. However, good maintenance of the teat cleaning system is very important for a good effect of teat cleaning.**


Abstract: Flushing of the teatcup liners between the milkings of two cows is a common procedure in AMS systems. In this investigation the standard procedure, flushing with cold water, is compared with flushing with a disinfecting fluid, composed of cold water and per acetic acid. Liners were contaminated with a suspension of Streptococcus agalactiae in milk, comparable with a severe inflammation of the udder. The log reduction in number of pathogens was 1.80 and 2.26 for respectively cold water and the disinfectant. The extra log reduction with a disinfectant was small and did not compensate for the negative effects of using disinfectants in a milking system (extra rinse necessary, higher risk of contamination of milk). Further experiments to show the effect of cluster flush on transfer of pathogens through liners are done with a cold water rinse only. 46 Cows were challenged with pathogens by milking with deliberately contaminated liners with a high dose of Streptococcus agalactiae prior to the cluster flush. Two liners (cross positioned front and rear) were flushed after contamination, the other two liners were not flushed. The udder health of the cows was measured during one week after the challenge. In none of the foremilk samples Streptococcus agalactiae could be recovered and none of quarters showed signs of an inflammation (increase in SCC or conductivity). The effect of a cluster flush on the rate of new infections could not be established in this experiment. However, based on the results of the reduction of pathogens in liners, it is recommended to perform a cluster flush to reduce the number of pathogens in the liner.


Abstract: In several European countries there is a demand that milk producers with automatic milking systems (AMS) must clean the milking system three times a day. Cleaning an AMS reduces possible milking time as well as consuming considerable amounts of hot water and detergents. Therefore, it is important to acquire greater knowledge during practical conditions to better understand the consequences of less frequent cleaning. This study was carried out on 13 Dutch and 9 Swedish farms during a period of 4 month. All AMS brands were included in the study, the two investigated treatments were cleaning with 8 and 12 hours intervals. Milk quality was analysed for total bacterial count (TBC), coliform count (CC), psychrotrophic count (PC) and thermoduric count (TC). The AM-systems were tested before and after each period of cleaning with one of the two cleaning frequencies. If necessary the systems were adjusted to the demands set by the manufacturer. To ensure that milk cooling and cleaning have been done correctly during the sampling period, in the Swedish farms the temperature was monitored in the milk pipe and in the bulk tank.

In both countries the difference for TBC was significant for the two different cleaning frequencies, even though the difference is small. In the Netherlands also a significant difference was obtained for the other groups of bacteria. In some farms, probably depending on type of AM-system and on management, the TBC is low in all cases, with no difference between two and three times cleaning per day.
Depending on the payment system for milk quality, the number of coliform bacteria when two system cleanings per day are performed can be above the level for first quality milk. It is suggested that the less frequent change of filters could attribute to this.

When AM-systems have a sanitary design, are optimised for cleaning, are well maintained and controlled, a good milk quality can be achieved with two system cleanings per day. This will reduce consumption of water, energy and chemicals and will increase the milking capacity. But defects in the construction or in the procedures will show sooner and will have a larger effect on milk quality.


Abstract: The aim of the present study was to investigate the efficiency of the removal of *Clostridium tyrobutyricum* spores and manure slurry from teats using the DeLaval VMSTM teat preparation module, and to compare the results with conventional manual teat cleaning. The mean total numbers of spores recovered in the milk for the control, manual and VMSTM cleaning were 32,246 cfu, 10,805 cfu and 616 cfu, respectively (p<0.01). The conventional cleaning and the VMSTM removed 65% and 98% of the spores, respectively. The results after conventional cleaning were in line with other similar studies and the VMSTM was comparable to very careful manual double cleaning.


Abstract: Prevention of antibiotic residues in milk is an important aspect in milk production to ensure health protection for the consumer and high quality of milk for dairy processing. Limited information is available on the potential impact of milking frequencies associated with Automatic Milking (AM) on excretion of veterinary drugs in milk. Under experimental conditions the excretion of antibiotics in milk was studied in health cows (somatic cell count in composite milk below 100 000/ml) after intramammary treatment with 4 different commercially available drugs at milking frequencies of 3, 2 and 1.5 times/day. The concentrations of antibiotic residues in cow composite milk sampled at every milking time were determined by HPLC methods and compared to the Maximum Residue Limits (MRL) for each compound.

For drugs containing cefquinome or penicillin or a combination of penicillin, nafcillin, and dihydrostreptomycin significantly (p < 0.05) shorter excretion periods were observed in cows milked 3 times per day compared to cows milked 1.5 times per day. For one drug containing ampicillin and colistin differences were not significant. Higher concentrations of residues in milk were determined with shorter intervals between treatment and next milking.

