New Design and Performance Standards for Milking Systems: Energy Implications

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<u>Energy Calculations (Hot Water) (Vacuum Pump)</u> / How a Milking Machine Works / Simple Checks of a Milking System / Design and Performance of Clean-In-Place (CIP) Systems

A typical milking system in the US accounts for about seventy-five percent of all the energy consumed on (electrified) dairy farms. Typically, electrical demand curves for dairy farms look similar to Figure 1 and Figure 2. Farm energy use is often highly correlated with utility peak demand—and thus can make up a larger percentage of peak kW load than kWh consumption (Peebles and Reinemann, 1994). Three major components of this energy demand are milk cooling, water heating, and vacuum pump operation.

Simple energy efficiency measures applied to dairy farm milking centers can reduce operating costs for the farmer and lower peak loads for the utility during critical times of the day. Some energy efficiency measures that have been successfully implemented include installing milk precoolers, water preheaters, and energy efficient lighting, and reducing the capacity of over-sized vacuum pumps. This paper will discuss some simple milking system design changes and their effect on milking system energy use. New national and international standards for design and performance of milking systems is discussed, along with the effect of adopting these standards on energy consumption in dairy farms. Future papers to be included in the National Dairy Database will cover other energy efficient technologies and strategies.

New Milking System Standards

In the last 6 years, remarkable changes have occurred in our knowledge and understanding of the milking and cleaning performance of milking systems. Recent field studies suggest that milking systems, especially those in parlors, tend to be over-dimensioned and under-designed. In general, the larger the milking system, the more it is over-sized. Historically, vacuum pumps have been oversized to account for leaky systems and inefficient control of vacuum levels, and to enhance system reliability. New system evaluation procedures indicate that the performance and energy efficiency of many milking systems can be improved markedly by a few simple design changes and a more thorough equipment service and maintenance program.

A new national standard for the construction and performance of milking systems was published in 1994 (ASAE S518: 1994). This ASAE standard was based on a Draft International Standard (DIS/ISO 5707: 1994) which has been reviewed and revised extensively during the past several years. Both standards are in the process of being updated and re-published as new national and international standards and they are expected to be adopted in July 1996**.** Adoption of the new standards can significantly reduce the amount of energy consumed in a milking center.

Before the details of the new standards are revealed, it is important to have a good understanding of how a milking machine works. For an overview of a milking system, **click here**. To skip over the review and learn more about the new standards, read on.

New Standards

The new standards will incorporate new performance guidelines which 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 University of Wisconsin-Madison.

One goal of an effective milking system is to maintain a steady vacuum level in the milking units. The level of vacuum in the milking units will fluctuate naturally due to vacuum fluctuations in the milkline and the combined effects of pulsation and milk flow through individual milking units. The research at UW-Madison showed clearly that transient vacuum drops of less than 0.6 inches of mercury (" Hg) in milkline vacuum, or receiver vacuum, had little or no effect on the normal cyclic vacuum changes in the milking units. Such small transient vacuum changes are completely lost, or over-ridden, by the larger cyclic changes generated within each milking unit by pulsation and milk flow through milking units.

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 milking units and have no significant effect on milking characteristics, mastitis, or milk quality. When vacuum fluctuations in the milkline exceed 0.6" Hg, the resulting vacuum fluctuations in the milking units are usually increased above the normal-operating fluctuations.

New Standards - Milkline Sizing

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 (Gates et al, 1982). Slug flow conditions create a situation where milk is blocking the pathway for air flow and therefore 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 flowrates, including the transient air flows caused by cup changing and liner slips.

New recommendations for sizing milklines (Tables 1, 2, & 3) are based on this performance guideline to ensure that stratified flow is the normal flow condition for milking high-producing cows in parlors. 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 in parlors 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. Table 3 outlines recommendations for round-the-barn (RTB) systems. The differences between the first two tables implies that *the milking staff plays an important role in maintaining a high degree of vacuum stability in the milkline*. The guidelines assumes that the cross-sectional area of the milkline(s) is not substantially reduced by fittings such as butterfly valves.

