MAKING THE MOST OF MACHINE-ON TIME: WHAT HAPPENS WHEN THE CUPS ARE ON?

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Machine milking, like a good marriage, is an exercise in compromise. Obsession with one goal at the expense of the others is seldom the optimal solution. The main goals of machine milking are to remove the available milk from each cow's udder quickly and completely, without slipping or falling, with minimum discomfort to the cow and minimum damage to her teats. Balancing these goals requires compromise because:

- Maximizing milking speed often results in less complete and/or less gentle milking.
- Maximizing completeness of milking generally results in slower and less gentle milking.
- Maximizing gentleness results in slower milking and may result in less complete milking.

How quickly, how gently, and how completely should we aim to milk each cow and how should we balance these goals? Basic concepts and relevant research results are outlined in this paper to help managers of modern milking parlours achieve a balanced approach to milking and make the most of the machine-on time.

<u>How quickly can we expect to milk each cow?</u>

Milk flow-rate curves of individual cow milkings provide a good starting point for understanding the "machine-on" part of the milk harvesting process (eg, Bruckmaier & Hilger, 2001; Schukken et al. 2005). Two sets of milk flow-rate curves from Bruckmaier & Hilger (2001) are reproduced as Figures 1 and 2 below. These curves illustrate several interesting and important lessons.

All but one of the six curves in Figure 1 show the undesirable but common characteristic of delayed milk ejection, ranging from about 0.8 to 1.8 min after clusters were first attached. In this particular study, delayed milk letdown was due to a combination of reduced milk yield and inadequate pre-milking stimulation. The results support Bruckmaier’s conclusion that the time required for milk ejection is closely - and inversely - related to the amount of milk in an udder. Delayed milk ejection problems also occur frequently when cows are unsettled at - or shortly before - the time of cluster attachment, or when the timing of cluster attachment does not coincide with the time of milk ejection. All of these causes of delayed milk ejection and low milk flow at the start of milking have everything to do with milking management and nothing to do with the milking machine.

The same 6 curves are reproduced in Figure 2 but, in this Figure, each curve is overlaid with an extra curve showing milk flow-rate characteristics immediately following 1 min of manual stimulation. The potential for improving the efficiency of milk extraction is illustrated in 5 of these 6 pairs of curves. It is evident that either more milk was extracted, or the cow milked more quickly, or machine stripping yield was reduced by pre-stimulation. The only situation where manual stimulation made no difference was for the fresh cow milked at 12 h intervals.

Figure 1. Milk flow-rate curves for two cows (cow 1 in early lactation and cow 2 in late lactation) that were milked at 4, 8 and 12 hr intervals without pre-milking stimulation (from Bruckmaier & Hilger, 2001). The time when milk ejection occurred is marked on each curve.