After intramammary treatment of clinical mastitis with cefquinome no significant difference of excretion times was detected between cows milked 2 times (n=15) or 1.5 times (n=4) per day. In these cows only milk yield had a significant influence on excretion time with shorter excretion times in high yielding cows (p < 0.05).

The indicated withholding periods for milk were sufficient for all drugs. Nevertheless it is recommended to milk treated cows at least twice per day, because prolonged excretion was determined in healthy cows milked less frequently.


Abstract: Teat cleaning is necessary to prevent milk from contamination with manure, dirt and included bacteria. Clean udder and teats before milking is also a requirement according to
Council Directive 89/362/EEC. A lot of research has already been done to investigate the effect of teat cleaning on milk quality. In automatic milking (AM) systems the mechanisation of teat cleaning has become part of the procedure. Still missing is the online control of teat cleaning efficiency. The assessment of the teat cleaning efficiency of different types of cleaning devices in AM systems was the subject of this research.

The methods for evaluating teat cleaning efficiency had to be developed for this purpose. Part of these methods was presented in deliverable D13, another part is presented in this deliverable.

Two different approaches were chosen for evaluation of teat cleaning devices: In the first approach teats were artificially contaminated with a tracer substance and carry over of the tracer into milk was determined. The protocol consisted of applying a mixture of poppy seed and manure (20\% w/w) on teats of ten cows per farm. Five cows were milked after teat cleaning and five cows were milked without a previous teat cleaning. Milk per cow was filtered through a cotton filter. The filters were dried and the poppy seed was counted.

Two farms per brand of AM system were selected by the producers/suppliers. Six brands including 12 farms and two farms with conventional milking systems were tested. Results showed significant effects of teat cleaning versus no teat cleaning and between different brands. From three brands teat cleaning was effective (more than 85\% reduction in poppy seed in milk versus no cleaning) and from three other brands teat cleaning was less effective (50-70\% reduction in poppy seed in milk). Conventional teat cleaning gave a reduction of 99\%. Teat cleaning in practice might be less effective, because the waiting time after application was less than one hour and the adhesion of poppy seed is probably less strong than of dried manure and/or bacterial spores.

In the second approach a combination of visual evaluation of teats before and after teat cleaning, sediment tests after teat cleaning and the determination of total bacterial counts and ATP in teat swabs taken before and after cleaning was applied. 6 brands with 3 farms per brand were tested. On every farm 50 cows were sampled on two teats each.

Results showed large variation within and between individual farms. An analysis of variance showed that significant differences existed between teat cleaning efficiency of 4 brands versus 2 other brands. The ranking of brands regarding teat cleaning efficiency was similar independent of the method applied and also consistent with the results from part 1 of this study. Only for one brand deviating results were found by the combination of 4 methods. This was probably due to the fact, that no samples could be taken from teats directly after teat cleaning. The cleaning effect determined in this case was at least in part due to teat washing during milking.

The comparison of teat cleaning devices with brushes with those working with cups showed different effectiveness dependent on teat contamination level. Brushes seemed to be less effective with low level contamination, leading to a higher bacterial load on teat surfaces when teat contamination was low. With high contamination levels, brushes were more effective than cups in removing bacteria and organic material.

An analysis of variance was carried out to find out which of the factors brand, farm, position of quarter and initial contamination of teats was most important for teat cleaning efficiency. Although significant differences between brands were found, the most important factors were the individual farm and the initial contamination before teat cleaning. These findings underline the importance of management to ensure an effective teat cleaning. In the last deliverable of this work package different management factors will be evaluated regarding their influence on teat cleanliness.

From some observations during this study it can be concluded that good maintenance of the cleaning device is important for an effective teat cleaning procedure. Based on the findings from our study a pragmatic approach for evaluation of teat cleaning efficiency on farms is suggested. The procedure is based on ATP measurements with HyLite® 2 in teat swabs suspended in 8.0 ml sodium-peptone solution. 50 cows per farm should be sampled after teat cleaning at two teats each. Not more than 25 \% of teats should exceed a proposed value of 3.2
Log_{10} RLU after cleaning. This approach can also be applied on farms with conventional milking systems.


Abstract: During an investigation on teat cleaning efficiency of different Automatic Milking (AM) systems working in practice differences were detected not only between systems of different brands but also between farms working with the same AM system. In addition, teat contamination before cleaning was of significant influence on teat cleaning efficiency. Therefore the second part of the study focused on management factors to determine which measures are significantly associated with teat contamination.

