AIRFLOW REQUIREMENTS, DESIGN PARAMETERS AND TROUBLESHOOTING FOR CLEANING MILKING SYSTEMS

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INTRODUCTION

Effective chemical solutions at the proper temperature must contact all surfaces of the milking system for sufficient time and with sufficient velocity for successful cleaning. A wide variety of clean in place (CIP) system designs are used to meet these objectives. These have been developed through trial and error over a number of years. Common design rules of thumb often result in excessive vacuum pump size, hot water and energy use and operational cost. There has been a lack of information for system design and troubleshooting methods to evaluate cleaning performance and identify sources of cleaning failures. The most common method for evaluating the success of a cleaning system is a plate count of the milk in the bulk tank. Newer testing procedures such as PI count are more accurate indicators of the adequacy of system cleaning. These tests still indicate only overall system performance but do little to identify the specific causes of cleaning failure.

AIR INJECTED SLUG FLOW DYNAMICS

Air injection is used on virtually all modern milking systems in North America to produce slug flow and enhance cleaning. An understanding of the basic dynamics of slug formation, slug growth and decay are essential to properly setup and troubleshoot a cleaning system. An air injector is an automatically controlled air valve which is usually mounted on the milkline or washline. Air and water are admitted alternately into the pipeline by opening and closing the air injector valve. This process produces a slug of water which travels through the pipeline. Ahead and behind the slug, the pipe is partially filled by a liquid layer which moves in the same direction as the slug but at a lower velocity (Figure 1).

The slug picks up liquid at its face and loses liquid at its tail as it travels. The rate of water pickup is directly proportional to the fill depth in the pipe ahead of the slug. If fill depths are greater than about 20 percent, as usually occurs in the first 10 to 20 meters (30 to 60 feet) of slug travel, the slug will grow longer. If pipe fill is less than 20 percent, as is the case in the remaining pipeline, the slug length decreases. In a pipeline adjusted according to the recommendations given here a slug will lose about 1 meter of length for each 20 meters of travel (1 foot / 20 feet) and will be filled to about 20 percent of its total volume when averaged over the entire milkline. The initial slug must be long enough so that sufficient slug length is maintained at the end of the pipeline.

Slug velocity is controlled by the amount of air admitted through the air injector. There are limits to the range of slug velocities obtainable. If the velocity is below about 4 m/s (13 ft/s) it is difficult to maintain a slug. If velocities are above about 12 m/s (40 ft/s) excessive mixing of air into the slug acts to break it apart. Mechanical cleaning action is enhanced by increased slug velocity but is reduced when air is mixed into the slug. The optimal range for cleaning appears to be between 6 and 10 m/s (20 to 33 ft/s). The amount of air admitted through the injector should therefore be adjusted to achieve slug velocities in this range.

One air injection cycle is composed of a closed or off phase in which water is drawn into the system and an open or on phase in which air is admitted. Many air injectors are adjusted with open times too short to allow the slug formed at the air injection point to travel completely around the pipeline. The slug then breaks and travels for some distance as an elongated wave which does not fill the pipe section. This wave may be picked up as a slug in the next air injection cycle, however, a portion of the top of the milkline will have no contact with the cleaning solution resulting in a cleaning failure. If one slug is formed at the beginning of the cleaning circuit and maintained throughout, all surfaces are <u>assured</u> contact with the cleaning solution. This is therefore recommended and is the basis for the setup and troubleshooting guidelines presented here. For more details on CIP slug flow dynamics see Reinemann and Grasshoff (1992, 1993).

COMPONENT SIZING AND SYSTEM CONTROL

The following design and control concepts apply to all system designs. Special requirements for particular system layouts are given in the following section.

<u>Water draw per air injection cycle</u>: Receiver volume and geometry determine the maximum allowable slug size delivered to the receiver at the end of the milk line. This usually amounts to about one third of the receiver volume. Water in excess of this will flood the sanitary trap. Delivery of the maximum size slug to the receiver during each injection cycle will provide the greatest washing action in both the receiver and milkline in the shortest time. The approximate initial slug length, or water drawn in per air injection cycle, can be calculated knowing its desired final length, total travel distance and average decay rate over the length of travel (Eq. 1).

