SIZING VACUUM PUMPS FOR MILKING

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The vacuum pump extracts air from a milking system at a rate which is nominally constant. However, the rate at which air enters the system varies continually during operation. To keep the vacuum constant, therefore, additional air is admitted at a varying rate through the vacuum regulator to maintain the total air inflow rate constant. The sole purpose of providing the additional pump capacity during milking, is to cope with transient air admission through the milking units.

Transient air flowrate during cup changing or fall-off

Transient air flow occurs when teatcups are applied or removed from udders, when a liner slips, when a milking cluster falls or is kicked off, or when a milking unit is moved from one stall to another in a stanchion barn. US figures for air usage during milking, summarized in Table 1, show that unit fall-off has by far the greatest air demand during milking.

As shown in Table 2, the free air flowrate through an individual milking cluster is about 1130 L/min (40 CFM) in a typical lowline system. When longer milk hoses (2.4 m, or 8 ft length) are used, as in a typical highline system, the free air flowrate through an individual cluster is 200-400 L/min lower for the same vacuum level. The air flowrate through a single teatcup held fully open is about half that for the individual cluster. Although this flowrate is considerably greater than the figures given in Table 1, it indicates that transient air admission during cup changing could be up to about 2250 L/min (80 CFM) if 4 careless milkers were changing units simultaneously.

One solution to contingencies such as cup falling is the more widespread use of claws with effective, automatic shut-off valves. The majority of claws used in western Europe have automatic shut-off valves. However, automatic shut-off valves cannot compensate for the effects of careless cup changing. In the USA, a more common solution has been to install vacuum pumps with sufficient reserve capacity to "overwhelm any operational event that could cause either the vacuum level or liner action to deviate from desired uniformity" (personal communication, W.C. Fairbank, 1984). More recent innovations include the development of dual vacuum systems, and variable-speed vacuum pumps which help to maintain a constant milking vacuum by responding quickly to changes in the amount of transient air admitted during milking.

Some options for calculating vacuum pump capacity

Present guidelines given in 3-A Accepted Practices (3-A, 1990) call for a minimum vacuum pump capacity of 170 L/min (6 CFM) per unit, with a minimum of 1000 L/min (35 CFM) for any milking system. Following is a summary of some existing or proposed alternatives.

Option 1. Adopt the new ISO guidelines for Effective Reserve.

The new draft International Standards Organization (ISO) guidelines for Effective Reserve provide a possible basis for USA to use for calculating the required pump capacity. It is likely, however, that these ISO guidelines will be regarded as too low by most Americans unless claws with effective automatic shut-off valves are used. The proposed new ISO formulas are as follows.

For pipelines and weigh jar machines, with automatic shut-off valves in the claw:

200 + 30n L/min (where n is the number of units) for up to 10 units
[(7 + 1n) CFM]

500 + 10(n - 10) L/min free air for more than 10 units
[18 + 0.3(n - 10) CFM]

For installations without shut-off valves, the ISO proposal is to add 200 L/min (7 CFM) to the base requirement:

400 + 30n L/min for up to 10 units, [(14 + 1n) CFM]

or 700 + 10(n-10) L/min for more than 10 units, [27 + 0.3(n - 10) CFM]

Some examples of recommended pump capacities based on these figures are given in Table 3.

Option 2. Adopt or adapt the 1990 Canadian guidelines.

The current Canadian guidelines (1990) for minimum vacuum pump capacity are approximately:

280 L/min (10 CFM) per unit	for up to 3 units
200 L/min (7 CFM) per unit	for 4-6 units
170 L/min (6 CFM) per unit	for 7-12 units
130 L/min (4.5 CFM) per unit	for 13-20 units
70 L/min (2.5 CFM) per unit	for 21-30 units

As shown in Table 3, these guidelines produce numbers that are similar to the current 3-A figures for 4 units, higher than 3-A for 12-16 units, and progressively lower than 3-A figures for systems with more than 24 units. This option is said to provide adequate capacity for both milking and cleaning of medium and large systems in Canada. It has two disadvantages, however: it seems to be too low for small systems, and it is based on pump capacity rather than on a minimum effective reserve capacity.

Option 3. Proposed revision of 1978 Californian guidelines.

