CONTROL STRATEGIES FOR MILKING PARLOR
CLEAN-IN-PLACE SYSTEMS

D. J. Reinemann, R. W. Peebles, G. A. Mein

ABSTRACT. Results of a laboratory study of air and water flows in air-injected Clean-In-Place (CIP) systems for milking machines are presented. The effects of milk hose length, lift and air admission on water flow rates were examined for a typical milking unit. System design and control guidelines to assure uniform distribution of water and air to the milking units are presented. Control strategies and system designs to reduce the vacuum pump requirements for cleaning were developed and tested. Keywords. Milking machines, Milking parlors, Cleaning, CIP, Sanitation, Energy.

Clean-In-Place (CIP) technology is used extensively for cleaning milking machines. Current recommendations for milking parlor CIP design and use of cycled air admission have been neither well-defined nor documented. Improper control of air and water flow during cleaning is a common cause of cleaning failure. Commonly used design guidelines often result in excessive vacuum pump size, hot water use, and operational costs.

The internal diameter of pipes, hoses, and equipment components can range from 6 mm in short milk tubes to 98 mm in milklines. Flow velocity and two-phase flow patterns are affected by the diameter of system components and air injection method. Slug flow is normally used to clean milklines, although some systems are designed to flood the milkline during cleaning. The milking units and ancillary equipment may be flooded during cleaning or alternately flooded and emptied using cycled air injection. The use of cycled air injection through milking units has been referred to as controlled flushing pulsation by Lind (1990).

British standards cite a minimum of 1.5 L/min per unit for cleaning milking parlor systems with recorder jars and specify a minimum vacuum pump capacity of 480 L/min for any clean-in-place facility. No guidelines are given in these standards for air injection techniques or air admission rates (BSI, 1988). Field observations suggested that the minimum acceptable flow rate for cleaning milking units was 3 L/min. Systems with certain types of milk meters were thought to improve the removal of residual milk from milking units and milk meters in flooded systems with increased system vacuum during the prerinse process. The use of cycled air admission and controlled flushing pulsation also improved prerinse performance without using a higher vacuum level. No measurements of water or air flow rates were reported, however. Lind (1990) noted that unequal distribution of water to all units is a problem in large parlors and the capacity of the milk pump is often the limiting factor in the flow rate through each unit. He also recommended using cycled air admission with air passing through both milking units and the milkline.

Canadian guidelines recommend air admission for cleaning but give no details for the location or volume of air admission (Agriculture Canada, 1990). The 3A Accepted Practices, commonly used in the United States for cleaning recommendations, do not specify vacuum pump requirements or system details for cleaning, but do specify a minimum vacuum pump capacity of 990 L/min (35 cfm) for any system (IAMFES, 1990).

The most detailed publication on CIP for milking systems (WREP, 1978) recommended air injection be located so air passes through both the milkline and milking units. No details were given, however, as to the air and water flow rates required for successful cleaning. The document suggested large milking parlor systems should be cleaned sequentially, first washing the milkline and then the milking units by controlling valves in the wash water draw lines. This type of system is commonly used on large parlors in the United States with either manual or automatic control valves to divert wash water to various parts of the system. A recent publication describes a similar automatically controlled system as a parallel wash system (Guo et al., 1993).

An experienced observer of parlor CIP systems in the U.S. suggested a flow of 16 L over a 10 min wash cycle (1.6 L/min) was adequate for cleaning most milking units. Wide variations in the flow through units were noted as a common problem. Cycled air injection on unit wash lines was considered detrimental, especially concerning flow balance between units. Air vents in the jetters were considered to improve cleaning performance (Spencer, 1994).

Australian standards (SAA, 1986) require wash lines be sized to meet the manufacturer’s specifications for the minimum water flow rate per jetter (although most manufacturers do not specify this value). This standard further requires the water flow rate through any unit be greater than 3 L/min, and the flow rate through the first...
unit should not exceed that through the last unit by more than 50%. This standard does not give guidelines for air injection methods or airflow rates. Milking parlor CIP systems in Australia and New Zealand are routinely set up using these water flow recommendations. Milking unit cleaning apparatus (jetters) are commonly supplied with variable flow adjustment to achieve the desired flow rate and balance between units. Systems installed according to these recommendations have been observed to achieve successful cleaning. It was noted, however, that little work had been done to determine the minimum liquid flow rates needed for cleaning (Hubble, 1994).

It is clear from this review that more information is needed for milking machine CIP design. Current recommendations are neither well-defined nor documented and are in some cases contradictory. The methods to control air and water flow are not well understood.

**OBJECTIVES**

The objectives of this study were to:

1. Determine the flow characteristics of individual milking units and distribution of flow across milking units in common milking parlor designs.
2. Develop and test CIP system designs and control strategies for uniform flow distribution across milking units.
3. Develop and test control strategies to reduce the vacuum pump capacity required for milking parlor CIP systems.