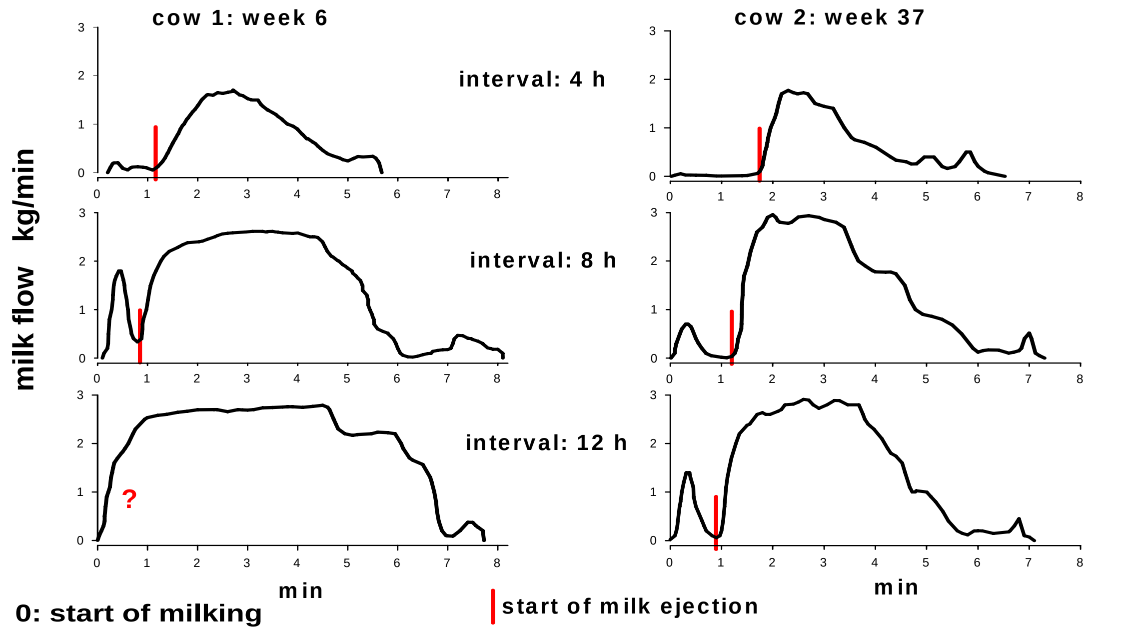
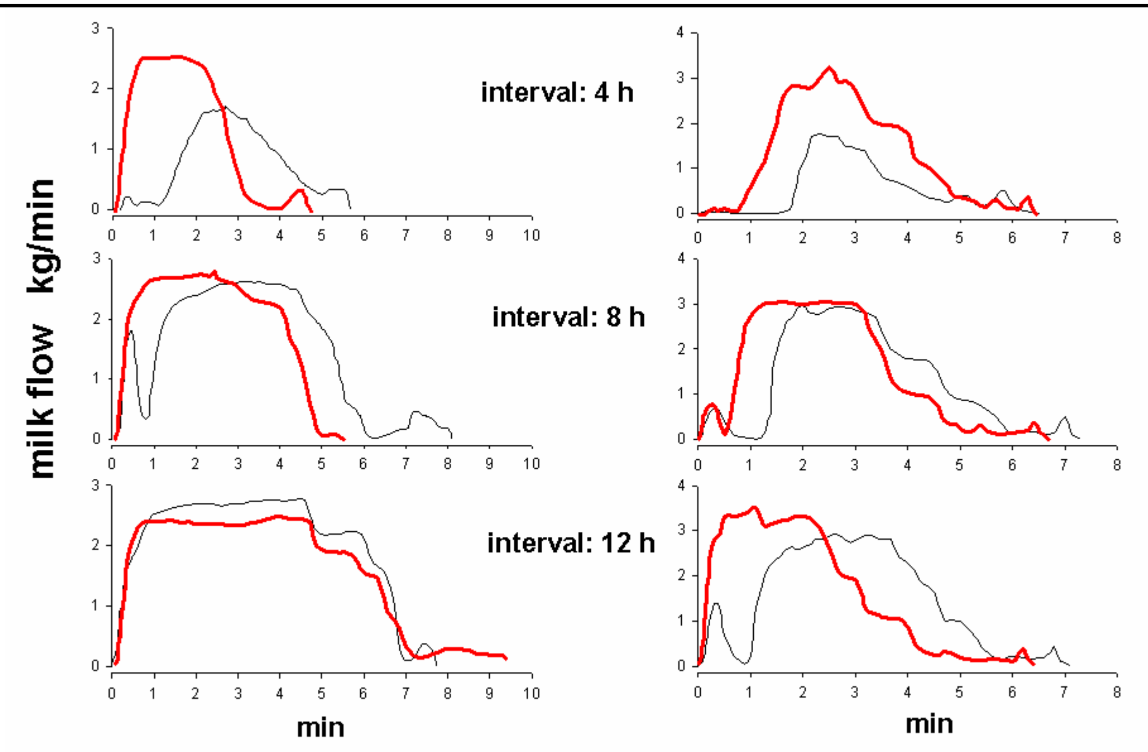


Figure 2. Improved milking characteristics following 1 min of pre-milking udder stimulation for the two cows shown in Figure 1(from Bruckmaier & Hilger, 2001).



The period of delayed milk ejection

If our goal is to "make the most of machine-on time", it is obvious that the period of no (or very low) milk flow at the start of milking should be eliminated. The solution used in Figure 2 has a cost, however. In this particular study, the 'cost' was the labour cost of 1 min per cow spent cleaning and stimulating each udder. Farmers, advisers and milking equipment companies in different parts of the world have adopted different strategies to streamline or ignore this repetitive, labour-intensive task. For example:

