# Sizing Vacuum Pumps for Cleaning Milking Systems

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Paper presented at the 1995 annual National Mastitis Council Conference

## Introduction

Early pipeline milking systems were commonly flooded during cleaning. Flood cleaning is practical for systems with small diameter milklines, short pipelines and few milking units. Flood cleaning becomes impractical as milkline diameter and length and the number of milking units is increased. Excessive water volume is required and the flow velocities and corresponding mechanical cleaning action produced are low. Air injection was introduced to overcome these limitations.

Early attempts at air injection used steady air admission. This was accomplished with a fixed orifice that admitted a steady flow of air to the milk pipeline during the entire cleaning cycle. Steady air admission reduces the water volume in the system and increases flow velocities slightly when compared to flood cleaning. This strategy provides very little control, however, of water delivery to the receiver and can result in flooding of the sanitary trap.

Cycled air injection was introduced later as system size continued to increase. Cycled air injection further reduces water volume, greatly increases flow velocity, and improves control of water flow when compared to steady air admission. Cycled air admission is used on most modern milking systems with milkline diameters 2 inches (48 mm) or more.

Despite its widespread use, air-injected cleaning has been poorly understood. Cleaning failures have resulted from inadequate cleaning flow dynamics caused by improper system design or control. Common design rules of thumb also result in excessive vacuum pump size, hot water use and operational cost. Several field surveys show that milking systems commonly have far greater vacuum pump capacity than that required for milking (1,5). This is due, in part, to the common belief that greater vacuum pump capacity is required for cleaning than for milking. Some researchers have suggested installation of two vacuum pumps with a single pump operating during milking and two pumps during cleaning (4).

Recommendations for the vacuum pump capacity required for milking and cleaning are being reviewed by both US and international standards organizations (5,6). Misunderstanding of the design and control of air-injected cleaning systems has been a major barrier to reducing vacuum

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[1] Acknowledgments: This research was supported by the Wisconsin Center for Demand Side Research and the following members of the Milking Machine Manufacturers Council of the equipment Manufacturers Institute, Alfa Laval Agri, Babson Brothers Company, Bou-Matic, and Universal Dairy Equipment Company.

pump size in milking systems.

Recent research has resulted in a better understanding of air-injected flow in milklines (2,7,8), and flow dynamics in milking parlor CIP systems (3,9). The results of this research have been used to develop recommendations for the minimum vacuum pump capacity, and system design and control guidelines to make effective and efficient use of air injection. These recommendations are presented here.

## Pipeline System Cleaning Circuits

Typical Round-The-Barn (RTB) pipeline cleaning circuits are illustrated in Figures 1, 2, and 3. The objective of air-injected cleaning of RTB systems is to produce slug flow in the milkline. In RTB systems the milking units are usually flooded. Water drawn from the wash vat passes through milking units suspended in the wash vat or mounted in a manifold into the milkline. Air injectors are mounted on the water draw line, manifold or directly on the milkline. The single loop system uses only one air injection point (Figure 1). Double-Y pipeline configurations commonly use a single air injection point to produces slugging in two milklines simultaneously (Figure 2). The pipeline is divided into two separate flow paths in the Single-Y configuration, with a water supply and air injection point for each (Figure 3).

## Milking Parlor Cleaning Circuits

Although system designs vary considerably, typical features of milking parlor CIP systems are shown in Figure 4. Milking parlor systems differ from RTB pipeline systems in that milking units are commonly attached to wash assemblies (teatcup jetters) fed from a wash line and cleaned in the parlor. This water-draw pipe network and jetters make up the wash manifold. Water and air enter the milkline at intervals rather than at a single point as in RTB systems. Cycled air injection may enter through the wash manifold (A1 in Figure 4), the milkline (A2 in Figure 4) or both. When air is injected only through the wash manifold (A1) it is common to include a hose or pipe from the water drawline directly to the milkline (the dashed line in Figure 4).

Flow velocity and two phase flow patterns are determined by the diameter of system components and water and air flowrates. Internal diameters range from 5/16 inch (8 mm) in short milk tubes to 4 inches (98 mm) in milklines and in excess of 6 inches (150 mm) in milk meters and weigh jars. Flow velocities and flow patterns thus vary greatly in the different parts of the system. Slug flow is normally used to clean milklines in milking parlor systems. Some systems still flood milklines during cleaning, however. The flow through the jetters and milking units is not slug flow. Milking units are either flooded or alternately flooded and emptied (3). Large components such as some milk meters and recorder jars are generally cleaned with a spray or sheet of water over the interior surfaces. The objectives and optimal control strategies for air and water admission to milking units and other components differ from those for the pipeline.

