"The milking system is the most important equipment a dairy farmer owns. It "harvests" the cash crop – milk. It comes into intimate contact with every cow two or more times a day. It's used 365 days of the year – no matter what the weather, and even when the calendar says it's a holiday".

That's the introduction for a new booklet, *"Maximizing the Milk Harvest"* published by the Milking Machine Manufacturers Council (MMMC, 1993). This excellent booklet is a revised edition of the long-running series published by the MMMC. It has been revised completely because, in the last five years, remarkable changes have occurred in our knowledge and understanding of the milking and cleaning performance of milking systems.

Recent field studies suggest that large milking systems tend to be over-dimensioned and underdesigned. New system evaluation procedures indicate that the performance and energy efficiency of many large milking systems could be improved markedly by a few simple design changes, and by more thorough equipment service and maintenance programs.

Machine milking is a unique example of a mechanical process that requires the willing cooperation of an animal for its success. Therefore, let's start with a brief review of the changing physiological characteristics and needs of high-producing dairy cows.

The principles for good milking are well known: cows' teats should be clean and dry for milking; cows should be milked gently, quickly and completely, with minimal machine stripping or overmilking. However, the ways in which these principles are applied is changing as milk production levels continue to rise, because high producing cows have:

1). Lower pre-milking stimulus requirements than low producers.

2). Longer milking times (in spite of their higher average milk flow rates).

3). Higher incidence of teat-end rings, or eversions.

4). Higher risk of new mastitis infections.

Here's a brief summary of the evidence for, and implications of, these changes.

Response to Premilking Manual Stimulation: Present-day, high-producing Holstein-Friesian cows appear to need little or no manual stimulation to maximize milk production. Although no data have been published for cows producing 20,000 lbs. milk or more per year, all of the available evidence from studies with lower producing cows indicates that high producers are relatively easy to stimulate and that oxytocin half-life is unlikely to be a limiting factor *(see review by Mein and Thompson, 1993).* Therefore, the basis of good premilking udder preparation should be to ensure that teat cups are applied:

• To visibly clean, dry teats with meticulous attention to detail, to reduce the risk of mastitis and to maintain top quality milk.

• At or soon after the time of milk ejection, when teats become plump with milk.

• With minimal time and effort for manual stimulation.

Longer Milking Times: Although peak flow rates and average milking rates tend to be higher in higher producing herds, it is quite clear that high-producing cows take longer to milk out. Field studies in England, France and the U.S. *(Stewart et al, 1993),* and the simulation studies of Thomas et al (1993) all show remarkably consistent results. On average, cows giving 20-25 lbs. of milk per milking take about 5 minutes to milk, and cows producing 30-35 lbs. take about 6 minutes. The conclusion: add 1 minute to the mean milking time per cow for each 10 lbs. increase in mean milk yield per milking.

The combined effects of longer milk-out times and shorter pre-milking prepping times in high-producing herds means that for optimum or more efficient labor utilization milking systems should be designed with more units per operator. Simulation studies on parlor performance by Thomas et al (1994) indicate that a 10-lb. increase in mean milk yield per cow per milking would reduce the number of parlor turns by about 0.7 turns per hour in double-16 or double-20 parlors.

Can we adjust the milking machine so that cows producing 40 lbs. per milking could still be milked out in 6 minutes? The three easiest variables with the greatest influence are vacuum level, pulsation ratio, and the threshold settings on automatic cluster detachers.

It is common knowledge that increasing the system vacuum level, eg. from 13.5 to 15 inches of mercury ("Hg) and widening the pulsator ratio (eg. from 50:50 to 60:40 or to 70:30) results in faster milking times. On the other hand, a comprehensive review of teat tissue reactions to milking indicates that machine-induced teat congestion and edema, incidence of teat lesions and, perhaps, new mastitis infection rates, tend to increase with increasing vacuum level and wider pulsator ratio *(IDF, 1994)*. It seems that we must reach a compromise between machine settings for fast milking and for maintaining healthy teats.