- In North America and western Europe, most farmers use a milking routine in which the cleaning and preparation time is reduced to 10-15 s per cow followed by a wait (lag time) of 60-90 s to allow milk ejection to occur before the cluster is attached. This routine has been shown to be as effective as, and far more labour-efficient than, a continuous period of 1 min of manual stimulation.
- In Australia and NZ, most farmers have abandoned the repetitive task of routine cleaning and pre-milking stimulation. For better or for worse, a typical milking routine involves no wash or only minimal washing of visibly dirty teats, with clusters applied as soon as each cow enters her milking stall. The rationale for this minimal prepping procedure is that the udders of pasture-fed cows remain relatively clean between milkings. Furthermore, the spectacular production responses to stimulation seen in the 1960s have been bred out of modern NZ herds by selection of AB bulls for high milk yield and low stimulus response (Phillips, 1987).
- In all dairying countries, good managers try to create a calm 'maternal' environment in which cows are encouraged to enter their milking stalls voluntarily, quietly and in a receptive state to elicit milk ejection.
- Manufacturers of Automatic Milking Systems have automated the process of cleaning and pre-milking udder stimulation with varying degrees of success. This element of the milking routine is perhaps the best suited to automation because of the paramount importance of good milk ejection and udder hygiene in the milking process, the relative ease of automation (compared with cup attachment and milk sensing) and its enormous physical demand and risk of repetitive stress injury for milking personnel.
- At least one major equipment manufacturer offers an automatic machine-stimulation system in which liner movement is restricted to prevent milk flow for a pre-determined period following cluster attachment.
- The NZ-based company Sensortec has developed a novel sensing system that may help to streamline - or to utilise - the period of delayed milk ejection in conventional parlours. A single conductivity (EC) sensor is installed in the milk hose downstream from the claw. The pulsator is modified so that, within 10 s of cluster attachment, only one liner pulsates normally for the next 15 cycles while the other three liners are held closed to prevent milk withdrawal from those quarters. Temperature-compensated EC of the first quarter milk is measured during this period. The sequence is repeated for the 2nd, 3rd and 4th teatcups, the relative EC values are compared, and pulsation is restored to all liners for normal milking.

A study by Bruckmaier & Blum (1996) provides a clearer picture of the physiological basis for automated machine-stimulation. These researchers showed that blood oxytocin increased to similar concentrations in response to either manual stimulation or stimulation by the pulsating liner and remained elevated during the entire milking period. The fact that oxytocin concentration remained elevated throughout the milking period is interesting in view of the conventional wisdom that oxytocin in the bloodstream has a half-life of about 4 min (Gorewit et al. 1983). Although the old half-life story may be correct, it may be only half the story because the tactile stimulus provided by teatcup liners appears to provide adequate stimulus for continued (intermittent?) oxytocin release throughout milking.

The 'bimodal' curves shown in Fig 1 result from: 1) initial emptying of milk that had drained into the teat sinus and lower udder cistern in the inter-milking period followed by 2) true milk ejection after an interval that varies with degree of udder fill. Thus, the bimodal characteristic is not due to a 'second letdown' as it is sometimes called. As illustrated in Figure 1, the milking machine provides enough tactile stimulus to elicit milk ejection. The varying stimulation requirements of cows at different stages of lactation and varying milking frequency are also apparent. Once milk ejection has occurred, teatcup action provides sufficient stimulation to continue oxytocin release at a rate that maintains the ejection response as previously released oxytocin is slowly metabolized. A release of adrenalin due to fear or discomfort can interrupt milk ejection and it is only under this circumstance that a 'second letdown' might occur after adrenaline is metabolized and oxytocin concentrations restored. This process is likely to take several minutes.

A review of experiments on the effect of stimulation on milking speed indicates that cows can be divided into three general groups.

- Cows that have a very low stimulation requirement and therefore do not benefit much from increased stimulation.
- Cows with a moderate stimulation requirement that show big changes in milk flow/machine on time with moderate increase in stimulation.
- Cows with very low peak milk flowrates (probably because of small-diameter teat canals) who, therefore, do not show a big response to increased stimulation because, by the time the cistern is empty, stimulation has been achieved by the machine regardless of what happened before clusters were attached.

The period of increasing flow-rate following milk ejection

All of the milk flow-rate curves in Figures 1 and 2 show a brief period - varying from about 30 to 60s - during which flow-rate increases rapidly. This rapid increase reflects the gradual stretching of the teat canal until it reaches its maximum effective diameter. Vacuum level and pulsation characteristics have little effect on the rate at which the teat canal creeps open during this period.

The period of peak milking rate

The effective diameter of the open teat canal remains more or less constant through the peak flow-rate period. This is the period when vacuum level, pulsation rate and ratio have their dominant effects on milking speed. These effects have been widely discussed elsewhere and are well-known. For most types of conventional liners, a good compromise between fast milking and gentle milking characteristics is achieved by setting the system vacuum to maintain an average claw vacuum within the range 36-42 kPa (10.5-12.5 inHg). As for pulsation settings, milking speed is optimised when the liner is held open for 500-600ms and teat congestion is minimised when the D-phase (the liner closed phase) is at least 150 ms or 15% of each pulsation cycle. The dominant influence of the liner is less well-understood and is discussed in more detail later. Figures 1 and 2 illustrate the following characteristics of the peak flow period which are representative of most dairy cows:

- The height of the peak flow-rate plateau is not affected much by the degree of udder filling for either cow.
- The length of the peak flow-rate period increases with increasing degree of udder filling (i.e., with higher milk yield and/or longer intervals between each milking).
- The peak flow period represents a surprisingly low proportion of total machine-on time, especially for low yielding cows.

