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Design Considerations for Milking Machines Used in Brazil

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Abstract. *ISO standards present performance requirements and design guidelines for milking machine installations. The design guidelines are largely based on typical operating conditions in high producing herds using European genetics. Some milking machine design parameters have a substantial influence on the energy used during the milking process. The objective of a larger study was to perform a survey of milking practices in Brazil and document the milking characteristics and milk quality implications of varying degrees of crossbreeding and the use of calves for pre-milking stimulation. The information from this larger study was used to perform this review of milking machine design to determine the energy implications of a milking machine designed for Brazilian conditions. Aspects of reducing the capital cost and cleaning efficiency are also reviewed.*

Keywords. Milking Machines, Design, Energy, Milk Quality

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Introduction

ISO standards (ISO 5707, 1996) present performance requirements and design guidelines for milking machine installations. These milking machine design guidelines can have a substantial influence on the cost of a milking machine installation and the ongoing costs for cleaning and sanitation chemicals, hot water and energy used during the milking process. The design guidelines presented in ISO 5707 are based on the milking characteristics of dairy herds in Europe and the USA.

Brazil has the second largest dairy herd in the world and is the sixth largest milk producing country. Most Brazilian dairy farms are made up of crossbred cows (mainly Holstein crossed with Zebu breeds). The predominance of crossbred cows in Brazil can be explained by their dual purpose for beef and milk as well as their ruggedness and better adaptability to a tropical environment when compared to purebred Holsteins.

The objective of a larger study (Costa 2002) was to perform a survey of milking practices in Brazil and document the milking characteristics and milk quality implications of varying degrees of crossbreeding and the use of calves for pre-milking stimulation. The information from this field study was used to perform this review of milking machine design to determine the energy implications of a milking machine designed for Brazilian conditions. Aspects of reducing the capital cost and cleaning efficiency are also reviewed.

Opinion Survey

An opinion survey was administered to 135 dairy producers in April 2001 at Agrishow, a major Brazilian agricultural exposition, in order to obtain information on milking, breeding and general management practices and the decision-making framework used by Brazilian dairy farmers. The results of these interviews showed that only 10% of the dairy farmers used pure Friesian-Holstein genetics in their herds and the remaining percentage had crossbred Friesian-Holstein genetics with breeds traditionally used in hot climates (such as Gir, a Zebu breed).

Approximately 3/4 of producers who had crossbred cows in their herd reported the use of calves for pre milking stimulation. According to these farmers, the presence of calves during milking is important, if not essential, to stimulate the milk letdown of crossbred cows. In addition, the presence of a calf is thought to reduce the aggressive behavior of these cows, thus ensuring easier handling during milking. Some producers indicated that milking crossbred cows without their calves may result in a shortened lactation period, mainly in 1H:1Z cows (50% Holstein and 50% Zebu). About 37% of the farms surveyed milk by hand, 41% use a mobile or "bucket" milking machine and 22% use a pipeline milking machine in a milking parlor. Further details of this survey are presented by Costa (2003).

Milking Characteristics

A field survey was done in the months of May, June and July in 2001 and 2002 to quantify the milking characteristics of the crossbred cows typical of the Brazilian dairy herds. Data from 1419 crossbred cows, (426 1H:1Z, 545 3H:1Z and 448 7H:1Z) were collected on 12 farms in the Brazilian states Minas Gerais and São Paulo. Each sub-category (three types of cross, each with and without calf) was represented by at least 3 farms and each farm had at least 2 sub-categories represented. Milk meters were used to record the milk yield of individual cows in one-minute intervals during one morning milking. These data were used to calculate the total yield, total milking time, average flow rate (total yield/total time) and peak flow rate (maximum one minute yield). Statistical analyses of the data were performed using the SAS[®] Mixed

Procedure to examine the effect of crossbreed, farm, presence of calf, lactation number, and stage of lactation on the peak milk flow rate and the time to reach peak flow (elapsed time from unit attachment to the peak flow time interval).