## Vacuum Pump Requirement For Cleaning

The vacuum pump capacity required for these various system designs can be summarized as:

$$Qp = aQc + nQs + Qx \quad \textbf{(1)}$$

where: Qp = minimum vacuum pump capacity, (scfm or L/min).
a = number of cycled air injection flow paths operating simultaneously.
Qc = Flowrate of cycled air admission (scfm or L/min).
n = number of milking units.
Qs = steady air usage per milking unit (scfm or L/min).
Qx = Additional steady air usage by other components (scfm or L/min)

The first term in Equation 1 is the air flowrate of **cycled** air admission. The recommended value of Qs is the air admission required to produce 23 ft/s (7 m/s) slug velocity in the milkline and is given in Table I. This airflow rate is dependent upon the diameter but not length of the milkline. Research has shown that the maximum mechanical cleaning action is achieved with slug velocities of 23 to 33 ft/sec (7 to 10 m/s), (2,7,8). The ratio of the air injector open to close time is typically 50% or less for cycled air injection. Specifying the air flow for the minimum velocity will ensure that the system vacuum level will remain relatively constant for 23 ft/s (7 m/s) slug velocity. The system and will recover to the regulated vacuum set point between slugs for slug velocity up to 33 ft/s (10 m/s). The air injection rate through the wash manifold is typically less than that for the milkline. The value of Qc based on the diameter of the milkline will provide a generous allowance for cycled air admission to the wash manifold. Systems with multiple milkline loops or cycled air admission to parlor wash manifolds can have two or more air injectors open simultaneously or a single air injector supplying air to multiple flow paths (a > 1). Control strategies to address this situation are discussed below.

The second term is the **steady** air flow of all component operating during cleaning. It is convenient to express this term as the air flow per unit times the number of units. This steady air flow includes that for claw air vents, pulsation, system leaks and air used by any additional components. In many applications the milking units are flooded with steady air admission only at the claw air vents. This steady air admission adds turbulence to the claw and long milk hose but not to the liners. Field experience suggests that claw air vents provide sufficient turbulence to clean most milking units. Most systems operate pulsators during cleaning. Pulsation prevents the liners from staying in the closed position and possibly reducing cleaning of the liner surface. Pulsation also acts to increase the turbulence of wash solutions in liners. There is no clear evidence, however, that pulsation improves cleaning of liners.
The steady air admission for pulsation and claw air vents is about 1.5 scfm (42 L/min) for most commercial milking units. A value or 2 scfm (56 L/min) is suggested for Qs for RTB systems and parlor systems washing only milking units. This provides sufficient extra capacity to allow for system leaks.

Some equipment such as milk meters and flow sensors are thought to require additional air admission for proper cleaning. This is accomplished by cycled air admission to the wash manifold (A1 in Figure 4) or steady air admission to the wash manifold at a single point near the wash vat or at each teatcup jetter. Steady air admission increases flow velocities and decreases

water flowrate through components downstream of the admission point.
Additional steady air admission rates for commercial systems range from 1 to 2 scfm per milking unit. Some milk meters are also fitted with air vents that can admit up 0.2 to 0.3 scfm of steady air. The value of Qs should be increased accordingly for systems with additional steady air admission or milk meters fitted with air vents. The maximum steady airflow rate for any current system design is about 4 scfm per milking unit. An extra allowance (Qx) may also have to be made for additional components operating during cleaning such as air lubrication for some vacuum regulators (7 to 28 scfm).

## **Comparison of Vacuum Pump requirements for Cleaning and Milking**

The vacuum pump capacity suggested for milking is compared with the range of vacuum pump capacity required for cleaning in Figure 5. The vacuum pump capacity suggested by Mein et al. (6) is 35 scfm + 3 scfm per milking unit. The minimum requirement for cleaning is for one air injector open at any one time and 2 scfm per milking unit (a = 1, Qs = 2). The medium level for cleaning is 2 flow circuits receiving cycled air injection simultaneously and 2 scfm per unit (a = 2, Qs = 2). The maximum for cleaning is for 1 air injector open and 4 scfm per unit (a=1, Qs = 4). The vacuum pup requirement for cleaning is less than that for milking for all scenarios for systems with less than 14 milking units. The requirement for cleaning exceeds that for milking only for large milking parlors with extra steady air admission.

