

# System Design and Performance Testing for Cleaning Milking Systems

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As milking systems become more complex, particularly in automated milking parlors, there is an increasing need for engineering information on design and troubleshooting. Improper use of air injection in milking machine CIP systems and inadequate distribution of cleaning solutions are common causes for excessive vacuum pump sizing and cleaning failures. Research conducted at the University of Wisconsin Milking Research and Instruction Lab (UW-MRIL) in cooperation with members of the Milking Machine Manufacturers Council (MMMC), the Energy Center of Wisconsin (ECW), and the UW Center for Dairy Research (UWCDR) has been directed at gaining a better understanding of the physics of Clean-In-Place (CIP) systems for milking machines. These studies have resulted in test methods to evaluate performance and design guidelines for efficient CIP systems. The methods presented here can be used to properly locate and adjust air injection to assure efficient and effective circulation of cleaning solutions.

Both laboratory studies and field experience on an increasing number of commercial dairy farms show that the vacuum pump requirements for cleaning can be less than that for the new recommendations for milking (4). If milking machine CIP systems are designed and operated properly, significant energy savings can result from both reduced hot water use and reduced vacuum pump capacity (4,5,7). A properly functioning CIP system aids in the production of consistently high milk quality, less trouble for the dairy operator and fewer callbacks for the equipment dealer.

## Fundamental Concepts of Milking Machine CIP Systems

Cleaning is accomplished by a combination of chemical, thermal and physical processes. There are four parts to most cleaning regimes:

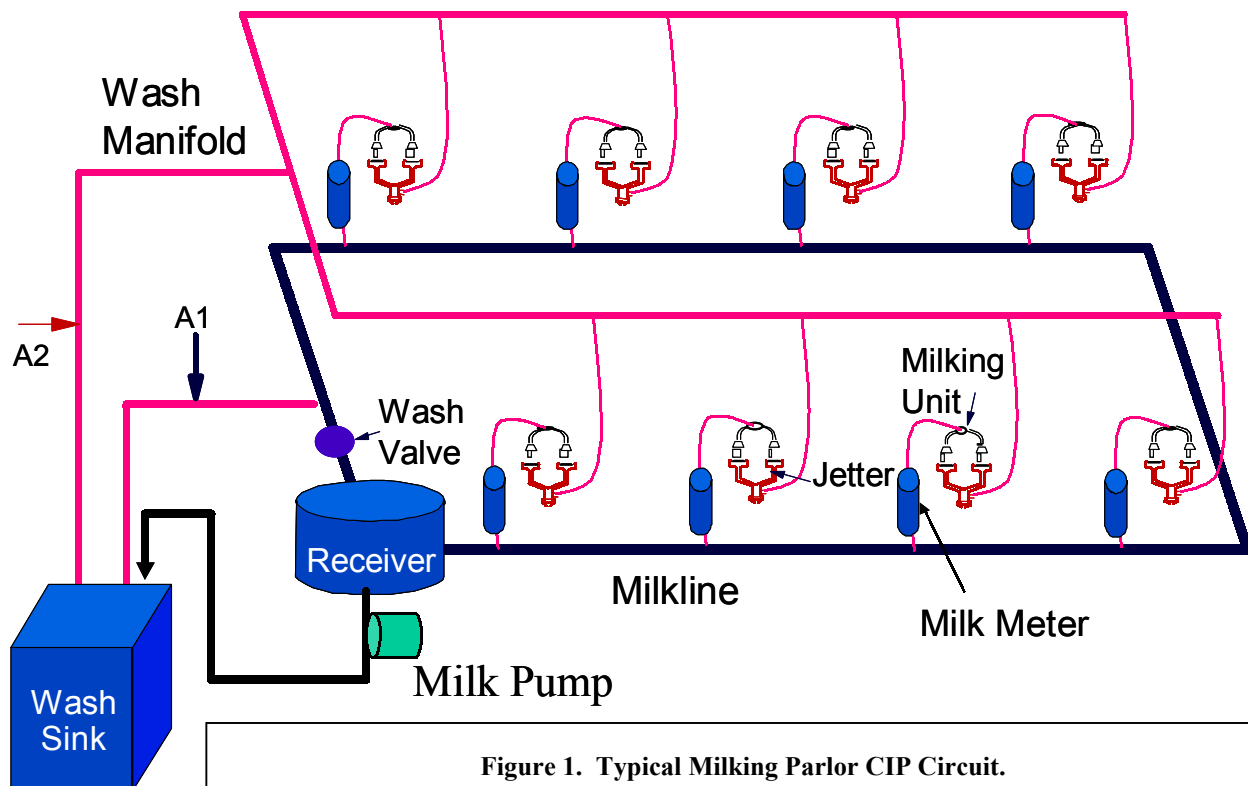
1. An initial rinse, performed immediately after milking is completed, to remove most of the residual milk remaining in the system.
2. A wash cycle, usually with an alkaline detergent, to remove organic soils such as milk fat and proteins. Most detergents require water temperature above 110 F for maximum effectiveness. Detergent concentrations need to be adjusted to account for water hardness.
3. An acid rinse cycle to remove mineral deposits from milk and hard water. The acid rinse also inhibits growth of bacteria during the time the milking equipment is not in use.
4. A sanitizing cycle, usually circulated immediately before milking, to kill bacteria resident in the milking system.