The main effect of calf (its presence for pre-milking stimulation) on peak milk flow rate was not significant, although the trend for milk peak flow rate was slightly higher for cows milked without a calf (Figure 1). As expected, cows with higher percentage of Holstein showed a higher milk peak flow rate as well as higher milk production.

There did appear to be some interactive effects between breed, calf and lactation characteristics. The 7H:1Z cows with calf appeared to have a reduced peak milk flow. For 3H:1Z cows, the presence of the calf was associated with higher milk peak flow rate, but only in the beginning of the lactation. For the 1H:1Z cows, the presence of a calf was associated with a higher peak milk flow rate during the first two thirds of lactation (Costa 2002).

The association between calf and time to peak flow was significant for crossbred categories 3H:1Z and 7H:1Z, with cows with calf reaching peak flow rates sooner. However, this association may not be related to the presence of the calf by itself, since cows milked with calf are typically stimulated for a longer time before the attachment of the milking unit. This same trend appeared for 1H:1Z cows but the difference was not significant. This lack of significance may be a consequence of the small sample size of cows without calves (49), resulting in larger variability and therefore reducing the chances of reaching significance.

Stimulation Requirements

For 7H:1Z cows, our results show that the calves may be associated with reduced peak milk flow

Figure 1. Milk peak flow rate for different crosses with and without calf used for pre-milking stimulation (error bars represent 95% confidence intervals).

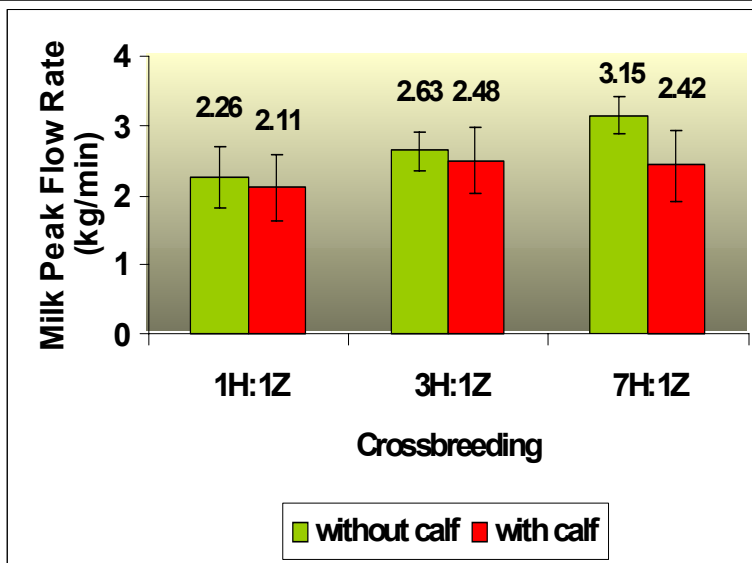
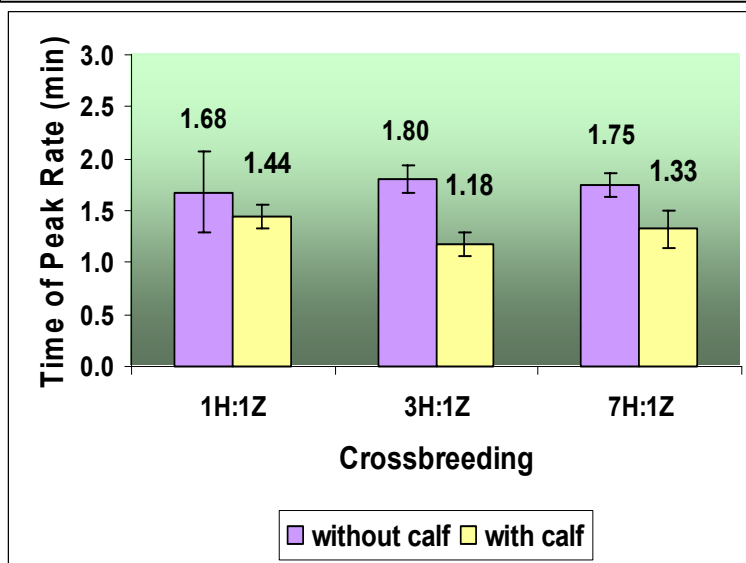


Figure 2. Time to reach milk peak flow in different crosses with and without calf used for pre-milking stimulation (error bars represent 95% confidence intervals)



(inhibiting instead of stimulating the milk letdown) as well as reduced milk harvested by the milking machine (Costa 2003).