The investigation was performed on 18 farms. Differential bacterial counts in bulk tank milk were determined to find potential failures in milk quality. High coliform counts on 8 farms indicated insufficient teat cleaning and/or failures in system cleaning. On 14 farms thermotolerant bacteria exceeding 200 cfu/ml showed potential problems with system cleaning although TBC was well below 10000 cfu/ml, but thermotolerant bacteria may also have originated from bedding material. In fresh bedding material different levels of bacterial contamination were found, with lowest total bacterial counts in specially treated sawdust and in sand. Coliform bacteria on teat surfaces are not necessarily due to faecal contamination, because these bacteria were also found in fresh bedding.

The hygiene management on farms was evaluated by means of a questionnaire-based interview with the farmer. In addition, a checklist was used to determine the actual hygiene status of certain areas on the farm. An analysis of variance was performed including 45 questions of the questionnaire and 17 aspects of the hygiene checklist.

AM specific management factors associated with high average teat contamination on farms were: replacement of teat cleaning device < once per year, moderate/poor status of the teat cleaning device, average milking frequency per day < 2.5 and no selection of cows for robot acceptance (p<0.10). Factors not directly related to AM involved contamination of cubicles: less than one cubicle per cow, cows lying on alleys present in the herd, addition of fresh bedding material less than once per day, no selection of cows for udder health, moderate/poor status of bedding material and moderate/poor status of claws were significantly related to high teat contamination. Additional factors like the general impression of the robot, cleaning frequency of the milking box, status of teat cups and the use of cow brushes in the barn were probably more closely related to the general attitude of the farmer towards hygiene than to teat cleanliness. Other factors can be regarded as generally accepted hygiene measures, because nearly all farmers practised cubicle cleaning twice per day, shearing of udders and cutting of tail heads. These factors should therefore be considered as basic hygiene measures.

Although the cause and effect relationship between parameters used to evaluate hygiene management on farms and teat cleanliness was not always very strong these factors should be considered when improvements of teat cleanliness are intended. **Even with very good conditions it will be unavoidable that individual cows will have soiled teats, but farm management should aim for clean udders in the majority of cows.** Apart from those factors which are specific for AM systems (e.g. frequency of replacing teat cleaning devices, milking frequency) it can be expected that the factors mentioned above can also improve teat cleanliness on farms with conventional milking systems.


Abstract: Within hygiene management in dairying effective teat cleaning before milking is a precondition to ensure high quality of raw milk. The teat cleaning efficiency of Automatic
Milking (AM) systems was investigated applying different methods. All brands currently used in practice were included: DeLaval, Insentec, Lely Industries, Fullwood, Prolion/Gascoigne Melotte and Westfalia Landtechnik GmbH. **Significant differences in teat cleaning efficiency of different brands were determined** (p<0.05), showing the necessity to improve teat cleaning efficiency of at least two brands. Variation between individual farms was of significant influence on teat cleaning efficiency with differences between the 3 farms working with the same AM system (p<0.05). Also of influence was the initial contamination of teats before cleaning. These results indicate that **farm management is important to ensure low teat contamination levels**. High coliform counts in bulk tank milk exceeding 100 cfu/ml suggested insufficiencies of teat cleaning on 8 farms, although in some cases these were accompanied by high counts of thermoduric bacteria indicating failures in system cleaning. On 18 farms with AM systems management aspects with regard to teat cleanliness were studied by means of a questionnaire based interview with farmers and a checklist on the actual hygiene status of barns. The outcome was compared to teat contamination measured by determination of TBC (total bacterial counts) and ATP (adenosine-tri-phosphate) from teat swabs taken before teat cleaning.

AM specific management factors associated with high teat contamination were: replacement of teat cleaning device less than twice per year, moderate/poor status of the teat cleaning device, average milking frequency per day <2.5 and no selection of cows for robot acceptance (p<0.10). **Factors not directly relate to AM involved contamination of cubicles: less than one cubicle per cow, cows lying on alleys present in the herd, addition of fresh bedding material less than twice per day, no selection of cows for udder health, moderate/poor status of bedding material and moderate/poor status of claws were significantly related to high teat contamination.** Additional factors like the general impression of the robot, cleaning frequency of the milking box, status of teat cups and the use of cow brushes in the stable were probably more closely related to the general attitude of the farmer towards hygiene than to teat cleanliness.


