Sensors and management support in high-technology milking

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ABSTRACT: Two directions can be distinguished in the development of high-tech milking equipment: 1) high-capacity milking parlors with a high throughput of cows per person per hour and 2) automatic milking systems in which manual labor is replaced by a milking robot.

High-capacity milking parlors are developed in such a way that one operator is able to milk many cows, partly by automation and partly by optimization of available labor. In such parlors, one operator can milk up to 125 cows per hour. This means that there are only a few seconds available for udder preparation. In an automatic milking system, a robot takes over all manual labor during milking. Currently available systems have one robot arm working with one milking stall (one-stall system) or one robot arm working with more milking stalls (multiple-stall systems). Cows have to go to the automatic milking system voluntarily. Therefore, there is a large variation in milking intervals. Moreover, a large variation between milkings and between cows was observed in milk flow rate, machine-on time and udder preparation time.

Both developments in high-tech milking have effects on the milk ejection. The small amount of time dedicated to udder preparation in high-capacity milking parlors has negative effects on the milk ejection, among others leading to more bimodal milk flow curves and longer machine-on time. In automatic milking systems, the variation in time between udder preparation and cluster attachment and in milking frequency might have an effect on milk ejection. Lactation physiology can play a role in solving the questions around milk ejection in high-tech milking systems.

The introduction of high-tech milking systems makes decision support systems using sensors necessary. These systems should assist in detection of abnormal milk and mastitis. To a lesser extent, diseased cows need to be brought to the attention of the dairy farmer. Some sensors are currently available for this purpose, but they do not fulfill all demands. In the near future other sensors might be developed. It is important that this development is demand driven and not technology driven. Lactation physiology can play an important role in the determination of milk components useful for automatic detection.

Key Words: Milking Parlor, Automatic Milking System, Milk Ejection, Sensors

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Introduction

Milking cows is an important part of the activities of a dairy farmer. The first purpose is to harvest the milk, which is carried out 1 to 3 times per day, depending on the region and applied farm system. Since the first attempts to develop milking machines in the end of the 19th century, many changes have been made. An important improvement was the development of the milking parlor, which started in the 1930's. The introduction of milking parlors improved the productivity of the milker greatly (Dodd and Hall, 1992). The development of milking parlors has continued to the current day. A next big step was the introduction of electronics into milking technology (Ordolff, 2001), starting with automatic take-off of milking clusters, followed by the development of individual cow identification in the 1970's. Both facts were important to the automation of milking, and the availability of individual cow identification can be regarded as the key of further automation in the milking parlor. Based on individual cow identification, monitoring of the physiological status of a cow became possible (Eradus and Jansen, 1999). The latest step in the development of milking technology is the complete automation of the milking procedure, including teat cup attachment. First initiatives for automatic milking (**AM**) were made in Europe (Rossing et al., 1985; Grimm and Rabold, 1987; Marchant et al., 1987; Montalescot, 1987) in the middle of the 1980's. In 1992, the first AM systems were installed on commercial (Dutch) dairy farms (Bottema, 1992).

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Currently, two trends can be distinguished in the application of milking technologies on dairy farms: 1) high capacity (in terms of milkings per person per hour) milking parlors and 2) AM systems. The major change for management in high capacity milking parlors, is the decrease in available labor per cow. For instance, the cow throughput for a double 10 herringbone parlor has been estimated to range between 60 and 101 cows/h, depending on the efficiency of the milker (Armstrong et al., 1994). Efficiency of the milker can be defined as speed of working, but also in the number of tasks carried out. The time used for udder cleaning and preparation for certain circumstances have been estimated to be less than 9 s/cow (Armstrong et al., 1994). This decreased preparation time is less than the advised 15 s/cow. This might have effects on the milk let down. Although required because of legislation, many farmers do not check foremilk in order to increase the throughput of cows. This might affect the detection rate of abnormal milk and/or clinical mastitis.

Although the time that the milker spends at a cow decreases in a high-capacity milking parlor, there is still the presence of a person. Each and every cow will pass the milker every day. Problems with cows can still be detected. With an AM system, there is no milker present at milking and thus there is no obligatory contact between the herdsman and the cows. At the same time decision-making, which takes place during milking will not be possible anymore. This means that sensors will have to take over part of the monitoring work of the herdsman. Moreover, in an AM system, the way of working is completely changed. Cows can be milked 24 h per day and will visit the AM system more or less voluntarily. This means that the milking frequency varies between farms, cows, and even within cows between days. Moreover, the time between preparation and attachment of clusters might vary from milking to milking, depending on the process of teat detection. This may have effects on the milk let down of the cows.