For 3H:1Z cows, the benefit of using calves is questionable. According to our data, there was an association between the use of a calf and increased peak milk flow, but only in the beginning of the lactation period.

Although the overall average of milk peak flow rate for 1H:1Z cows was not significantly different with or without calf, the group with calf had a slightly higher average in the first two thirds of lactation. This fact combined with the producers' opinion that some cows do not have milk letdown without calves could be a consequence of a more developed maternal instinct in Zebu cows. For cows that have this "emotional" blockage, the use of calves may be helpful. Genetic selection may be capable of reducing this effect. The use of a calf may still be desirable however, to keep 50% Holstein:50% Zebu cross cows calm during milking.

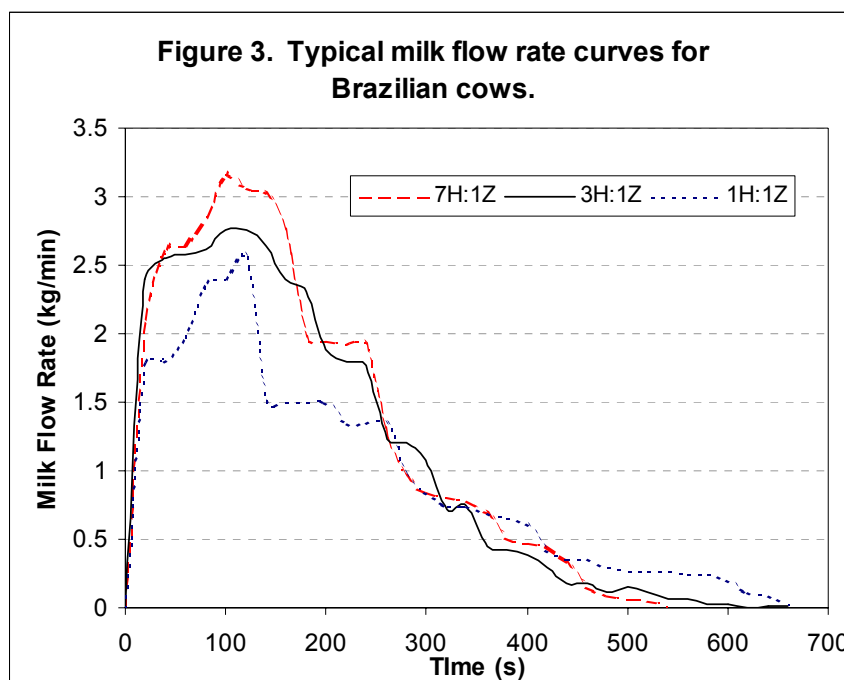
The differences observed in the time to reach peak flow are probably due more to differences in the 'prep/lag' time rather than stimulation. It is also difficult to determine how much milk the calf is able to harvest before unit attachment. The harvest of milk by the calf before the milking unit is attached would tend to shift the peak milk flow period earlier in the period of machine milking. Further details of this survey including milk quality and milk yield are presented by Costa (2003).

Milking Machine Design

Milkline Sizing

Several aspects of milking machine design must be considered for use in the specific conditions encountered in Brazil. General rules for milklines in ISO 5707 state that the center of the milkline shall not be more than 2 m above the animal's standing level, milklines shall have a continuous fall towards the receiver and shall not have restrictions that obstruct milk flow or drainage. If milklines are installed to form a loop, then each end of the loop shall have a separate full-bore connection to the receiver vessel. If several loops are used, two ends may be grouped together directly in front of the receiver to form a single line which has adequate cross sectional area for the combined milk and air flow rates. The benefits of looping the milkline result in a reduction in air flow rate per slope when a milking unit is changed or a liner sip occurs.

