New Concepts in Milking Equipment Evaluation and Airflow Dynamics

Graeme A. Mein, *Ph.D.*
Professor, Milking Research, Dept. of Dairy Science and Dept. of Medical Sciences, School of Vet. Medicine, UW-Madison, WI 53706; Director of Research, Bou-Matic, DEC International, Madison, WI USA.

Abstract

No component of any milking system can influence the milking characteristics of a cow, or her risk on mastitis infection, unless it affects either liner vacuum, the liner wall movement or liner pressure applied to the teat, or teatcup weight distribution between udder quarters. Therefore, better quantitative measures of performance of the milking unit ("milkability") are needed.

For trouble-shooting faults in system plumbing or regulator location and performance, milking systems should be tested at the operating vacuum (not necessarily 15" Hg), with the regulator connected and operating, the air flowmeter connected at or near the receiver and, preferably, with the teatcups plugged and operating. Measurement errors are common because of the effects of air flow on vacuum level. New concepts of effective reserve and manual reserve are discussed. Performance guidelines are proposed for carrying capacity of milkines, effective reserve and regulator efficiency, pump capacity and vacuum drop in pipelines.

If it doesn't make any difference at the teatcup, it doesn't make any difference. This is because the teatcup liner is the *only* component of the milking system that comes into contact with the cow's teat. Consequently, no other component of a milking system can influence the milking characteristics of a cow, or her risk of mastitis infection, unless it affects either liner vacuum, the liner wall movement or liner pressure applied to the teat, or the teatcup weight distribution between udder quarters.

More emphasis is needed on developing quantitative measures for analysing the performance of the milking unit. Some of the parameters to evaluate "milkability of the unit", as defined by Dr. David Reid, are being developed at the UW-Madison Milking Research and Instruction Laboratory (UW-MRIL). The weight of the milking cluster and the weight distribution within the cluster, for example, and the drag on the teats and udder caused by milk hoses that are too long, too short or incorrectly placed, are critical to the success or failure of a milking system.

The degree of mechanical stress applied to the teat tissues during the liner-open phase of pulsation is directly related to the vacuum level at the teat-end and the liner diameter. In simple terms: the force applied equals pressure (vacuum) times the cross sectional area of teat exposed to the vacuum. Both vacuum level and vacuum stability in the teatcup have subtle but perhaps critical effects on how far and how fast the liner moves open and closed. The force or pressure applied to the teat-end by the liner in the collapsing/collapsed phase of pulsation is critical to the integrity of the teat tissue. For exactly the same vacuum and pulsator settings, the force applied to the teat-end may be too little, just right to achieve the purposes of pulsation, or too much depending on the type and condition of the liner.

Mean vacuum *level* at the teat-end is markedly affected by the length and diameter of the milk hoses, the height of the milkline, the rate of air flow and milk flow, and restrictions to flow caused by extra components fitted between the claw and milkline. The regulator has a relatively minor effect on vacuum *stability* at the teat-end compared with the effects of "unplanned" air flow (e.g. liner slips), milk flow through the short milk tubes and claw, and of planned air flow (size and location of air vents).

So, what is an acceptable level of vacuum and vacuum stability in the teatcup? We dance here on the fine line between science and folklore, a position that is all too familiar in the field of machine milking.

Vacuum level in the teatcup

Dairy regions as diverse as Canada[1] and Scandinavia[2] agree that teat-end vacuum should not exceed 50 kPa (about 15 inches of mercury, " Hg). Both USA[3, 4] and Scandinavia[2] agree that the average teat-end vacuum during the peak flow period of milking should be 36 to 40 kPa (11-12" Hg). This guideline is an arbitrary level based on experience. However, it is supported by recent scientific studies which indicate that: (i) the teat canal is almost fully distended at an applied vacuum level of 40 kPa[5]; (ii) machine-induced edema in the teat apex increases with increasing vacuum level.[6]

Thus, both recent research and extensive field experience suggest that a **mean claw vacuum within the range 10.5-12.5" Hg (35-42 kPa) during the**

period of peak milk flow for a representative sample of cows is a good compromise level which ensures that most cows will be milked quickly, gently and completely.

