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Effect of automatic milking systems on milk quality*

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ABSTRACT

Automatic milking systems (AMS) have been associated with various milk quality problems. Today, several problems are solved. One of the problems still existing is a high concentration of free fatty acids in milk from AMS compared with conventional systems. The present study shows that cooling of the milk in a plate cooling exchanger close to the milking unit decreases the formation of free fatty acids (FFA) in milk, and a rapid cooling of the milk before pumping over long distances will be a suitable solution to improve milk quality in AMS systems. Furthermore, a review of milk quality parameters, such as somatic cell counts (SCC), total plate counts (TPC) and freezing point from AMS is presented.

KEY WORDS: automatic milking systems, free fatty acids, cooling of milk, somatic cell counts, bacteria, milking frequency

INTRODUCTION

In automatic milking systems, the cows are milked by assistance of robots. By sensor technology, the robot finds the teats, and cleans them before cluster attachment. The cows voluntarily attend the milking unit, and the cows are offered concentrate feed during milking. Automatic milking systems have been commercially available since 1992, and the numbers of units have increased rapidly during the last years. At the end of 2005, 418 dairy farms in Denmark used automatic milking systems, 300 in Sweden, 159 in Finland and 107 in Norway (Kärnfullt, 2006). This corresponds approximately to 6-8% of the total bulk milk in Denmark and Sweden. The country with the highest number of AMS is Holland with around 550 herds milked by AMS. World-wide there are around 3000 herds milked with AMS (www.lr.dk/ams, 2006).

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Compared with conventional milking (i.e. milking twice daily), milking is going on the whole day and therefore the milk is frequently pumped to the milk bulk tank at the farm, which involves new cooling strategies. Furthermore, automatic milking often requires harsher mechanical treatment of the milk due to longer distances between milking unit and milk bulk tank and continuous pumping of smaller amounts of milk. Another factor altered from conventional milking is an increased milking frequency due to the fact that cows have free access to the milking unit. Since the introduction of AMS in the 90s, it has been reported that the milk from here was poorer compared with conventional systems. Especially the increased concentration of FFA in milk from AMS has been in focus since year 2000. With the steadily growing number of automatic milking systems, the quality of dairy products can be impaired in the future if the problems with milk quality are not solved.

The objective of this work is to demonstrate the efficiency on FFA in milk of cooling milk as soon as possible in the milking system. Furthermore, the paper will present a review of how AMS affect the milk quality.

RESULTS AND DISCUSSION

Free fatty acids

FFA in milk from AMS. Since the introduction of AMS, one of primary milk quality defect has been elevated concentrations of FFA in milk, and this problem is still not solved. Justesen and Rasmussen (2000) reported that level of FFA was higher in milk from AMS than in milk from conventional milking systems (Table 1). In a Dutch study with 28 farms, it was registered that the concentration of FFA in milk significantly increased after introduction to AMS (Klungel et al., 2000). Recently, Abeni et al. (2005) compared an AMS and a double-8 herringbone, both installed in the same free stall barn. The group of cows milked in the AMS produced milk with a significantly higher concentration of FFA compared with the traditional system.

Table 1. Free fatty acids in milk from conventional and automatic milking systems (AMS)

	Before introduction of AMS, or conventional	AMS	Reference
FFA, meq/100 g fat	0.86	1.13	Justesen and Rasmussen, 2000 (Denmark)
	0.38	0.53	Klungel et al., 2000 (Netherlands)
	0.51	0.72	Abeni et al., 2005 (Italy)

Lipolysis

Lipoprotein lipase (LPL) is the enzyme mainly responsible for lipolysis in raw milk. FFA are products of lipolysis. LPL originates from the mammary gland, where it is involved in the uptake of blood lipids for milk synthesis. The enzyme is active in lipid-water interfaces. Its optimum temperature is 33°C, and pH optimum is about 8.5. It is a relatively heat labile enzyme which is mostly inactivated by a high temperature-short time heat treatment. In milk, LPL is mainly associated with the casein micelles (Hohe et al., 1985). LPL is brought into contact with the triglycerides when the milk fat globule (mfg) membrane is disrupted and casein coats the formed lipid-water interface. In spite of the high amount of LPL in milk, lipolysis is limited since milk fat is protected by the MFG membrane and raw milk is normally stored at temperatures far below the optimum temperature of LPL. Furthermore, products of hydrolysis of the triglycerides, FFA, inhibit the enzyme, presumably due to the FFA binding to the LPL.

