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DEFINING ACCEPTABLE MILK QUALITY AT TIME OF MILKING

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It is an important criterion that milk for consumption is produced by healthy cows. The milker (operator) has the possibility (and obligation) of observing the cow and the foremilk before attachment of a conventional milking unit. Milk from cows with abnormal foremilk can be identified and withheld from delivery. Clinical mastitis, blood, and colostrum are the abnormalities being looked for. Blood in the milk is rare outside the colostrum period but may appear due to teat injuries. The immunoglobulin content of colostrum is high and colostrum differs in colour and viscosity from normal milk but normally the stage lasts from 2-5 days of lactation only. However, clinical mastitis occurs much more frequently and the prevalence is normally around 0-15% of the cows and is an everyday checkpoint. Clinical mastitis covers a whole variety of conditions ranging from thin watery milk to milk being strongly abnormal in consistency, colour, smell, and taste. Consequently, the milker may use different senses to detect and sort milk according to quality. In principle, automatic milking systems have the same opportunities to test the milk but sorting of milk requires an exact definition of what is normal and acceptable and what is unacceptable for human consumption. So far, definitions of acceptable milk quality in relation to blood, colostrum, or clinical and subclinical mastitis have not been set. These definitions are needed in order to develop sensors capable of precisely detecting and discarding unacceptable milk. By determining precise thresholds, manufacturers of automatic milking systems will have the possibility of developing bio-sensors, which can meet our goal of delivering healthy milk from healthy cows solely.

Automatic Milking and Udder Health

Automatic milking offers the possibility of more frequent and voluntary milking with considering the needs of the cows and pre-set management decisions. The more frequent milking may have positive as well as negative effects on udder health. Frequent milking flushes the teat canal more often during removal of the milk and leaves shorter time for bacteria to grow within the udder between milkings. However, the time between milkings may not be evenly distributed within and between cows resulting in fluctuating and short (5 h) as well as very long milking intervals (> 18 h). Short milking intervals leave shorter time for the teat tissue to recover whereas long intervals offer longer time for invading bacteria to multiply in the tissue. The milking technique used for automatic milking should benefit udder health and teat condition since it is mainly based on milking of the individual quarter. Many unknown factors contribute to the battle between the host and the bacteria and the influence of automatic milking on the udder health is so far based on speculations. Reports from several countries indicate that the bulk milk cell count increases with the introduction of automatic milking. An increase may be due to an increase in

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the new infection rate or in the number of clinically and chronically infected cows delivering milk for consumption.

All Danish farms with automatic milking systems (AMS) are enrolled in a self-monitoring programme and participate in the official milk yield recording. Rasmussen et al. (2001) analysed individual cow cell count data from one year before the introduction of AMS to one year after. Data from 69 farms were included. Three new variables were defined based on the monthly cow cell count. NewSCC was defined as the percentage of cows at each recording that had a sudden, significant rise in cell count. OldSCC was the percentage of cows with an increased cell count. CullSCC was the percentage of cows culled due to a high SCC. There was a sudden and significant increase in NewSCC at the start of automatic milking and the frequency was higher throughout the first year with AMS than the previous year with conventional milking, figure 1. There was no difference in OldSCC and CullSCC between the years. Rasmussen et al. (2001) conclude that farms with AMS had more new infections during the first year of automatic milking than in the previous year with conventional milking. The increase appeared suddenly and was synchronised with the onset of automatic milking. The number of cows with elevated SCC decreased slowly after 3 months. They do not have a conclusive reason for the increase but suggest that more attention should be paid to the introductory period. Additionally, the Danes experienced an increase in bulk milk SCC (Justesen and Rasmussen, 2000) in the introductory period of AMS indicating that the monitoring system was either not used or not reliable for the detection of clinical mastitis.