## Optimal Control Strategies

*Multiple Loop RTB Pipelines:* Double-Y RTB systems (Figure 2) admit cycled air at a single point but must produce slug flow in two milklines simultaneously (a = 2 in equation 1). These systems are reliable only if the length of milkline and number of fittings is the same for both loops. These systems should not be used when the milkline loops are of uneven length or different configuration. Single-Y, RTB systems (Figure 3) divide the two milkline loops into two separate flow paths. This allows for optimal control on both loops and can also reduce the air requirements for cleaning. The two air injectors may be opened simultaneously (a = 2 in equation 1). Slug velocity must then be reduced in the shorter leg to account for length differences (7). If the two air injection points are sequenced so that only one air injector is admitting air at a time, the control of the system will be improved and the air requirements reduced to that of a single loop pipeline (a = 1). It is possible to wash systems with large differences between loop lengths with this method. This control strategy requires an air injection timer with three control periods as follows: 1) injector A1 open, injector A2 closed, 2) Injector A1 closed, injector A2 open and 3) both injectors closed.

*Milking Parlors With Multiple Receivers:* Some large milking parlors are installed with two milkline loops each with its own receiver. This design can result in two air injectors being opened simultaneously or a single injector providing air for both pipeline loops (a = 2). Sequencing injectors as described above for RTB systems will, however, reduce the maximum cycled air admission to that for a single pipeline (a = 1).

*Milking Parlors With Cycled Air Injection To The Wash Manifold:* This configuration may result in two air injectors open simultaneously or a single injector providing air to both the milkline and wash manifold (a = 2). Cycled air admission to the wash manifold increases the flow velocity through the units but can decrease slug action in the milkline (7,9). The objectives and optimal timing of air injection to the wash manifold differ significantly from that for the milkline. Cleaning performance will be improved if these two air injection cycles are sequenced as described above with the open times for each injector set for optimal performance for the two flow circuits. The air injector on the wash manifold should be opened first to move water in the manifold, through the units and into the milkline. The milkline air injector should then be opened to slug the milkline. Sequencing air injection in milking parlor systems with two milkline loops and cycled air injection to wash manifolds can reduce the maximum cycled air injection to that for a single loop pipeline (a = 1).

Milking Parlors With Extra Steady Air Admission*:* Steady air admission at each unit, (in addition to the claw air vent), is an alternative to cycled air admission to the wash manifold. This air is commonly admitted through an orifice in the teatcup jetter. Some milk meters and most recorder jars have a separate water supply line for cleaning. Extra steady air can also be admitted through orifices in these hoses. The steady airflow rate required for adequate cleaning will depend on the piece of equipment being cleaned. Commercially available jetter air vents admit an additional 1 to 2 scfm per unit. This additional steady air admission will require greater vacuum pump capacity than cycled air admission to the wash manifold when air injectors are sequenced. There is no evidence to suggest the optimal level of steady air admission or if steady air admission provides better cleaning than cycled air admission.

*Control Of Water Flow In Milking Parlors:* The air and water flow should be evenly distributed between milking units and components to optimize the efficiency and effectiveness of the cleaning process. The water flowrate through units in US milking parlors commonly exceeds that shown to obtain adequate cleaning in other parts of the world. Furthermore, because of the excessive flowrate through the first several units, wash lines may be drained of water, resulting in little or no flow through units at the end of the wash manifold (9). Restrictors to reduce water flow rate should be place at each milking unit rather than a single point at the wash vat.

*Minimum Water Volume:* The minimum water volume to ensure proper flow dynamics can be calculated from Table II. Water volume less than this minimum will result in draining of the wash vat and unintended air admission. This is a common cause for the loss of flow control and resulting cleaning failure. The milkline will be about 20% full of water if the air admission rates and air injector timing are set properly. Additional water must be available to fill milking units, milk hoses, all CIP lines that are not air-injected and the milk transfer line. Allowance must also be made for about 1/3 of the receiver volume and enough reserve in the wash vat so that water drawlines remain submerged. Water may also be required to fill other ancillary equipment such as, milk meters, and precooling devices.