**MATERIALS AND METHODS**

**SINGLE MILKING UNIT TESTS**

The apparatus used to measure the flow characteristics of an individual milking unit during cleaning is illustrated in figure 1. Water was drawn from a wash sink, through a 48 mm ID stainless steel jetter line to a milking unit/jetter assembly, and finally to a weigh jar. Water and air were separated in the weigh jar, with the air continuing to a 73 mm ID milkline. Both milk hose and jetter hose were 16 mm ID. The total hose length from the jetter line to the weigh jar was varied from 2.4 to 6 m. System vacuum was varied between 30 and 55 kPa. Vacuum was measured in both the 48 mm ID jetter line and weigh jar. The elevation difference (lift) between the jetter line and weigh jar was varied from 0.7 m (weigh jar above jetter line) to –2.2 m (weigh jar below the jetter line).

**MILKING SYSTEM TESTS**

A second study was conducted to examine the flow dynamics for multiple milking units in a typical parlor CIP configuration (fig. 2). The experimental system consisted of 12 milking units attached to a 11 m loop of 73 mm ID milkline. Water was drawn from a wash sink through a 40 mm ID jetter line located 2.0 m above the milkline. For tests I-IV, the total length of the jetter line, from the wash sink to the end of the jetter line, was 25 m. For tests V-VII the jetter line length was reduced to 14 m. Artificial milking unit/jetter combinations were made of PVC pipe. The internal volume (700 mL) and air admission rate (10 L/min) and water flow rate of the artificial units were typical of commercial milking units. Hoses with 16 mm ID and total length of 3.5 m were used to connect from the jetter line to the milkline. The system vacuum was set at 45 kPa. Flow restrictors, when used, were placed in the jetter hose between the jetter line and each artificial unit.

Air vents representative of commercial jetter-fork air vents, with air admission rates of 32 L/min, were placed in the jetter hose for several trials.

The water flow through each of the 12 units was measured one at a time, by collecting water in a weigh jar placed in-line between the artificial cluster and milkline. Flow measurements at each unit were replicated. The pressure difference across each artificial unit and hose was measured in the hoses at the exit from the jetter line and the entrance to the weigh jar. Cycled air admission was admitted in either the jetter line (near the wash sink), the milkline, or both. When cycled air admission was applied to the jetter line only, an additional hose was connected between the jetter line and milkline, as is typical in practice. The conditions for each test were as follows:

<table>
<thead>
<tr>
<th>Test</th>
<th>Air Injection to Milk Line (A1) Open/ Closed Time (s)</th>
<th>Air Injection to Jetter Line (A2) Open/ Closed Time (s)</th>
<th>Water Flow Restrictors*</th>
<th>Jetter Air Vent (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3 / 13 Closed</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>II</td>
<td>3 / 17 Closed</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>III</td>
<td>3 / 25 Closed</td>
<td>Y (4.8 mm)</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>IV</td>
<td>Closed</td>
<td>10 / 15</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>V</td>
<td>Closed</td>
<td>7 / 1</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>VI</td>
<td>Closed</td>
<td>4 / 11</td>
<td>Y (4.8 mm)</td>
<td>N</td>
</tr>
<tr>
<td>VII</td>
<td>(Sequenced) 3 / 20</td>
<td>13 / 10</td>
<td>Y (5.6 mm)</td>
<td>N</td>
</tr>
</tbody>
</table>

* Restrictors located in 16 mm Jetter hose
RESULTS AND DISCUSSION

SINGLE MILKING UNIT TESTS

The relationship between water flow rate and vacuum difference across a commercial milking unit/jetter combination is shown in figure 3 for two experimental conditions. Data with varying lift, hose length and air admission were fitted to a model, derived from the Bernoulli equation, in the following form:

\[ \Delta V = C_1 + C_2 L_h Q_w^2 + C_3 \Delta z \]  

where

- \( \Delta V \) = vacuum difference across milking unit and jetter hose assembly (kPa)
- \( C_{1,2,3} \) = regression coefficients
- \( L_h \) = total hose length (m)
- \( Q_w \) = water flow rate through each unit (L/min)
- \( \Delta Z \) = lift, elevation difference between milkline and jetter line (m)

Results of the regression analysis are given in table 1. Regression coefficients were also calculated with a term for the frictional loss through the milking unit/jetter assembly. The coefficient for this term was small compared with the term for frictional loss through the hose and did not improve the correlation coefficient of the model. The milking unit/jetter assembly is thus not a major restriction compared with the milk hose. Water flow rates through the unit/jetter assembly ranged from no flow to more than 20 L/min for the scenarios tested. Increasing hose length, increasing the lift between the wash line and milkline, and extra air admission all acted to reduce the water flow rate though the unit for a given vacuum difference. Extra air admission decreased the value of the lift coefficient \( C_3 \), as expected because of reduced density of the water column.