Abstract: In a series of investigations we have tested the stimulatory effect of the teat cleaning devices of the different AMS types and of subsequent teat cup attachment. Teat preparation induces the release of oxytocin (OT) and hence alveolar milk ejection already before the milking vacuum is applied to the teats. If milking is performed at short intervals from previous milking or in late lactational stages, i.e. at low degrees of udder filling, small amounts of cisternal milk and a long latency period until milk ejection in response to a pre-stimulation (up to 3 min) occur concomitantly. Due to the frequent occurrence of short intervals between milkings, an adequate pre-milking stimulation adapted to the expected actual degree of udder filling is crucial for a successful milking process. In a multi-box AMS udder cleaning caused immediate release of OT and after cows have moved to the milking box and teat cups were attached alveolar milk was available for milking. Several types of single stall AMS provide sequential cleaning of the teats one by one via two rolling brushes before the attachment of teat cups. this type of udder cleaning induced release of OT and milk ejection, too. Thus, alveolar milk is available immediately after attachment of the teat cups. Also in AMS with teat cleaning via warm water in a special teat cup OT is released immediately after the start of cleaning. It could be shown that even water temperatures as low as 12 to 15 degrees Celsius induced normal OT release and milk ejection. In some of the tested AMS an individual adaptation of the cleaning time to the actual udder filling was possible. At very low udder filling a prolonged teat cleaning reduced the total milking time whereas a prolonged teat cleaning in well filled udders just consumed additional time. In conclusion, all tested AMS teat cleaning systems are suitable for pre-stimulation to induce milk ejection already before the start of milking.

van der Vorst, Y, K Bos, W Ouweltjes, and J Poelarends. 2003. Farm and Management Factors Affecting
Abstract: In the Netherlands, 28 farms were visited to gain more knowledge on possible risk factors affecting milk quality on farms that milk with an AM-system. Milk quality parameters that were studied were total plate count (TPC), bulk milk somatic cell count (BMSCC) and the level of free fatty acids (FFA). Possible risk factors studied on the farms concerned general farm characteristics, animal health, AMsystem, cleaning, cooling, housing, management of the farmer and the hygiene on the farm. The results showed that TPC was significantly related to milk yield of the herd, cleaning of the area around the AM-system and the hygiene on the farm. Farms with high TPC had a lower milk yield and the cleaning around the AM-system was not done properly. The overall hygiene on these farms was also not very good. BMSCC appeared to be significantly related to milk yield of the herd and the number of milkings before replacement of the liners. A lot of farmers replace the liners much too late, resulting in a higher risk for BMSCC. Farms with a low BMSCC in general had a higher milk yield. In addition farms with a high FFA level appeared to have on average more alert messages from the tank guard. Those farms also appeared to have less feeding places per cow and cows were dirtier compared to farms with a low FFA level.

Helgren, JM, and DJ Reinemann. 2003. Survey of Milk Quality on United States Dairy Farms Utilizing Automatic Milking Systems. ASAE Annual International Meeting Technical Paper No. 033016. Abstract: Milk quality parameters were recorded for United States dairy farms utilizing automatic milking (AM) from August 2000 to June 2003. Additional farms were admitted to the study as they began operation, so that the full data set includes 12 AM farms. Somatic cell count (SCC) and total bacterial count (TBC) data was analyzed and compared to corresponding data from conventional farms in Wisconsin as well as data from European AM installations. The geometric mean SCC was 267,000 cells/ml and geometric mean TBC was 13,300 cfu/ml for all U.S. AM farm data collected. The study featured two primary objectives. The first was to assess seasonal variations in milk quality on AM and conventional farms. The second was to assess changes in the quality of milk from AM installations as the amount of time the system had been in operation increased. A clear and significant seasonal effect was evident for the SCC data, with higher values observed during the summer months (July, August, and September). There was no significant difference in SCC between AM farms and conventional farms. There was slight evidence of a seasonal effect on TBC. TBC of milk from AM farms was found to be lower than that from conventional farms. There is some evidence that both SCC and TBC decrease as the amount of time a farm utilizing AM increases.

Van der Vorst, Y, K Knappstein, and MD Rasmussen . 2002. Milk quality on farms with an automatic milking system: effects of automatic milking on the quality of produced milk. Wwww.Automaticmilking.Nl. Abstract: Recent milk quality data from farms with an automatic milking system (AM- system) were analysed for four consecutive groups (based on date of installation) and compared to data from conventional farms. Data of 99 Danish farms, 33 German and 262 Dutch farms were included and analysed for possible relations and courses in the milk quality from January 1997 until January 2001. Data of Dutch farms that milked twice (n=295) or three times a day (n=40) in conventional milking parlours during the same period, were used as controls. Milk quality was slightly lower when milking with an automatic milking system, in all three countries. The poorest levels of all measured parameters were found in the first six months after introduction of the AM-system. After this period the milk quality improved slightly and all farms then produced to a stable level (with exception of free fatty acids (FFA)). However, other than bulk milk somatic cell count (BMSCC), the quality from farms with an AM-system remained slightly lower than from conventional farms. Differences between farms were seen both in averages and in variance. This, together with the knowledge that the milk quality improves about 6 months after introduction indicates that improvements are possible.