Both directions of milking technology, high capacity milking parlors, and AM systems, indicate a need of management support to be able to allocate the attention of the herdsman to those cows that need it: management by exception. Therefore, sensors will be useful and necessary. Since the 1980's, work has been carried out on the development and application of in-line sensors. Most work was concentrated on electrical conductivity, which is currently still the most applied technique for in-line mastitis detection but is not suited for automatic separation. Sensor development up to now was technique-driven. A demand-driven approach will be better and the following questions need to be answered before further development of sensors: What information is necessary to optimize the basic process of milking, and what information is necessary to support the decision-making process around milking, e.g., detection of clinical mastitis. Because of the increased societal interest in animal health and welfare, these questions have to be answered within the constraints that milk must be a safe product, produced by healthy, well-managed animals in a hygienic and animal-friendly environment.

Besides the need for more management information, application of high-tech milking changes milking procedures. These may influence the milk let down. Although available data to date provide some information, the full short- and long-term consequences of the indicated changes in milking procedures on milk production are not fully known.

The goal of this paper is to describe the demands for management support and sensors and to describe the important aspects influencing the milk ejection in high-tech milking.

Milking in a High-Capacity Milking Parlor

Milking parlors have been in development since the 1930's. However, spread of this technology went slow, and only after the development of the herringbone parlor in New Zealand in 1952, the number of installations increased more rapidly (Dodd and Hall, 1992). In northwestern Europe, most dairy farms changed from bucket milking towards a milking parlor in the 1970's. The large-scale introduction of the bulk milk tank and free stalls helped this rapid change in those years. In general, two types of milking parlors can be distinguished: static and rotary parlors (Whipp, 1992). In a rotary parlor, each cow enters and leaves individually. Because of the movement of the cows in the rotor, the milker does not have to walk very much. The design of static parlors varies widely. The best-known types are the side-open (tandem), herringbone, and the parallel parlor. In side-open parlors, cows are let in one by one. In the herringbone and parallel parlor, cows are let in by groups. Last types of parlors can be installed with rapid exit gates, which means that all cows in a group can leave simultaneously, thus increasing the throughput of cows.

In a milking parlor, the milker has to perform a number of work routines. The time spent on these routines, to a large extent determines the capacity of a milking parlor in cows per hour (Table 1). An optimization of work routines increases the maximum number of cows per hour per man from 50 to 65. Automation of the cluster removal, teat disinfection and cow let-out, increases the maximum number of cows per hour to 100 (Table 1). These maximum numbers should be seen as a theoretical maximum, in which a milker is continuously working. Moreover, the capacity of cows per hour is also dependent on the milking time per cow (Whipp, 1992).

Milking with an Automatic Milking System

An AM system has to take over the "eyes and hands" of the milker and therefore these systems need to have electronic cow identification, cleaning, and milking devices and computer-controlled sensors to detect abnormalities. In this section, the various components of an AM system will be briefly described.

Table 1. Effects of different work routines in parlor performance[1]

	Type of milking parlor[2]		
Element	Not automated (min/cow)	Somewhat automated (min/cow)	Fully automated (min/cow)
Let in and feed	0.25	0.05	0.05
Foremilk	0.10	0.10	0.10
Wash and dry teats	0.20	0.20	0.20
Attach cluster	0.20	0.20	0.20
Remove cluster	0.10	0.10	Auto
Disinfect teats	0.10	0.10	Auto
Let out cow	0.20	0.10	Auto
Miscellaneous	0.05	0.05	0.05
Total	1.20	0.90	0.60
Max. cows/person hour	50	65	100

[1]Source: Whipp, 1992.
[2]Milking parlors range from non-automated, where everything has to be done by hand, to a fully automated milking parlor, where almost everything is automated.

All commercially available AM systems are based on milking stalls, in which concentrates can be supplied. Most AM-systems are provided with milking stalls that modify the posture of the cow to improve performance of the system (Mottram, 1992; Mottram et al., 1994; Devir et al., 1996). In some AM systems, the length of the milking stall can be adjusted to the length of the cow (Devir et al., 1996). There are one-stall systems, in which each milking stall is serviced by one robot and multi-stall systems, in which one to four milking stalls are serviced by one robot.

