Sizing Milking System Milklines and Airlines

Douglas J. Reinemann, Assistant Professor of Agricultural Engineering
University of Wisconsin - Madison

Steven B. Spencer, Professor of Dairy Science
The Pennsylvania State University

Graeme A. Mein, Visiting Professor of Dairy Science and Medical Sciences - School of Veterinary Medicine
University of Wisconsin – Madison

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The design of modern milking systems is the result of extensive field experience and trial and error. As milking systems become more complex, particularly in automated milking parlors, there is increasing need for engineering information for design and troubleshooting.

There are several piping systems in a modern milking machine which must be sized to perform milking and CIP cleaning functions properly. The various piping systems must carry milk, air, or both while maintaining the proper vacuum levels to perform the milking function. The flow paths of milk and air for typical pipeline and recorder milking systems are illustrated in Figures 1 and 2.

The piping systems which may be found in milking machines and their functions are:

In pipeline systems - those systems without recorder (weigh) jars

> <u>Milklines</u> transport <u>milk and air</u> from the milking unit to the receiver in pipeline systems. Milklines supply milking vacuum to the claw. Steady air flow unobstructed by undersized lines or slugs of milk will produce a reasonably stable milking vacuum supply throughout the milkline system.

In recorder systems - those systems with recorder (weigh) jars

> <u>Milk transfer Lines</u> transport <u>only milk</u> from recorder jars (weigh jars) to the receiver. These sanitary lines carry no air and do not supply milking vacuum.

> <u>Milking vacuum lines</u> transport <u>only air</u> from recorder jars (and some type of milk meters) to the sanitary trap. These sanitary lines supply milking vacuum to the recorder jar which is connected to the claw by the long milk tube. These lines also transport water from the wash vat to the recorder and milking unit during washing.

In both pipeline and recorder systems

Main airlines transport only air from the sanitary trap or distribution tank (header tank, balance tank) to the vacuum pump where it is removed from the system. These are non-sanitary lines.

Pulsator airlines transport only pulsation air from pulsators to the distribution tank or main air line. These non-sanitary lines supply the desired vacuum level to the teatcup pulsation chambers. Pulsation air is cyclically removed from the pulsation chambers to open and close the liners to perform the milking function. Pulsator airlines may also transport air used from various vacuum-operated devices such as automatic milking unit detachers.

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 water solutions must completely fill the pipe cross section to assure cleaning of all surfaces. This is accomplished by flooding lines or by forming slugs of cleaning solutions. Milk hoses and milking units are usually flooded during cleaning. Milk pipelines are generally washed by producing slug flow. Air injection provides the force to form and move these slugs through pipelines. Air and water are then 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 via the milk/wash transfer line.

Sanitary pipes carry milk and/or wash solutions and are typically constructed of stainless steel. Some sanitary fittings such as elbows, valves, and various milking machine components are made of various types of plastic. Synthetic rubber is used for flexible hoses which carry milk and air from the milking unit to the rigid pipeline. Non-sanitary pulsator and main vacuum supply lines, intended to carry only air, are typically constructed of PVC plastic.

The milking system is under partial vacuum. A steady vacuum level is important for the uniform function of the milking unit. The regulator controls the vacuum level in the system by admitting air to balance the air entering the system and the air being removed from the system. If more air is entering than being removed the vacuum level drops. If more air is being removed than is entering the vacuum level rises.

PIPE SIZING CONSIDERATIONS

The main concern when sizing milking system pipes is to limit vacuum fluctuations to some acceptable level. No US standards have been developed for vacuum drop limitations in milking system. The authors suggest a maximum vacuum drop of 0.5 inches of mercury from the pump to the receiver. The type of fluid (air,milk, or water) flowing in the pipe, the speed at which it is flowing, the pipe diameter, length and number and type of fittings must be known to predict vacuum drop. In the case of mixed gas-liquid flows the flow pattern must also be known. The appropriate pipe dimensions must be chosen to satisfy both milking and cleaning functions of the system.

Fittings and restrictions can account for a major portion of the vacuum drop across the system. Fitting losses can exceed the loss in straight pipes in systems with excessive bends, tees and other fittings. For both milk and air lines it is desirable to keep pipe length and the number of fittings to a minimum. This will reduce the cost of the system, reduce vacuum drop and fluctuation, and make vacuum control and cleaning easier.