Typically, the system vacuum should be set between 12.5" and 13.5" Hg for lowline milking, and between 14" and 15" Hg for highline milking, according to guidelines in the MMMC booklet (1993). Usually, this will result in a mean vacuum level in the claw within the range 10.5" and 12.5" Hg during peak milk flow for a representative sample of cows. I try to set the system vacuum at the higher end of these ranges so that cows are milked as fast as possible, but still within the range recommended to maintain gentle milking conditions.

Pulsator ratios of 60:40 to 70:30 milk cows quickly and comfortably when narrow-bore teat cup liners are used. Because there's less margin for error at wide ratios like 70:30, excellent testing and ser-

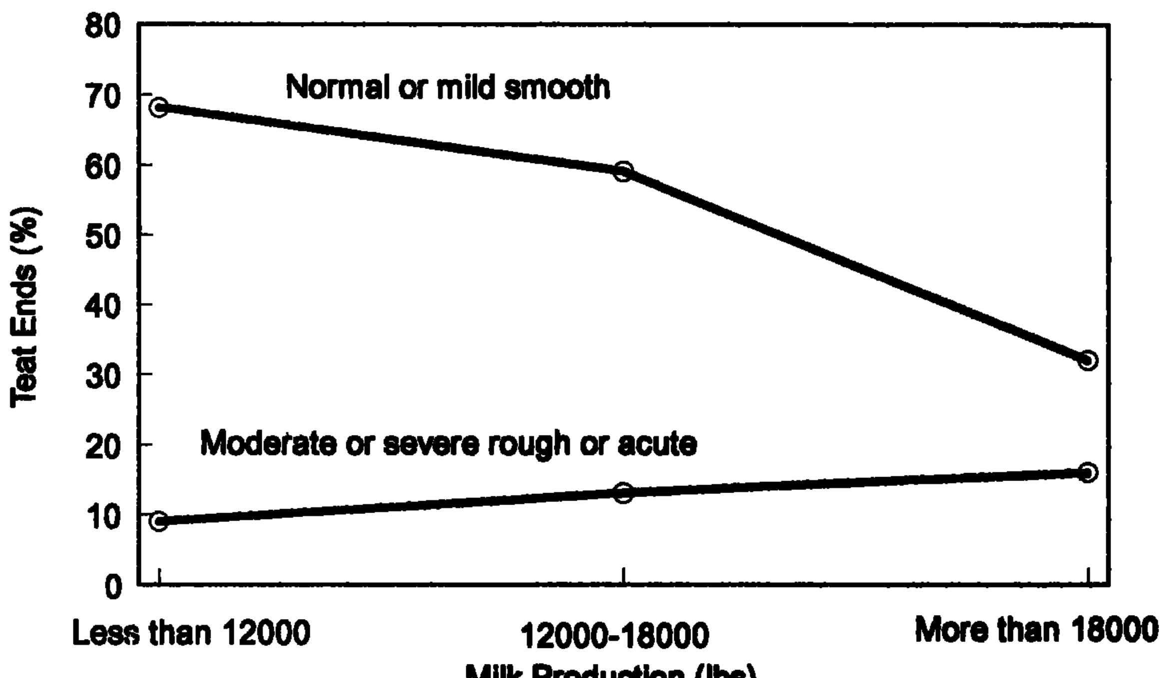


Figure 1. Changes in teat end condition with 305-d milk production. [Adapted from Seiber, 1979]

vice programs are needed to maintain pulsators in top condition.

Pulsation rates somewhere around 50-60 cycles per minute work fine. The small additional gain in milking speed at higher pulsation rates tends to be offset by poorer teat-end condition. Although the system vacuum level could be lowered to compensate for this more aggressive pulsation action, milking speed would then be slower!

Average milking time per cow was reduced by 0.5 minutes, and teat condition was improved, in a Danish experiment when the threshold setting on the automatic take-offs was raised from 0.44 to 0.9 lbs. milk per minute *(Rasmussen, 1992)*. Milk yield and milk composition were the same for each group of cows. Alternatively, the delay time could be reduced from about 20-30 seconds after the threshold flow rate setting down to 10 seconds. This change would save about 20-40 seconds per parlor turn.