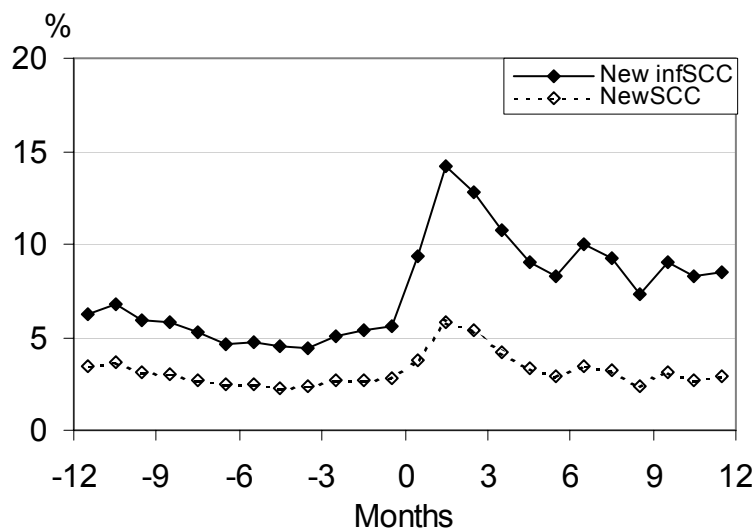


Figure 1. New infection rates based on calculations of acutely elevated SCC as a percentage of all cows (NewSCC) or of cows at risk (New-infSCC). Values are from 12 months before to 12 months after the introduction of automatic milking on 69 Danish farms (Rasmussen et al., 2001).

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Current Measurement Techniques for Detecting Mastitis

Detection of mastitis by automatic milking systems is mainly based on measurement of conductivity. It is generally believed that conductivity will detect changes in the milk before new clinical signs develop. However, detection of chronically infected quarters by this method is more questionable. Automatic milking systems on the Danish market are tested according to the guidelines of Rasmussen and Jepsen (2000). The tested systems were able to detect up to 39% of quarters with clots in the foremilk and 34% of quarters with CMT 5. A relative threshold of 115% in conductivity pinpointed 70% of quarters with abnormal foremilk but 5 times as many with normal milk. It was concluded that the tested systems based solely on conductivity do not detect quarters with abnormal milk or high cell count sufficiently well. Currently, more sophisticated software is being developed, conductivity sensors improved, and other parameters such as milk flow, milk yield, colour, and homogeneity of the milk introduced for detecting mastitis.

Definitions of Acceptable Milk Quality

The golden standard of acceptable milk from mastitic cows is based on visual inspection of foremilk. But, our control is based on the measurement of bulk milk somatic cell count (SCC) and consequently, a monitoring and control system has to be based on some form of visual inspection of the milk as well as a direct or indirect measurement of SCC. Cows without clots or blood in the foremilk normally deliver milk for consumption. Detection of clots in the foremilk depends on the skills of the milker and on the practical conditions under which the foremilk is performed. Hillerton (2000) states that the sensitivity is 80% for detecting cows with clinical mastitis during foremilk but the specificity is 100%. If clots can be found in the milk at any time during milking, the quarter suffers from clinical mastitis. It becomes more difficult if the selection criterion is determined on SCC. Bulk milk SCC is used as the main criterion for acceptable milk in relation to subclinical mastitis but also as an indicator of when to dump milk from cows with clinically abnormal foremilk. Classification of the inflammatory status of a quarter was earlier based on a threshold of 500,000 cells/ml, but lately Hillerton (1999) has suggested that the threshold of 200,000 cells/ml would improve discrimination better between infected and uninfected quarters. Based on the likelihood of infection and altered manufacturing properties, Smith et al. (2001) conclude that milk from quarters with SCC >200,000 cells/ml, with or without clinical signs, is abnormal milk. SCC at the quarter or cow level may not always be the best determinant of the mastitis status of a quarter or cow. However, SCC is currently the only parameter that can be interpreted from quarter to bulk tank milk and it is widely used for this purpose and as an indicator of the milk quality.

Bulk tank, cow, or quarter level?