Abstract: The cleaning of udder and teats before milking contributes to the image of hygienic food production. Teat and udder surfaces belong to the main sources of bacteria in raw milk. Therefore appropriate cleaning procedures are necessary to reduce the microbial contamination of raw milk. As part of workpackage 6 within the European project "Implications of the Introduction of Automatic Milking on Dairy Farms" a protocol was developed to evaluate mechanised teat cleaning devices that are in operation in automatic milking systems.

The evaluation of teat cleaning procedures will be based on a combination of four methods: visual inspection, sediment test on teat swabs and determination of total bacterial counts (TBC) and ATP in teat swabs. The results of visual inspection are largely dependent on the evaluating person and also vary within testing person when the same material is evaluated repeatedly. Nevertheless, visual inspection and sediment tests are suitable to determine teat cleanliness if cleanliness is defined as the absence of visible contamination with dirt and/or manure. For cleaned teats identical scoring by the two methods was determined in 95.8 % (n=96). The total impression of udder cleanliness seemed to be mainly influenced by the status of the udder basis. By comparison of TBC and ATP in teat swabs taken before and after teat cleaning a differentiation of cleaning efficiency of manual teat cleaning methods was possible. By wet cleaning with subsequent drying a better teat cleaning effect was achieved: the reduction of TBC in Log10 units was 1.50 (wet cleaning with subsequent drying of the udder) versus 1.11 (dry cleaning), the reduction of ATP in Log10 RLU was 1.26 versus 0.56. The efficiency of manual cleaning methods will serve as a reference for the following evaluation of mechanised cleaning devices applied in practice during the second part of the study. Another approach for the evaluation of teat cleaning efficiency was based on artificial contamination of teats with cobalt and subsequent determination of its carry over into milk, but could not be validated yet. The loss of cobalt after application on teats was high. Although carry over from teats and from teat cleaning devices into milk was found, no difference between cleaning and no cleaning of teats could be determined when the method was applied on an automatic milking system. Additional experiments are necessary to validate the cobalt method.


Abstract: The bacteriological quality of milk and problems due to bacterial contamination under automatic milking (AM) systems and the experiences from 4 German farms working with AM systems of 3 different manufacturers are presented.
SURVEY OF MILK QUALITY ON UNITED STATES DAIRY FARMS UTILIZING AUTOMATIC MILKING SYSTEMS

J.M. Helgren and D.J. Reinemann

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ABSTRACT. Milk quality parameters were recorded for United States dairy farms utilizing automatic milking (AM) from August 2000 to June 2003. Additional farms were admitted to the study as they began operation, so that the full data set includes 12 AM farms. Somatic cell count (SCC) and total bacterial count (TBC) data was analyzed and compared to corresponding data from a cohort of conventional farms in Wisconsin as well as data from European AM installations. The geometric mean SCC was 268,000 cells/ml and geometric mean TBC was 13,300 cfu/ml for the entire data set. The first major objective of this study was to assess seasonal variations in milk quality on AM farms, also making a comparison to data from conventional farms. The second was to assess changes in the quality of milk from AM installations as the amount of time the system had been in operation increased. A clear and significant seasonal effect was evident for the SCC data, with higher values observed during the summer months (July, August, and September). There was no significant difference in SCC between AM farms and the cohort of conventional farms. There was some evidence of a seasonal effect on TBC. TBC of milk from AM farms was found to be lower than that from the cohort of conventional farms. There is some evidence that both SCC and TBC decrease as the amount of time a farm utilizing AM increases.

Keywords. automatic milking machines, milking robots, milk quality, somatic cell count, standard plate count

INTRODUCTION

The introduction of automatic milking systems is arguably the most significant technological change in the dairy industry since machine milking in the late 19th century. Much like milking machines did for previous generations of farmers, automatic milking systems have the potential to enhance quality of life for the dairyman and his cows as well as increase milk production and quality.

The number of automatic milking (AM) systems installed throughout the world has increased dramatically in the last five years. In late 1997 just over 100 farms were using AM systems; by early 2004 over 2200 farms were using AM worldwide. As these systems proliferate, a key concern is the quality of milk produced and how it compares to that produced with conventional milking technology.

The primary difference between conventional and AM systems is that with AM the dairyman is not present as each cow is milked. The human eye and judgment can no longer be depended on to assess the health of the cow and quality of her milk. Instead, the AM system and its array of sensors must be relied on to make these assessments. Additionally, the design of an AM system is sufficiently different from its conventional counterparts that other aspects of how the system is managed, especially with respect to cleaning, must be rethought.