Several investigations have shown that the activity of LPL in whole milk is not correlated to FFA content in raw milk (Salih and Anderson, 1979; Bachman and Wilcox, 1990a; Cartier and Chillard, 1990). On the other hand, other studies show that the activity of lipoprotein lipase in the cream fraction is related to the level of lipolysis (Ahrne and Björck, 1985; Bachman and Wilcox, 1990; Cartier and Chillard, 1990). Consequently, the formation of FFA is assumed to be dependent on MFG susceptibility to action of lipases. LPL preferentially hydrolyses fatty acids in position sn-1 and sn-3. The fatty acids placed with high frequencies on position sn-1 and sn-3 are C4, C6, C18 and C18:1 (Jensen, 2002). This is in agreement with the recent report by Ouattara et al. (2004) who demonstrated that C4, C6 and C18:1 were the most frequent free fatty acid in a mixture of raw and pasteurized milk stored at 4°C for 48 h. Lipases synthesized by bacteria or yeast can also be present in milk. However, if milk is properly stored and has an acceptable hygienic quality, microbial lipases are not an important factor for lipolysis.

The FFA can provide rancid flavour in dairy products. The development of a rancid flavour in milk is greatly affected by the composition of FFA. It is mainly the fatty acids with chain length from 4 to 12 that contribute to the rancid flavour. Duncan and Christen (1991) observed that the flavour threshold in milk for added C4 is 0.20 µmol/ml compared with 0.55 µmol/ml for C18:1. Likewise, Urbach et al. (1972) reported that a concentration of 3 ppm added C4 is the flavour threshold in butter, while the threshold for C14 is 100 ppm. Culturing or acidification of the milk increase the appearance of rancid flavour at the same level of FFA, presumably as a result of changing the ratio of fatty acids to fatty acid salt (Tuckey and Stadhouders, 1967).

The classic division of lipolysis in milk is between spontaneous and induced lipolysis. The factors affecting spontaneous lipolysis include milking frequencies, udder health and stage of lactation. Induced lipolysis is caused by homogenization, pumping and temperature fluctuations.

Cooling of milk

Pumping of milk in model systems has demonstrated that the milk fat globule is most resistant towards lipolysis when the milk is pumped at 4-5°C, and the maximum formation of FFA is ~15° (Deeth and Fitz-Gerald, 1974; Fitz-Gerald, 1974; Bhavadasan et al., 1982; Hisserich and Reuter; 1984; Wiking et al., 2003, 2005).

In a full-scale experiment in our conventional milking parlour, we installed a plate cooling exchanger, which was placed in the milking parlour as close as possible to the milking unit. Here, the milk was cooled down to 4°C before further pumping to the bulk tank. The milk flow in the milking systems was controlled by a variable frequency pump in order to control the cooling more precisely and economically. The samples were collected just before the inlet to the bulk tank by a small separation pump, which was controlled by the main milk pump frequency, so the sample represents milk throughout the whole milking session of 120 Danish Holsteins cows. Figure 1 shows that the cooling system significantly ($P<0.001$) decreased the formation of FFA in the milk.

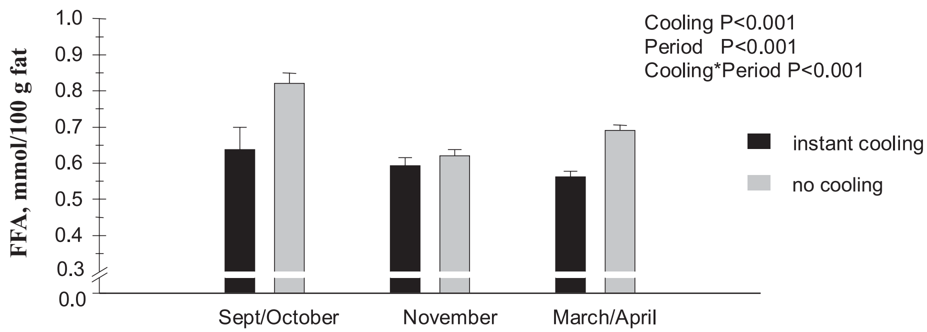

Figure 1. The effect of cooling of milk in the milking parlour compared with no cooling. The concentration of free fatty acids were analysed 24 h after milking by using the B.D.I. method