Each AM system has an active teat detection system to localize the teats. Construction of teat detection sensors proved to be technically quite difficult, and this problem has been solved in various ways. Manufacturers have used ultrasonic sound, laser techniques, and vision techniques (Artmann, 1997) to find the position and place of the teats in reference to a fixed point on the robot arm. In fact, the system creates a three-dimensional view, so the system knows where to attach the teat cup to the teat. Different types of robot arms are used in the various types of AM systems (Artmann, 1997; Rossing and Hogewerf, 1997), varying from grippers that pick up the teat cups one by one from a storage rack at the side of the stall, robot arms that pick a whole milk rack at the same time or robot arms integrated with the milk rack.

There are several principles of teat cleaning with AM systems: Sequential cleaning by brushes or rollers, simultaneous cleaning by a horizontal rotating brush, cleaning with water in the same teat-cup as used for milking or cleaning by a separate "teat cup like" device. Besides cleaning the teats, automatic cleaning devices also stimulate the milk letdown process. Stimulation of the milk ejection reflex is necessary for efficient milking. The most important stimuli are udder and teat cleaning and the action of the milking machine (liner wall movement). It is not known if there is a difference between the teat cleaning methods of the different AM systems with respect to the intensity of the milk ejection reflex. However, it is clear that an automated pretreatment is more repeatable than manual pretreatment. This might have a positive effect on the milk ejection.

High-Tech Milking and Milk Ejection

Important parameters in the evaluation of high-tech milking systems are milk yield and milk flow. More indirectly related to milking, effects on health are important.

High-Capacity Milking Parlors

Although machine milking has developed well over the years and cows are producing more milk due to breeding and management, the basic regulation of milk ejection has not changed (Bruckmaier, 2001). The milk, secreted by epithelial cells, accumulates in alveoli and cisterns. The cisternal milk (milk stored in large mammary ducts and cisternal cavities) is immediately available when the milking starts. But the alveolar milk (milk stored in alveoli and small milk ducts) needs to be actively expelled through the release of oxytocin. The cisternal milk fraction comprises not more than 20% of the total milk yield (Pfeilsticker et al., 1996). Therefore, the most important milk fraction is the alveolar milk. A rapid and complete ejection of this milk fraction is essential for a good result of the milking. To reach a good milk ejection, sufficient lag time between the onset of tactile teat stimulation and the actual start of milking is important. This time normally ranges from 1 to 2 min. (Bruckmaier et al., 1994; Bruckmaier and Hilger, 2001).

The most important change in a high-capacity milking parlor with a high throughput (cows/person per hour) compared with lower throughputs, is the amount of time that the milker can spend on each cow. In Table 1, effects of change in time for work routines on theoretical throughput of cows in terms of cows per hour are given (Whipp, 1992). There are not many field data on actual performance of various high-capacity milking parlors. The most complete review is summarized in Table 2 (Armstrong et al., 1994). These data are collected on commercial farms with large herds and high-capacity milking parlors. The maximum throughput measured, was 128 cows/h for a one-person operated milking parlor. The minimum throughput measured, was 49 cows/h. Recalculated in maximum amount of available time per cow, this varies from 1 min and 13 to 28 s per cow. This time includes all time per cow, including post milking teat disinfection, entrance and exit times. From the same study, standardized time spent on udder preparation was on average 10.5 and 8.7 s, respectively, for a double 20 herringbone parlor with two operators and a double 20 parallel parlor with two operators.