<u>Milk pump capacity</u>: The capacity of the milk pump is often a limiting factor in CIP system design. The water introduced during each air injection cycle must be removed by the milk pump. If not, the sanitary trap will flood. Increasing system vacuum and discharge head from milk filters, plate coolers or any other device in the milk discharge line will reduce pumping capacity. The milk pump capacity at system vacuum and operating discharge head should be determined from a manufacturers pump capacity curve and measured vacuum and discharge pressures or by measuring the time required for the pump discharge to fill a known volume (bucket or sink) under operating conditions. The milk pump capacity divided by the water introduced per cycle will yield the minimum air injection cycle time (Eq. 2). The system should be operated near this level so the maximum cleaning work is done before wash solutions cool.

Air admission rate: Air admission rate through the air injector is the key to controlling slug velocity. The air admission rate can be controlled by changing the system operating vacuum and/or by controlling the restriction through the air injector (usually by adjusting the size of the air inlet orifice). Recommended ranges for air admission through the air injector for various pipeline sizes are given in Table I. Increasing air admission above the maximums suggested in the Table will result in reduced slug density and reduced mechanical cleaning action in the milkline.

Table I. Air injection rate required to produce slug velocities from 6 to 10 meters per second (20 to 33 ft/s).

Line Size	Air flow rate	Vacuum Differential
48mm (2")	6-12 L/s (12-25 scfm)	20-35 kPa (6-10 "Hg)
60mm (2.5")	9-18 L/s (18-39 scfm)	18-32 kPa (5-9 "Hg)
73mm (3")	13-27 L/s (27-58 scfm)	15-28 kPa (4-8 "Hg)
98mm (4")	23-49 L/s (48-104 scfm)	10-20 kPa (3-6 "Hg)

Air admission through the injector can be calculated from the slug velocity using Eq. (3). Slug velocity can be measured using a vacuum recording device (see troubleshooting section). The air admission rate of an air injector can also be measured using an air flow meter as follows: With the vacuum regulator deactivated, measure difference between the air admission at or near the receiver with the air injector open and closed. The air injector controller will have to be bypassed to hold the air injector open for measurement purposes. This test should be done at 20 kPa below the regulated system vacuum during washing because this will be the approximate vacuum level at the air injector during washing. Most air flow meters are calibrated to read correctly at 50 kPa (15 "Hg) vacuum. Compensation must be made for air flow readings taken at the lower vacuum levels required for this test. Typical multi orifice air flow meters will read about 10 percent high at a vacuum of 30 kPa (9" Hg) and about 30 percent high at a vacuum of 15 kPa (4.5" Hg). If the air admission rate of the air injector is known under the operating conditions, the resulting slug velocity can be calculated directly using Eq. (3).

The air injector may have to be adjusted to admit more or less air if the slug velocity is not in the appropriate range. Reducing the regulated system vacuum during washing or restricting the air injector will reduce air admission rate. Some milk/wash valves may short circuit a significant volume of injected air directly to the receiver. The valve may have to be fitted with closer tolerances or the air injection rate increased to overcome this effect.

Air injector open time: The air injector open time should be set so that the slug formed at the beginning of the line has enough time to travel completely around the milkline circuit. The suggested range of slug velocities is 6 to 10 meters per second. The injector open time is then calculated by dividing the total slug travel distance by the average slug velocity (Eq. 4). If air injectors are mounted on a wash line remote from the milkline the length of the wash line should be added to the slug travel distance and injector open time increased accordingly.

The injector open time may have to be adjusted slightly from the calculated value to assure adequate washing of the receiver while avoiding flooding. In most cases the injector should be closed just before slug enters the receiver to slow the slug and avoid the entry of excessive water into the sanitary trap. Large volume receivers may need increased slug volumes in order to properly wash the top of the vessel. If increased slug action is desired to wash all receiver surfaces the air injector can be left open until the slug completely enters the receiver.

Air injector closed time: Some water will be drawn into the pipeline when the air injector is open. This water will form part of the next slug. The closed time should be long enough to finish drawing the remainder of the desired water per cycle. The water draw can be determined by measuring the drop in the wash sink during the injector open and close times. This is best done during the first few air injection cycles before water is returned to the sink by the milk pump. If all or most of the desired water volume is drawn in during the injector open time, the injector cycle time (open +closed) will be less than, or only slightly longer, than the minimum required. Restriction of the draw line is necessary in this situation to achieve efficient water usage. Restrictions should be placed between the air injector and the wash sink. The detachable portion of the draw line or hose used to draw water into a wash manifold are good locations for these. This will reduce the water draw rate during the air injector closed phase and not restrict air flow during air injection. Certain milk/wash valves will bypass more water than others. Injector closed time may have to be increased to compensate for excessive bypass of water to the receiver.