Regulations on bulk milk SCC is not a matter of human safety but of suitability. The European Union enforces a maximum bulk milk SCC of 400,000 cells/ml. This level is meant as an indirect control of the number of clinically infected cows delivering milk for consumption. Eberhart et al. (1982) estimated that 13% of the cows were infected at this bulk milk SCC level.

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Further analysis of data collected by Justesen and Rasmussen (2000) showed that the bulk milk SCC's were likely to be <400,000 cells/ml if less than 5% of the cows had visually abnormal foremilk, Figure 1. However, the absence of cows with clinical signs did not ensure that bulk milk SCC was <200,000 cells/ml. We do not want to drink milk from a quarter with clots in the foremilk but our attitude changes if there are a few flakes in the foremilk from one quarter and the rest is diluted with normal milk from the three other quarters. Clearly, the foremilk was abnormal but does this mean that all milk from this quarter or this cow is unsuitable for consumption? SCC is used as a measurement of inflammation and as such of abnormal milk. We have to decide if discarding milk should include some sort of visual appearance and/or inflammatory markers as well and if all quarters of all cows have to be normal in order to deliver milk for consumption. Clearly, the fewer quarters producing abnormal milk, the more suitable the product becomes (Smith et al., 2001).

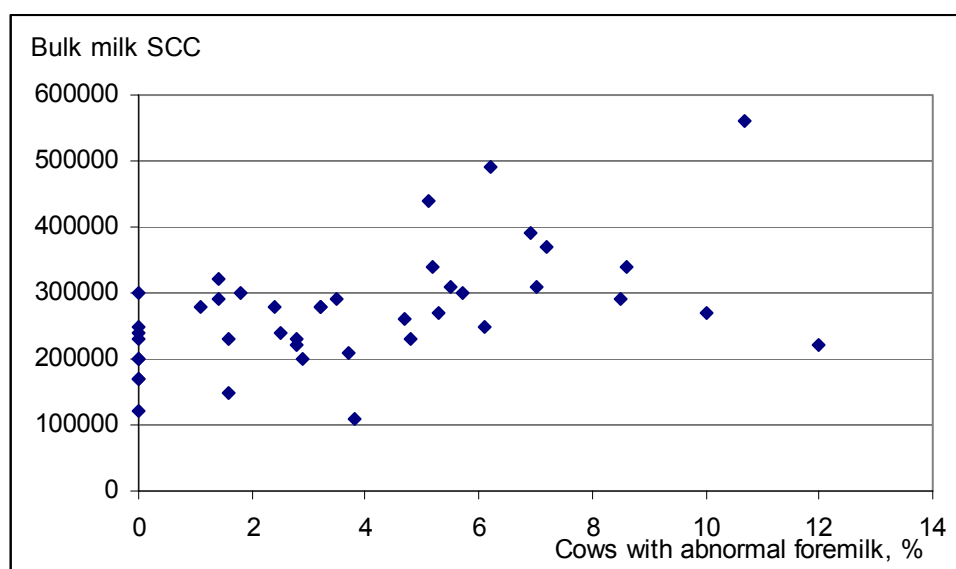


Figure 1. Plot of bulk milk SCC versus the percentage of cows with abnormal foremilk delivering milk. Results were based on data from Justesen and Rasmussen (2000).

Visual appearance of foremilk and SCC

Rasmussen (2001) evaluated the interrelationship between visual inspection of foremilk, CMT-scoring of foremilk, and the cell count of composite milk. Cows where all quarters had normal milk had low cell counts in the composite milk and only 4% of the samples had $>10^6$ cells/ml, Table 1. Cows that had at least one quarter with clots in the foremilk had a geometric mean SCC of 10^6 cells/ml and 54% had $>10^6$ cells/ml. Even when all quarters had visually normal foremilk, 13% of the composite milk samples exceeded 400,000 cells/ml but not all samples were above this threshold if one or more quarters had clots in the foremilk. Cows with blood or flakes in the foremilk had intermediate cell counts in composite milk. CMT-score of foremilk differentiated better between cows with high and low SCC in composite milk than visual inspection of foremilk. Rasmussen (2001) concluded that measurement of SCC of composite milk only and

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discarding milk above certain thresholds will not ensure that milk from all cows with clinically abnormal foremilk is withheld from delivery. Low thresholds of SCC will reduce the frequency of cows with abnormal milk but increase the discarding of milk from cows with visually normal foremilk.