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

	Maximum number of units per slope					
			Slope			
Nominal Line Size	0.8%	1.0%	1.2%	1.5%	2.0%	
48 mm (2 inch)	2	3	3	4	5	
60 mm (2.5 inch)	6	6	7	9	10	
73 mm (3 inch)		11	13	14	16	19
98 mm (4 inch)		27	30	34	38	45

NOTES:

1. A slope of 0.8% is equivalent to 1 inch fall in 10 feet. A slope of 1.2% is equivalent to 1 ½ inch fall in 10 feet. Milkline slopes greater than 1.6% (2" per 10 ft) are not recommended unless the cow platform and milklines slope in the same direction.

2. Over sizing the milk pipeline is not recommended, as it results in excessive use of energy, water, and cleaning chemicals.

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

	Maximum number of units per slope					
			Slope			
Nominal Line Size	0.8%	1.0%	1.2%	1.5%	2.0%	
48 mm (2 inch)	1	1	2	2	3	
60 mm (2.5 inch)	4	4	5	6	8	
73 mm (3 inch)		9	10	12	13	16
98 mm (4 inch)		24	27	31	36	41

NOTE:

Looped milklines have two slopes which contain milking units. The above numbers can be multiplied by two to obtain the total number of milking units.

Table 3. Stanchion Barns: Looped Milklines with units attached every 30 seconds per slope.

	Maximum number of units per slope			
	Slope			
Nominal Line Size	0.8%	1.0%	1.2%	1.5%
48 mm (2 in.)	2	3	3	4
60 mm (2.5 in)	6	9	*	*
73 mm (3 in)	*	*	*	*

* Indicates an unlimited number of units can be used when attached at 30 second intervals. If more than one operator is attaching units on the same slope, the mean attachment rate may be faster than one every 30 seconds. If so, then the guidelines from Table 1 could be used.

New Standards - Airline Sizing

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. Excessive vacuum drops are caused by high air flowrates, small line sizes, and too many tees or elbows. Recommendations for sizing the main airline relative to pump capacity, line length, and fittings are given in Table 4.

Table 4. Recommended minimum pipe sizes (inches internal diameter) for the main airline of a milking system.

Vacuum pump	Approx. length of main airline (feet)				
capacity, cfm	10	20	40	60	80
50	2	2	3	3	3
70	3	3	3	3	3
100	3	3	3	3	3
150	4	4	4	4	4
200	4	4	4	4	4
250	4	4	6	6	6
300	6	6	6	6	6
350	6	6	6	6	6
400	6	6	6	6	6

NOTE:

The main airline is defined as the pipeline between the vacuum pump and the sanitary trap near the receiver. Calculations are based on a maximum vacuum drop of **0.5**" Hg between the receiver and vacuum pump. The 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. In cases where excessive fittings and bends are used, minimum pipe size may need to be larger.

Pulsator Airline

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, 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 airline.

Regulator Airline

Differences in vacuum levels between the receiver and regulator should not exceed 0.2" Hg. The most common cause of ineffective vacuum regulation is an excessive vacuum difference between the receiver and regulator because of either improper regulator location or excessive restrictions in pipelines and fittings between these two components. 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 according to the guidelines given in Table 5.

Regulators mounted on or near the distribution tank often tend to oscillate because 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 teatcups. See ***Efficiency of Regulation*** for more information on vacuum regulation.

Table 5. Recommended minimum pipe sizes (inches internal diameter) for the regulator airline, if installed.

Manual Reserve, cfm	Equivalent length of regulator airline (feet of straight pipe)				
	10	20	40	60	80
50	2	3	3	3	3
70	2	3	3	3	4
100	3	3	4	4	4
150	3	4	4	4	6

200	4	4	4	6	6
250	4	4	6	6	6

NOTE:

The regulator airline is the branch line connecting the regulator to the main airline, (preferably near the receiver). These calculations are based on a maximum vacuum drop of 0.1" Hg between the regulator and the main airline.

New Standards - Reserve Vacuum Pump Capacity

To have 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). A brief explanation of “effective reserve” and the effectiveness of vacuum production and control follows.

"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 teatcups plugged and under vacuum
* the regulator connected and working
* air admitted into the receiver to drop the receiver vacuum by 0.6" Hg.

A recent field study (Mein et al, 1995) showed that:

* 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 milking units.
* Larger systems (with 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.
* No system appears to need any more than 120 cfm Effective Reserve.
* The suggested range of 35 cfm minimum ER and 120 cfm maximum ER will provide adequate reserve for vacuum stability during milking.
* 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:

$$ER = 35 \text{ cfm} + 1*n$$

where n = number of milking units

NOTE:

When milking units are equipped with automatic vacuum shut off, effective reserve probably does not need to be this high. However, the new standards do not cover systems with automatic vacuum shut off.