The internal diameter of the milkline shall be such that the vacuum drop between the receiver and any point in the milkline does not exceed 2 kPa with all units operating at the designed milk and airflow rate. Design



guidelines are provided in ISO 5707 for groups of cows averaging 4 and 5 L/min. A peak flow rate of 4 L/min is somewhat higher than typical Holstein herds in the US and Europe. A peak flow rate of 5 L/min represents the fastest 20% of high producing cows in the US and Europe and is recommended only for very high-producing or fast milking herds.

These peak flow rates are considerably higher than those found in Brazilian herds. The same procedure used to develop the ISO design guidelines (Reinemann et al., 1995) was applied to the milking characteristics of Brazilian cows. As stated in ISO 5707, the installer and client should agree on the design flow conditions based on expected peak milk rate for the herd and the expected rate of unit attachment. The field data collected for this study was used to create typical milk flow curves from Brazilian crossbred cows (Figure 3). These typical flow rate curves for individual animals were combined with a range of milking unit attachment rates to obtain the expected peak milk flow rate in the milking line for a varying number of milking units (Table I).

The maximum milk flow rate to maintain stratified flow conditions was then calculated for various transient air admission rates, milking line diameter and milking line slopes (Table II). These calculations assumed a steady air admission to milk flow rate of 3.3:1 to allow for air admitted by milking unit air vents. The data from these two tables were then combined to derive the maximum number of milking units per milking line slope for peak flow rates representative of Brazilian cows (Table III).

Vacuum Pump Sizing

ISO 5707 states that the vacuum pump shall be capable of meeting the operating requirements of the milking installation along with those of other equipment whether operating continuously or intermittently during milk, and with creation of a demand for air. Furthermore, the installation with automatic shutoff valves at the milking unit shall have a minimum effective reserve of:

$$ER \geq (200 + 30n) \text{ L/min}$$

for pipeline and weigh jar systems with $n = 2$ to 10 units

$$ER \geq [500 + 10(n - 10)] \text{ L/min}$$

for pipeline and weigh jar system with $n = 11$ or more milking units

$$ER \geq (80 + 25n)$$

for bucket milking machines with $n = 2$ to 10 milking units

$$ER \geq 330 + 10(n - 10)$$

for bucket milking machines with 11 or more milking units.

For installations without automatic shutoff valves at the milking units, the minimum effective reserve shall be increased by 80 L/min for bucket milking machines and by 200 L/min for other types of milking machines.

The vacuum pump capacity includes this minimum effective reserve plus

- Airflow demand for all equipment operating during milking and cleaning such as pulsators, air inlet, and vacuum operated milk pumps.
- 10 L/min + 2 L/min for each fixed milking unit or 1L/min for each milk cock for leakages
- Leaks in airlines (5% of the rated pump capacity, or smaller if claimed by the installer)
- Regulation leakage in accordance with the manufacturer's information
- Adjustments for pressure drop in the main airline and the altitude of operation.

In order to obtain the maximum amount of air available from the vacuum pump, the main airline (from the receiver to the vacuum pump) should be sized to limit the vacuum drop to 1 kPa or less. Design guidelines for this purpose are provided in ISO 5707.

Table I. Maximum expected milk flow rates for various breeds and milking unit attachment intervals.