Table 1. Log. SCC of composite milk and percentage of samples > 200,000, 400,000, and 10^6 cells/ml by visual appearance of foremilk (worst quarter). (Rasmussen, 2001)

Worst quarter	No.	Log SCC	SCC > 200, %	SCC > 400, %	SCC > 1000, %
Normal	1761	5.04	26	13	4
Blood	24	5.43	58	29	83
Flakes	102	5.41	55	33	13
Clots	171	6.00	83	74	54

Visual inspection and CMT-scoring were performed on about 800 foremilk samples and the corresponding quarter milk was analysed for SCC. CMT-score on foremilk correlated well with the cell count of milk from the quarter. About 1% of the quarters with CMT 1 or 2 on foremilk had a SCC > 10^6 cells per ml. Out of the quarters with clots in the foremilk all had a SCC > 10^6 cells per ml in the milk produced specifically from that quarter, Table 2. Of quarters with milk appearing normal, we found that 6% had a cell count above 1 mill. per ml, which were mainly of newly calved cows. Discarding the milk from quarters with SCC > 200,000 cells/ml according to Smith et al. (2001) will dump the milk of 140 quarters (18% of 778, Table 2) with visually normal foremilk and this number should be compared with 27 being visually abnormal. Such a low SCC threshold on the quarter basis will ensure that abnormal milk is withheld from delivery but also cause large amounts of milk to be dumped.

Table 2. Log. SCC of quarter milk and percentage of quarters > 200,000, 400,000, and 10^6 cells/ml by visual appearance of foremilk.

Appearance of the foremilk	No.	Log. SCC	SCC/ml	SCC > 200, %	SCC > 400, %	SCC > 1 mill., %
Normal	778	4.7	386,000	18	12	6
Watery and flakes	10	5.7	1,198,000	80	60	40
Clots in the milk	17	7.0	14,401,000	100	100	100

Visual scoring of clinical mastitis

A test panel of 15 persons including 5 milk quality inspectors, 5 milkers, and 5 consumers scored the visual appearance of milk from cows with clinical mastitis and high SCC. The panel scored a total of 120 dishes with milk 4 at a time (simulating scoring of milk from 4 quarters). The milk samples were milked out and transported to the panel for scoring within 15 min. The scoring was not performed immediately at foremilk as usual, which may have caused the milk to curdle. The samples were scored as being normal, watery, containing clots, blood, or colostrum. The test

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panel did not agree on the scoring and only 10% of the samples had exactly the same score by everybody. Milk quality inspectors agreed the most and consumers the least. Consumers are only used to look at milk taken directly from the fridge and as an example a high fat percentage made them score normal milk as colostrum, figure 3. We did not have a conclusive score of the milk samples but could only compare the scoring with the SCC and a colour scanning. Milk samples that most of the test panel scored as having clots had high SCC's. However, 25% of the samples scored as normal milk had SCC $>10^6$ /ml and some were even above 10^7 /ml. It is not possible to differentiate between high and low SCC milk samples just by visual appearance.

Milk samples were colour scanned. The R^2 -value of logSCC regressed on the outcome of the colour scanner was 0.26 but 0.65 for the visual mean score of each sample regressed on the colour. There seems to be a possibility of using colour scanning to differentiate between normal and abnormal appearance of the milk as confirmed by Ouweltjes and Hogeveen (2001). However, if we want to dump milk with high SCC we have to measure this property more directly.