Vacuum pump capacity: During washing air is drawn into the system through 1) the air injector, 2) equipment operating during washing, 3) the minimum air requirement of the vacuum regulator and 4) system leaks. Maintain sufficient water reserve in the wash sink so that milking units suspended in the wash sink or water draw lines do not draw air during the wash cycle. The air drawn in through the injector during the time it is open can be estimated or measured (see air admission rate section). Additional air admitted to the system through equipment, regulator and system leaks can be measured in the same way as for system usage during milking.

If the regulated vacuum level for cleaning differs from that during milking, the test should be done at the regulated washing vacuum level. This system usage air admission together with the air admitted through the air injector ($A_s + A_i$) must be removed by the vacuum pump over the course of one air injection cycle. If the air admission during the injector open phase exceeds the vacuum pump air flow capacity, the system vacuum will fall. The vacuum level in the system can be allowed to vary if appropriate adjustments are made. The system should, however, recover to the vacuum set point during the air injector closed phase. The range of acceptable vacuum pump capacity is calculated using Eq. (5).

If the vacuum pump capacity is greater than the maximum figure, system vacuum will be maintained during washing. Vacuum pump capacity above this level will not improve cleaning performance. If vacuum pump capacity is between the maximum and minimum recommended range system vacuum will drop during the air injection open phase, but recover to the regulated vacuum level during the injector closed phase.

Vacuum level during washing: Vacuum stability during washing is not an important factor as it is during milking. In some situations it may be advantageous to change the system vacuum level washing. Decreasing the vacuum level will result in: 1) decreased air admission rate through the injector, 2) decreased water draw rate, 3) increased milk pump capacity, and 4) increased vacuum pump performance. Increasing vacuum level will have the opposite effect on these parameters.

If water draw rates exceed milk pump capacity, lowering vacuum will both decrease water draw rate and increase milk pump capacity and vacuum pump performance. Lowered vacuum level is thus an alternative to installing a restriction in the water draw line. If vacuum is lowered during washing the air injector orifice size must be increased to admit sufficient air to maintain the desired slug velocity.

Increased vacuum level will overcome unavoidable restrictions in the water draw line and increase air injection rate if the air injector orifice cannot be changed. Appropriate adjustments to injector cycle times and/or air injector restriction should be made whenever vacuum levels are increased or decreased.

USING A VACUUM RECORDER TO TEST CLEANING PERFORMANCE

A vacuum recording device, commonly used by milking equipment dealers to evaluate milking system performance, can provide valuable information for troubleshooting cleaning systems. Most modern electronic vacuum recorders have sufficiently rapid response time for this task. A two-channel vacuum recording performed at two points on the milkline (points 1 and 2 in Figure 3) during washing is shown in figure 2. The two channels are recording the same slug as it moves through the milkline. Moisture traps should not be used when making the physical connection to the line. If a trap is used it will very quickly fill with water and may distort readings. Connection from the milkline (milk inlet or needle through a rubber gasket) to the recorder is best done with sections of transparent tubing 3 to 6 meters (10 to 20 feet) in length. These tubes should be observed closely and bled often to prevent water from reaching the recorder.

Vacuum Drop: A rapid vacuum drop is measured when the slug passes the test points (c and d in Figure 2). The vacuum drop across a slug (b) is a direct measure of the mechanical cleaning action produced. This vacuum drop across the slug will decrease slowly as it travels through the line due to slug shrinkage. The desired vacuum drop across the slug will depend on the line diameter and the slug travel distance. The figures in Table I indicate the recommended range of slug vacuum differential for differing milkline size. The differential at the beginning of the milkline should be near the maximum of the range and near the minimum of the range near the end of the milkline. Although a single test point can be used to check for vacuum drop and slug presence, no relational information is provided for determining slug velocity or length. A two channel recording is recommended.

Inadequate or slowly varying vacuum drop indicate that the slug is either moving very slowly or it is short (less than 1 meter, 3 ft) and/or that excessive air is passing through the slug. These phenomena decrease the cleaning action of the slug. Slug length can be increased by increasing air injection closed time and drawing more water per cycle into the system. A possible cause for low slug velocity and inadequate vacuum drop across a slug is an excessively leaky milk/wash valve.