Teat End Condition: Healthy teat skin provides the best defense against all types of pathogens. Furthermore, smooth healthy teat skin is easier to clean and easier to keep clean compared with rough or damaged teat surfaces. The act of milking aggravates all types of teat lesions, however. Machine milking is the main cause of teat canal erosion (variously known as teat orifice "eversion", "rings", fibrous rings or epithelial hyperplasia), hemorrhagic blisters near the teat end, and much teat chapping.

A high prevalence of teat end lesions is common in high-producing cows milked by machine,especially in early lactation. The progressive deterioration in teat end condition with increasing 305-day milk yield is shown in Figure 1 on the preceeding page. Less than 9% of teat ends were classed as normal for cows giving more than 18,000 lbs. milk (305d) *(Seiber, 1979)*. The design and action of the teat cup might need to be modified to maintain the teats of high-producing cows in acceptable condition.

New Mastitis Infections: Cows that milk faster have higher infection risk. Cows with more patent (slack) teat canals also have higher infection risk during their dry periods. Thus, high-producing cows may have higher mastitis infection risk because of the indirect relationship between high production, high milking rates, and more patent teat canals *(see review by Mein & Thompson, 1993)*.

Management practices to keep udders clean, such as clipping or "flaming" udders and use of clean bedding materials, and milking practices such as pre-milking teat preparation and post-milking teat disinfection, will require meticulous care and attention to detail to minimize the unavoidably higher risk of mastitis in high-producing, fast-milking cows.

Performance Guidelines for Milking Systems

A new national standard for the construction and performance of milking systems was published last year (ASAE S518: 1994). This new ASAE standard is based on a Draft International Standard, DIS/ISO 5707:1994, which has been reviewed and revised extensively during the past 3 years. Both standards incorporate new performance guidelines to provide a common basis for evaluating the great variety of types and sizes of milking systems used throughout the world.

The new performance guidelines for sizing milklines, vacuum supply lines, and vacuum pumps, are based on recent research at the UW-Madison. This research showed clearly that transient vacuum drops of less than 0.6" Hg in milkline or receiver vacuum had little or no effect on the normal cyclic vacuum changes in the milking clusters. Such small transient vacuum changes are completely lost, or over-ridden, by the larger cyclic changes generated within the cluster by the combined effects of pulsation and milk flow from the cluster.

The new performance guidelines are based on these conclusions: that transient vacuum changes of 0.6" Hg or less in the milkline or receiver are hardly measurable in the claw and have no significant effects on milking characteristics, mastitis, or milk quality.

Why choose an odd value such as 0.6" Hg for a national standard? Firstly because 0.6" Hg is equal to 2 kiloPascals (2 kPa) in the internationally-accepted SI unit of pressure. And, more importantly, because vacuum fluctuations in the claw are usually increased whenever the milkline vacuum drops more than 0.6" Hg.

Sizing milklines: Fluid flow in milklines typically varies between "stratified flow" (when milk flows in the lower part of the milkline and air can flow in a clear, continuous path above the milk) and "slug flow" (when intermittent slugs of milk fill the entire cross-section of the milkline). Stratified flow is the preferred flow condition to maintain a reasonably stable vacuum supply to the cluster during milking. Slug flow conditions almost always induce a transient drop in milkline vacuum greater than 0.6" Hg. Transient vacuum drops caused by slug flow are characterized by a rapid drop in milkline vacuum below the average stable level in the receiver, and rapid recovery when the slug enters the receiver.

The key performance indicator of stratified flow, therefore, is that milkline vacuum should not fall more than 0.6" Hg below receiver vacuum, at the designed milk and air flow rates, including the transient air flows normally associated with cup changing and liner slips.

New recommendations for sizing milklines (Tables 1 & 2) are based on this performance guideline to ensure that stratified flow is the normal flow condition for milking high-producing cows in parlors or stanchion barn installations, now and into the next decade. It is important to remember that occasional slug flow will occur due to excessive air admission during cup changing or cup falling. Such transient vacuum drops associated with occasional slug flow will have little or no effect on milking performance, mastitis, cell count or milk quality unless they are severe enough to increase the incidence of liner slips and cup falling. The recommendations in Table 1 are for operators who take reasonable care to limit the amount of air admitted into the system during cup application and removal. The guidelines in Table 2 are more conservative for more typical operators. The differences between the two Tables implies that the milking staff play an important role in maintaining a high degree of vacuum stability in the milkline.