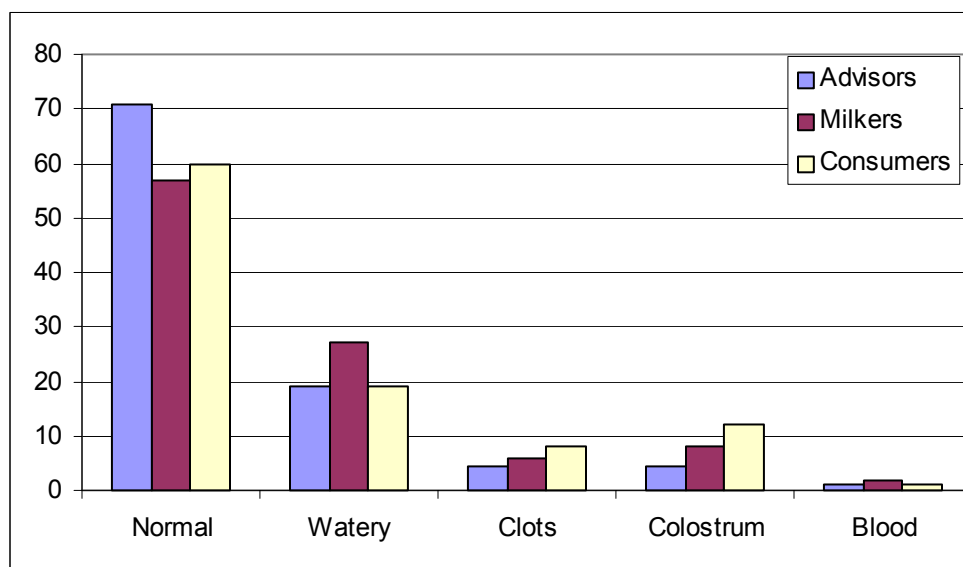


Figure 3. Visual scoring of dishes with normal milk and milk from quarters with clinical mastitis. Milk quality advisors, milkers (operators), and consumers formed the test panel.

Blood in the milk

The test panel scored 120 dishes 4 at a time with different percentages of blood and either 0.5 or 3.5% fat. Milk samples were scored as being normal, slightly pink, or pink. The test panel was able to detect milk samples with 0.1% blood. The consumer group did best and scored 37% of the samples with 0.1% blood as normal versus 60-70% of the other two groups, figure 4.

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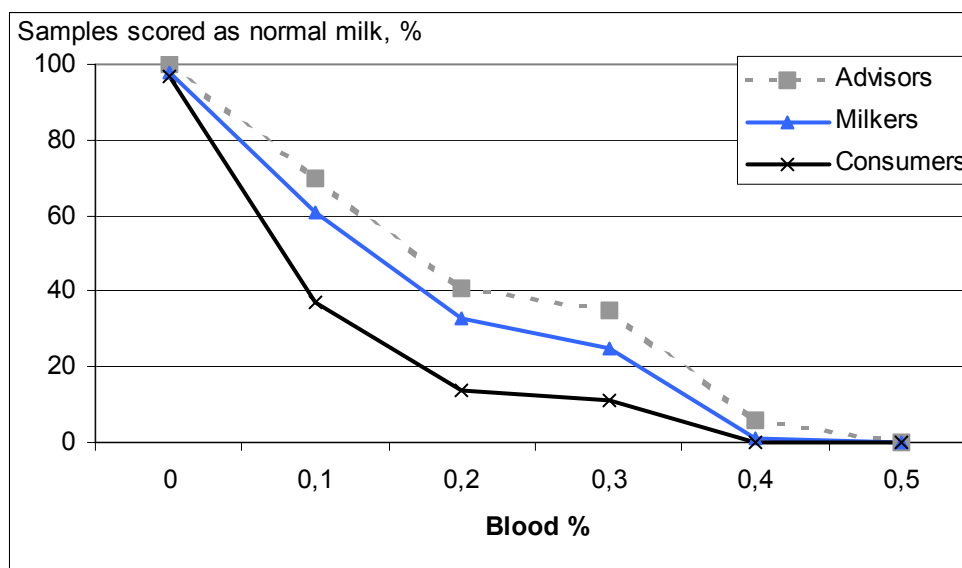


Figure 4. Visual scoring of dishes with normal milk and milk containing blood. Milk quality advisors, milkers (operators), and consumers formed the test panel.