## Summary and Recommendations

*With proper system design and control strategies the vacuum pump capacity* required for cleaning is *less than that for milking. The vast majority of milking systems will have sufficient vacuum pump capacity for cleaning if sized according to the following relationship:*

$$Qp = Qc + nQs \qquad (2)$$

Where: Qp = minimum vacuum pump capacity, (scfm or L/min).
Qc = Flowrate of cycled air admission (scfm or L/min)
to produce 23 ft/s (7 m/s) slug velocity in milkline from Table 1.
n = number of milking units.
Qs = steady air usage per milking unit (scfm or L/min),
2 scfm (55 L/min)

Exceptions this may include systems designed with cycled air injection supplied to multiple flow paths simultaneously, large milking parlor systems that make use of extra steady air admission or systems with ancillary components requiring extra air during cleaning. Sequencing air injection will allow systems with multiple flow paths to be cleaned with the vacuum pump capacity calculated from equation 2. This optimal control strategy requires an air injector controller with multiple timing cycles and will make the most efficient use of the vacuum pump capacity for cleaning. If steady air admission is kept below 3 scfm per milking unit, or cycled air admission is substituted for steady air admission the vacuum pump capacity for cleaning can be reduced to less than that recommended for milking for large parlor systems. Many of these recommendations have been implemented successfully on RTB pipeline systems. Limited testing has also been done on milking parlor systems. Field testing will continue in the coming year to confirm the adequacy of these recommendations on a variety of system designs.

## References

1. Doane, M.K., Natzke, R.P., Bray, D.R., Scott, N.R. & Delwiche, M.J. 1982. Air flow utilization in milking parlors. Journal Dairy Science **65:**835-842.

2. Grasshoff, A. and D. J. Reinemann. 1993. Zur Reinigung von Milchsammeleitungen mit Hilfe einer 2-Phasen Stroemung. Kieler Mischwirtshaftliche Forschungsberichte, **45**:205-234

3. Lind, O. 1990. Cleaning-In-Place (CIP) Of The Milking Machine: Physical Forces. Proc. Seminar on Machine Milking and Mastitis, Aarhus, Denmark, August 6-8 1990. pp 162-173

4. Ludington, D.C. and R. Pellerin. 1992. Vacuum Technology and Energy Considerations. Proc. National Milking Center Design Conference, Harrisburg, Pennsylvania, November 17-19. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

5. Mein G.A., D.R. Bray, L.S. Collar, A.P. Johnson and S.B. Spencer. 1994. Sizing Vacuum Pumps For Milking. Proc. ASAE/NMC Dairy Housing Conference, 31 January, Orlando, Florida.

6. 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. Proc. Annual Meeting of the National Mastitis Council, February 22, Fort Worth, Texas.

7. Reinemann, D.J. and J.M. Book. 1994. Airflow Requirements, Design Parameters and Troubleshooting for Cleaning Milking Systems. Proc. ASAE/NMC Dairy Housing Conference, 31 January, Orlando, Florida.

8. Reinemann, D.J., and A. Grasshoff. 1994. Two Phase Cleaning Flow Dynamics In Air-injected Milklines. *Transactions of the ASAE*, **37**(5):1531-1536.

9. Reinemann, D.J. and R.W. Peebles. 1994. Flow Dynamics in Milking Parlor Clean-In-Place Systems, ASAE Technical Paper No. 943567, Presented at the International Winter Meeting of the American Society of Agricultural Engineers, Atlanta, Georgia, December 13-16.

Table I. Air injection rate to produce slug velocities of 7 m/s.

| Milkline Diameter | Air flowrate |
|---|---|
| 2" (48 mm) | 14 scfm (390 L/min) |
| 2.5" (60 mm) | 20 scfm (570 L/min) |
| 3" (73 mm) | 28 scfm (790 L/min) |
| 4" (98 mm) | 49 scfm (1300 L/min) |

Table II. Example calculation for the minimum water volume required per wash cycle for proper flow dynamics in a typical 16 unit milking parlor. NOTE: the water requirement for milk meters, wash vat and precoolers are approximate and may vary with different component designs.