Table 1: Milking Parlors: looped milkline with units attached simultaneously by careful operators.

nominal line size	0.8%	1.0%	1.2%	1.5%	2.0%
	---- maximum no. of units per slope ----				
48mm (2")	2	3	3	4	5
60mm (2.5")	6	6	7	9	10
73mm (3")	11	13	14	16	19
98mm (4")	27	30	34	38	45

NOTE: A slope of 0.8% is equal to a 1-inch drop in 10 feet. A slope of 1.2% is equal to a 1.5-inch drop in 10 feet. Milkline slopes greater than 1.6% (2" drop in 10 feet) are not recommended unless the cow platform is sloped in the same direction as the milkline.

Table 2: Milking Parlors: looped milkline with units attached simultaneously by typical operators.

nominal line size	0.8%	1.0%	1.2%	1.5%	2.0%
	---- maximum no. of units per slope ----				
48mm (2")	1	1	2	2	3
60mm (2.5")	4	4	5	6	8
73mm (3")	9	10	12	13	16
98mm (4")	24	27	31	36	41

Sizing airlines: Differences in vacuum levels between the pump and receiver should not exceed 0.6" Hg. Higher readings, indicating greater vacuum drops, result in decreased air flow reserve at the receiver. Greater vacuum drops are influenced by small line sizes, too many Tees or elbows, or high air flows. Recommendations for sizing the main airline relative to pump capacity, line length and fittings are given in Table 3.

Vacuum fluctuations in the far end of the pulsator airline should not exceed 0.6" Hg. The current 3-A dimensional guidelines seem adequate: that is, 2" for up to 14 units, 3" for 15 or more. If 2" line is acceptable up to 14 units per side, then 3" should be acceptable for up to 32 units based on the simple ratio of the pipe areas. Therefore, 4" pulsator airlines could be used for systems with more than 32 units per side.

Differences in vacuum levels between the receiver and regulator should not exceed 0.2" Hg. Higher readings indicate higher vacuum differences which reduce regulator performance because of either improper location, or excessive restrictions in pipelines and fittings between the receiver and regulator. The most common cause of low regulator efficiency is an excessive vacuum difference between the regulator and the receiver. Regulators mounted on branch lines often perform inefficiently unless the connecting lines are adequately sized to minimize frictional losses. Branch lines are fine as long as they are sized generously. Guidelines for sizing the regulator branch line are given in Table 4.

Regulators mounted on or near the distribution tank often tend to oscillate of the cyclic vacuum changes in pulsator airlines. Preferably, the regulator (or its sensor) should be connected near the sanitary trap so that it can sense, and quickly respond to, vacuum changes caused by"unplanned" air admission entering the system through the teat cups.

Reserve pump capacity: In 1992, Paul Blackmer (DVM, Veterinarians' Outlet, CA) proposed a practical performance criterion to demonstrate adequate vacuum pump capacity for milking:

> Vacuum fluctuations in or near the receiver should not fall more than 0.6" Hg below the intended vacuum level during the course of normal milking (including cup attachment and removal, liner slips and cluster falls).

This proposal has been tested by a Task Team of the National Mastitis Council's Machine Milking Committee. The Task Team has just completed a two-part field study to determine the minimum Effective Reserve required to achieve an acceptable degree of vacuum stability during milking. Before describing the main conclusions and recommendations of the NMC Task Team, here's a brief explanation of the term "Effective Reserve" and some related indicators of the effectiveness of vacuum production and control:

• "Effective Reserve" is an airflow measurement of the spare (or "reserve") pump capacity actually available to maintain the receiver vacuum stable within 0.6" Hg when extra air enters the system during milking. The test assumes that a vacuum drop of 0.6" Hg is an acceptably small drop which has little or no effect on milking performance and which is sufficient to allow the regulator to close. It is measured with:

– All the teat cups plugged and under vacuum.

Table 3: Recommended minimum pipe sizes (inches internal diameter) for main airline of a milking system.