The consumers typically scored samples with 0.1% blood as normal if all 4 samples had the same percentage of blood or some were higher. This was seen for higher percentages as well. All members of the panel scored milk with 0.5% blood as being pink. Out of the samples with 0.1% blood, the panel scored 67% of the samples with 0.5% fat as being normal versus 45% of the samples with the 3.5% fat in the milk. Foremilk normally has a low fat percentage, which then makes it more difficult to point out milk samples with a low content of blood. My conclusion from the test panel results is that milk samples with 0.4% or more blood all will be scored as pink and samples with 0.1% blood can be visually detected if they are compared with milk samples without blood. To explore the lower limit, an additional test was carried out with scoring of pictures of milk containing blood. Containers with 0.05% blood were not scored to be different from containers without blood. If we accept 0.1% blood in the milk as the upper limit on a quarter level and that this will happen in a maximum of 3 out of 300 lactation days, then we will always have <1 ppm blood in the bulk tank. Discarding of milk with >0.1% blood will ensure that bulk milk will be visually free of blood. This statement concerns the red blood cells only because all precursors of the milk come directly or indirectly from the blood. Colour scanning was excellent in detecting low amounts of blood in the milk. The R^2 -value of blood percentage regressed on the outcome of the colour scanner was 0.998 and the $SD=0.009\%$, which makes it possible to detect 0.02% blood in the milk and then of course discard milk with more than 0.1% blood.

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Colostrum

The milk composition and properties of the milk change radically during the first days after calving. Immunoglobulins are the major constituents of colostrum and the content drops about 10-fold during the first four milkings but has not reached minimum even one week after calving. Moreover, the content may change due to differences in milking frequency, which may be higher or lower than twice daily milkings. It is a normal procedure to deliver the milk for human consumption about 4-5 days after calving whenever the colour seems “normal”. We have found a high correlation between colour measurements and the content of immunoglobulins (Madsen and Rasmussen, unpublished results). SCC is naturally high at calving and SCC of uninfected quarters decrease during the first days after calving and gets <400,000 cells/ml after about 3 days of milking. The high immunoglobulin content affects coagulation and moreover, pasteurisation was not possible of colostrum from the first two milkings, which may cause problems for the dairy industry. Madsen and Rasmussen have not yet finalised the analysis but the authors are optimistic in being able to determine an acceptable threshold.

Conclusions

Dumping of clinically abnormal milk at the time of milking should be based on properties directly related to the homogeneity of the (fore)milk. Indirect measurements of SCC in quarter or composite milk do not ensure that all abnormal milk is discarded. Colour scanning of milk is a useful tool in order to avoid blood and colostrum contamination of the milk and shows promising results to detect clinical mastitis as well.

Acknowledgements

When citing this article please use the following reference:

Rasmussen, M.D. (2002) *Defining acceptable milk quality at time of milking*. Proceedings from The First North American Conference on Robotic Milking, Plenary IV-9, March 20-22, 2002, Toronto, Canada. Published by Wageningen Academic Publishers, Wageningen, The Netherlands (www.wageningenacademic.com).

This study is performed within the EU project *Implications of the introduction of automatic milking on dairy farms* (QLK5 2000-31006) as part of the EU-program 'Quality of Life and Management of Living resources'. The content of this publication is the sole responsibility of the authors, and does not necessarily represent the views of the European Commission nor any of the other partners of the project. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use, that may be made of the following information.

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