Approximate values for the 8 h and 12 h curves for the two cows in Fig. 1 are shown in Table 2.

The period of low milk flow-rate

The low flow-rate period starts when the milk flow pathway from at least one udder quarter starts to become restricted in the region of the liner mouthpiece. It is no coincidence that the change from peak flow to low flow for successive quarters can be seen most clearly in the curve for cow 1 milked at 12 h intervals. These well-defined, relatively steep steps are a more common characteristic of higher-yielding, well-stimulated cows, especially when milked with well-maintained clusters that hang evenly on udders. They demonstrate the point that the “tail-end” of machine-on time usually can be improved by giving more attention and care to the “front end” of milking - that is, by adopting a milking routine which ensures that most teats are plump with milk when clusters are attached.

The slopes and lengths of milking curves during the low flow-rate period - as well as the quantities of milk obtained in this period - are useful indicators of deficiencies in both milking management and characteristics of the cluster. As a general comment, liner design and cluster characteristics have a greater influence than either vacuum level or pulsation settings during the low flow-rate period.

If the teat sinus is emptied early in milking, the liners will reposition higher on teats. This upward movement of the liner early in milking is a likely contributor for a longer ‘dribble phase’ at the end of milking, contributing to increased teat congestion by extending the low flow period at the end of milking and/or a premature shutoff of the passage between udder and teat sinus resulting in less complete milking. Common machine factors linked with a prolonged low flow-rate period (long “dribble times”) include:

- poor type or condition of liner
- clusters that are too light (in relation to the bore of liner used and/or the system vacuum)
- clusters that hang unevenly on the udder because the connecting hoses are too long, too short, twisted, or poorly aligned in relation to the cow.

The small flush of milk at the end of the milking period in Figs 1 and 2 results from machine stripping. The downward pressure applied during stripping helps to open the passage between the udder and teat sinus and facilitates drainage of any milk trapped in the udder cisterns.

<u>Effects of liners on the speed, gentleness and completeness of milking</u>

Liner design usually has a greater effect on milking characteristics than any other machine factor. Comparative studies in Ireland showed 33% differences in milking times, eight-fold differences in the incidence of teatcup slips, and six-fold differences in strippings yield between liner types (O'Shea and O'Callaghan, 1980). Furthermore, comfortable liners minimise the risk of teat damage, thereby encouraging better cow behaviour throughout milking.

The results of many comparative experiments and observations from field experience are summarised in Table 1 (adapted from Mein et al. 2003b). It is intended as a general guide only. The indicative changes should be interpreted with caution because it is often difficult to separate effects that are inter-dependent.

Table 1 confirms our opening statement that liner design is a compromise between competing goals. Small changes in most of the physical dimensions listed in the table tend to improve one or more milking characteristics but also decrease other desirable performance characteristics.

Table 1. General trends in the milking characteristics of liners resulting from small variations in liner dimensions. Explanation of symbols:
Milking performance is improved (+) or improved markedly (++)
Milking performance is decreased (-) or decreased markedly (- -)

Change in physical dimension (eg, by 10%)	Milking speed	Strip yields	Cup slips or falls	Cow comfort (reduced teat congestion)
Mid-barrel bore is increased	+	-	+	-
Upper barrel bore is increased		-	+ +	- -
Ratio of mid-barrel bore to MP lip diameter is increased		- -	+ +	- -
MP lip is thickened or stiffened		-	+	-
MP cavity height is increased	-		+	- -
Effective collapse length is increased	+			+
Liner tension is increased	+		-	-
Liner wall is thickened*	+			Depends on liner vacuum

* Some of the subtle but surprising effects of liner wall thickness are discussed in the following section.

Milk:Rest ratio and Compressive Load (CL)

The first pulsation cycle in Figure 3 shows the concept of Milk:Rest ratio as it is understood and applied by many (perhaps most?) milking machine technicians and dealers. The second cycle illustrates the "true" Milk:Rest ratio which is determined by measuring the average vacuum in the pulsation chamber at which milk starts to flow from the teat (Mein et al. 2003; Bade et al. 2007). Measurement of the true Milk:Rest ratio helps to explain why some liners milk faster than others and why some liners appear to induce more teat-end hyperkeratosis than other liners.

Figure 3. A vacuum record showing two cycles of pulsation chamber vacuum (PCV) with the liner vacuum (LV) and the "assumed" Milk:Rest ratio superimposed onto the first pulsation cycle. The assumed ratio of 50:50 is based on a touch point or liner offset of 10 kPa (about 3 inHg). The "True Milk:Rest ratio" for this liner is superimposed onto the second cycle.