cows	Attachment intervals	Milk flow rate (kg/min)	Maximum milk flow rate (l/min)																
			Number of units per slope																
			2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0.88 H	5	3	6.3	9.5	12.6	15.7	18.7	21.8	24.8	27.9	30.9	33.9	37.0	39.8	42.7	45.5	48.4	51.1	53.9
0.75 H		2.7	5.5	8.3	11.0	13.8	16.6	19.3	22.1	24.7	27.4	30.0	32.6	35.3	37.9	40.5	43.1	45.7	48.2
0.50H		2.5	5.1	7.7	10.2	12.6	15.0	17.4	19.8	22.2	24.5	26.9	29.3	31.4	33.5	35.6	37.5	39.3	41.1
0.88 H	10	3	6.3	9.4	12.4	15.5	18.5	21.3	24.2	26.9	29.7	32.3	35.0	37.6	40.2	42.8	44.9	47.0	49.0
0.75 H		2.7	5.5	8.3	11.0	13.7	16.3	18.9	21.5	24.1	26.7	29.3	31.8	34.2	36.6	39.0	41.4	43.7	46.0
0.50H		2.5	5.1	7.7	10.2	12.6	15.0	17.4	19.8	22.2	24.5	26.9	29.3	31.4	33.5	35.6	37.5	39.3	41.1
0.88 H	20	3	6.2	9.2	12.1	14.9	17.5	20.1	22.7	24.8	26.8	28.7	30.7	32.6	33.8	34.8	35.6	36.4	37.2
0.75 H		2.7	5.5	8.2	10.8	13.4	15.9	18.3	20.7	23.0	25.0	26.9	28.7	30.5	31.7	32.9	34.0	34.7	35.5
0.50H		2.5	5.0	7.3	9.5	11.3	13.1	14.7	16.2	17.7	19.2	20.5	21.9	23.2	24.6	25.5	26.4	27.1	27.9
0.88 H	30	3	6.2	9.0	11.8	14.4	16.5	18.5	20.4	22.1	23.1	23.9	24.7	25.4	25.9	26.3	26.5	26.6	26.6
0.75 H		2.7	5.5	8.1	10.7	13.1	15.4	17.4	19.2	20.9	22.1	23.2	24.0	24.4	24.8	25.1	25.3	25.4	25.5
0.50H		2.5	5.0	7.1	8.9	10.5	12.0	13.5	14.8	16.2	17.1	18.0	18.7	19.3	19.9	20.4	20.7	21.0	21.3
0.88 H	50	3	6.2	8.8	10.7	12.7	13.8	14.7	15.4	15.8	16.0	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
0.75 H		2.7	5.4	8.0	10.1	11.9	13.2	13.9	14.4	14.8	15.0	15.1	15.2	15.2	15.2	15.2	15.2	15.2	15.2
0.50H		2.5	4.9	6.7	8.2	9.6	10.7	11.4	12.1	12.5	12.9	13.1	13.4	13.4	13.4	13.4	13.4	13.4	13.4
0.88 H	70	3	5.9	8.5	10.4	11.3	11.8	12.1	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
0.75 H		2.7	5.3	7.6	9.4	10.4	10.8	11.0	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
0.50H		2.5	4.6	6.0	7.3	8.0	8.6	8.9	9.2	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
0.88 H	90	3	5.7	7.6	8.5	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
0.75 H		2.7	5.3	7.1	8.3	8.7	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
0.50H		2.5	4.4	5.7	6.5	7.1	7.5	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8

Table II. Maximum milk flow rate (l/min) to maintain stratified flow conditions for various transient air admission rates, milklime diameters and milklime slopes.

Transient air (l/min)	25				50				100				200			
Internal Diameter (mm)/Slope (%)	0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2
38	7	11	15	17	5	9	12	14	3	6	8	10	2	3	5	6
48.5	16	23	29	34	12	20	26	31	9	16	21	26	5	10	14	18
60	29	42	52	61	25	39	49	58	21	33	43	51	14	25	33	41
73	49	71	88	102	45	68	84	98	40	61	78	92	31	50	66	80
98	107	152	187	217	102	149	184	213	96	142	176	206	84	129	163	192

Table III. Maximum number of milking units per slope with milking units attached every 10 seconds (* = unlimited number of milking units per slope).