Eide, Fairbanks and Smith (personal communication to the Milking Machine Manufacturers Council, May, 1981) recommended that the USA guidelines for pump capacity be revised as follows:

280 L/min (10 CFM) per unit	for up to 10 units
210 L/min (7.5 CFM) per unit	for 20 units
170 L/min (6 CFM) per unit	for 30 units
140 L/min (5 CFM) per unit	for 40 units

The Californian team proposed that these air flow requirements could be reduced by 15% in systems using automatic detachers. Their recommendations for pump capacity included an allowance of 55 L/min (2 CFM) per unit for "the functional base load", that is, the air used by pulsators and milking clusters.

This option is higher than the current 3-A guidelines for systems up to 24 units but it does not meet the industry perception that 4-unit systems are under-pumped. The figures in Table 3 are taken directly from a chart provided by the Californian team in 1981. These figures are similar to the current Canadian guidelines over most of their range.

Option 4. Cornell guidelines.

Doane et al (1982) published results of measurements of air usage during milking in 31 commercial parlors. Their recommendations for "generous standards for pump capacity" were 900 L/min (32 CFM) base allowance plus 45 L/min (1.6 CFM) per unit. Table 3 shows that these figures are similar to the current 3-A guidelines for 4 units but they are much lower than all others (including ISO) for medium and larger systems. They would not provide sufficient reserve to cope with a unit fall-off.

All of the options listed in Table 3 recommend pump capacities that are less than the minimum specified in the current 3-A national standard for systems with 32 units or more. At the lower end, none of these options provide sufficient reserve to cope with a single unit fall-off. Which, if any, one of the options is "right"? Is there a more rational way to size vacuum pumps for efficient milking performance? We need answers to the following types of questions. How much air really enters the milking system during cup changing or cup falling on typical farms? How frequently do clusters fall off or get kicked off? Should we design for 2 or more fall-offs in large systems? What is the effect of transient air admission on vacuum stability in the teatcup? What are the consequences of inadequate plumbing combined with poor regulator location on vacuum stability?

Frequency of unit falls during milking

According to Doane et al (1982), the incidence of unit falls involving high (or acute) air admission are rare and brief events. This view is supported by the results of Spencer and Rogers (1991). They reported the incidence of cup falling to be:

0.066 to 0.114 at 42 kPa (12.5" Hg),
0.005 to 0.027 at 44 kPa (13" Hg), and
0.001 to 0.028 at 50 kPa (15" Hg).

Goodger (personal communication, 1993) recorded 7-8 unit falls and 8-10 units kicked off in his observations of over 4000 cow-milkings in 26 midwestern herds, i.e. an estimated frequency of one fall-off or cluster kicked off per 230 cows milked (an incidence of 0.004). On the basis of such figures from Goodger, and from Spencer and Rogers, the probability of two milking clusters falling or being kicked off simultaneously would be about 1 per 1,000 to 1 per 1,000,000 cows milked at a vacuum of 13" Hg (44 kPa) or more. This low probability suggests that it is not necessary to design for 2 simultaneous falls in small or medium-sized systems (less than 32 units?) unless the system is operating at very low vacuum (less than 40 kPa, or 12" Hg), or unless milking units are used which are either uncomfortable or designed to fall off frequently.

In larger systems, it would be prudent to design for the possibility of 2 simultaneous falls (2260 L/min, or 80 CFM). The chances of 3 simultaneous falls seems too remote to be of practical interest, however.

How much vacuum stability is stable enough?

Recent research at UW-Madison (Mein et al, 1993) showed clearly that vacuum fluctuations in the claw are usually increased whenever milkline vacuum fluctuations exceed 2 kPa (0.6" Hg). 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 over-ridden, by the larger cyclic changes generated within the cluster by the combined effects of pulsation and milk flow from the cluster.

These results provide the rationale for new performance guidelines for sizing milklines, airlines 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 (Mein, 1993).

The relevant criterion for an adequate pump capacity for milking is that **vacuum fluctuations in or near the receiver should not exceed ± 2 kPa (±0.6" Hg) during the course of normal milking (including cup attachment and removal, liner slips and cluster falls).**

Field study of pump capacity and effective reserve

The current task of the NMC sub-committee is to measure and agree on the minimum Effective Reserve required to achieve this degree of vacuum stability during milking. Twenty farms have been selected in different regions of the USA to cover both stanchion barns and automated parlors, from 4-unit barns up to the 80-unit parlor systems. Our starting hypothesis was that an Effective Reserve of 1130 L/min (40 CFM) basic reserve plus 15 L/min (0.5 CFM) for each unit above 10 units might be sufficient to achieve the required degree of vacuum stability.