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It is the responsibility of the chemical consultant to prescribe the chemical concentrations, water volume and temperature to be used, based on results of water tests and configuration of the milking CIP system. The chemical consultant should be trained and equipped to perform water quality tests, measure water temperatures and determine if the appropriate chemicals are being used. However, most chemical consultants are not equipped to properly diagnose CIP circulation problems.

It is the responsibility of the milking equipment installer to assure that the appropriate equipment is available and it is set up in such a way that cleaning solutions can be circulated through the milking system for effective cleaning. Setup and troubleshooting of CIP flow dynamics should only be attempted by a qualified service technician with the proper test equipment. Many CIP circulation problems require modification of the system configuration which also requires specialized service tools.



Although system designs vary considerably, typical features of milking parlor CIP systems are shown in Figure 1. Cleaning solutions must be transported from the wash vat through the sanitary parts of the system and back to the wash vat during the CIP process. These solutions must make contact with all milk contact surfaces for sufficient time, and with sufficient physical action, to assure cleaning. 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 in short milk tubes to 4 inches or more in milklines and in excess of 6 inches in milk meters and weigh jars. Flow velocities and flow patterns therefore vary greatly in the different parts of the system. Air injection is normally used to produce slug flow in milklines. Some systems still

flood milklines during cleaning, however. The objectives and optimal control strategies for air and water admission to milking units and other components differ from those for the pipeline. The flow through the jettors and milking units is not slug flow. Milking units are either flooded or alternately flooded and emptied. Large components such as some milk meters and recorder jars are generally cleaned with a spray or sheet of water over the interior surfaces.

In milking parlor CIP systems, milking units are commonly attached to wash assemblies (teatcup jettors) fed from a wash line and cleaned in the parlor. This water-draw pipe network and jettors make up the wash manifold. Cycled air injection may enter through the wash manifold (A1 in Figure 1), the milkline (A2 in Figure 1) 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 1). Air and water are separated at the receiver jar. The air travels to the distribution tank and is removed from the system by the vacuum pump. Water is returned to the wash vat by the milk pump through the milk transfer line.

Milklines must be sloped between 1 and 2 percent toward the receiver jar to prevent slugging in milklines during milking. All other pipelines, hoses and components must also be installed so that they will drain by gravity between cleaning cycles and after cleaning is complete. Drainage is an important aspect of cleaning, because any standing water in the system increases the risk of bacterial growth between milkings and mixing of different cleaning chemicals during cleaning.

Table I. Milking CIP System Control Points

Control Point	Effect
Air Injector Open Time (seconds)	Slug travel distance
Air Admission Rate (cfm) or (L/min)	Slug velocity
Air Injector Close Time (seconds)	Water draw per cycle and initial slug length
Water Flow Restrictors at units	Water flow to each unit Goal is even distribution to all units
Water flow restrictor on line feeding milkline	Reduce water flow to milkline to allow milk pump to keep up
Water Volume	Prevent draining of the sink

### Setup and Troubleshooting Procedures

The control points of a CIP system and the affects of each are summarized in Table I. Proper test equipment is required to properly diagnose CIP circulation problems. Setup and troubleshooting of CIP flow dynamics should only be attempted by a qualified service technician with the proper test equipment. A vacuum recording device, commonly used to evaluate milking performance, is an essential piece of test equipment to assess air injected slug flow during cleaning. Most vacuum recorders have sufficiently rapid response time for this task. More detail on diagnostic methods using a vacuum recorder and analysis of round-the-barn pipeline

systems are given in (9). The following procedure has been developed to diagnose CIP circulation problems.