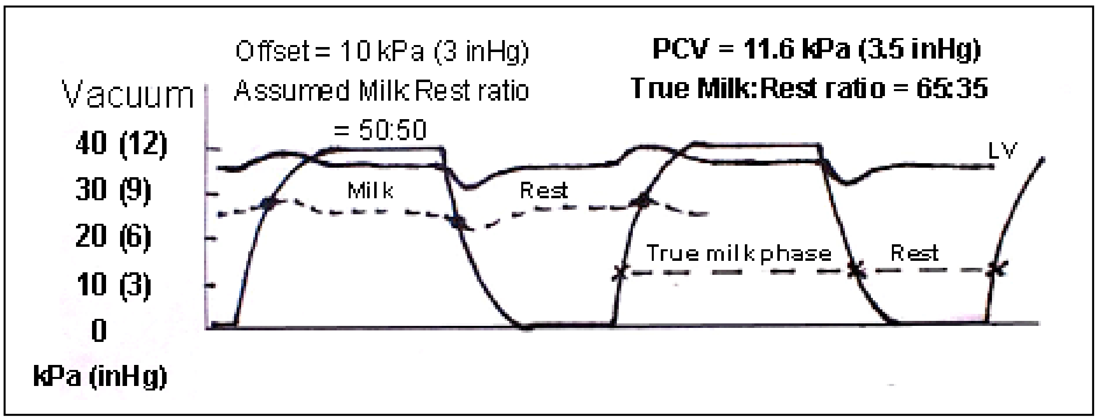
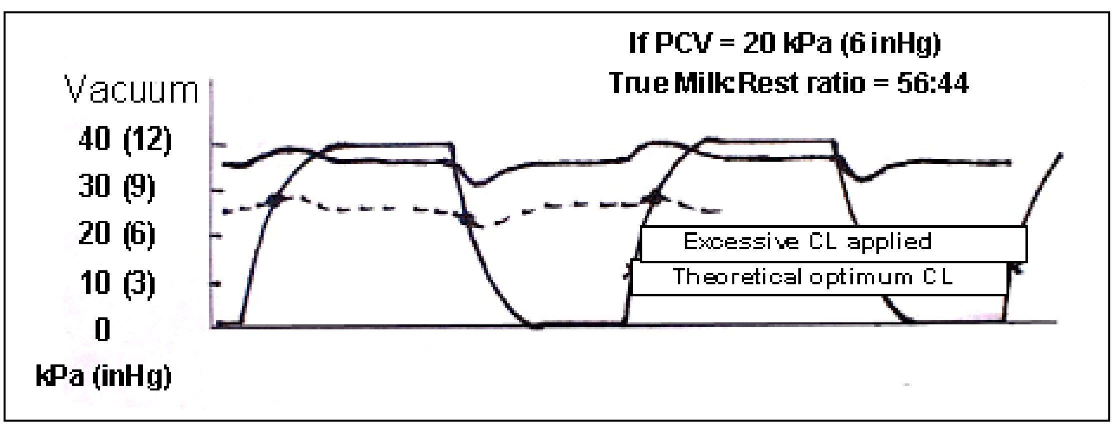


Figure 4. The same record of PCV as in Figure 3. The superimposed lower box shows the range of PCV (8-12 kPa; 2.5-3.5 inHg) which is equivalent to the theoretical optimum range of CL applied by the closed liner. The superimposed upper box represents the upper range of values measured for some commonly-used liners in the USA (up to about 20 kPa; 6 inHg).



A liner for which PC vacuum averages about 20 kPa (6 inHg) when milk just starts to flow from the average teat, would have a true Milk:Rest ratio of about 56:44 as shown in Figure 4. Other things being equal, this liner would milk more slowly than the liner represented in Figure 3 because the milk phase is shorter in each pulsation cycle. At a pulsation rate of 60 c/min, this time difference would be (650 - 560) ms = 90 ms per cycle = 14% shorter milking time per cycle.

According to Mein et al. (2003a), liners for which average PC vacuum exceeds about 13-14 kPa when milk starts to flow probably apply unnecessary and unproductive compression to many teat-ends. This conclusion implies that liner CLs greater than 13-14 kPa (about 4 inHg) are likely to be associated with poorer teat-end condition scores (that is, with more hyperkeratosis).