Vacuum pump	approximate length of main airline				
capacity	10'	20'	40'	60'	80'
50 cfm	2	2	2	3	3
70 cfm	3	3	3	3	3
100 cfm	3	3	3	3	3
150 cfm	4	4	4	4	4
200 cfm	4	4	4	4	4
250 cfm	4	4	6	6	6
300 cfm	6	6	6	6	6
350 cfm	6	6	6	6	6
400 cfm	6	6	6	6	6

NOTES: The main airline is defined as the pipeline between the vacuum pump and the sanitary trap near the receiver. Calculations are based upon a maximum vacuum drop of 0.5" Hg between the receiver and the vacuum pump. This table includes an allowance for the equivalent length (feet of straight pipe) of one distribution tank, one sanitary trap and 8 elbows.

In systems with two receivers, the theoretical maximum air flowrate in the two separate airlines between the distribution tank and the sanitary traps may be halved. The size of these split lines could be reduced according to the values in the table corresponding to half the vacuum pump capacity.

Table 4: Recommended minimum pipe sizes (inches internal diameter) for the regulator airline, if installed.

manual	equivalent length of regulator airline				
reserve	10'	20'	40'	60'	80'
50 cfm	2	2	2	3	3
70 cfm	3	3	3	3	3
100 cfm	3	3	3	3	3
150 cfm	4	4	4	4	4
200 cfm	4	4	4	4	4
250 cfm	4	4	6	6	6

NOTES: The regulator airline is the branch line connecting the regulator to the main airline. These calculations are based upon a maximum vacuum drop of 0.1" Hg between the regulator and the main airline.

– The regulator connected and working.

– Air admitted into the receiver to drop the receiver vacuum by 0.6" Hg.

The NMC Task Team concluded (Mein et al, 1995) that:

1. All milking systems should have sufficient Effective Reserve (ER) to cover the possibility that at least one milking unit might fall off during milking. This implies a minimum ER of 35 cubic feet per minute (cfm) free air for any conventional milking system without automatic shut-off valves in the claw.

2. Larger systems (more than 32 units) should have sufficient reserve to cope with *two* simultaneous falls even though the likelihood of these events occurring simultaneously seems very low.

3. No system appears to need any more than 120 cfm Effective Reserve.

4. The suggested range of 35 cfm minimum ER and 120 cfm maximum ER will provide adequate reserve for vacuum stability during milking.

5. A simple formula for ensuring generous ER for systems with up to 80 units is: a basic reserve of 35 cfm, plus an incremental reserve of 1 cfm per unit.

"Manual Reserve" is a measurement of the airflow capacity potentially available to maintain the receiver vacuum stable within 0.6" Hg if the regulator could close completely. It is measured with:

– The regulator disabled (put out of action).

– All the teat cups plugged and under vacuum.

– Air admitted into the receiver to drop the receiver vacuum by 0.6" Hg.

Table 5: Pump horsepower and number of milking units (from Bray, 1992), based upon 10 cfm per HP for oil or lobe pumps; 7.5 cfm/HP for water ring pumps.

HP	oil or lobe pumps (no. of units)	water pumps (no. of units)
5	1-5	1
7.5	6-12	2-6
10	13-20	7-12
15	21-35	13-24
20	36-50	25-35
25	51-67	36-47
30	68-80	48-57

In summary: Effective Reserve is measured with the regulator working. Manual Reserve is measured with the regulator disabled. The difference between these airflow measurements is "Regulator Leakage".

Another useful indicator of the effectiveness of the vacuum regulation system is the "Regulator Percent Closure" (also known as "Regulator Efficiency").

$$\text{Regulator Percent Closure} = \frac{\text{Effective Reserve} \times 100}{\text{Manual Reserve}}$$

A Regulator Closure of 100% would mean that the regulator can close completely in response to a vacuum drop of 0.6" Hg below the working vacuum in the receiver. A good practical guideline is that Regulator Closure should be 90% or more. This guideline is the simplest practical indicator of the combined effects of the sensitivity of the regulator, the amount of reserve pump capacity provided, and the effects of airline sizes and other restrictions to air flow between the regulator and the site of measurement.

The efficiency of vacuum regulation can be improved on many installations. Regular cleaning and maintenance of the regulator is an important part of the solution. However, poor regulator performance often results from inappropriate regulator location combined with inadequate airline sizes to cope with excess vacuum pump capacity. The vacuum regulator should be moved and/or airline sizes and pump capacity adjusted to provide an Effective Reserve of 90% or more of the available Manual Reserve (MR).