Because the effects of these differences have not been fully characterized, AM systems have not enjoyed the same legal status as their conventional counterparts. The United States Food and Drug Administration (FDA) issues the Pasteurized Milk Ordinance (PMO), which establishes
rules for the production of milk shipped across state lines in the U.S. Changes to the PMO are proposed, debated, and voted on at the National Conference of Interstate Milk Shippers (NCIMS). At the 2001 NCIMS, a proposal was submitted to study the impact of AM systems on the quality and safety of the U.S. raw milk supply (28th National Conference, 2001). At the time of that meeting, the PMO had no provisions for AM installations, and U.S. systems were considered "experimental." At the 2003 NCIMS, changes to the PMO were proposed that would accommodate AM systems (29th National Conference, 2003). The data in this paper was submitted in support of that proposal. The state delegates voted to endorse those revisions and the FDA concurred, thus accepting the proposed provisions for AM in the PMO.

Recent studies have compared the quality of milk harvested with AM systems to conventional systems. In one such study the somatic cell count (SCC) of cows milked with the AM system was found to be significantly higher than cows milked conventionally, although still in good standing (Davis and Reinemann, 2002). Two other studies found no significant effect of milking method on SCC (Svennersten-Sjaunja et al., 2000; Shoshani and Chaffer, 2002).

Objectives

Europe has larger installation base and longer history with regard to AM. Several studies on milk quality and AM in Europe have been presented (Svennersten-Sjaunja et al., 2000; Shoshani and Chaffer, 2002; van der Vorst et al., 2002). The objective of this study was to assess milk quality on U.S. AM farms, making use of methods similar to those used in the European studies. The specific questions of interest in this study were:

- Are there differences in milk quality (bulk tank SCC and TBC) between AM and conventional farms?
- Is there a seasonal variation in milk quality on AM farms or differences between AM and conventional farms?
- Does the milk quality on AM farms change with the amount of time the farm has been in operation?

Materials and Methods

Data Collection

The data set for this study was acquired according to recommendations made at the 28th meeting of the NCIMS. Those recommendations stipulated that standard plate count (SPC) and somatic cell count (SCC) are to be tested for every tank of milk produced on an AM farm. However, in order to maximize the number of farms in the study, some were admitted that sampled at less than the recommended frequency, or reported plate loop count (PLC) instead of SPC. Results from both SPC and PLC are referred to as total bacterial count (TBC) in this paper. The full data set from all AM farms spanned the period from August 2000 to June 2003, although data for that entire period is available for only one farm. Data from other farms was added as they began operation; in total data from twelve farms was collected.

Milk quality data from a cohort of farms including all licensed Wisconsin dairy farms producing Grade-A milk and not using AM was obtained from the Wisconsin Department of Trade, Agriculture, and Consumer Protection (DATCP). If SCC or TBC data was reported more than once per day on any individual farm the values were averaged to yield a single value, and any farms with missing data points were omitted. Although not all of the AM installations included
in the study were located in Wisconsin, it was felt that the Wisconsin data would provide for an adequate comparison.

**Statistical Methods**

A logarithmic transformation was used on both SCC and TBC to normalize the distribution of these data. Mixed model analyses were used to analyze the data with repeated measures of the milk quality (SCC or TBC) made on the experimental unit of farm. Akaike's Information Criterion (AIC) was considered when choosing a covariance structure; a first order autoregressive correlation was found to be most appropriate for all models. Backwards elimination was used to determine the final statistical models. Significance was assessed at the 95% confidence level (p < 0.05).

**AM Compared to Conventional Farms**

A random sample of 200 conventional farms was chosen as the cohort. Milk quality data for conventional farms was available once per month, while one milk quality data point per month was randomly selected from the AM farm data set. The data used for this analysis was from January 2002 to March 2003, a 15-month interval during which all 12 of the AM farms are represented. A categorical variable, MC (month count), was defined as the number of months since January 2002. The conventional farm randomization and AM farm randomization was performed five times with each data set analyzed using the following model:

\[
\text{Response} = \mu + \text{milking method} + MC + (\text{milking method} \times MC) + \varepsilon \quad \text{(Model 1)}
\]

\[
\text{Response} = \log (\text{SCC}) \text{ or } \log (\text{TBC})
\]

\[
\mu = \text{population mean of response}
\]

\[
\text{Milking method} = \text{AM or conventional}
\]

\[
MC \ (\text{month count}) = \text{categorical variable, 1 to 15}
\]

\[
\varepsilon = \text{error}
\]

**Milk Quality Changes with Time of Operation**

The data set for investigating changes in milk quality as AM farms gained experience used only the first 12 months of operation for each AM farm because at the time of this study there were few farms that had been operating more than a year. Additionally, a one-year interval was considered sufficient to capture any changes in milk quality due to the learning curve of AM users.