"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 (that is, put out of action)
* all the teatcups plugged and under vacuum
* air admitted into the receiver to drop the receiver vacuum by 0.6" Hg.

In summary: Effective Reserve is measured with the regulator working.

Manual Reserve is measured with the regulator disabled.

Efficiency of Regulation

The difference between manual reserve and effective reserve is called the "Regulator Leakage", or the amount of air the regulator admits when it should be fully closed. High regulator leakage indicates an inefficient vacuum regulator.

The accepted measure of the efficiency of vacuum regulation is defined as:

$$\text{Regulation Efficiency} = \frac{\text{Effective Reserve} \times 100}{\text{Manual Reserve}}$$

A Regulation Efficiency of 100% would mean that the regulator can close completely in response to a vacuum drop of 0.6" Hg below the working vacuum measured in, or near, the receiver. In theory, the regulator should close fully at this level of vacuum drop, since any additional air admitted into the system will only increase the vacuum drop. A good practical guideline is that Regulation Efficiency 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.

Improving Regulation Efficiency

The efficiency of vacuum regulation can be improved on many systems. Regular cleaning and maintenance of the regulator is important for preserving the efficiency of a regulator (see **Testing, Service, and Maintenance of Equipment**). Keeping air filters and regulator parts clean also will help to maintain the efficiency of the regulator.

However, poor regulation efficiency 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).

The best location for the vacuum regulator is as close to the area requiring regulation, the teatcup, as possible. Since the vacuum regulator must be on an airline, the closest point to the teatcup is near the sanitary trap. Many farms simply place the regulator in a convenient location. This practice has resulted in inefficient vacuum regulation and excessive energy use. Properly located regulators can quickly sense and respond to teatcup vacuum changes.

A recent study (Collar, et al. 1995) showed that 12 of 13 farms studied had sufficient air available for milking (effective reserve) but had excessive manual reserve. Because of inefficient vacuum regulation, the vacuum pumps were moving up to five times more air than necessary for milking. By moving the vacuum regulator closer to the sanitary trap, many of the dairies that participated in the study were able to switch to a smaller vacuum pump or gear down existing motors to reduce air flow (and energy consumption).

New Standards - Vacuum Pump Capacity

Many vacuum pumps in use today are oversized. Common design rules of thumb (10 cfm per milking unit) have resulted in pumps that are much larger than required—even when compared with current (oversized) standards! This oversizing is a result of the common belief that this much capacity is needed for cleaning. When in fact, recent research has shown that, with proper system design and control strategies, the *vacuum pump capacity required for cleaning is less than that for milking.* Significant opportunities exist for reducing vacuum pump capacity while maintaining the same, or better, milking system performance.

Pump Capacity for Milking

New guidelines for pump capacity have been included in the new ASAE Standards. Assuming that ER is at least 90% of MR, a simple guideline for estimating the minimum pump capacity is:

* a basic reserve of 35 cfm, plus an incremental allowance of 3 cfm per unit.

Vacuum Pump Capacity = 35 cfm + 3n + air used by special components

where n = number of milking units

Such a guideline will 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. Although extra pump capacity might be needed to allow for certain ancillary components during milking and/or washing (Mein et al, 1995), this guideline will provide adequate airflow capacity for efficient cleaning of properly designed CIP systems (Figure 3).

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 3). Thus, significant energy savings can be achieved on many farms by a few simple design changes for milking and cleaning. For example, 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 (Mein et al, 1995).

In addition, certain vacuum pumps operate more efficiently than others. The table below lists the various types of vacuum pumps available and their associated efficiencies. To run a sample calculation of the energy implications of adopting the new vacuum pump sizing standards, **click here**.

Table 6. Typical Efficiencies of Vacuum Pumps (from Ludington, et al, 1995)

vacuum pump type	efficiency, cfm/kW at 14" Hg
vane	14.8
blower	14.2
water ring	9.7
turbine	6.4

NOTES:

(1) Vacuum pumps generally come in size increments of 25 or 50 cfm, for example, 50 cfm,75 cfm, 100 cfm,150 cfm etc. When sizing a vacuum pump, it is generally best to determine the required size and then purchase the next available (larger) size pump. When the system is installed (at full capacity), perform the tests and then "gear down" the pump to the required capacity. As the pump wears or equipment is added, the pump can then be "geared up" to meet the system requirements.