| Milkline | Diameter | Length in Feet | Multiplier | Gallons |
|---|---|---|---|---|
| | 4" | | 0.12 | |
| | 3" | 100 | 0.07 | 7 |
| | 2.5" | | 0.05 | |
| | 2" | | 0.03 | |
| | 1.5" | | 0.02 | |
| Wash draw and milk transfer lines | Diameter | Length in Feet | Multiplier | Gallons |
| | 3" | | 0.34 | 0 |
| | 2.5" | | 0.23 | 0 |
| | 2" | 40 | 0.15 | 6 |
| | 1.5" | 80 | 0.09 | 7.2 |
| | | Receiver(s) Volume (Gallons) | Multiplier | Gallons |
| | | 12 | 0.33 | 4 |
| | | Number of Milking Units | Multiplier | Gallons |
| | | 16 | 0.25 | 4 |
| | | Number of Milk Meters | Multiplier | Gallons |
| | | 16 | 0.25 | 4 |
| Milk Hose | Diameter | Length in Feet | Multiplier | Gallons |
| | 9/16" | | 0.012 | |
| | 5/8" | 160 | 0.016 | 2.6 |
| | | Number of Precoolers | Multiplier | Gallons |
| | | 1 | 2 | 2 |
| | | Number of Wash Vats | Multiplier | Gallons |
| | | 1 | 8 | 8 |
| | | | Total Gallons | 44.8 |

Figure 1. Single Loop Round-The-Barn Pipeline Cleaning Circuit.

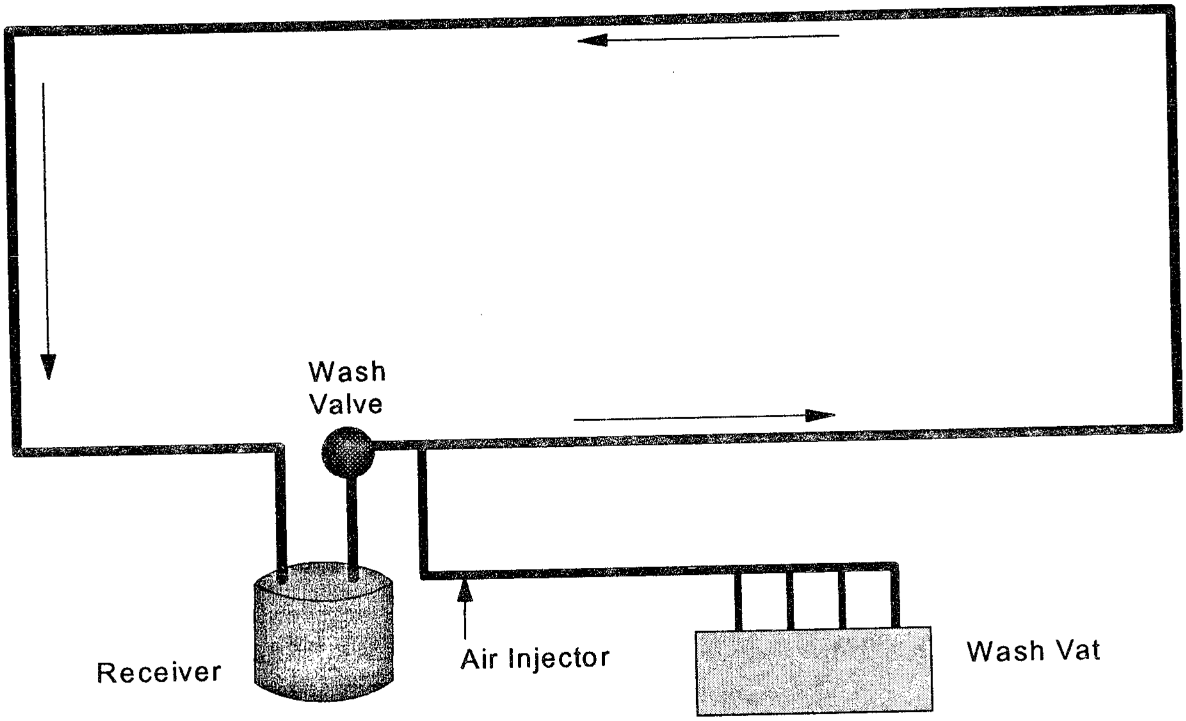

Figure 2. Double-Y Round-The-Barn Pipeline Cleaning Circuit.