1) Sketch and measure system: Understanding CIP flow circuits is the first step in CIP system diagnosis. A sketch such as that shown in Figure 2 should be made indicating the diameter and length of all lines and location of critical components such as receiver(s), wash sink(s), air injector(s), wash valve(s) and any other ancillary equipment that is cleaned or used for cleaning. Observe a complete cleaning cycle and observe whether air is being drawn in at the wash sink. Document methods of operation, including the cycles used, air injector timing, approximate water volume for each cycle and any manual or automatic operation of valves before or during the wash cycle.

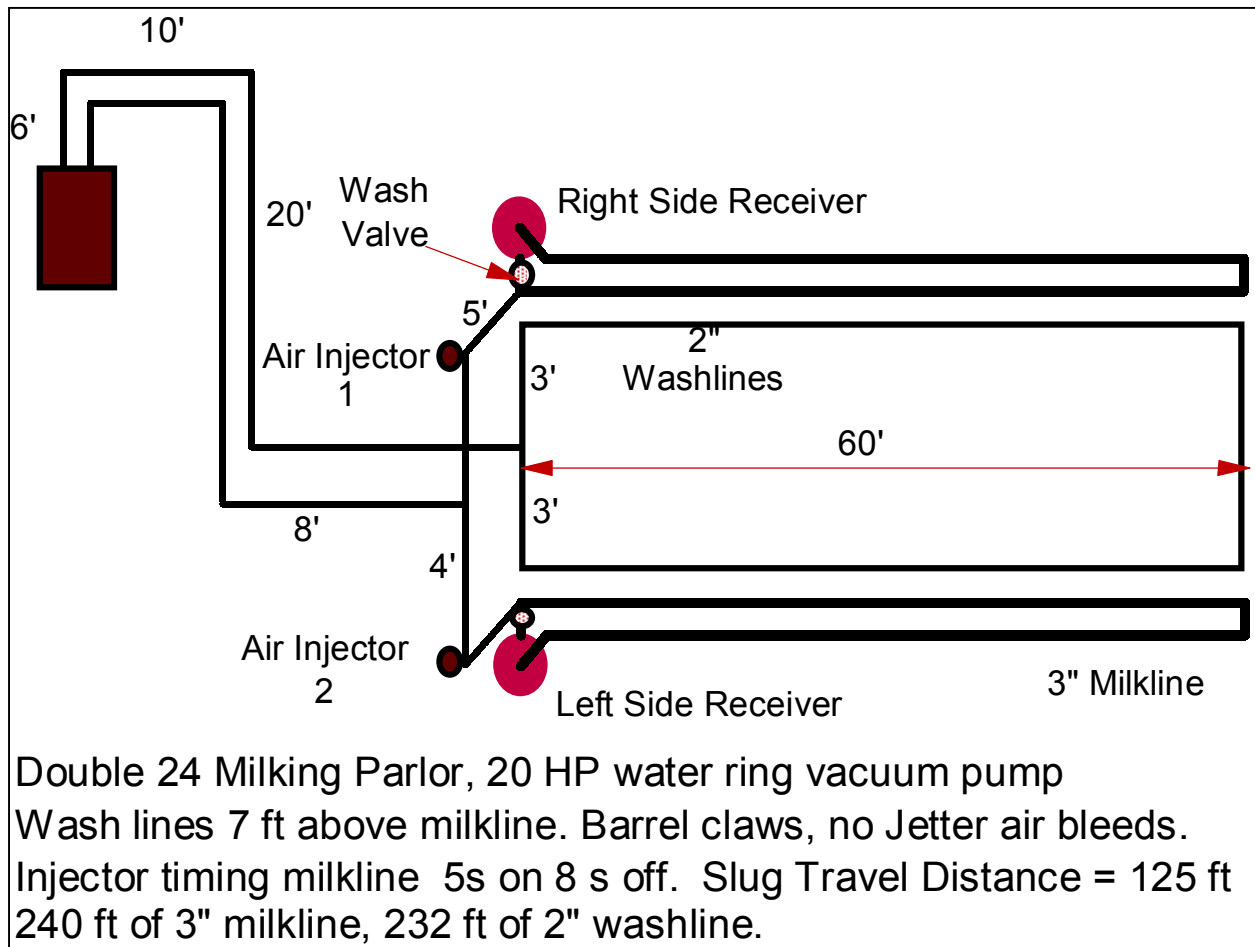


Figure 2. Example sketch and measurements of milking parlor CIP system.

2) Set air injector open time: The air injector open time is a relatively easy number to calculate and should be the first step in setup of an optimal cleaning cycle. The length of time that the air injector is open together with slug velocity determine the travel distance of the slug. The slug formed at the point of air injection should travel to the receiver without breaking. Measure the distance that the slug must travel **from the point of air injection** to the receiver. Divide the slug

travel distance by the desired slug velocity to determine the air injector open time. Slug velocity for optimal mechanical action is between 23 and 33 feet per second (1,6,10,11,12). Velocities above 33 feet per second have been shown to reduce the effectiveness of cleaning chemicals (10). Use a value of 25 feet per second unless the system configuration would warrant a different speed (9).