(2) On the horizon is an adjustable speed drive (ASD) for vacuum pumps which would allow the vacuum pump to slow down and speed up in response to vacuum demand. The electronic controller for the ASD acts as the "regulator", thereby eliminating the need for a traditional vacuum regulator. This technology has been tested and proved effective and energy efficient, but is not yet commercially available.

Vacuum Pump Capacity for CIP cleaning

The objective of air injected CIP cleaning is to produce slugs of water and cleaning solution at the proper velocity and with the proper control. Commonly, improper use of air injectors and inadequate distribution of cleaning solutions results in cleaning failures. If optimal control strategies (including sequencing of air injection) are used, the vast majority of milking systems will have sufficient vacuum pump capacity for cleaning if sized according to the following relationship:

$$Q_p = Q_c + nQ_s$$

where:

Q_p = minimum vacuum pump capacity for CIP cleaning (cfm)

Q_c = flowrate of cycled air admission (cfm) to produce 23 ft/s slug velocity (recommended for effective cleaning) in milkline.

Q_c rates for various pipe diameters:

milkline diameter	Q_c (cfm)
2"	14
2.5"	20
3"	28
4"	49

n = number of milking units

Q_s = steady air usage per milking unit and system leaks (2 cfm)

For more detailed information on CIP systems, see **System Design and Performance Testing for Cleaning Milking Systems**.

Examples of the effects of the new design improvements on some dimensions—air flow capacities and wash water requirements—are given in Tables 7 and 8 for Double-10 and Double-24 parlors.

Table 7. Comparison of current Accepted Practices with new standards for a D-10 milking system without milk meters.

	Current Practices	New Standards
Min. vac. pump capacity	123 cfm (3-A, 1990)	95 cfm (Mein et al, 1995)
Motor power: Oil or Lobe (@ 10 cfm/HP)	15 HP	10 HP
Water ring (@ 7.5 cfm/HP)	20 HP	15 HP
Main airline	4"	3" (from Table 4)
Milklines	2 x 3" loops (3-A, 1990)	1 x 3" loop (from Table 2) (Slope of 1%, or 1.2"/10 ft)
Manual Reserve (estimated by assuming 2 cfm used per unit)	83 cfm	45 cfm
Effective Reserve	45 cfm (with 55% Reg. Closure)	43 cfm (with 95% Reg. Closure)
Pump capacity required for CIP cleaning	100-120 cfm (5-6 cfm/unit)	68 cfm
Water used per wash cycle	83 gal	45 gal (from new recommendations)

Table 8. Comparison of current Accepted Practices with new performance guidelines for a D-24 milking system without milk meters.

	Current Practices	New Standards
Min. vac. pump capacity	290 cfm (3-A, 1990)	180 cfm (Mein et al, 1995)
Motor power: Oil or Lobe (@ 10 cfm/HP)	30 HP	20 HP

Water ring (@ 7.5 cfm/HP)	40 HP	25 HP
Main airline	6"	4" (from Table 4)
Milklines	2 x 4" loops (3-A, 1990)	2 x 3" loops (from Table 2) (Slope of 1.2%, or 1.5"/10 ft)
Manual Reserve (estimated by assuming 2 cfm used per unit)	194 cfm	84 cfm
Effective Reserve	78 cfm (with 40% Reg. Closure)	76-80 cfm (with 90-95% Reg. Closure)
Pump capacity required for CIP cleaning	240-290 cfm (5-6 cfm/unit)	124-152 cfm (from Figure 3)
Water used per wash cycle	150 gal	85 gal (Reinemann & Mein, 95)

Laboratory research, field studies and experience on a wide range of commercial farms strongly support the revision to the current ASAE standards for vacuum pump capacity. However, the process of review and revision of the 3-A Accepted Practices and ASAE S 518 Standards are not completed yet. These changes have been accepted by the Technical Committee of the ASAE and should take effect in late 1996. In the interim, dairy farmers who wish to take advantage of the potential savings in 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 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 and/or for extra airflow capacity during washing if the system has not been set up according to the new guidelines for efficient CIP cleaning (Reinemann, 1995).