Phase 1: Before milking, an air flow meter (AFM) is connected at a convenient place on the main airline to adjust the Effective Reserve by bleeding off any surplus pump capacity. Using a transducer with an electrical output, vacuum stability in or near the receiver is recorded during milking for at least 2 turns per side, or at least 20 min in stanchion barns. If the receiver vacuum has not varied by more than ±2 kPa (0.6" Hg) during the measuring period, then the AFM is opened to reduce the reserve by 300 L/min (10 CFM). If vacuum fluctuations exceeded ±2 kPa, then the AFM is closed by 300 L/min.

The vacuum regulator is re-adjusted, if necessary, to maintain the system at the required working vacuum. Vacuum stability in the receiver is recorded for a further period of at least 2 turns per side, and the AFM adjusted again, if necessary, to increase or decrease the Effective Reserve capacity by 300 L/min. This procedure is repeated to find the appropriate minimum level of Effective Reserve that will achieve the required degree of vacuum stability for each milking system.

Phase 2: Effective Reserve, Mean Milking Times and Milk Yields

On the same 20 systems, a 3-week crossover trial will be conducted with experimental periods of 1 week as follows.

Week 1: Set the Effective Reserve at 300 L/min (10 CFM) above the minimum determined previously. Re-adjust vacuum regulator, if necessary, to maintain the system at the required working vacuum. Collect data on mean milking times per herd, and mean milk yields per cow for 1 week, by asking the owner/manager to record the time from first unit on to last unit off for each milking, the number of cows milked, and the total milk obtained per milking.

Week 2: Set the Effective Reserve to the level first found on the particular farm. Re-adjust vacuum regulator and collect data as for Week 1.

Week 3: Repeat Week 1.

Results: At the time of writing, field results are still coming in from Phase 1. Phase 2 will start as soon as the first phase is completed. Preliminary results indicate that our proposed guideline of 1130 L/min (40 CFM) minimum Effective Reserve will be close to the mark for small milking systems, and that 2260-3400 L/min (80-120 CFM) might be a reasonable upper limit for larger systems (up to 80 units).

Conclusions

Although it is too early to draw any conclusions from our field project at this stage, some conclusions can be made on the basis of other relevant national and international standards and guidelines, and our measurements and estimates of air admitted during milking.

1) The USA can achieve a more flexible guideline by specifying a minimum Effective Reserve rather than the minimum pump capacity for any milking system.

2) An excellent, performance criterion for an adequate pump capacity for milking is that vacuum fluctuations in or near the receiver should not exceed ± 2 kPa (± 0.6" Hg) during the course of normal milking (including cup attachment and removal, liner slips and cluster falls). This performance guideline could also be applied to systems with innovations such as dual vacuum systems, variable-speed vacuum pumps, and claws with automatic shut-off valves.

3) All milking systems should have sufficient reserve capacity to cope with at least one fall-off. This means a minimum Effective Reserve of about 1130 L/min (40 CFM) for any conventional milking system.

4) Medium and larger systems should have sufficient reserve to cope with two simultaneous falls even though the likelihood of these events occurring simultaneously is very low. The chances of three fall-offs occurring simultaneously seems too remote to be of any practical importance.

5) A more relevant situation in large milking systems is careless cup application by multiple operators: for example, 4 operators each admitting 570 L/min (20 CFM) at the same time as another unit falls off. In this case, the total air inflow rate could be as high as (570 x 4) plus 1120 = 3400 L/min (120 CFM). This unlikely set of simultaneous events indicates a reasonable upper limit for Effective Reserve in systems up to about 80 units.

6) The suggested range of 1130-3400 L/min (40-120 CFM) for Effective Reserve would provide adequate reserve capacity for efficient cleaning of properly designed CIP systems with up to 100 mm (4 inch) milklines (Reinemann and Book, 1994).

7) This suggested range confirms the present industry view that small systems seem to be under-pumped but large systems are over-pumped. Interestingly, both the 1991 Canadian guidelines and the 1981 Californian recommendations for sizing vacuum pumps in medium and large systems would give Effective Reserves within the range suggested in this paper.