These theoretical considerations were supported by preliminary field data presented in Figure 4 of Mein et al. (2003a) and, more recently, by the results of a comparative study of five different liners in a Wisconsin herd (Reinemann and Mein, unpub). Average milk flow-rate means for these liners varied by about 9% (0.52 in 6.1 lb/min). The liners included three (listed as L1, L2 and L3 in Bade et al. 2007) which differed in wall thickness of the liner barrel. Relevant results:

- Liner L1, which had the thinnest barrel wall (2.5mm), applied an average CL over 16 kPa (> 4.7 inHg) and had the lowest average milking rate - ie, it was the most 'aggressive' and slowest milking liner.
- Liner L3, which had the thickest barrel wall (2.9mm), applied the lowest average CL (about 13 kPa, 3.8 inHg) and had the highest average flow-rate - ie, it was the most 'gentle' and fastest milking liner.

Both these CL values were above the theoretical minimum CL required to relieve congestion in the teat apex. The implication is that the slower milking performance of the L1 liner (relative to liner L3) was associated with the unnecessarily high CL applied to the teat. The higher CL of liner L1 changed the true milk:rest ratio and shortened the milking phase by about 10% relative to that for liner L3.

<u>How completely should we aim to milk each cow?</u>

In Rasmussen's pioneering study (Rasmussen, 1993), milking time was reduced by 0.5 min per cow with no loss of milk yield when the end-of-milking setting for automatic cluster removers (ACRs) was raised from 0.2 kg/min to a flow-rate threshold of 0.4 kg/min (from 0.45 to 0.9 lb/min). Milking equipment companies soon realised the potential for shortening machine-on time for individual cows and for reducing herd milking times. Threshold flowrate settings for ACRs were raised from default settings of about 0.3 kg/min up to 0.5 kg/min (0.7 lb/min up to 1.1 lb/min) for herds milked twice per day, and to levels as high as 0.9 kg (2 lb) per min for some herds milked thrice daily. At the same time, the typical settings of 10-20 sec time delay for cup removal were shortened to 0 - 5 sec. Under typical conditions of milking management in large commercial herds in the USA, these changes reduced milking times by up to 1 min per cow with no reported loss of milk yield, no change in SCC or mastitis levels.

These excellent results were obtained in high-producing herds milked three times per day with (typically) good pre-milking teat preparation, calm consistent milking routines, narrow-bore liners, and milking units that were positioned carefully on the udder by the operator(s) at the start of milking. Because these milking conditions are rare in Australia, several experiments have been conducted under more typical Australian milking conditions (including twice-daily milking, minimal udder pre-milking preparation, use of relatively wide-bore liners, and no particular care to ensure good cluster balance or alignment).

The first results (Clarke et al. 2004) showed that the use of timed maximum milking durations coupled with ACR threshold setting of 0.4 kg/min (whichever came first) could save up to 35% of normal milking time of slow milking cows with no adverse effect on their daily milk yield (averaging up to 26 L/d; 57 lb/d), milk composition, teat condition or cow behaviour. Subsequent studies (Clarke et al., in preparation) indicate that early termination of milking had no significant effect on incidence of clinical mastitis, sub-clinical mastitis or average SCC in healthy quarters or in quarters sub-clinically infected with either *S. aureus* or *Str. uberis* mastitis pathogens. These relationships have not been examined in *Str agalactiae* herds.

<u>Making the most of machine-on time</u>

How quickly can we milk cows?

The times for each period of milking, listed in Table 2, help to identify opportunities for 'making the most of machine-on time'.

Table 2. Approximate times for each period of milking for the two cows milked at 8 and 12 h intervals (from Figure 1)

Treatment	Time to milk ejection (min)	Increasing flow plus peak flow periods (min)	Low flow rate period (min)	Total machine-on time (ignoring the variable time taken for machine-stripping)
Early lactn. 8h	0.9	3.6	2.5	7.0
Total time/d for 3X	2.7	10.8	7.5	21.0
Early lactn. 12h	0	4.6	2.4	7.0
Total time/d for 2X	0	9.2	4.8	14.0
Late lactn. 8h	1.2	2.1	2.7	6.0
Total time/d for 3X	3.6	6.3	8.1	18.0
Late lactn. 12h	0.9	2.8	2.3	6.0
Total time/d for 2X	1.8	5.6	4.6	12.0

The following conclusions can be drawn from the preceding discussion and the values in Table 2:

- Machine-on time could be shortened by 0 - 1.2 min per milking by eliminating the period of delayed milk ejection at the start of milking. This reduction can be achieved solely by changes in milking management.
- Machine-on time could be shortened by reducing the length of the peak flowrate period. Mean claw vacuum could be raised to quite high levels (eg., 50 kPa, 15 inHg or more) and/or pulsator ratio could be widened to 80:20 with little risk of damage to teat tissues during this period. Pressure within the teat sinus remains at intramammary pressure and the tough teat skin acts like a strong string bag, thereby protecting the more delicate inner

tissues from excessive distension and congestion. Raising the claw vacuum and/or widening the pulsator ratio could shorten the peak flow-rate period by perhaps 10-20%. Attempts have been made to implement varying vacuum level during milking to take advantage of the ability to increase milking speed during the peak milk flow period without undue stress on teat tissues. These devices have not achieved their full potential probably because they have been implemented on a whole-udder rather than quarter basis. The simple conventional approach of increasing vacuum for the entire period of milking has a relatively small effect in reducing cups-on time (compared to optimizing milk ejection and ACR setting) while increasing teat congestion and hyperkeratosis (when implemented with the same liner).