In a study carried out in the research milking parlor of the Research Institute of Animal Husbandry (Lely-

Table 2. Capacity (cows per hour) for high-capacity milking parlors (including power operated entrance and exit gates, crowd gates and detachers) under good management for one operator[1]

Parlor type	Slow operator	Fast operator
Rotary parlor		
8-stall Tandem	58	—[2]
Herringbone parlor (standard exit)		
Double 10	49	92
Herringbone parlor (rapid exit)		
Double 10	60	101
Double 12	88	110
Double 16	123	128
Parallel parlor		
Double 10	84	91
Double 12	72	106
Double 14	110	121
Double 20	122	128

[1]Source: Armstrong et al. (1994).
[2]No minimum and maximum figures were available.

stad, The Netherlands), four different methods of udder preparation were applied to four groups of 11 cows with an equal distribution of parities. There were four procedures for udder preparation: 1) cleaning and attachment (8 s), 2) cleaning, stripping and attachment (8 s plus stripping), 3) cleaning, manual stimulation, and stripping (25 s plus stripping) and 4) cleaning and attachment (8 s) and automatic stimulation (30 s with a pulsation rate of 250 cycles min^{-1} and a pulsation ratio of 50%). Cows were milked twice per day with intervals of 13 and 11 h. There was no difference in milk yield between the four treatments (Table 3). The extended manual preparation (including stripping) showed the best results in this study. The machine-on time was 29 s lower than the machine-on time for only cleaning. Moreover, the percentage of milkings without a bimodal milk flow curve was 60%, compared with 20% for the standard cleaning and 34% for the cleaning and stripping. A bimodal milk flow curve shows at the beginning of the milking a fast increase in milk flow when the cisternal milk is released. Then the milk flow decreases sharply because the alveolar milk is not yet released. When the milk ejection starts the alveolar milk (the largest milk fraction) is released and the milk flow increases again. Also, the average milking time in phase one (the start of milk ejection) is shorter with the extended udder preparation. These results show that a short udder preparation time delays the start of the milk ejection, since the percentage of bimodal milkings increased. Moreover, it has negative effects on the machine-on time.

The data above show that the preparation time in high capacity milking parlors is much lower than the 1 min necessary for an optimal release of oxytocin. Short udder preparation times gave a delayed milk ejection and longer machine-on times. A longer preparation gave shorter milkings and is less inefficient than thought on forehand. Mechanical stimulation or a change in milking method can help to overcome the inefficiencies. Since continuous tactile stimulation during the udder preparation is not necessary, it is possible to first clean the udders of three cows and then attach the milking clusters of these three cows.

Automatic Milking System

To be milked in an AM system, cows have to more or less voluntarily move to the AM system themselves (Rossing et al., 1997). This means that there are no equal milking intervals anymore, which was illustrated in a study of Hogeveen et al. (2001), using data from 66 cows on an experimental farm, milked with an AM

Table 3. Effects of different udder preparation procedures on duration of milking, milk yield, and milk flow of evening milkings[1]

	Standard	Standard + stripping	Extended + stripping	Standard + automatic
Duration (s)	10	16	31	40[2]
Machine-on time (min)	5.20	5.12	4.91	5.21[2]
Milk yield (kg)	11.5	11.5	11.4	11.6
Average flow (kg/min)	2.28	2.33	2.43	2.32
Max. flow	4.02	4.08	4.17	4.04
Milk flow profile[3]				
Phase 1	75	70	56	73
Phase 2	98	93	101	109
Phase 3	113	119	113	107
Phase 4	25	26	25	23
Milk in phase 2 (%)	31	30	33	34
Milkings not bimodal (%)	20	34	60	35

[1]Source: Research Institute for Animal Husbandry, Lelystad, The Netherlands.
[2]Time is including the 30 s automatic stimulation time.
[3]The milk profile curve is divided into 4 phases: phase 1 is the start of the milk ejection, phase 2 is the period of a high, constant milk flow, phase three is the decline in milk flow, and phase 4 is the low milk flow at the end of milking.

Table 4. Milk yield and milking intervals divided over the lactation stage[1]

		Milk yield (g/h)			Milking interval (h*100)		
Lactation stage (days)	#Milkings	Avg	Min	Max	Avg	Min	Max
1–30	9152	1505	243	3000	899	107	2400
31–60	9352	1690	435	3375	844	168	2351
61–90	8367	1589	317	3016	881	130	2397
91–120	8929	1503	341	3081	875	120	2399
121–150	8600	1424	307	2868	873	103	2400
151–180	8299	1373	422	2789	872	172	2395
181–210	8043	1307	261	2878	886	162	2398
211–240	7839	1222	271	2254	902	245	2387
241–270	7220	1111	329	2353	962	182	2385
271–300	6399	1007	235	2266	1022	122	2400
301–330	4044	947	176	2328	1066	207	2399
331–360	2387	946	159	2056	1105	250	2394
>360	3989	853	159	2000	1108	138	2388