APPENDIX 1. CALCULATING THE PUMP CAPACITY REQUIRED TO PROVIDE THE MINIMUM EFFECTIVE RESERVE

The following guideline for sizing new vacuum pumps is based on:

1) an assumed air consumption of 55 L/min (2 CFM) free air per unit for pulsators and air vents in the clusters;
2) additional allowances for air consumption of any special components or fittings (e.g., air lubrication of some vacuum regulators, air vents in some types of milk meters, air sweeps for some types of backflush systems);
3) an agreed minimum Effective Reserve specified for a system.
4) typical or maximum allowances for regulator leakage, system leakage, and vacuum drop between the pump and receiver;
5) an extra 10% margin for new pumps to allow for some deterioration in pump capacity during the working life of the pump.

NOTE: Points #4 and 5 add up to an extra 33% margin as shown below.

Air consumption of units

Pulsator 28-42 L/min (1-1.5 cfm)
\+ Air vent 8-14 L/min (0.3-0.5 cfm)
= 55 L/min (2 CFM) per unit

Allowances for leakage, vacuum drop, and pump wear

Regulator leakage (10% of pump capacity)
\+ System leakage (10% of pump capacity)
\+ Vacuum drop in lines (2 kPa, 3% approx.)
\+ Pump wear (add 10% of pump capacity)
= 33% extra pump capacity

New pump capacity

1) 55 L/min (2 CFM) per unit for basic unit consumption
2) + extra air consumption of any special components
3) + minimum Effective Reserve specified for the system
4, 5) Total of these items X 1.33 = Recommended Pump Capacity

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Table 1. Air usage during milking, L/min and cubic feet per min (CFM) free air (from Spencer, 1978).

	L/min	CFM
Pulsation (per unit)	28-42	1.0-1.5
Claw air vent (per claw)	8-14	0.3-0.5
Liner slip	28-170	1.0-6.0
Unit attachment	3-225	0.1-8.0
Unit fall-off (per fall)	570-1400	20-50

Table 2. Air flowrate through milking clusters (from Mein and Reinemann, unpublished, 1992)

Cluster	**1 teatcup**		**4 teatcups**	
	CFM	**L/min**	**CFM**	**L/min**
Alfa Laval 01 liners & auto. shut-off claw [a]	21	600	42	1200
Bou-Matic Visishells & Flo-Star claw [a]	24	670	40	1130
Germania	21	600	37	1035
Surge 10050 liners & Eclipse oval claw	26	750	42	1200
Westfalia 4021-0241-004 liners & claw	29	820	45	1270
2.4 m (8 ft) long milk hose plus:				
Bou-Matic cluster as above	18	510	34	955
Bou-Matic cluster & Milk Sentry			26	735
Westfalia Bio-Milker	13	370	24	670
Goose-neck inlet alone				
14 mm (9/16")	1500 L/min (53 CFM)			
16 mm (5/8")	1955 L/min (69 CFM)			

[a] Automatic shut-off valves close at an instantaneous air flowrate of about 900 L/min (30 CFM), i.e. just as the third teatcup opens.

Table 3. Comparison of different options for calculating the minimum pump capacity. (Effective reserve[a] is given in brackets where appropriate in the Table)[b]

	Number of milking units				
Option	4	12	16	32	48
Current 3-A					
L/min	1000	2040	2720	5430	8150
CFM	35	72	96	192	288
1. New ISO (w/out auto. valves)					
L/min	980	1840	2180	3560	4950
(Eff. Res.)	(520)	(720)	(760)	(920)	(1080)
CFM	35	65	77	125	175
(Eff. Res.)	(18)	(28)	(29)	(34)	(38)
2. Canada (1990)					
L/min	1020	2550	3170	4445	5575
CFM	36	90	112	157 (est)	197
3. California proposed (1981)					
L/min	1130	3115	3680	5235	6085
CFM	40	110	130	185	215
With detachers					
L/min	1130	2970	3115	4530	5235
CFM	40	105	110	160	185
4. Cornell (1982)					
L/min	1075	1445	1640	2350	3115
CFM	38	51	58	83	110

[a] Effective Reserve is defined as the air flow that can be admitted near the receiver, to lower the vacuum 2 kPa (0.6" Hg) below the working vacuum, when the regulator is connected and operating, and all teatcups are plugged and operating.

[b] A reasonable basis for estimating the required capacity of new vacuum pumps to ensure the minimum Effective Reserve is given in Appendix 1 as:
* 55 L/min (2 CFM) per unit for basic unit consumption
* plus extra air consumption of any special components
* plus minimum Effective Reserve specified for the system
* Total of these items X 1.33 = Recommended Pump Capacity