Undersized systems will result in larger vacuum differences across the system under steady flow conditions and larger vacuum fluctuations under dynamic conditions.

Oversized systems complicate the cleaning task because of the difficulty of producing slug flow in larger diameter lines and because the surface area which must be cleaned is increased. Larger diameter lines thus require larger vacuum pumps, more hot water and more cleaning chemicals.

Larger pipes also increase system volume which adds damping to the system. Increased damping will decrease the speed and magnitude of a vacuum drop caused by unintended air admission but the time to recover system vacuum will be longer. There is no information at this time as to the effect of these different types of vacuum fluctuation on milking performance.

MILKLINES

The current 3A Accepted Practices recommendations for milkline sizing are shown in Table I. They do not take into account the slope of the line or the level of continuous or transient air admission. Spencer and Bray (1991) have conducted field measurements which indicate that the carrying capacity 3 inch pipelines exceed the 3A recommendation.
The maximum number of milking units per milkline slope will depend upon the average peak milk flow rate of the herd, the rate at which units are attached and the maximum continuous and transient airflow. Continuous airflow is introduced by claw or liner air bleeds. Transient airflows are introduced by liner slip, unit attachment, and unit falloff. The maximum transient airflow will depend on factors such as whether automatic air shut off valves are installed on the claw, and the total restriction to air flow for the type of milking unit used. Data is currently being collected to provide design information for these factors.

Preliminary results for two inch lines from research currently under way at the University of Wisconsin Milking Research and Instruction Laboratory to investigate the effect of transient air admission, line diameter, line slope and line length on the carrying capacity of milklines are shown in Figure 3. Results for 1.5, 2.5, 3 and 4 inch lines will be available soon. The results of this study will be presented to the international and US standards organizations in the coming year. It is expected that these standards will be revised in the near future.

The limiting factor for the carrying capacity of the milkline in Figure 3 has been taken as the combination of milk and air flows for which slugging of milk occurs. Slugging increases vacuum fluctuation during milking. Figure 3 shows the transition lines above which vacuum fluctuations of 2 kPa (0.6 " Hg) or more occur as a result of slugging. While there is no clear evidence that the vacuum fluctuations associated with moderate slugging adversely affect milking performance, slugging of milk has been shown to increase lipolysis of milk. The effect is likely to be far smaller than damage to milk which occurs in the milk pump.

The effect of slope on carrying capacity of a given line size is clearly indicated in Figure 3. The carrying capacity of the milkline increases dramatically with slope. No adverse effects have been observed on factors affecting vacuum stability when slopes were increased to 2 percent.

A common cause of slugging in round the barn pipelines is insufficient slope or a flat spot. This problem usually occurs on the part of the line nearest the receiver. If this is the case, resloping the milkline is a far less expensive method of eliminating slugging than increasing line size.

Undersized or undersloped milklines will experience greater vacuum fluctuation if slugging occurs. This may slow milking if slug flow occur frequently. On the other hand, oversized milklines will not improve milking performance and will require excessive hot water, chemicals and vacuum pump size during washing. Thus the cost of going to the next larger size milk line is not limited to the cost of the pipe itself. It is likely that a larger vacuum pump and water heater will be required, Ongoing costs for vacuum pump electricity, hot water and cleaning chemicals will also result.

MILK TRANSFER LINES

There are currently no US standards regarding the sizing of milk transfer lines although guidelines have been established in Canada (Agriculture Canada, 1990). The size of these lines will have no direct effect on milking performance since they act only to empty recorder (weigh) jars after milking is completed. Milk is generally moved from the recorder jar through the milk transfer line to the receiver by vacuum. Increasing the size of this line will make this transfer process faster. The time to empty will also depend upon whether recorders are emptied one at a time or in groups. Milk transfer lines are not commonly looped, although looping may facilitate cleaning and speed emptying of recorder jars.

Milk transfer lines also carry cleaning water from the recorder jar or milk meter and the milking units to the receiver. This may be the limiting factor when sizing these lines. These lines should be at least as large as the line supplying wash water to the recorder jars and milk meters. Studies are currently underway at the University of Wisconsin Milking Research and Instruction Laboratory on the flow dynamics of CIP cleaning systems. Until more information is available it is best to rely on the experience and judgement of a qualified milking equipment dealer in sizing these lines.