Vacuum stability in the teatcup

Usually, the average fluctuation in claw vacuum is estimated as the band width of the typical vacuum record, obtained near the claw outlet, during the peak flowrate period of milking for individual cows. These fluctuations are often, incorrectly, described as teat-end fluctuations. Cyclic vacuum fluctuations at the teat-end are always greater than those measured in the claw simply because they are generated by the cyclic opening and closing of the liner to achieve pulsation. Thus, it is not possible (or necessary) to achieve a perfectly stable vacuum at the teat-end.

Average claw vacuum fluctuations of less than about 2" Hg (7 kPa) for lowline systems, or 3" Hg (10 kPa) for highline systems, are considered desirable. No scientific evidence or field data suggests that we have to aim any higher than this. We should, however, take steps to minimize the differences in vacuum fluctuations between the claw and liner. **Key factors are to ensure that the internal diameter of short milk tubes is at least 10 mm (about ⅜") and that claw air vents admit about 6-10 liters free air per min (0.2-0.35 CFM) per milking unit.**

Performance guidelines for the milking system

Recent research at UW-MRIL showed clearly that vacuum fluctuations in the claw are usually increased whenever milkline vacuum fluctuations exceed 0.6" Hg.[7] The effect is roughly additive: a transient drop of say 2" Hg in milkline vacuum results in a transient drop of about 2" Hg in the claw. However, transient vacuum drops less than 2 kPa (0.6" Hg) in milkline or receiver vacuum have little or no effect on the normal cyclic vacuum changes in the milking clusters. Such small transient vacuum changes are completely lost, or overridden, by the larger cyclic changes generated within the cluster by the combined effects of pulsation and milk flow from the cluster.

These results provide useful new performance guidelines for sizing milklines, vacuum supply lines, and vacuum pumps. They are all **based on the conclusion that transient vacuum changes of 2 kPa (0.6" Hg) or less in the milkline or receiver are hardly measurable in the claw and they have no significant effects on milking characteristics, mastitis, or milk quality.** The new performance guidelines are as follows.

Sizing milklines.

Fluid flow in dual purpose 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 2 kPa. 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 any transient drop in milkline vacuum should not exceed 2 kPa (0.6" Hg) below receiver vacuum, at the designed milk and air flowrates, <u>including the transient air flows normally associated with cup changing and liner slips.</u>**

New recommendations for sizing milklines (Appendix 1, from ref. #7) 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 conditions will have little or no effect on milking performance, mastitis, cell count or milk quality.

Sizing airlines.

Differences in vacuum levels <u>between the pump and receiver</u> should be less than 0.5" 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 unreasonably high air flows. Recommendations for sizing the main air line relative to pump capacity, line length and fittings, are given in Appendix 2 (from ref. #8).

Differences in vacuum levels between receiver and regulator should be less than 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 (see later).

Differences in vacuum levels *between the receiver and the teatcup pulsation chambers* should not exceed 2 kPa (0.6 kPa) according to the new ISO standard.[9] For practical purposes, this could be translated as **"the mean vacuum level in the far end of the pulsator**

airline should not differ by more than 0.5" Hg from the receiver vacuum". To make the measurement at the far end of the pulsator airline, the relevant clause in ASAE standards EP445[10] states that "The adaptor shall be attached to the pulsator stall cock farthest from the vacuum source, with all other milking units operating. Vacuum (pressure) variations shall be recorded for a minimum of 1 minute."

System vacuum.

The regulator vacuum should be set to provide whatever vacuum level is required to provide an **average claw vacuum within the range 10.5 to 12.5" Hg** during the peak milk flowrate period for most of the cows in a herd.

Reserve pump capacity.

Dr. Paul Blackmer's performance guideline for adequate reserve capacity is that **vacuum fluctuations in or near the receiver should not exceed + 0.5" Hg during the course of normal milking (i.e., including cup attachment and removal, liner slips and cluster falls).**

This criterion appears to be an excellent and practical guideline. A sub-committee of the NMC Machine Milking Committee is conducting a field study to evaluate the proposal and make recommendations for pump capacity for a range of sizes of milking systems. A common industry opinion is that current US guidelines for sizing vacuum pumps are too low for small systems, in the right range for systems with about 8-12 units, but they result in un-necessarily high reserve for larger systems. The field project should be completed in time for the NMC meeting in February, 1994.