Slug Velocity: Slug velocity is determined by measuring the slug travel distance between the two vacuum measurement points (e.g. 2 to 3 in Figure 3) and dividing by the time between vacuum drops on the recording (a in Figure 2). When checking the velocity it is important to have the tests points at least 10 meters (30 feet) apart in order to get an accurate measurement. When checking for the presence of a slug (vacuum drop only) test points may be closer together. The slug normally accelerates to its stable velocity in the first 5 meters (15 feet) of travel. The slug velocity in this region will therefore be slower than in the rest of the system. A rapid increase in slug velocity in the later portion of travel is an indication that the slug is shrinking rapidly and will likely dissipate.

Slug length: Slug length can be calculated by multiplying the measured slug velocity by the time during which the rapid vacuum drop occurs (c). Rapid sampling and display rate is required to accurately measure slug length. When checking the length of the slug, the recorder should be set on the highest sampling rate and fastest chart speed for the most accurate reading. The duration of rapid vacuum drop early in the line (b in figure 2) will normally be longer than that later in the line (d in figure 2) indicating the decrease in slug length as it travels.

These measurements can be used to aid in system setup particularly for adjustment of air injection cycle times and air admission rates. After system setup, vacuum recordings should be made along the entire milkline to assure that good slugging is occurring at all points in the system. These test are particularly important on the return legs of Y systems and before and after vertical sections of milkline (risers).

CONSIDERATIONS FOR VARIOUS SYSTEM DESIGNS

Single loop round-the-barn pipeline: Round-the-barn (RTB) pipelines with single loop milklines (Figure 3) are the simplest system layout. Water is drawn from the wash sink through milking units into the milkline. The air injector is mounted on the washline near the entry to the milkline. A slug is formed at the wash valve and moves through the pipeline back to the receiver. The water is returned to the wash sink by the milk pump.

The entire length of milkline is used as the slug travel distance. When more than 4 milking units are on a draw line the water draw rate may exceed milk pump capacity. Reducing the system vacuum during washing or adding a restriction in the draw line between the air injector and the units may be required to control water draw rate. Wash valves which automatically open to drain between each cleaning cycle are recommended to avoid mixing of different chemical solutions. Use the values from Table I to determine required air admission rates. Vacuum recordings should be performed at points 2 and 3 for existence of slugs. Check velocities between points 1- 2, 1- 3 or 2- 3 if Figure 3.

Double Y pipeline: The double Y pipeline configuration is common when the milk house is in the middle of the barn or in three row barns (Figure 4). This configuration be used only when lines on each side of the Y the are of equal length. When the sides are unequal it is common for the longer side to experience cleaning failure. It is recommended that the milk/wash valve and the wash manifolds be connected to the shorter common outgoing line. This allows for better control of slugs as they recombine in the longer common return line. When systems are set up according to these recommendations, the slug will split at the outgoing Y and slug velocity in the common return lines will be about double the velocity of that in each side. Set air admission rate through the injector using figures in Table I so that the single line velocity is about 12 m/s (40 ft/sec). This will result in velocities of approximately 6 m/s (20 ft/sec) on each loop.

The initial slug size must be double as it will split about evenly at the outgoing Y. Use the length of the line to the return Y to calculate initial slug length so that the slugs decay to near their minimum allowable length before recombining. The initial slug length must be increased by 1 m for every 10 m of length over 10 m (1 ft / 10 ft over 30 ft) on the common return line so that the combined slug will not decay before reaching the receiver. Check slug velocities between test points 2-5, and 3-4, and 6-7. Perform simultaneous recordings at points 2 and 3 to assure that the slug is splitting evenly between the two loops during each injection cycle and for slug existence at points 4, 5, 6 and 7 in Figure 4.

Single Y pipeline: The single Y configuration divides the pipeline into two separate flow paths (Figure 5). This is the recommended configuration if the milklines on each side of the receiver are of different length. Two air injection points controlled from a common timer are recommended. Water draw and air injection enter each side of the milkline and are separately adjustable to account for different lengths of line.

The velocity of the slug on the longer side should be higher that the velocity on the short side so that the slug on the longer side reaches the return Y before the slug on the shorter side reaches the receiver. This is accomplished by separate adjustment of the air admission rate on each injector. The initial slug lengths on each side are independently controlled by varying the number of units feeding each side or by using restrictors in the wash line between the units and air injection point. If the length of the short loop plus the common return is equal to the length of the long loop, slug velocities should be adjusted so that slugs meet at the return Y.