The distance between the milking parlour and the bulk tank was only 22 metres and still a significant effect was observed. In many AMS the pumping distance is longer. Furthermore, the problem with temperature fluctuations in the buffer or bulk tank in AMS will be avoided by cooling the milk close to the milking unit. The result indicates that the right cooling strategy of milking system can improve the milk quality regarding lipolysis.

By cooling the milk in a plate cooling exchanger, temperature fluctuations are avoided in the bulk milk tank. Some AMS have a buffer tank for up to 300 L milk, where the milk is pre-cooled before it is pumped to the bulk tank. However, there is a risk during periods with low milking intensity that the milk can be stored in the buffer tank for a long time. Temperature fluctuations of milk can cause major increases in the concentration of FFA (Statens Forsøgsmejeri, 1962; Cartier and Chillard, 1989).

Air and mechanical treatment

Mechanical treatments of the milk such as pumping and stirring subject MFG to physical stress. Higher flow velocities during pumping in pipes result in greater friction in the liquid itself and between the liquid and the pipe wall. These relative differences in flow velocity perpendicular to the flow direction are called wall shear rates. The wall shear rate depends on the diameter of the pipe and the flow velocity. The presence of air, the temperature of the milk and the fat content affect the stability of the MFG during mechanical treatments of milk. A recent survey of AMS in Denmark showed that the most frequent faults in AMS herds with high bulk milk FFA concentration were stirring (79%), pumping of milk (67%) and cooling of milk (58%) (Rasmussen et al., 2006). In milking systems, the milk is mixed with air, especially when air is used as a transport medium for the milk. The stability of the MFG is lowered by mixing with air during pumping or agitation of the milk. The contact between a MFG and an air bubble results in rupturing of the MFG, because membrane material and part of the core fat will spread over the air/milk plasma interface and will be released into the milk plasma when air bubbles collapse or coalesce (Evers, 2004). AMS systems have greater air intakes than conventional milking systems since the milking units of AMS are individual quarter milkers with rather long “short milk tubes”, individual shut off valves, foremilk separators, different kinds of flow meters and the milk normally has to be lifted several times before it enters the receiver. Such technical constructions may require different amounts of air for transportation of the milk compared to conventional milking units. Rasmussen et al. (2006) showed that decreasing the air inlet from the normal level of 4.5-7 L/min to 1.7 and 0 L/min in two types of AMS decreased the formation of FFA in milk, even though the milk samples were collected immediately after the quarter milk flow meter, so the milk and air was only mixed for short distance.

The average diameter of milk fat globules (MFG) can be affected through feeding of cows (Wiking et al., 2003, 2004, 2005). Diets with high levels of saturated fat supplements result in a high milk fat production and MFG with large average diameters. These milk types with large MFG are more susceptible towards coalescence and lipolysis during pumping compared with milk from cows fed a low fat diet or unsaturated fat supplements (Wiking et al., 2003, 2005).

Milking frequencies

A benefit of AMS is that the cows are more frequently milked, since they voluntarily attend the robot. Increased milking frequency enhances the milk yield. The average milking frequency in AMS is between 2.4-2.6 daily (Svennersten-Sjaunja et al., 2000; Hogeveen et al., 2001; Petterson and Wiktorsson, 2004). This implies that a large part of the cows is attending the milking robot three or four times per day. Table 2 shows that a draw back of increased milking frequency is higher concentration of FFA in milk. The difference in concentration of FFA is not present immediately after milking but first after 24 h storage (Slaghuis et al., 2004; Wiking at al., 2006), indicating that it is a weakness of the MFGM that causes the increased concentration of FFA in milk. The study from our laboratory was conducted as a half udder experiment, meaning that half of the udder was milked twice daily and the other half four times daily (Wiking et al., 2006). This had the result that the milk from the udder part milked four times contained significantly more FFA. We also observed that the average diameter of MFG was significantly larger in milk from four times milking than milk from two times milking. This could be one of the explanations for the weakness of the MFGM.