A starting hypothesis for the NMC sub-committee is that all systems should have sufficient reserve to cope with at least one unit fall-off. Therefore, vacuum at the receiver should not fall more than 0.5" Hg with one unit open. This hypothesis implies that all systems should have an Effective reserve of at least 40 CFM free air because that is the typical maximum air flowrate through one milking unit when it is held fully open. On this basis, the widespread industry view that small systems are under-pumped, while large systems tend to be over-pumped, is likely to be correct.

Because pump capacity decreases with increasing vacuum level (Fig 1, from ref. #11), the reserve pump capacity will be greater at 12" Hg (40 kPa) compared with 15" Hg (50 kPa) working vacuum. Other factors add to the increased reserve capacity at lower working vacuum: the air used by components, the system leakage, and the frictional losses in pipelines all decrease with decreasing vacuum level. These relationships, which are illustrated in Fig 1, provide strong support for testing a milking system at its actual operating vacuum level rather than at a nominal 15" Hg.

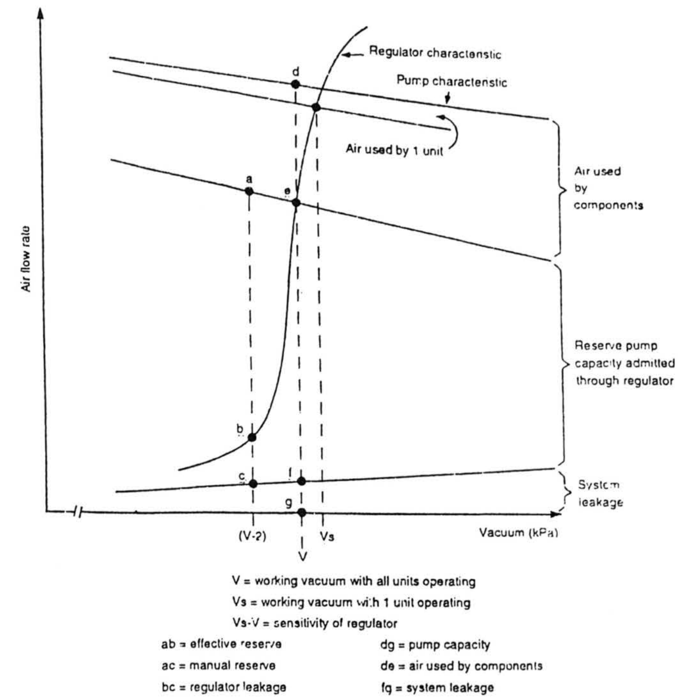

Figure 1. Relationship between pump capacity, air used by components, effective reserve, manual reserve, and the characteristics of the regulator.

Effective reserve, Manual reserve and Regulator leakage

Effective reserve is the best measure of how much of the reserve pump capacity is truly available to cope with "unplanned" air which is admitted through the teatcups when units are applied or removed, when teatcups slip or fall, or if clusters are kicked off. The test assumes that a vacuum drop of 0.6" Hg (2 kPa) below the stable vacuum level in the receiver is an acceptable drop which is sufficient to allow the regulator to close. An air flow meter (AFM) is connected at or near the receiver (or to the milking vacuum line in weigh jar systems). The AFM is opened gradually until the receiver vacuum drops by 0.6" Hg. The air flow reading on the AFM is recorded as the Effective Reserve.

Effective reserve

is defined as the reserve pump capacity measured by admitting air at or near the receiver to lower the vacuum 2 kPa (0.6" Hg) below that existing when all accessories and units are operating with the liners plugged.

Manual reserve

is defined as the reserve pump capacity measured by admitting air at or near near the receiver to lower the vacuum 2 kPa (0.6" Hg) below that existing when all units (with the liners plugged) and accessories, *except the regulator,* are operating.