Hot Water Use in CIP cleaning

In the examples in Tables 7 and 8, water use per wash cycle was reduced by almost 50 percent. Reducing hot water use can result in significant energy savings.

For each CIP cleaning, there are four wash cycles. Typically, water is provided at 110°F for three of the cycles and at 160°F for one cycle. Assuming an initial water temperature of 55°F, no water preheater, two milkings per day, and electric resistance water heating with an efficiency of 90 percent (to account for heat loss), the energy use for the various situations outlined in Tables 7 and 8 is shown below:

gallons/cycle	total gallons/wash	energy req'd (kWh/day)	energy cost/day (at $0.07/kWh)	energy cost/yr (at $0.07/kWh)
83 (D-10, current practices)	332	122	$8.54	$3117

45 (D-10, new recommendations)	180	66	$4.62	$1686
150 (D-24, current practices)	600	198	$13.89	$5070
85 (D-24, new recommendations)	340	56	$8.75	$3192

To determine the hot water energy savings for any other size barn that adopts the new practices for CIP cleaning, **click here**.

Testing, Service and Maintenance of Milking Equipment

The most common reason for milking system problems today is inadequate routine maintenance of milking equipment. The booklet "Maximizing the Milk Harvest" (Milking Machine Manufacturers Council (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 ten or twenty hours per day, results in a poor level of maintenance on many farms.

With reduced vacuum pump capacity, it will be more critical to have a regular testing, service and maintenance program to detect and minimize unplanned air admission. 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. Simple guidelines and checks for indicators of machine function are included in the section **Simple Checks of a Milking System**.

The MMMC booklet gives simple, clear guidelines for maintenance of milking and cooling systems. For more information about obtaining this booklet, **click here**. All milking machine companies and most milking equipment dealers have similar guidelines and most of them will provide service contracts for scheduled maintenance. Since 1990, MMMC member companies have adopted 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!

References

American Society of Agricultural Engineers Standards. ASAE S 518:1994 Milking Machine Installations—Construction and Performance. ASAE, St. Joseph, MI 49085.

3-A Accepted Practices for the Design, Fabrication and Installation of Milk Handling Equipment. 1990. *Dairy, Food and Environmental Sanitation* 9:679.

Collar, C.A., L.H. Brazil, and L.S. Collar. 1995. "Vacuum Technology on California Dairies." *Proc. Designing a Modern Milking Center*, Northeast Regional Agricultural Engineering Service 29 November - 1 December, Rochester, NY.

Gates, R.S., R. Sagi, and R.W. Guest. 1982. "Criteria for optimizing size and configuration of milk pipelines." *J. Dairy Science*, 65:410-418.

Ludington, D.C., R.A. Pellerin, J.H. Potter, G.S. Farmer, and A.T. Sobel, "Vacuum Pumps: Types and Controls." *Proc. Designing a Modern Milking Center*, Northeast Regional Agricultural Engineering Service 29 November - 1 December, Rochester, NY

Mein, G.A. 1992. "Simple checks of a milking installation." *Proceedings 31st Annual Meeting*, National Mastitis Council, Washington, DC.

Mein, G.A., D.R. Bray, L.H. Brazil, L.S. Collar, A.P. Johnson, and S.B. Spencer. 1995. "Effective reserve and vacuum pump capacity for milking." *Proceedings 34th Annual Meeting*, National Mastitis Council, Fort Worth, TX.

MMMC, 1993. *Maximizing the Milk Harvest*. Published by the Milking Machine Manufacturers Council of the Equipment Manufacturers' Institute, Chicago, IL.

Peebles, R.W. and D.J. Reinemann. 1994. "Demand Side Management/Energy Conservation Potential for Wisconsin Dairy Farms." Paper No. 943563, Written for Presentation at the 1994 International Winter Meeting Sponsored by the American Society of Agricultural Engineers, Atlanta, GA, 13-16 December.

Reinemann, D.J. 1995. "System design and performance testing for cleaning milking systems." *Proc. Designing a Modern Milking Center*, Northeast Regional Agricultural Engineering Service, 29 November - 1 December, Rochester, NY.

Reinemann, D.J. and G.A. Mein, 1995. "Sizing vacuum pumps for cleaning milking systems." *Proceedings 34th Annual Meeting*, National Mastitis Council, Fort Worth, TX.