Temporal trends for AM farms were assessed using a continuous variable, day of operation (DOP), defined as the number of days the AM farm had been in operation when a data point was collected. The month of the year (MOY) was also included as a categorical variable to capture seasonal effects.

\[
\text{Response} = \mu + \text{DOP} + \text{MOY} + (\text{DOP} \times \text{MOY}) + \varepsilon \quad \text{(Model 2)}
\]

\[
\text{Response} = \log (\text{SCC}) \text{ or } \log (\text{TBC})
\]

\[
\mu = \text{population mean of response}
\]

\[
\text{DOP \ (day of operation)} = \text{continuous variable, days farm has been in operation, 1 to 365}
\]

\[
\text{MOY \ (month of year)} = \text{categorical variable, month of the year data was recorded, January (1) to December (12)}
\]
ε = error

Results and Discussion

Descriptive Statistics

A total of 2035 SCC samples and 1658 TBC samples from AM farms were recorded. The geometric mean was 268,000 cells/ml for SCC (SD of log (SCC) = 0.23) and 13,300 cfu/ml for TBC (SD of log (TBC) = 0.59). The AM data from the 15-month window that was compared to the conventional cohort used 1391 SCC samples and 1148 TBC samples with a geometric mean of 254,000 cells/ml for SCC (SD of log (SCC) = 0.22) and 12,600 cfu/ml for TBC (SD of log (TBC) = 0.58). The conventional farm cohort included 166,020 samples for both SCC and TBC with a geometric means of 288,000 cells/ml for SCC (SD of log (SCC) = 0.24) and 14,800 cfu/ml for TBC (SD of log (TBC) = 0.49).

AM Compared to Conventional Farms

Somatic Cell Count

The results of model 1 indicated that time of year (MC) had a significant (p<0.0001) effect on SCC while the milking method was not significant, nor was the interaction between MC and milking method. The random sampling in the analysis causes slightly different LS mean values each time the model was run, although significance remained unchanged between runs. The LS means for five runs of the model are shown in figure 1. An increase in SCC during July, August, and September (the hotter summer months) is obvious, with lower values observed during other months of the year.
Total Bacterial Count

The seasonal variation analysis for TBC data also yielded somewhat different results each time the model was run. The LS means of TBC for the five runs are shown in figure 2. Model 1 indicated that the interaction between MC and milking method was significant in only four of ten runs and was removed from the model. With the interaction term removed, MC was significant in four of five runs while milking method was significant in all five runs. In each run, the LS mean TBC for AM farms (overall mean 8200 CFU/ml) was slightly lower than that for conventional farms (overall mean 15,000 CFU/ml).

There is a slight increase in log (TBC) during the summer months; however, the trend is not as pronounced as for SCC. The variation between model runs is partially explained by previous studies, which have shown TBC data to be characterized by sudden elevations known as "spikes" (Hayes, et al., 2001). Each run of the model includes a different random sample of the TBC data; if a random sample included a spike in a particular month, the least squares mean for that month may be quite different than in a run of the model that did not capture the spike. While there is some evidence of seasonal variation in TBC it is difficult to draw definitive conclusions about the interaction term in the model. However, it is reasonable to conclude that AM farms are capable of producing milk with equal or lower TBC than conventional farms.
**Milk Quality Variation with Duration of AM Farm Operation**

**Somatic Cell Count**

The goal of this analysis was to determine if milk quality improved with operating experience on AM farms, as has been observed in previous studies on European AM farms. Model 2 indicated that MOY was significant (p<0.0001), a result similar to that found with model 1 in the previous comparison with conventional farms. DOP was also significant (p=0.011) indicating a slight downward trend in log (SCC) in the first year of operation. The raw log (SCC) data and linear trend line are plotted in figure 3. The Monthly Mean represents a geometric average of all tanks from all farms for each month of operation. The errors bars show deviations of ±2 standard deviations from the mean. The US legal limit for SCC (750,000 cells/ml = 5.9 after log transformation; Grade "A" Pasteurized Milk Ordinance, 2001) is also plotted.

![Log(SCC) vs. Operating Duration](image)

Another useful way to examine the data is by the percentages of milk tanks over threshold values. Thresholds of 750,000 cells/ml and 400,000 cells/ml, the U.S. and European legal limits, respectively, were used for SCC (table 1).