Thus, the two procedures are identical, except that the regulator is disconnected for the measurement of Manual reserve. The relationship between the two measurements is shown in Fig 1. Clearly, Effective reserve is reduced by factors that increase the rate of air leakage through the regulator because:

Manual reserve = Effective reserve + Regulator leakage

When these measurements are made near the receiver, the subtle effects of vacuum drops in the airlines between the receiver, regulator and vacuum pump are often seen to have a marked effect on regulator performance and the Effective reserve. Under these measurement conditions, a useful practical guideline is that the Effective reserve should be 90% or more of the Manual reserve. Only a small percentage of milking systems in USA would meet this guideline, however. More typically, Effective reserve is not more than 50-80% of the Manual reserve because of inadequate plumbing combined with excessive pump capacity.

Regulators mounted on branch lines often perform inefficiently unless the connecting lines are adequately sized to minimize frictional losses. Regulators mounted on the distribution tank near the pulsator airlines often tend to oscillate, because they are affected by 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 or milk cocks.

Some regulators are designed with provision for "air lubrication", e.g. Sentinels. The designed air usage can be determined as follows.

1. With the AFM closed, adjust regulator to 16" Hg.
2. Open the AFM and measure air flow at the normal operating vacuum for the system.
3. Remove regulator and re-measure air flow at the normal operating vacuum for the system.
4. The difference in air flow between steps 2 and 3 is the designed air usage of the regulator.

The designed air usage should be subtracted from the Manual reserve before calculating the regulator efficiency. If the regulator efficiency still is below 90%, then further checks are recommended to determine the cause. The most common cause of low regulator efficiency is an excessive vacuum drop between the regulator and the receiver. Alternatively, the regulator may be dirty, faulty, or not correctly matched to the system. If the system is properly plumbed, the regulator should be allowed to sense a minimum of ⅔ rds (that is, 0.4" Hg) of the vacuum drop of 0.6" Hg applied at the receiver for the measurement of Effective Reserve. If the vacuum change at the receiver is 0.4" Hg or more, then the plumbing is acceptable and the implication is that the regulator is inefficient (dirty, faulty or poorly designed), or incorrectly matched to the size of the milking system.

The test results summarized in the table below are a striking example of the effects of air flow and vacuum drop on regulator performance. The pipeline layout for the 8-unit stanchion barn was typical of many US systems. The regulator was physically located within 2 ft of the sanitary trap but, because of the bends and other fittings used to connect it, the equivalent length of straight 2" pipe was about 23 ft. The test results indicate that regulator efficiency can be improved markedly by connecting the regulator sensing tube to a point near the sanitary trap. In this case, Effective reserve increased from 42% to 80% as a percentage of the Manual reserve.

Regulator sensing tube at V_3	**Vacuum measured at**		
	V_1	**V_2**	**V_3**
Operating Vacuum (AFM closed)	14.2"	14.2"	13.7"
Effective Reserve (37 cfm)	13.6"	13.7"	13.6"
Manual Reserve (88 cfm)	13.6"	14.2"	14.2"
Regulator sensing tube at V_2 and re-set system vacuum			
Operating Vacuum (AFM closed)	14.2"	14.2"	NM
Effective Reserve (70 cfm)	13.6"	13.9"	NM

Note: Measuring point V_1 was on the wash manifold; V_2 was at the outlet to the sanitary trap; V_3 was just below the regulator.

Recommendations for avoiding or minimizing measurement errors

Air flowrates and vacuum levels within a milking system vary according to well-established physical principles. They should be easy to measure. Nevertheless, many well-meaning individuals frequently do not measure correctly the things they think they are measuring carefully. The combined effects of instrument bias (particularly at high air flowrates), the sites selected for measurement, the connections used for attaching test instruments, the pipeline configuration, and the effects of vacuum drop in the connecting pipelines, mean that many of us unwittingly choose our own answers. The simple guidelines are:

1. The outlet of the air flow meter should not be restricted by connecting tubes, cones, or access ports. A 1.5" connector is acceptable for air flows below 50 CFM, a 2" connector can be used up to about 100 CFM, a 3" connector should be used to measure air flows above 100 CFM. In all cases, use the largest possible test port or adapter size.