Guidelines for pump capacity are desirable for advisors and farmers. Assuming that ER is at least 90% of MR, a simple guideline for estimating the minimum pump capacity would be a basic reserve of 35 cfm, plus an incremental allowance of 3 cfm per unit. Such a guideline would provide enough pump capacity to cover allowances for system leakage, pump wear, and also regulator leakage if the regulator is correctly located and adequately plumbed. However, extra pump capacity might be needed to allow for certain ancillary components during milking and/or washing *(Mein et al, 1995)*.

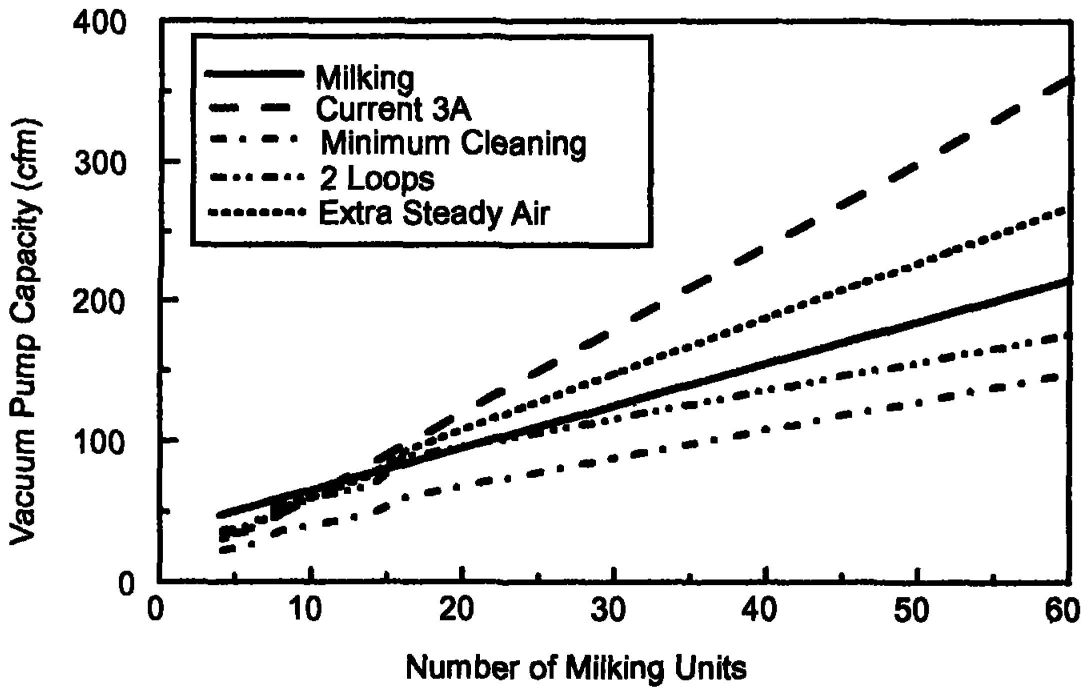
These results provide broad support for the simple guidelines for pump capacity which were published by Bray (1992) and which are reproduced as Table 5 for convenient comparison. These guidelines will provide adequate airflow capacity for efficient cleaning of properly designed CIP systems *(Figure 2, from Reinemann and Mein, 1995).*

Compared with current 3-A Accepted Practices, these recommendations would provide higher pump capacity for systems with up to 8-10 units, similar pump capacity for 12 units, and progressively lower total pump capacity for systems with more than 16 units (Figure 2).