[1]Data previously unpublished.

system (Lely Astronaut). The average milking interval was 9.2 h (2.6 milkings per day). However, very short and very long milking intervals were observed. Of all milkings, 17.6 and 4.2 percent had a preceding milking interval of, respectively, more than 12 and 16 h. In addition to long intervals, short intervals occurred also. For 9.7 and 0.5% of all milkings a preceding milking interval shorter than 6, respectively, 4 h occurred. The effects of milking interval on milk flow rate and milk yield were also studied. A longer milking interval was associated with an increase in milk flow rate, and this was not dependent on production level. Statistical models indicated that shorter milking intervals gave an increase in milk production (in terms of kg/h). However, the level of this effect was found to be dependent on the level of milk production.

Using the same dataset, milk yield and milking interval throughout the lactation were calculated and summarized in Table 4. It can be seen that the milk yield is highest from d 30 to 90 in postpartum. The minimum milking interval is found in the second period postpartum. Later in lactation the milking interval increases.

With an average milk yield of 11.8 kg/milking and an average milk flow rate of 2.5 kg/min, the average machine-on time was 5 min. Although most milkings had a machine-on time of approximately 4 min. (the median), a considerable number of milkings were much longer. Respectively, 8.6 and 2.7% had a machine-on time longer than 8 and 10 min. However, there was a large difference in machine-on time between the quarter with the shortest machine-on time and the quarter with the longest machine-on time.

For the same dataset, for each milking entrance time in the milking unit and time of removal of the last teat cup were recorded in hours and minutes. From these two figures the total duration of the visit of the milking unit was calculated. Furthermore milking speed was recorded in kilograms per minute and milk yield was recorded in units of 100 g. From these two figures, duration of milk flow was calculated in seconds. Preparation time per cow was estimated as total duration of visit minus duration of milk flow. Most milkings have a preparation time of approximately 60 s (Figure 1), but there is considerable variation. Very long preparation times, up to 300 s, are possible.

When automatic stimulation is used, it might be good to adjust the tactile stimulation to the cow. It has been shown that the necessary udder preparation time is dependent on the milking interval. Moreover, in that specific study it has been made plausible that the necessary udder preparation time is in fact dependent on the degree of udder filling (Bruckmaier and Hilger, 2001). A higher degree of udder filling (in terms of expected milk yield divided by the maximum storage capacity) makes a longer udder preparation time necessary. Given the large variation in milking frequencies and the effect of these on milk yield, a cow and milking specific adjustment of mechanical stimulation is even more important in AM systems. It has been shown that most milkings in an AM system have an udder preparation time of 1 min or more. With these preparation times, no additional measures are necessary. The very long attachment times do not have a negative effect on

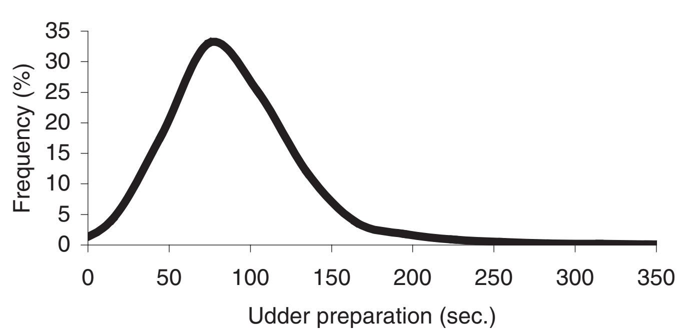

Figure 1. Frequency distribution of time between entrance of milking stall and milking (udder preparation time) in automatic milking (data previously unpublished).

Table 5. Demands for sensors to detect abnormal milk, mastitis cows and diseased cows to be used in high-capacity milking parlors or automatic milking (AM) systems

	High-capacity milking parlor		AM System	
Task	Sensitivity	Specificity	Sensitivity	Specificity
Separation of abnormal milk	+ +[1]	+/–	+ +	+ + +
Detection of mastitis	+	+/–	+ +	+
Detection of diseased cows	+/–	+/–	+ +	+/–

[1]The more + signs, the larger the necessity of a high sensitivity or specificity.

milk ejection, so there should not be a problem there (Bruckmaier et al., 2001). On the other hand, another study found lower levels of oxytocin release in automatic milking compared with "classical" milking (Marnet et al., 2001). In the latter study cows were brought to the automatic milking system twice a day to prevent an effect of changed milking intervals in the measurements of oxytocin. This way of automatic milking cannot be directly compared to automatic milking in practice, where cows have to move to the system voluntarily. Therefore, more research is necessary in lactation biology with respect to high-tech milking. This research should be directed to the development of optimal (cow and milking specific) automatic stimulation in high-capacity milking parlors and towards the effects of the variation in milking procedures of AM systems on milk ejection and milk synthesis.