3) Check slug velocity and adjust air admission rate: Slug velocity should be measured using a vacuum recorder and the air admission rate adjusted to achieve the desired velocity. The rate at which air is drawn in through the air injector determines the travel speed of the slug. A vacuum recording performed simultaneously at two points on the milklime during cleaning is shown in Figure 3. The physical connection to the milklime is best done with a tee inserted in-line with a milk hose near the milk inlet. Sections of transparent tubing 10 to 20 feet in length should be used to connect to the recorder. These tubes should be observed closely and bled often to prevent water from reaching the recorder. To minimize the risk of water entering the vacuum recorder, it is advisable to leave the hoses detached except when a measurement is being taken. Moisture traps will very quickly fill with water and are not recommended. The two channels are recording the same slug as it moves through the milklime (points 1 and 2 in Figure 1). A single channel recorder can also be used but is not as convenient. The following information can be gained from these vacuum recordings:

Slug Velocity: Slug velocity can be calculated by dividing the slug travel distance between the two measurement points (e.g. 1 to 2 in Figure 1) by the time between vacuum drops (a in Figure 3). The test points should be at least 30 feet apart for an accurate measurement.

Vacuum Drop: A rapid vacuum drop is measured when the slug passes the test points. The vacuum drop across a slug (b) is a measure of the mechanical cleaning action produced. The recommended range of vacuum drop across the slug are given in Table II. The vacuum drop should be near the maximum of the range at the beginning of slug travel. This vacuum drop across the slug will decrease slowly as it travels through the line due to slug decay and air entrainment.

Inadequate vacuum drop across the slug indicates that the slug is very short (less than 3 ft) and/or that excessive air is passing through the slug. A slow rate of vacuum drop indicates that the slug is moving slowly, usually because of excessive water in the pipeline or an excessively leaky milk/wash valve.