In the field study conducted by the NMC Task Team, improved system design produced big improvements in the effectiveness of vacuum regulation on most milking systems. Because of the improved regulator performance, the available pump capacity (and, therefore, the Manual Reserve) could be reduced by at least 50 cfm for 14 of the 19 systems, and by more than 100 cfm on nine of these systems. Thus, significant energy savings were achieved on most farms with no evidence of reduced milking performance for any of the herds. If the cost of electrical energy is 10¢ per kWh, then the energy cost for a 10-HP pump running 18 hours/day is over $500 per month *(Table 4 in Mein et al, 1995).*

An example of the effects of these design improvements on some dimensions, air flow capacities and wash water requirements, is given in Table 6 for a Double-24 parlor. There is strong evidence from laboratory research, field studies and experience on a wide range of commercial farms to support a revision of the current national standards for vacuum pump capacity. However, the process of review and possible revision of the 3-A Accepted Practices and ASAE S-518 Standards may take 12 months or more. In the interim, dairy farmers who wish to take advantage of the potential savings in

Figure 2: Vacuum pump capacity required for cleaning and milking. Milking requirements are from Mein et al. 1995. The minimum requirement for cleaning is one air injector open at any one time and 2 cfm per milking unit. The medium level for cleaning is for two air injectors open or two flow circuits with cycled air injection simultaneously and 2 cfm per unit. The maximum for cleaning is one air injector open and 4 cfm per unit.



energy and water use will need to seek permission for such variations from the relevant State regulatory authorities. Furthermore, because most milking equipment suppliers will be reluctant to install systems which do not meet current national standards, the owner should be prepared to sign a waiver that he/she wants a system with lower pump capacity.

Another interim option for large milking systems would be to install 2 pumps which, when run together, meet current 3-A standards and, when only one pump is running, would meet the new minimum requirements for Effective Reserve. If so, the second pump can be used as a stand-by in case of breakdowns.

Table 6: Comparisons of current accepted practices with new performance guidelines for a double-24 milking system without milk meters.

	current practices	adequate for efficient milking and cleaning with good design
min. vac. pump capacity	290 cfm (3A, 1990)	180 cfm (Mein et al, 1995)
motor power; oil or lobe (@ 10 cfm/HP)	30 HP	20HP (from Table 5)
motor power, water ring (@ 7.5 cfm/HP)	40 HP	25 HP (from Table 5)
milklines	2 x 4" loops (3A, 1990)	2 x 3" loops (from Table 2) (slope of 1.5" per 10')
manual reserve (estimated by assuming 2 cfm used per unit)	194 cfm	84 cfm
effective reserve	78 cfm (with 40% regular closure)	76-80 cfm (with 90-95% regular closure)
pump capacity required for C.I.P. cleaning	240-290 cfm (5-6 cfm/unit)	124-152 cfm (from Figure 2)
water used per wash cycle	212 gallons	85 gallons (Reinemann & Mein, 1995)

Testing, Service & Maintenance Of Milking Equipment

Excellent new procedures for milking system evaluation have been developed by a Task Team chaired by Andrew Johnson, DVM, for the National Mastitis Council's Machine Milking Committee. In addition, a systematic visual check can indicate the milking machine faults likely to be associated with mastitis or teat condition problems, or with slow or incomplete milking. Guidelines for the three best indicators of machine function during milking are given in the 1992 NMC proceedings *(Mein, 1992)*. They are:

- The condition of teats when cups are removed.
- The completeness of udder evacuation.
- The frequency of slipping or falling teat cups.

The most common reason for milking system problems in the 1990's is inadequate routine maintenance of milking equipment. The booklet *"Maximizing the Milk Harvest"* (MMMC, 1993) makes a simple analogy: "A car driven at 60 mph for 10 hours per day will travel more than 200,000 miles in one year. Milking equipment, like the car, has many moving parts that wear over a period of time." The lack of down-time for maintenance in large dairies, combined with the lack of awareness of the gradual deterioration of components used for 10 or 20 hours per day results in a poor level of maintenance on many farms.

The MMMC booklet gives simple, clear guidelines for maintenance of milking and cooling systems. All milking machine companies and most milking equipment dealers have similar guidelines and most of them will provide service contracts for scheduled maintenance. Starting in 1990, member companies of the MMMC have developed a Certification Program for their technical staff and dealers to ensure that training courses conducted by individual companies contain the same minimum requirements. These training courses will, or should, include specialized training in the new concepts for improved system design and performance outlined in this paper.

With improved system design, some of the potential savings from reduced energy costs, water and cleaning chemical costs could be invested profitably in more thorough routine maintenance of equipment and facilities. That would be a "win-win" for all participants: dairy farmers, milking staff, equipment manufacturers and dealers, and for the cows!

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notes