The maximum slug velocity will occur in the common return line. Set the air admission rate from Table I so that the velocity on the short loop is about 6 m/s (20 ft/s). Set the injector open time and initial slug length so that this slug will travel all the way back to the receiver. Set slug velocity on the long run to reach the return Y at the end of air injector open time. This slug will drain back to the receiver during the injector close time. Initial slug length may have to be increased to account for accelerated slug decay in the common return line. Check slug velocities between points 1-4, and 2- 3 in figure 5. It is especially important to assure that consistent slugging is occurring at all points in the line with a vacuum recording device (points 3,4 and 5 in Figure 5).

Parlor Systems: Parlor systems differ from round-the-barn pipeline systems in that milking units are commonly attached to a wash line/jetter circuit and cleaned in the parlor (Figure 6). Air may be injected through the unit washing assembly (A1 in Figure 6), in the milkline (A2 in Figure 6) or both. Water and varying amounts of air are added to the milkline throughout much of its length rather than at a single point as in RTB systems. The design objective is the same as for RTB pipeline systems: 1) one slug should be formed at the milk/wash valve when the injector opens; and 2) this slug should then be moved around the entire milkline to assure contact with all surfaces.

The major problem in washing parlor systems is obtaining adequate distribution of water to all units and even distribution among the units. Methods currently used for even distribution include limiting the number of units on any one wash feed line, increasing the size of wash feed lines and dividing the system into several sub-circuits with automatic control valves. Virtually all parlor units with detachers have an automatic vacuum shutoff valve in the milk hose of each unit. With a simple modification to most existing equipment, the automatic vacuum shut off valve can serve as a control point for dividing parlor cleaning systems into manageable sub-circuits to assure adequate cleaning of both milking units and the milkline. Further research is needed to develop design guidelines for implementing control strategies for optimizing water distribution in parlor systems.

The methodology developed for RTB pipeline systems has been successfully used in parlor situations with up to 16 units (8 per side). Preliminary laboratory and field studies indicate that it is common for multiple slugs to form in the milkline in parlor systems. This probably because the distribution of water in the milkline is more uniform than in RTB pipeline systems resulting in several points in the system with sufficient fill for slug formation especially when water draw rates are not controlled. Some equipment such as milk meters and sensors may require air injection for proper cleaning. Air injection through the wash line tends to increase flow velocities through units but decreases slugging action in the milkline.

Milk pump capacity is often a limiting factor in milking parlors. Special consideration must be given to controlling the total water draw rate to avoid exceeding the capacity of the milk pump. Prechilling devices and filtering assemblies can significantly reduce milk pumping capacity. It is particularly important to measure milk pump capacity and water draw rate to determine the minimum allowable air injection cycle time and maximum allowable injection cycles per minute in parlor systems. Milk pump capacity, water draw rate and slug presence and velocity can be measured in the same way as in RTB pipeline systems.

An additional water feed line to the milkline near the wash valve is sometimes added to parlor systems. The size of this extra drop line should be the same size as the drops to the units to maintain efficiency of water use. Some companies suggest installation of an automatic control valve triggered off the air injector in this drop line so that only air travels through this line during the injector open time. When the air injector is mounted on a pipe remote from the milkline, i.e near the wash sink, a restrictor should be installed between the air injector and the wash sink to limit water draw but not air injection. Add the length of this draw line between the air injector and the milkline to the total slug travel distance.

Measure slug velocity between points 1-2 in Figure 6. Check for existence of slugs at points 1, 2, 4, 6 and 8 in Figure 6. In all parlor systems it is important to assure even distribution of water to all units to make most efficient use of wash water and ensure proper cleaning of all units. The vacuum differential across the milking unit/jetter assembly will determine the water flow through each unit. Check for distribution of water between units by measuring the vacuum differential between points 3-4, 5-6, etc in Figure 6.