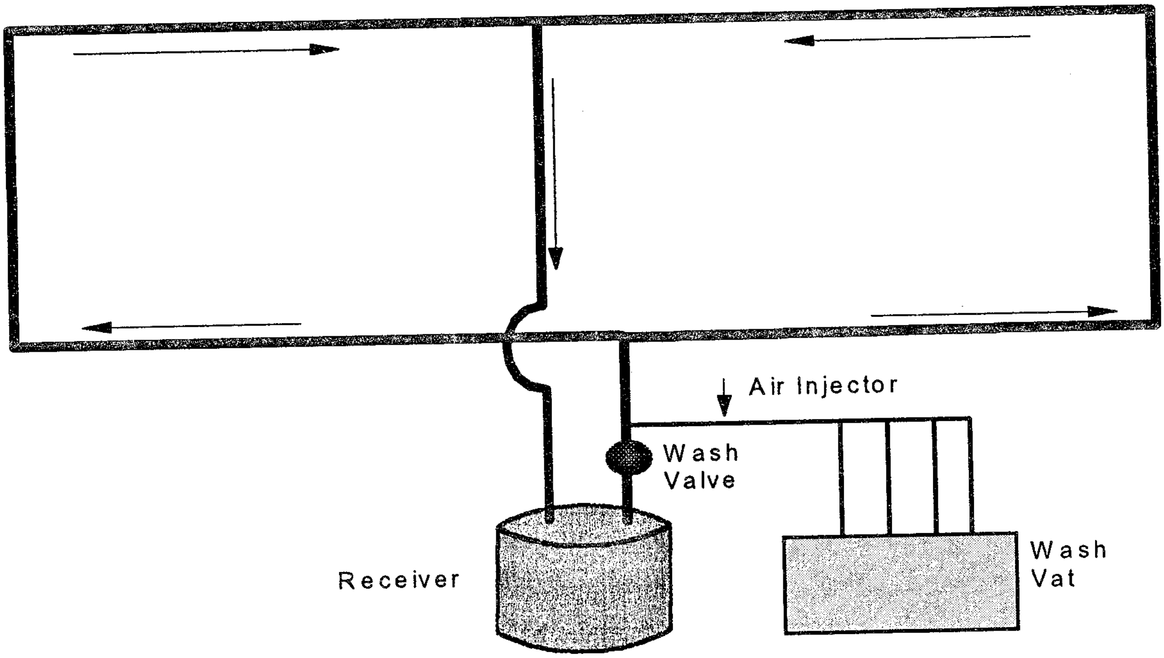

Figure 3. Single-Y Round-The-Barn Pipeline Cleaning Circuit.