Transient air:		50 l/min Slope (%)				100 l/min Slope (%)				200 l/min Slope (%)			
Nominal internal diameter (mm)		0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2
0.88 H 3 l/min	38	1	2	3	4	1	1	2	3	0	1	1	1
	48.5	3	6	8	10	2	5	6	8	1	3	4	5
	60	8	13	18	22	6	11	15	19	4	8	11	14
	73	16	30	*	*	13	24	*	*	10	18	28	*
	98	*	*	*	*	*	*	*	*	*	*	*	*
0.75 H 2.7 l/min	38	1	3	4	5	1	2	2	3	0	1	1	2
	48.5	4	7	9	11	3	5	7	9	1	3	5	6
	60	9	15	19	24	7	12	16	20	5	9	12	15
	73	17	33	*	*	15	26	*	*	11	20	31	*
	98	*	*	*	*	*	*	*	*	*	*	*	*
0.50 H 2.5 l/min	38	1	3	4	5	1	2	3	3	0	1	1	2
	48.5	4	8	10	12	3	6	8	10	1	3	5	7
	60	10	16	22	28	8	13	19	23	5	10	13	17
	73	20	34	*	*	17	30	*	*	12	22	33	*
	98	*	*	*	*	*	*	*	*	*	*	*	*

Cleaning

The amount of cleaning solution required to provide adequate contact with all surfaces and adequate mechanical cleaning action is proportional to the internal volume of the milking machine (Reinemann et al 2003). There is increasing interest in cleaning systems that reduce energy consumption and minimize other environmental impacts. These overall goals can be aided by using air injection to ensure that the mechanical cleaning forces are used to their greatest advantage. Optimization of mechanical cleaning action will result in reduced use of cleaning chemicals and hot water.

Assuring an adequate mechanical cleaning action typically requires very little added cost but relies on the skill of the equipment installer. As milking machines become more complex, the task of assuring adequate mechanical cleaning action in all parts of the milking machine also becomes increasingly complex. The objective in air-injected flow is to form a 'slug' of cleaning solution and move this slug around the entire pipeline. Slug velocities of 7 to 10 m/s maximize the wall shear stress developed while minimizing the variation of shear stress along the pipe. The rate of air admission to the milkline should be controlled to achieve these slug velocities. Air admission rates above this maximum will result in reduced slug density and reduced mechanical cleaning action in the milkline. Methods for adjusting cycled air injection are presented by Reinemann et al., (1997, 2003a).

Keeping pipe lengths, pipe diameter and the number of fittings to a minimum will improve the efficiency and effectiveness of the cleaning process as well as reduce the installation and operational costs of the milking machine. The receiver should be located in such a way that the number of bends and fittings in the milkline are kept to a minimum and in a location that will not interfere with movement of the operators during milking. The wash sink is generally located near the bulk tank inlet to facilitate the switch in piping from milking to cleaning configurations. The length of piping from the milk room to the parlor should be kept to a minimum to reduce cleaning water volume, heat loss during cleaning and difficulties controlling circulation.

Conclusion

Our field data indicates that adequate pre-milking stimulation can be achieved without the use of calf suckling before milking for $\frac{3}{4}$ Holstein and above. The use of a calf may still be desirable however, to keep 50% Holstein: 50% Zebu cross cows calm during milking, and may furthermore improve stimulation in early lactation cows.

The peak milk flow rates for Brazilian cows are considerably lower than the Friesian-Holstein cows used to develop milkline sizing guidelines in international standards. Milking machine design guidelines specifically adapted to the conditions in Brazil can result in considerable savings in:

- Capital investment of milking machines,
- Ongoing cost of cleaning and sanitation,
- Reduction in peak power requirements and energy used;

Such savings can be observed through the use of specific Brazilian design guidelines, while still providing excellent milking performance and labor efficiency.

Milkline diameters can be kept to a minimum by using looped milklines, using the maximum practical slope on milklines and using care to limit air admission when attaching milking units. Minimizing milkline diameter and maximizing milkline slope will also aid in the ease of cleaning

and will minimize ongoing consumption and the cost of cleaning chemicals and hot water. The proper use of air injectors can also help to reduce chemical and hot water use.

Peak power demand and energy savings can also be realized by careful design of vacuum production and control systems. The use of variable speed drive vacuum controllers can reduce energy requirements. Less costly means to reduce energy use and peak demands are to:

- Use milking units with automatic shutoff valves
- Minimize air leaks in the milking machine
- Use vacuum regulators with little or no air “leakage”
- Size main airlines to keep vacuum drop between the receiver and vacuum pump under 1 kPa.
- Size vacuum pumps to these conditions.

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