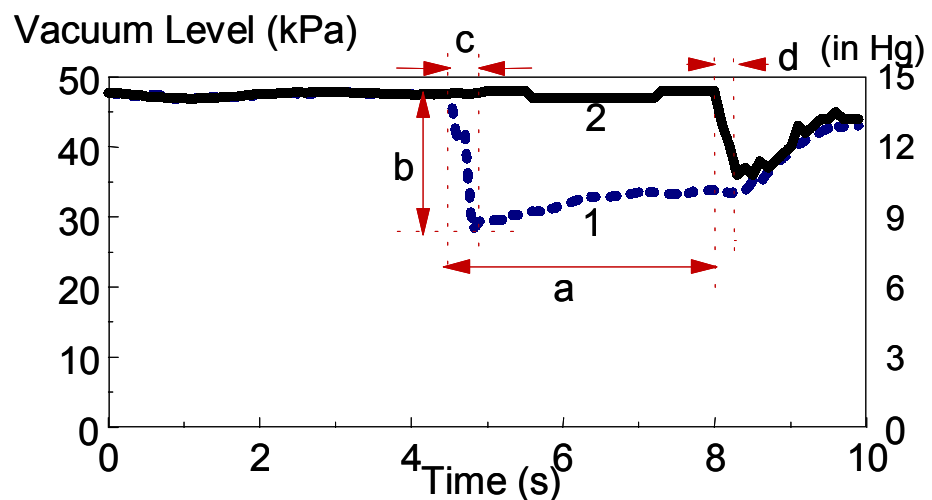


Figure 3. Two channel Vacuum Recording of Slug Flow in Milkline.

Table II. Recommended range of vacuum drop across the slug.

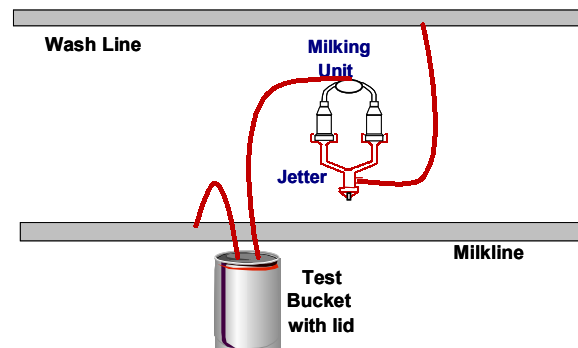
Milkline Diameter	Vacuum Drop
2"	5.3 - 11."Hg
2.5"	4.4 - 9.5 "Hg
3"	3.8 - 8.6 "Hg
4"	3.2 - 7.1 "Hg

4) Set air injector closed (off) time: The amount of water drawn in during each cycle is determined by the amount of time the air injector is closed or off. If the sanitary trap is flooding or excessive water is being transferred through the trap, the close time should be reduced. The close time should be adjusted so the size of the slug reaching the receiver is just sufficient to wash the receiver. If the close time is reduced to the minimum value available on the controller and flooding still occurs, the capacity of the milk pump may need to be increased. Many parlors use “add water” lines to supply water to the milkline in addition to that supplied by the milking units. The water flow through these lines should be restricted in most applications to avoid flooding the system. Independent control of water and air flow is required to archive proper slug velocity and water draw rates.

5) Water flow through milking units: The flow rate through milking units and milk meters can be measured using the method illustrated in Figure 4. The objective when setting up a parlor is to have uniform flow through all milking units (4,8). If the highest and lowest water flow vary by more than 50% flow restrictors should be installed at each milking unit to balance the flow.

Preliminary results from field studies indicate that 0.8 gallons per minute (3 L/min) is sufficient to clean most milking units. While many units will clean at flow rates below 0.8 gpm (3 L/min), the risk of cleaning failure appears to be increased. Some milk meters may require water flow rates higher than 3 L/min for effective cleaning. After flow distribution is balanced make sure that there is sufficient reserve in the wash sink so that the

sink will not empty allowing air to enter the wash manifold. Air entry at the wash sink results in a loss of control over slugging. The method illustrated in Table III can be used to estimate the water volume required for each wash cycle so that the sink will not drain.



**Figure 4. Kink milk hose and place test bucket in line between milking unit and milk line. Un-kink hose for 2 to 5 minutes and measure the amount of water collected in the bucket.**

6) Final vacuum recorder testing and unit flow tests. After the system has been adjusted according to steps 1 to 5, repeat vacuum recorder testing of slug flow. Check for the presence and strength of slug at the beginning, end and other critical locations in the milkline. Fine adjustment of the air injector should be performed at this time. The air injector should close just

before the slug hits the receiver jar. If the air injector remains open after the main slug reaches the receiver, excessive water will be carried through the sanitary trap. After fine adjustment of the air injector, recheck unit flow at critical locations including the first, last, and middle units on both sides of the parlor, and on any units with visible buildup.

### Vacuum Pump Capacity and Control Strategies

New standards have been proposed for the minimum vacuum pump capacity required for milking (2,3). With proper system design and control strategies, the vacuum pump capacity *required for cleaning is* less than that for milking. If optimal control strategies, including sequencing of air injection (4), 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, (scfm).