Table 2. Effect of milking three or four times compared with twice daily on free fatty in milk

	2X	3X	4X	Reference
FFA, meq/100 g fat	1.14		1.49	Wiking et al., 2006[1]
	0.72	0.99		Klei et al., 1997[2]
	0.42	0.71		Slaghuis et al., 2004[3]
	0.33	0.44		Jellema, 1986[3]

[1] used the auto-analyser method, [2] used the copper soap method, [3] used the BDI-method for FFA content analysis

Total bacteria count and somatic cell count

Internationally, the two most important milk quality parameters in relation to the milk payment system is TBC and SCC. The introduction of AMS in the late 90´s increased the number of TBC and SCC in the bulk tank compared with the time before the farms used AMS. Table 3 shows four surveys that all observed that the number

Table 3. Total plate count, somatic cell count and freezing point in milk from AMS, before and after introduction to AMS

TPC		SCC × 1000		Freezing point		Reference
pre-	after	pre-	after	pre-	after	
8000	9000	233	217	-0.520	-0.517	Klungel et al., 2000 (The Netherlands)
8000	12000	181	192	-0.521	-0,516	Vorst and Hogeven, 2000 (The Netherlands)
7400	13100	246	261	-0.525	-0.517	Rasmussen et al., 2002 (Denmark)
3800	8300	142	166	-0.531	-0.518	Salovuo et al., 2005 (Finland)

of TBC and SCC in the bulk tank increased after the herds were introduced to AMS. The period of sampling lasted 3 to 12 months after introduction of AMS. In the Finnish survey which only included three farms in year 2000, the increase for TBC and SCC was not significant (Salovuo et al., 2005). Increasing the cleaning frequency of the milking system from 2 to 3 times a day lowers TBC in the bulk milk (Benfalk and Gustafsson, 2004). A European study reported that both SCC and TBC decreased with time of experience that a farm utilizes AMS (van der Vorst et al., 2002). Recently, an American survey supported this (Helgren and Reinemann, 2006). Furthermore, they found now significant differences in the level of SCC and TBC between AMS and conventional systems. Today in Denmark, the difference between the average national TBC and the average TBC for AMS is around 3000 and for SCC 1500 (www.lr.dk/ams, 2006). These are small differences and it seems that the problems can be controlled.

Freezing point

The introduction of AMS also led to an increase in freezing point of bulk tank milk (Table 3). A freezing point closer to 0°C indicates that water has been added to the milk, therefore the freezing point is a part of the milk payment system. The main reason for the increased water content in the bulk tank milk was cleaning water left in the system. This technical problem seems to be solved now since the difference between AMS and conventional systems, today, is negligible (www.lr.dk/ams, 2006).

Spores and antibiotics

The level of spores of anaerobes in bulk milk has been reported to increase in AMS compared with conventional systems (Rasmussen et al., 2002). Spores of anaerobes originated from manure on the teat surface, so an increase in spores in the milk indicates insufficient cleaning of the teats by the robot. The recent data from Denmark show very little difference between the average content of spores in AMS milk and the national average (www.lr.dk/ams, 2006).

Focus is also on the fact that there are frequently more accidents with antibiotic residues in milk from AMS compared with conventional milking systems. The reason seems to be that the milk producer forgets to add the information about the antibiotically treated cows into the management programme for the milking robot.

CONCLUSIONS

The present study demonstrates that cooling the milk in a plate exchanger just after the milking unit is a solution to lower the concentration of FFA in a milking system compared to cooling the milk in or at the bulk tank. In AMS this cooling system may contribute to reduce the elevated FFA levels. However, the effect of higher milking frequencies and harsh mechanical treatment of the milk are issues that need to be addressed.

Other milk quality parameters from AMS, like freezing point, TBC and SCC have improved during the latest years, and can be controlled with good management.

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