- Machine-on time can be shortened markedly by reducing the length of the low flow-rate period. High vacuum levels cannot do much to shorten this period and may be counter-productive because the real limit to flow-rate is partial blockage of the milk flow pathway between the udder cistern and teat sinus. Reductions can be achieved by selecting liners for their clean milking characteristics, by use of relatively heavy, well-balanced clusters, by raising ACR threshold settings and/or by truncating the milking time of slow cows.
- Total machine-on time per day would have been 6-7 min longer when these two cows were milked at 8 h (3 times/d) compared with 12 h intervals (2 times/d).
- More than 5 min of this 6-7 min difference would have been in the low flow-rate period. An extra 5 min of low flow-rate milking implies that teats would be subjected to an additional 300 pulsation cycles every day when cows are milked 3X compared with 2X. Teat tissues are subjected to higher vacuum within the open liner during the low flow-rate period (thereby inducing more distension and tissue congestion) as well as greater compression applied by the closed liner (thereby increasing the incidence or severity of teat-end hyperkeratosis).

It is important to keep the goal of fast milking <u>per cow</u> in perspective relative to the goal of quicker milking of the <u>herd</u>. The percentage of time that teatcups are attached to teats is, typically, only about 30% in a herringbone or parallel parlour with one cluster per stall. The limiting factor in turning a parlour side is the last unit detached on that side, which is a complicated statistical function of when units are attached to individual cows, the average and standard deviation of cups-on time for each cow. The average cups-on time per cow is not always (in fact not usually) the limiting factor in cows/hour milked. As long as the average cups-on time is not the limiting factor in cows/hour there are advantages in extending the cups-on time to improve the gentleness and/or completeness of milking for most cows.

How gently?

There are several aspects to gentleness of milking. They include teat tissue congestion, teat-end hyperkeratosis and teat canal integrity (keratin dynamics). Each of these categories has different causal factors and some compromise is needed to achieve a reasonable degree of gentleness in all categories. A new paper (Ohnstadt et al. 2007) on teat condition problems provides a basis for determining changes to milking management or the milking machine to address these aspects.
For most types of conventional liners, a good compromise between fast milking and gentle milking characteristics is achieved by setting the system vacuum to maintain an average claw

vacuum within the range 36-42 kPa (10.5-12.5 inHg), pulsator ratio within the range 60:40 to 65:35, and the pulsation rate at about 55-60 c/m.

Liners should be chosen based on their physical properties at the intended average claw vacuum. Liners with barrel wall thickness >3mm (>0.12 in) tend to milk faster because the CL they apply is lower and closer to the theoretical optimum range. The CL applied by any given liner will increase as the average claw vacuum is increased. Many commercial liners apply an unnecessarily high cyclic pressure to the teat-end, especially when used at high milking vacuum levels. As well as increasing the incidence or severity of teat-end hyperkeratosis, such liners may milk more slowly because the true length of the milk phase is reduced relative to the rest phase.

How completely?

Completeness of milking becomes less important as milking frequency increases. For example, in an automatic milking system in which cows might be milked 4 or more times per day, the balance of goals shifts to making each milking as quick and gentle as possible rather than striving for completeness at each milking. Likewise herds that are milked 3 times per day would likely benefit from placing higher priority on speed and gentleness at the expense of completeness, compared with a herd milking twice per day. The practical upper limit for ACR threshold settings is likely to be the peak flow-rate of the slowest-milking quarter - ie, about 0.5-1 L/min (approx 1-2 lb/min). A useful criterion is that detacher flow-rate thresholds can be increased to reduce cups-on time until a noticeable drop in daily production is detected (Stewart et al. 2002).