REFERENCES

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EQUATIONS

I_o	=	Injector open time (s)
I_c	=	Injector close time (s)
L	=	Total length of slug travel in milkline, milk/wash valve to receiver (m)
D	=	Internal diameter of milkline (mm)
R	=	Receiver volume (L)
W	=	Water drawn in per cycle (L)
M	=	Milk pump capacity under operating system vacuum and discharge head (L/m)
A_i	=	Air admission through air injector under operating conditions (L/m, standard air)
A_p	=	Vacuum pump capacity (L/m, standard air)
A_s	=	System air admission from unit operation, regulator and leaks (L/m, standard air)
V_{slug}	=	Slug velocity (m/s)
Vac	=	System vacuum during washing (kPa)

$$W = \frac{R}{3} + \frac{L\ D^2}{26000} \qquad (1)$$

$$Io + Ic > 60\,\frac{W}{M} \qquad (2)$$

$$A_i = \frac{V_{slug}\ D^2}{17}\ \frac{100 - Vac}{100} \qquad (3)$$

$$I_o = \frac{L}{V_{slug}} \qquad (4)$$

$$A_i + A_s < A_p < A_i + A_s \frac{I_o}{I_o + I_c} \qquad (5)$$

EQUATIONS
(American Units)

I_o	=	Injector open time (s)
I_c	=	Injector close time (s)
L	=	Total length of slug travel in milkline, milk/wash valve to receiver (ft)
D	=	Pipeline Diameter (in)
R	=	Receiver volume (Gallons)
W	=	Water drawn in per cycle (Gallons)
M	=	Milk pump capacity under operating system vacuum and discharge head (GPM)
A_i	=	Air admission through air injector under operating conditions (cfm, standard air)
A_p	=	Vacuum pump capacity (cfm, standard air)
A_s	=	System air admission from unit operation, regulator and leaks (cfm, standard air)
V_{slug}	=	Slug velocity (ft/s)
Vac	=	System vacuum during washing (in Hg)

$$W = \frac{R}{3} + \frac{L\ D^2}{1200} \quad (1)$$

$$Io + Ic > 60\,\frac{W}{M} \quad (2)$$

$$A_i = \frac{V_{slug}\ D^2}{2.5}\ \frac{30 - Vac}{30} \quad (3)$$

$$I_o = \frac{L}{V_{slug}} \quad (4)$$

$$A_i + A_s > A_p > A_s + A_i \frac{I_o}{I_o + I_c} \quad (5)$$

Figure 1. Slug Flow.

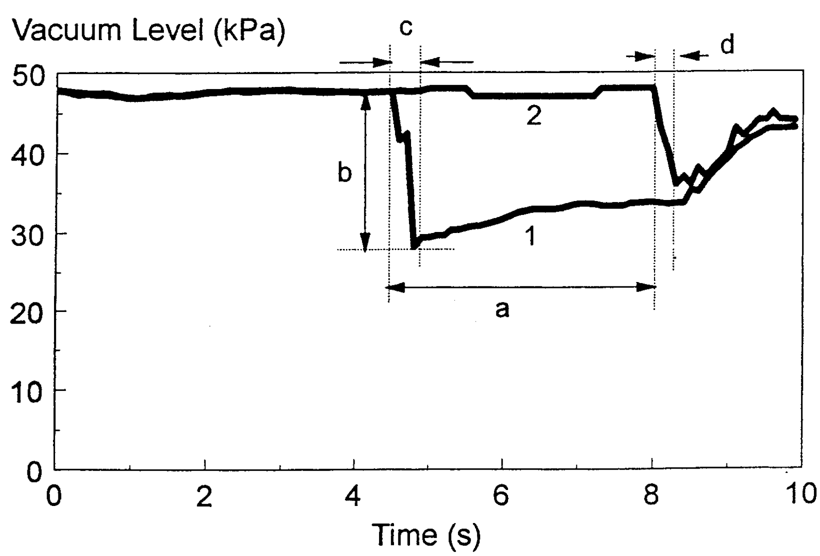

Figure 2. Example Dual Channel CIP Vacuum Recording

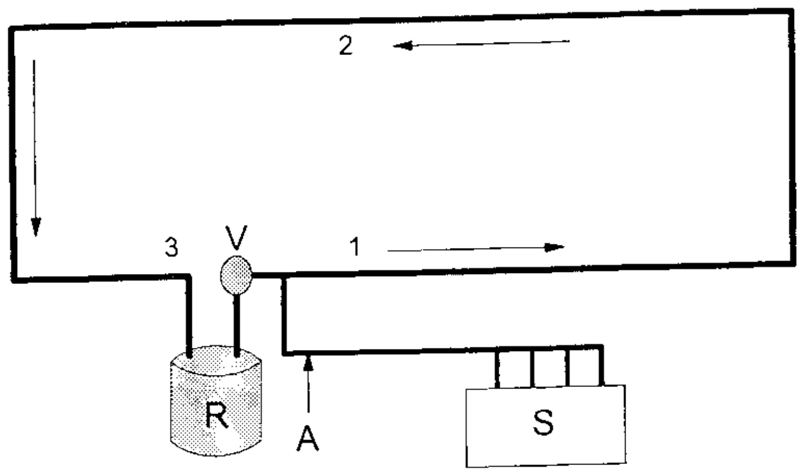

Figure 3. Single Loop Pipeline. Key for all system diagrams: R=receiver, S=wash sink, V=milk/wash valve, 1,2,3,... = test points.