2. Replace the Bourdon guage with a digital electronic guage of known accuracy for system analyses, and check the guage periodically against a mercury manometer.

3. Always try to measure the system vacuum in quiet air, e.g. directly into the receiver with a special test lid fitted with a vacuum connection; or at the first milk inlet in parlors; or in the vacuum supply line in weigh jar systems; or on the wash manifold in stanchion barns (with the system set in wash mode); or into a straight connecting pipe at least 5 pipe diameters upstream and downstream of any bends, other fittings or air entry points.

4. The simplest way to trouble-shoot regulator performance problems is to make a vacuum connection at or near the regulator (or its sensor) by tapping in a small hose barb. A convenient and readily available vacuum connector is a 3/16" x 1/8" brass male hose barb (Part No. 220B from Dorn Hardware in Wisconsin, costing 50c). A #10 screw protector (made by Servalite Inc. Moline, IL) works well as a firm-fitting plastic cap to seal the connector. These cost 8c each from Dorn Hardware in WI. To drill the hole, use an "R" drill bit or an 11/32" drill bit, then cut the thread using a 1/8" NPT (National Pipe Thread) #27 tap. This tap costs $4 from Dorn Hardware.

Appendix 1. Design guidelines to assure stratified flow in milklines

G.A. Mein and D.J. Reinemann
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Milking Parlor looped milkline with units attached every 10 sec per slope

Peak flowrate	5.5 L/min/cow (12 lb/min)
Steady air admission	10-20 L/min/unit (0.35-0.7 scfm)
Transient air admission	100 L/min/slope (3.5 scfm)

	Number of units per slope					
	Slope					
Nominal Line Size	0.5%	0.8%	1.0%	1.2%	1.5%	2.0%
48 mm (2 inch)	2	3	3	4	4	5
60 mm (2.5 inch)	4	5	6	7	8	10
73 mm (3 inch)	6	9	10	13	16	24
98 mm (4 inch)	21	(28)	(32)	(35)	(38)	(43)

Stanchion barn looped milklines with units attached every 30 sec per slope

Peak flowrate	5.5 L/min/cow (12 lb/min)
Steady air admission	10-20 L/min/unit (0.35-0.7 scfm)
Transient air:	100 L/min/slope (3.5 scfm)

	Number of units per slope			
	Slope			
Nominal Line Size	0.5%	0.8%	1.0%	1.2%
48 mm (2 inch)	2	3	3	4
60 mm (2.5 inch)	4	5	7	(8)
73 mm (3 inch)	6	(9)	(11)	(13)

Note: Figures in () indicate an unlimited number of units. If more than 1 operator is attaching units on the same slope, the attachment rate may be quicker. The figures in parentheses then apply. A slope of 0.8% is equivalent to 1 inch drop in 10 feet or run. A slope of 1.2% is equivalent to 1 1/2 inch drop in 10 feet. Peak flow rates are based on fastest 5% cows in the US and Europe.

Appendix 2. Recommended minimum pipe sizes (inches internal diameter) for the main airline of a milking system.

Vacuum pump capacity	Approx. length of main airline (feet of straight pipe)				
CFM-ASME	**20**	**40**	**60**	**80**	**100**
50	2	2	3	3	3
60	2	3	3	3	3
70	3	3	3	3	3
100	3	3	3	3	3
150	3	4	4	4	4
200	4	4	4	4	4
250	4	4	4	6	6
300	4	6	6	6	6
350	6	6	6	6	6
400	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.

These calculations are based on a maximum vacuum drop of 0.5 inches of mercury between the receiver and vacuum pump. The maximum air flowrate is normally from the vacuum regulator to the pump. Whenever additional air enters the milking clusters during milking, however, the maximum air flowrate is from the receiver to the vacuum pump.

This ready reckoner table includes an allowance for the equivalent length (feet of straight pipe) of one distribution tank, one sanitary trap and 4 elbows. If the system includes more than 4 elbows, then use the next pipe length column to the right for every 3 additional elbows.

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