Demands for Sensors in High-Tech Milking

With AM systems, because there is no milker present during milking, sensors have to take over detection of clinical mastitis and abnormal milk. Moreover, through general examination of the entering dairy cows, first signs of disease might be detected in conventional parlors. In milking hygiene regulations, the detection and separation of abnormal milk is mandatory (i.e., EU directive 89/362 and Pasteurized Milk Ordinance). The same holds for separation of not obviously abnormal milk from visibly sick cows. Because of the lack of time in high-capacity milking parlors, there is pressure on observation tasks, such as foremilk inspection. Therefore, in both AM systems and high-capacity milking parlors, sensors and the additional management software can support the herdsperson in taking correct decisions. The tasks for which sensors are necessary or can be useful are: detection of abnormal milk, clinical mastitis, and diseased cows.

In Table 5, the demands for sensors for management support in high-tech milking systems are given. These sensors can be seen as diagnostic tests, which can be characterized by epidemiological parameters such as sensitivity (the probability that a cow with a certain condition will be classified as having this condition) and specificity (the probability that a cow without a certain condition will be classified as such). Sensitivity and specificity are interdependent. If the threshold of a test is increased, the number of positive outcomes and thus the sensitivity will decrease. On the other hand, the specificity will increase. Therefore, thresholds have to be set in such a way that an optimal sensitivity and specificity is reached. However, for practical use the predictive values (positive and negative) of a test are more important. The predictive value is dependent on prevalence of the condition of interest. When discussing methods to detect clinical mastitis and abnormal milk the test characteristics described above should be taken into account.

As mentioned earlier, detection of abnormal milk is very important because it is mandatory in almost all dairy-producing countries. Under the current legislation, abnormal milk is almost equal to milk from cows with clinical mastitis. Besides, for food safety, the prevention of abnormal milk in the food chain is also important for the image of the milk products. The sensitivity for abnormal milk needs to be high under all circumstances. However, because a milker can check the milk before separation, the needed specificity for a high-capacity milking parlor is not necessarily high. On the other hand, since an AM system needs to separate milk automatically, the specificity for abnormal milk needs to be high in order to prevent false positive results and thus unnecessarily removed milk.

For detection of clinical mastitis, sensors and the attached management information system should assist the herdsperson in such a way that this person is able to treat cows with clinical mastitis easily and effectively. It is known that treating as early as possible gives higher cure rates (Milner et al., 1996). Detection of mastitis will in practice work with attention lists. The management information system can produce lists with cows for which abnormal sensor readings were given. These lists will be used to check individual cows at a later stage. It is important that as many cows with clinical mastitis as possible (preferably all) will be identified (high sensitivity). At least, cows with severe clinical mastitis (grave systemic and local symptoms) must be detected. However, if a cow with a mild clinical mastitis (mild local symptoms such as some flocks) is not immediately detected, from a veterinary point of view this will not be a large problem. The number of cows that are on the attention list and do not have clinical mastitis or other abnormalities should not be too high (low number of false-positive outcomes) which means a relatively high specificity. Because it is more difficult to search and control cows that are on an attention list, the specificity needs to be higher for AM systems than for high-capacity milking parlors. Moreover, although in high-capacity milking parlors foremilk of cows is not checked usually, an attentive milker can detect part of the mastitis cases without help. Therefore, the needed sensitivity for high-capacity milking parlors is a little lower than for AM systems.

An attentive milker can easily detect diseased cows. Therefore, in a high-capacity milking parlor, there is not much need for sensors. However, sensors may help the herdsperson, especially when employees who do not pay much attention to the cows, a situation that can occur on large farms, carry out the milking. With AM systems, the herdsperson has to check the cows in the barn. Attention lists may help in these tasks.

In the next sections, current sensors are discussed.