MILKING VACUUM LINES

There are currently no US standards regarding the sizing of milking vacuum lines although British standards give a performance standard. Milking vacuum lines are commonly 1.5 or 2 inch lines in US milking systems. These lines carry normal milking unit air admission plus any unintended air admission which occurs during milking. These lines are not required to be looped. Looping will, however, reduce the vacuum drop associated with unintentional air admission during milking. For example, a typical milking unit fitted with an automatic air shutoff valve will admit about 30 scfm of airflow during a falloff. This airflow will produce about 1.7 kPa (0.5 "Hg) vacuum drop across a looped milking vacuum line in a typical double 8 milking parlor. If this line were not looped a vacuum drop of about 4.5 kPa (1.3"Hg) would occur in similar circumstances.

The milking vacuum line usually supplies wash water to the recorder and milking unit during CIP cleaning. The line must be sized so that water volume and velocity are sufficient to accomplish the cleaning task.

PULSATOR AIRLINES

The design of the pulsator airline is more complex that the main vacuum air line because of intermittent flow and variation with regard to pulsation patterns. Capacity requirements vary with respect to pulsation phase (simultaneous versus alternating) and whether pulsators are operated in or out of synchronization. In addition, pulsator operation may influence the vacuum drops which occur in the rest of the milking system.

There is a wide range of pipe sizes recommended for pulsator airlines relative to the number of milking units in use. Guidelines are often compiled without experimental evidence of performance. In general pulsator pipes are greatly over sized on farms today. This is primarily due to the low cost of PVC plastic piping and reduced need for pipe supports with larger diameter piping.

The pulsator airline sizes suggested by 3A accepted practices and adopted by the milking machine manufacturers council are shown in Table II. These sizes have proven to be adequate in most systems. As a performance guide, Spencer and Mein (1991) suggest no more than 1.7 kPa (0.5" Hg) vacuum fluctuation occur at the far end of the pipe during pulsator operation. Additionally a change in the 'A' phase of the pulsator wave form of less than 5% is recommended when all pulsators are in operation, as compared with the 'A' phase of single pulsator operating according to the manufacturer.

MAIN AIRLINES

The main airline must carry all air entering the system to the vacuum pump with minimal vacuum drop. The maximum air flow rate through the main air line is normally from the vacuum regulator to the pump. During washing and when air flow exceeds the vacuum reserve of the system during milking the maximum air flow rate is from the receiver to the vacuum pump. The 3A accepted practices use the number of milking units as a basis for to sizing the main airline.

An alternate approach using vacuum pump capacity and line length as the basis for sizing the main airline has been suggested by Spencer and Mein (1991), and is presented in Table III. This method is more precise as there is a wide variation in the air pumping capacity per unit. The method also assures that the vacuum drop across the main air line will not exceed 0.5 inches of mercury between the receiver and vacuum pump in the case of maximum air flow. Over 95 percent of the vacuum pump capacity is thereby usable. This recommendation will satisfy the 3A accepted practices on virtually all well designed systems.

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Table II. Milkline sizing (3A Accepted Practices)

Maximum number of milking units per slope	Milking pipeline size
4	2 inches
6	2.5 inches
9	3 inches

Table I. Minimum Sizes for Vacuum Pulsator Line (3A Accepted Practices)

Number of Units	Pipe Diameter
1-14	2 inches
15 or more	3 inches

Table III. Recommended minimum pipe sizes (inches diameter) for the main airline of a milking system.

Vacuum pump capacity CFM-ASME	Length of main airline (feet of straight pipe) 20	40	60	80	100
	Nominal Pipe Diameter (inches)				
50	2	2	3	3	3
60	2	3	3	3	3
70	3	3	3	3	3
100	3	3	3	3	3
150	3	4	4	4	4
200	4	4	4	4	4
250	4	4	4	6	6
300	4	6	6	6	6
350	6	6	6	6	6
400	6	6	6	6	6

Note: The main airline is defined as the pipeline between the vacuum pump and the sanitary trap near the receiver. These calculations are based on a maximum vacuum drop of 0.5 inches of mercury between the receiver and vacuum pump. This ready reckoner table includes an allowance for the equivalent length (feet of straight pipe) of one distribution tank, one sanitary trap and 4 elbows. If the system includes more than 4 elbows, then use the next pipe length column to the right for every 3 additional elbows.