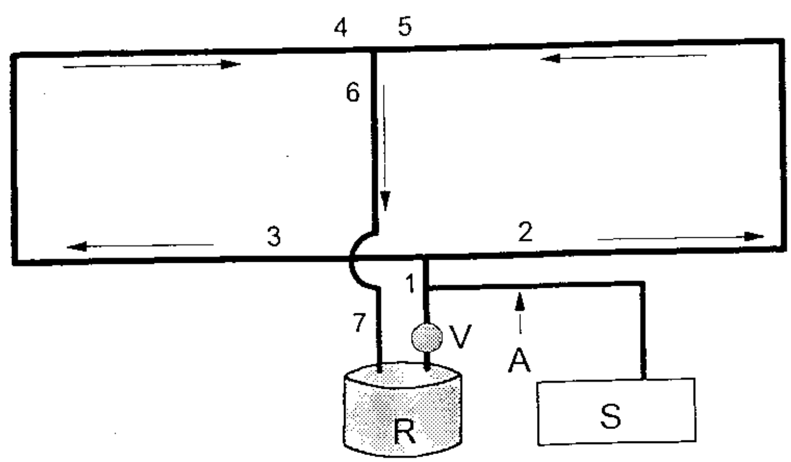

Figure 4. Double Y Pipeline

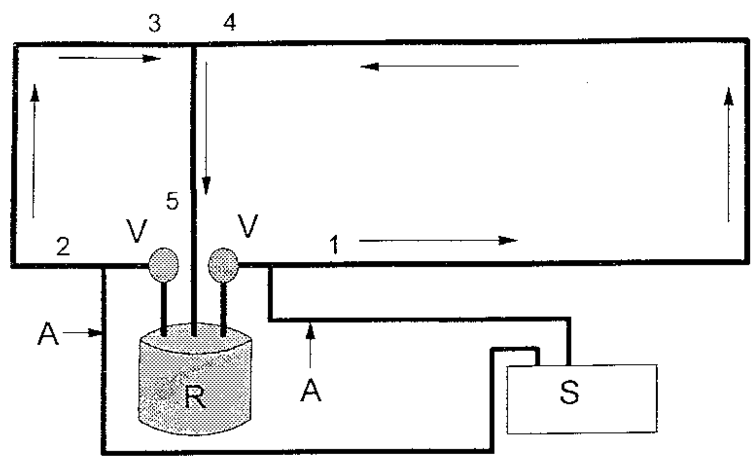

Figure 5. Single Y Pipeline

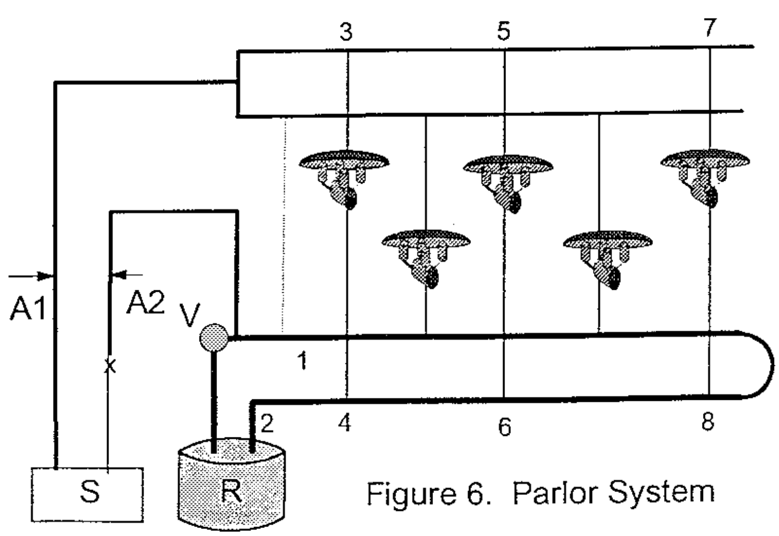

Figure 6. Parlor System