Electrical Conductivity

Electrical conductivity (**EC**) is a measure of the resistance of a particular material to an electric current. Because of increased blood capillary permeability, mastitis causes a change in ion concentrations and thus in EC. Typical EC of normal milk appears to be around 4.6 mS/cm (Neville and Jensen, 1995). When the EC of milk (at quarter level or at cow level) is increased this is an indication for mastitis (clinical as well as subclinical). However, the correlation between EC and SCC is not very high (Hogeveen et al., 1998), indicating that there are more factors influencing EC. Because EC is relatively easy to measure, it has for a number of years been commercially available. There are many studies carried out on the use of EC for mastitis detection (Hamann and Zecconi, 1998). Nielen et al. (1992) carried out a meta analysis and found varying results of 77 known studies up to 1992. The overall sensitivity was 66% with an overall specificity of 94%. Recent experiments with conditioned infections show that EC could very well be used (100% sensitivity) to detect clinical mastitis before clinical signs appear (Milner et al., 1996). However, these mastitis cases were artificially induced. Moreover, the measurements were done using a hand-held apparatus and not by in-line equipment. De Mol et al. (2001) described the most recent extensive field study. Commercially available in-line mastitis detection systems were used at 4 farms for several years. Test results of the software of the manufacturer gave sensitivity, varying from 18 to 36% and a specificity varying from 98.1 to 99.4%. On the same data, a special algorithm using not only EC data but also milk production and temperature data was applied. This model has the possibility to give data with various confidence levels (varying from 95 to 99.9%). At a confidence level of 95%, overall sensitivity and specificity were 80 and 98.6%, respectively. At a confidence level of 99.9%, these figures were respectively 55 and 99.3%, respectively, for sensitivity and specificity. With such characteristics, EC combined with other available sources of information, might well be used to generate attention lists for clinical mastitis.

The only known study on detection of abnormal milk reported a sensitivity of 39% (Rasmussen, 2000). When decreasing the detection threshold, the sensitivity would improve greatly, but also the number of false positive results would increase to unacceptable levels. Although this study was rather limited (138 cows were followed for 48 h), results are not unexpected. After all, there is a large correlation between abnormal milk and clinical mastitis, and results for detection of abnormal milk will probably not deviate very much from the results presented above. With those results, EC is not sufficient to withhold abnormal milk automatically. Too many milkings with abnormal milk will still be delivered and too much milk will be discarded unnecessarily, resulting in economic losses.

In the past, the development of sensors was merely technology driven rather than demand driven. Because of the existing relation between mastitis and EC, and the availability of EC sensors, this was the method that was developed and marketed. However, there was no clear demand for these sensors. The use of these sensors hardly had any added value to the current milking practice at that time. Partly this was due to insufficient performance of those sensors and the connected computer software, partly it was also due to the lack of a clear goal for usage. Detection of clinical mastitis in a milking parlor was not a large problem for dairy farmers. To make detection of subclinical mastitis useful, the farmer needs to know what to do when a case of subclinical mastitis is detected. Moreover, the performance of EC sensors to detect subclinical mastitis was bad (Nielen et al., 1995). It is important that proper algorithms for specific tasks will be developed. Proceeding work on algorithms (e.g. De Mol and Woldt (2001) can improve the sensitivity and especially the specificity of current and future sensors.

Color Measurement

Color measurement has shown to be a promising method to detect abnormal milk under laboratory circumstances (Ouweltjes and Hogeveen, 2001). Quarter milk samples taken from eight cows with clinical mastitis and dilution strings made by gradually diluting a mix of cow blood and consumption milk were used to evaluate the color measurement sensor. Both abnormalities due to clinical mastitis and blood in milk resulted in color values clearly different from those of normal milk. First results of a field study on two farms also showed promising results under practical circumstances (Espada and Vijverberg, 2002). More extensive field studies have to provide information on sensitivity and specificity of color measurement in practice.