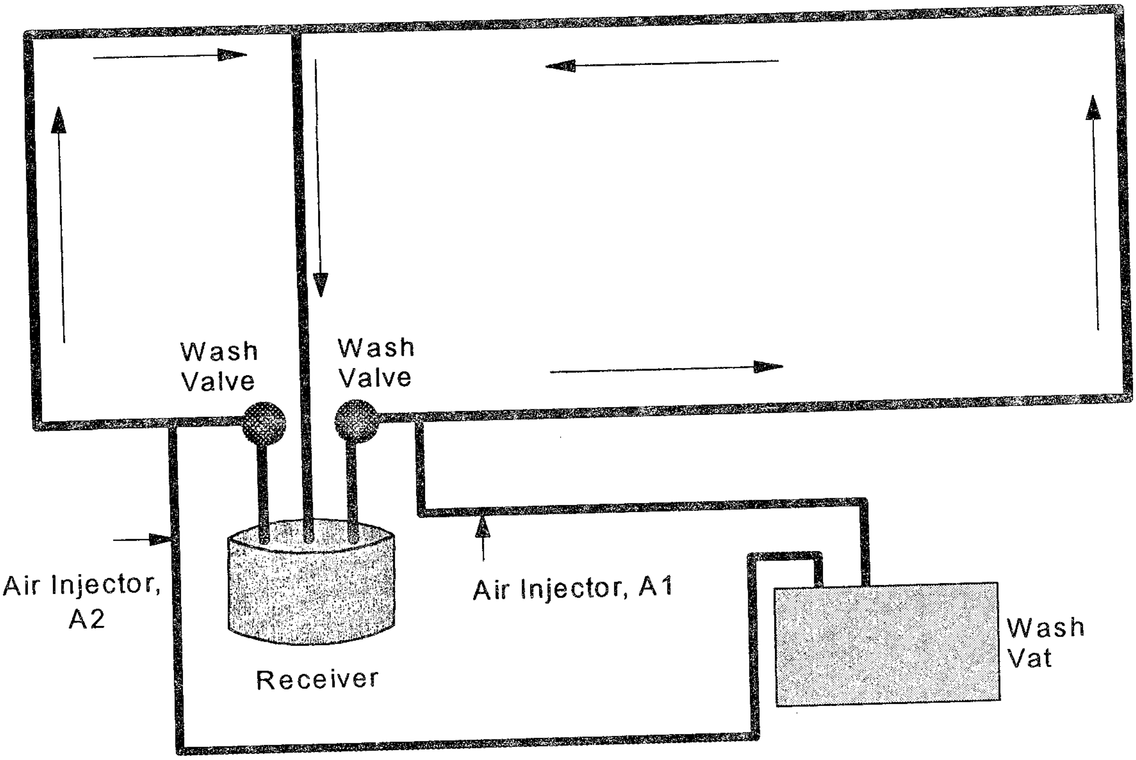

Figure 4. Typical Features Of Milking Parlor Cleaning Circuits.

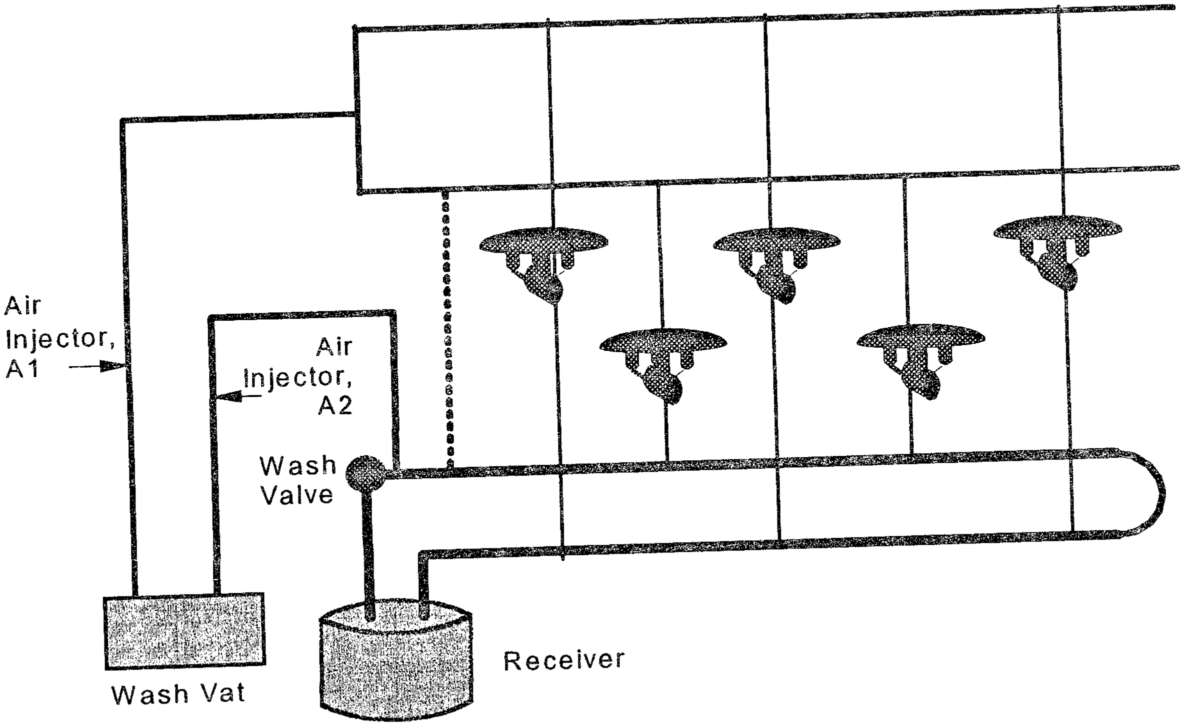

Figure 5. Vacuum pump capacity required for cleaning and milking. Milking requirements are from Mein et al. 1995. The minimum requirement for cleaning is for 1 air injector open at any one time and 2 scfm per milking unit. The medium level for cleaning is for 2 air injectors open or 2 flow circuits with cycled air injection simultaneously and 2 scfm per unit. The maximum for cleaning is for 1 air injector open and 4 scfm per unit.