MILKING SYSTEM TESTS

The water flow rates through each unit for tests I, II, and III are shown in figure 4. Cycled air admission was applied only to the milkline for all of these tests. The air injector was opened just long enough to move one slug from the wash valve to the receiver (3 s). The injector was closed just long enough to form a slug of sufficient size to travel to the receiver without breaking (16 to 28 s).

The water flow was non-uniform with unrestricted units (Test I), the greatest unit flow rate being almost eight times higher than the lowest. The water flow rate per unit was relatively constant for the first nine units and dropped off sharply. The addition of a jetter air vent reduced both the total water flow rate and the variation in flow (Test II). When flow restrictors were added to the jetter hoses, both the total water flow rate and variation were further reduced (Test III). Small oscillations in unit flow rate occur near the ends of the milkline, with a slightly lower flow rate observed in the line nearest the wash valve. This effect is caused by reduction in average vacuum behind the milkline slug and becomes more pronounced as the length of the milkline increases.

The results of studies with air admission to the jetter line only (tests IV, V, and VI) are shown in figure 5. When air was injected to the jetter line the lowest unit flow occurred either near the beginning or the middle of the jetter line. Water was pushed to the end of the jetter line.
when the air injector opened, thereby increasing flow through the distal units and reducing flow to proximal units. Uniformity of flow was more difficult to achieve when air was injected to the jetter line. In general, the most uniform flow distribution was obtained when the injector was closed long enough to flood the entire jetter line and all milking units and then opened just long enough to empty the jetter line and all units. Slight changes in this timing strategy resulted in highly non-uniform water distribution. More importantly, the air injector timing which produced the most uniform flow distribution through the units was not optimal for milking unit slugging (Reinemann and Grasshoff, 1994).

A new air injection strategy was developed to overcome limitations of conventional systems. The air injectors mounted on the milkline and jetter line were sequenced in the following manner. Both air injectors were closed until the jetter line and all milking units were flooded and a sufficient slug was formed at the wash valve. The milkline air injector (A1) was then opened just long enough to move one slug from the wash valve to the receiver. The milkline injector was then closed and the jetter line injector (A2) opened just long enough to empty the jetter line and milking units. The flow restrictor diameters were adjusted so that flow rate through each milking unit was 4 to 7 L/min.

### SUMMARY AND CONCLUSIONS

The distribution of water flow between units should be as uniform as possible to make the most efficient use of water and air when cleaning milking equipment. To avoid exceeding the capacity of the milk pump, the total water draw rate should be no more than that necessary. Milk pump capacity is often the limiting factor in CIP systems.

Adding flow restrictors at the jetter is an effective way of optimizing water flow rates for cleaning and balancing the flow between units. The water flow rate through unrestricted milking unit/jetter combinations can greatly exceed that required for adequate cleaning. Furthermore, because of excessive flow through some units, jetter lines may be drained of water resulting in little or no flow through other units.

Vacuum difference across units is not a good indicator of water flow rate in the full system tests. Units with low water flow rate had a large airflow through in the hoses which increased the variation in vacuum difference across the cluster.

Adding cycled air injection to the jetter line tends to push water to the end of this line when the air injector is opened, thus decreasing flow to proximal units and increasing flow to distal units. The opposite effect was observed with no cycled air admission to the jetter line where the flow capacity of the jetter line can limit the water available to the distal units.

If cycled air injection is applied to the jetter line, the air injector should be opened just long enough to push water out of the distal unit. The accelerated flow which occurs as the units clear should improve cleaning action in the milking unit and eliminate the need for steady air admission through the jetter. The use of jetter air vents will increase the vacuum pump capacity required for cleaning by approximately 32 L/min per milking unit. The injector should be closed at least long enough to flood the line and all units. Increasing the closed time beyond this will improve unit flow distribution and result in fewer air injection cycles per cleaning cycle.

Optimal air injector timing is usually different for jetter lines than for the milkline. If cycled air admission is applied to the jetter line, sequenced air injection should be used so that both jetter and milkline injection timing can be optimized. This will improve cleaning action in both parts of the milking system and reduce the vacuum pump capacity required for cleaning because both injectors will not be opened simultaneously.

Care must be taken to properly adjust the system to obtain sufficient water flow to each unit and balanced flow distribution. Sequenced air injector systems should be timed so that sufficient water is available in the milkline to form a slug. Air admission through the milk hoses from the jetter line injector can move water out of the milkline so an insufficient slug is formed when the milkline injector opens. The milkline injector should opened before the jetter line injector in a sequenced air injector system.

If optimal control strategies, including sequencing of air injection, are used the vast majority of milking systems will have sufficient vacuum pump capacity for efficient cleaning when sized according to the minimum requirement for milking in the ASAE standard S518 (ASAE, 1996).

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