Other Available Parameters

There are many parameters that are available and that can be used to distinguish cows, such as milk yield, number of visits to the AM system, concentrates intake and so on. These parameters were not directly meant for detection of mastitis or sick cows, but if used in a good decision support system, they can be useful. Many diseases influence the milk yield of cow, the activity (and thus the willingness to visit the AM system) and the feed intake on a short notice and often in a subclinical stage. Moreover, there are also temperature sensors developed and commercially available. Although milk yield and temperature are used by De Mol et al. (1999) to optimize the EC performance, these parameters are difficult to interpret automatically and are not very specific. Also pedometers, which are developed for estrus detection (Thompson et al., 1995), can be used to monitor the activity of a cow. Algorithms have been developed to use a combination of activity measurement, temperature, and milk yield for illness detection (De Mol et al., 2001). However, no results for illness detection are known. The BW of dairy cows (Maltz, 1997; Maltz et al., 1997) might also be used to detect general illness.

There are also some other developments that might be used in the future to further improve the detection of clinical mastitis and abnormal milk. Especially for the detection of abnormal milk new technologies should be used. Di-electrical constant, near infra-red technology (Tsenkova et al., 2001), image processing and diffusing wave spectroscopy (Dalgleish and Hallett, 1995; Elofsson et al., 1996) might be used. Many milk components are described to change due to mastitis. Under these are milk components such as somatic cells and lactose, but also enzymic changes (Kitchen, 1981). Lately, new research has been done in this direction (Eckersall et al., 2001). These changes might be useful for automatic monitoring of mastitis (Hamann and Kromker, 1997; Mottram, 1997). Given all these changes, biosensors might in the near future also be used to support the management in high-tech milking systems. The possibilities of using bio-sensors for NAGase to detect mastitis on-line are described (Mottram et al., 2000).

In this paper, sensors have been described to support the dairy farmer in milking related management, i.e., detection of mastitis and abnormal milk. However, there are also other abnormalities that can be detected with sensors. There are various types of sensors available for estrus detection (Firk et al., 2002) and recently a biosensor to predict estrus based on components in milk has been described (Velasco-Garcia and Mottram, 2001). Also, an optical instrument to detect metabolic changes due to microbial activity has been described (Firstenberg-Eden et al., 2002). The possibilities of using milk components to detect disorders have been reviewed by (Hamann and Kromker, 1997; Mottram, 1997).

Although there are many technological possibilities to support the dairy farmer in a high-tech milking system, it is important that before development and marketing of a technology, it is clear what the demands for sensors are. Table 5 in this paper describes roughly these demands for tasks around milking. However, the information in this table needs to be specified further. For instance, under the current regulations, abnormal milk can be regarded as milk with visible abnormalities (not smooth, not white). With the introduction of AM systems, discussions were initiated on definitions of abnormal milk (Rasmussen, 2001). These definitions must be clear before development of sensors can be started. Moreover, demands for sensitivity and specificity need also to be clear. Because there is so much to measure in milk, lactation physiology can assist in the determination of milk components useful for management support. When such components are described, engineers can use this information to start development. This is a demand-driven approach with a much higher probability of successful introduction than the technology-driven approach applied up to now.

Conclusions

Two directions of development of milking equipment have been described. The first, which is going on for a large number of years, is the development and installation of high-capacity milking parlors in terms of throughput of cows per hour per person. The second direction is the development of AM systems. Especially in large milking parlors, robots might be introduced to take over the task of one or more employees. These robots might be supervised by a controller. There will be a moment in the future when milking robots have taken over the manual labor on most farms. However, this moment might still be far away. As a matter of fact, it took also almost 70 yr after the introduction of the milking machine before nearly all farmers milked with a milking machine.

Both developments have effects on the milk ejection. The small amount of time dedicated to udder preparation in high-capacity milking parlors especially has negative effects on the milk ejection. In AM systems, the variation in interval between udder preparation and cluster attachment and in milking frequency might have an effect on milk ejection. Lactation physiology can play a role in solving the questions around milk ejection in high-tech milking systems.

The introduction of high-tech milking systems makes decision support systems using sensors necessary. In this paper, the future demands for sensors in high-technology milking systems are described. Electrical conducivity might still be a useful parameter to meet these demands. The other currently commercially available sensor for on-line detection of mastitis and abnormal milk is color measurement. No descriptions of algorithms and reports of overall performance are yet available. The current and future sensors and associated software should assist in detection of abnormal milk and mastitis. To a lesser extent diseased cows need to be brought to the attention of the dairy farmer. Although some sensors are available, in the near future other sensors might be developed. It is important that this development is demand driven and not technology driven. Lactation physiology can play an important role in the determination of milk components useful for automatic detection.

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