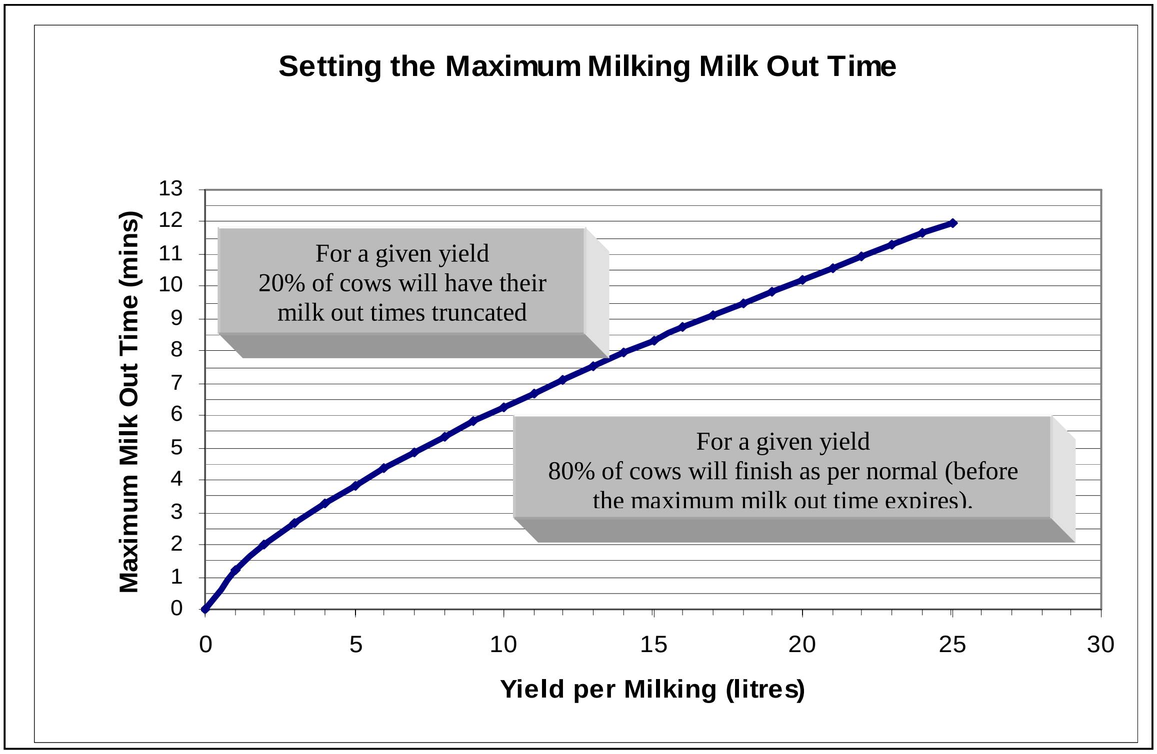
Until better data are available, a reasonable guideline for evaluating the completeness of milking is an average strip-yield per udder less than 0.5 kg for 2x herds or 0.75 kg for 3x herds when a representative group of cows is machine-stripped.

It is not uncommon for milking staff to manually remove the last unit on a side. This practice of arbitrarily truncating milking for a few slow-milking cows provides a clear indication of practical priorities for many dairy farmers. Several studies have been published indicating dramatic increases in parlour throughput by imposing a maximum cups-on time limit. The combination of a pre-set maximum milking time plus an end-point determined by ACR threshold (whichever comes first) has great potential to shorten milking times per herd by reducing or eliminating the bottlenecks caused by slow-milking cows. Our preferred goal should be:

- to milk most cows out as completely as possible within a reasonable time;
- to take clusters off slow-milking cows using a simple time-based formula which does not penalise cows that are slow-milking simply because they are high producers.

This excellent strategy is now being promulgated in Australia (Clarke et al. 2006). The intended goal, illustrated in Fig 5 for Australian conditions, is to remove clusters from at least 80% of cows at a conservative flow-rate threshold of about 400 mL/min (0.9 lb/min) while truncating the milking time of the slowest 20% of cows (relative to their milk yield per milking) and, thereby, inducing some undermilking in these cows.

Figure 5: Relationship between individual cow milk yield and maximum milk out time in Australian herds (from Clarke et al. 2006).



A recommended procedure to make the most of machine-on time

1. Document the present state of affairs in your milking parlour, including average machine-on time, average and peak milk flow rates, the range of average claw vacuum across fast and slow milking cows, the system vacuum, the length of the D and B phases of pulsation, and liner properties including MP lip and barrel diameters, true Milk:Rest ratio.
2. Optimize pulsation settings so that the D phase is about 200 ms (up to 50 ms less for speed priority, up to 50 ms more for gentle priority) and the B phase is about 550 mS (up to 50 ms less for gentle priority, up to 50 ms more for speed priority).
3. Assess teat condition and strippings yield when units are removed as measures of gentleness and completeness of milking.
4. Use the principles presented in this paper to achieve a more balanced approach to milking, putting machine-on time in context of total parlor performance and the well-being of your cows and workers.

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