$Q_c$  = Flowrate of cycled air admission (scfm) to produce 23 ft/s slug velocity in milkline:

Milkline Diameter	Air flowrate
2"	14 scfm
2.5"	20 scfm
3"	28 scfm
4"	49 scfm

$n$  = number of milking units.

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

For systems with more than one air injector, air injection should be sequenced so that both injectors are not open at once. Optimal air injector timing is usually different for wash manifolds than for the milk line. Sequenced air injection allows for optimization of both, thus improving cleaning action in the milking system as well as reducing vacuum pump requirements.

Strategic sizing and placement of flow restrictors at the jetter assemblies will enable precise control of the water flow to each unit to balance system flow distribution.

### Milking Parlor Design Considerations

Milking systems have specific requirements regarding the slope of pipelines and physical relationship between animals and machines. Other physical relationships, while not absolutely required, will greatly improve the performance of the milking system. The milking parlor building should therefore be designed around the milking system. Placement of a milking system in a building not designed specifically for it is likely to result in compromised milking and cleaning performance. Work with an experienced, qualified, milking equipment dealer to assure good results. The selection, design, and installation of a milk handling system must

consider local, state, and federal health requirements. Most milk for sale in the United States is governed by the FDA Pasteurized Milk Ordinance (PMO) and any added local interpretations.

There are several requirements of the milking system which influence building design. The most important of these is the slope of the milklines. Increasing slope greatly increases the carrying capacity of milklines. The pipeline length and slope position of the receiver and mounting requirements of ancillary equipment, such as milk meters, weigh jars, and pulsators, will determine the required clearances. All pipelines in the milking system must be sloped to a drain point. The slope of the other piping systems generally conforms to that of the milklines. The requirement for pipelines can cause clearance problems especially if the cow platform and parlor pit floor slope in the opposite direction as the milkline. Consideration of slopes and clearances are especially important if a parlor is built to be expanded at a later date. The milking system should be designed before the parlor, milk room and utility room so that the building will not compromise milking system design.

A cardinal rule for efficient and effective CIP system design is to keep pipe lengths and number of fittings to a minimum. This will reduce the installation and operational cost of the CIP system as well as improve both milking and cleaning performance. The receiver should be located in such a way that the number of bends and fittings in the milkline are kept to a minimum. The receiver should not be placed in a location that will interfere with movement of the operators during milking. Receivers are most commonly installed in the operator area, in breezeways or in the milkroom. The wash sink is generally located near the bulk tank inlet to facilitate piping to switch from the milking to cleaning configurations. The length of piping from the milkroom to the parlor should be kept to a minimum to reduce cleaning water volume, heat loss during cleaning and difficulties controlling circulation. The utility room should be located to minimize the length and number of fittings of the main air line connection vacuum pumps with the distribution tank and/or sanitary trap.

## **Conclusion**

Improper use of air injection is a major cause of cleaning failures and excessive vacuum pump sizing. The methods presented here can be used to properly locate and adjust air injection to assure efficient and effective circulation of cleaning solutions. If milking machine CIP systems are designed and operated properly, significant energy savings can result from both reduced hot water use and reduced vacuum pump capacity. A properly functioning CIP system aids in the production of consistently high milk quality, less trouble for the dairy operator and fewer callbacks for the equipment dealer.

Table III. Example calculation for the minimum water volume required per wash cycle for proper flow dynamics in a typical 16 unit (double 8) milking parlor. NOTE: the water requirement for milk meters, wash vat and precoolers are approximate and may vary.

Feet of Milkline	Line Diameter	Multiplier	Gallons
	4"	0.12	0
100	3"	0.07	7
	2.5"	0.05	0
	2"	0.03	0
	1.5"	0.02	0
Feet of Wash Draw and Milk Transfer Line	Line Diameter	Multiplier	Gallons
	3"	0.34	0
	2.5"	0.23	0
40	2"	0.15	6
80	1.5"	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
Feet of Milk Hose	Hose Diameter	Multiplier	Gallons
	9/16"	0.012	0
160	5/8"	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



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