<table>
<thead>
<tr>
<th>Month of operation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total tanks sampled</td>
<td>131</td>
<td>160</td>
<td>164</td>
<td>169</td>
<td>152</td>
<td>143</td>
<td>110</td>
<td>86</td>
<td>78</td>
<td>80</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>% &gt; 400,000 cells/ml</td>
<td>29</td>
<td>24</td>
<td>29</td>
<td>30</td>
<td>20</td>
<td>17</td>
<td>13</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>% &gt; 750,000 cells/ml</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3. Log (SCC) plotted versus the length of time the farm has been in operation.
The number of tanks sampled decreases with time because some farms included in the study have been in operation for less than a year. A very small percentage of farms with AM systems produced milk that exceeds the U.S. legal limit for SCC. This percentage shrinks to zero as the length of time the farm has been in operation increases. As expected, a greater number of U.S. farms exceed the lower European threshold. For instance, during the first four months of operation nearly 30% of all tanks sampled had somatic cell counts greater than 400,000 cells/ml. However, after 8 months this percentage decreased to about 5% of tanks.

These observations are consistent with European findings. A study of milk quality data spanning February 2001 to October 2001 from AM systems in Denmark, Germany, and the Netherlands shows a similar decrease in SCC as the duration of operation for the AM farms increases. Although month-to-month data is not available for the European farms, percentages of tank samples with SCC greater than 400,000 cells/ml in Denmark, Germany, and the Netherlands were 11.1%, 9.3%, and 5.5%, respectively (van der Vorst et al., 2002). A comparison can also be made to the Wisconsin conventional farm cohort for which 30% of all bulk tanks exceeded 400,000 cells/ml and 3.3% exceeded 750,000 cells/ml thresholds. AM farms in the US produced milk with SCC similar to conventional farms in the U.S. and AM farms in Europe.

**Total Bacterial Count**

The results of model 2 indicated that neither MOY (p=0.91) nor DOP (p=0.051) were significant. MOY was removed from the model and this refined model indicated that DOP was significant (p=0.047). The raw log (TBC) data and linear trend line are plotted in figure 4. The monthly mean represents a geometric average of all tanks from all farms for each month of operation and the error bars show deviations of ±2 standard deviations from the monthly mean. The US legal limit for TBC (100,000 cells/ml = 5 after log transformation; Grade "A" Pasteurized Milk Ordinance, 2001) is also plotted. There appears to be a very slight downward trend in the mean values as well as the variability in TBC.

It is notable that the maximum raw value for each month is attributed to a variety of farms; there is not a single "problem farm." Also, the reason for an extremely high bacteria count was often traced to an obvious cleaning system failure, such as a hose that became detached or pinched.

The percentages of tanks testing greater than thresholds of 30,000 cfu/ml and 100,000 cfu/ml are shown in table 2. The incidence of tanks exceeding both thresholds decreases with the amount of time the AM system has been in operation.

<table>
<thead>
<tr>
<th>Table 2. Percentages of tanks over thresholds for TBC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month of operation</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Total tanks sampled</td>
</tr>
<tr>
<td>% &gt; 30,000 cfu/ml</td>
</tr>
<tr>
<td>% &gt; 100,000 cfu/ml</td>
</tr>
</tbody>
</table>

This trend is similar to that observed in European studies (van der Vorst et al., 2002), which also showed a gradual decline in log (TBC), with an average value of about 4.2 (15,000 cfu/ml) one year after introduction of the system compared to an average TBC of about 10,000 cfu/ml in this study. In Denmark, Germany, and the Netherlands 2.5%, 7.7%, and 2.8% of tanks sampled during the study exceeded the 100,000 cfu/ml threshold. For the Wisconsin conventional farm
cohort, 10.5% of samples exceeded 30,000 cfu/ml, while 1.9% exceeded 100,000 cfu/ml. The bacterial quality of milk from AM farms in the U.S. thus compared well with European AM farms as well as conventional farms in the U.S.

![Log(TBC) vs. Operating Duration](image)

**Figure 4.** Log (TBC) plotted versus the length of time the farm has been in operation.

**Conclusion**

The results of this study provide insight into the quality of milk produced with AM systems. Two milk quality parameters were investigated: somatic cell count (SCC) and total bacterial count (TBC). This study found no significant difference in SCC between AM farms and conventional farms but did find strong evidence of a seasonal variation in SCC regardless of the type of milking technology used, with higher SCC associated with the summer months. There was evidence of a slight decrease in SCC on AM farms as the experience of the users increased. There was some evidence of seasonal differences in bacterial quality of milk as measured by TBC regardless of milking technology. Overall, the TBC of milk from AM farms was lower than for conventional farms and there was also evidence of a very slight decrease in TBC as AM experience increased.

**References**


