MINNESOTA EXTENSION SERVICE

UNIVERSITY OF MINNESOTA
AGRICULTURE

Minnesota Milking Equipment Research: Myths and Facts

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INTRODUCTION

Machine milking involves a unique interaction among the milking system, cow and operator. All three contribute to the quantity and quality of the milk harvest and the cow's mammary health. The complex milking system and its interaction with biological systems (i.e., cow and operator) makes research on milking systems very difficult because of the large number of factors to either control or measure. Long-term studies with many animals and tests are needed to obtain enough data to reduce the inherent variability in biological systems and to detect statistically significant factors and their relationships. In on-farm field tests, it is often difficult to obtain "controlled" comparisons.

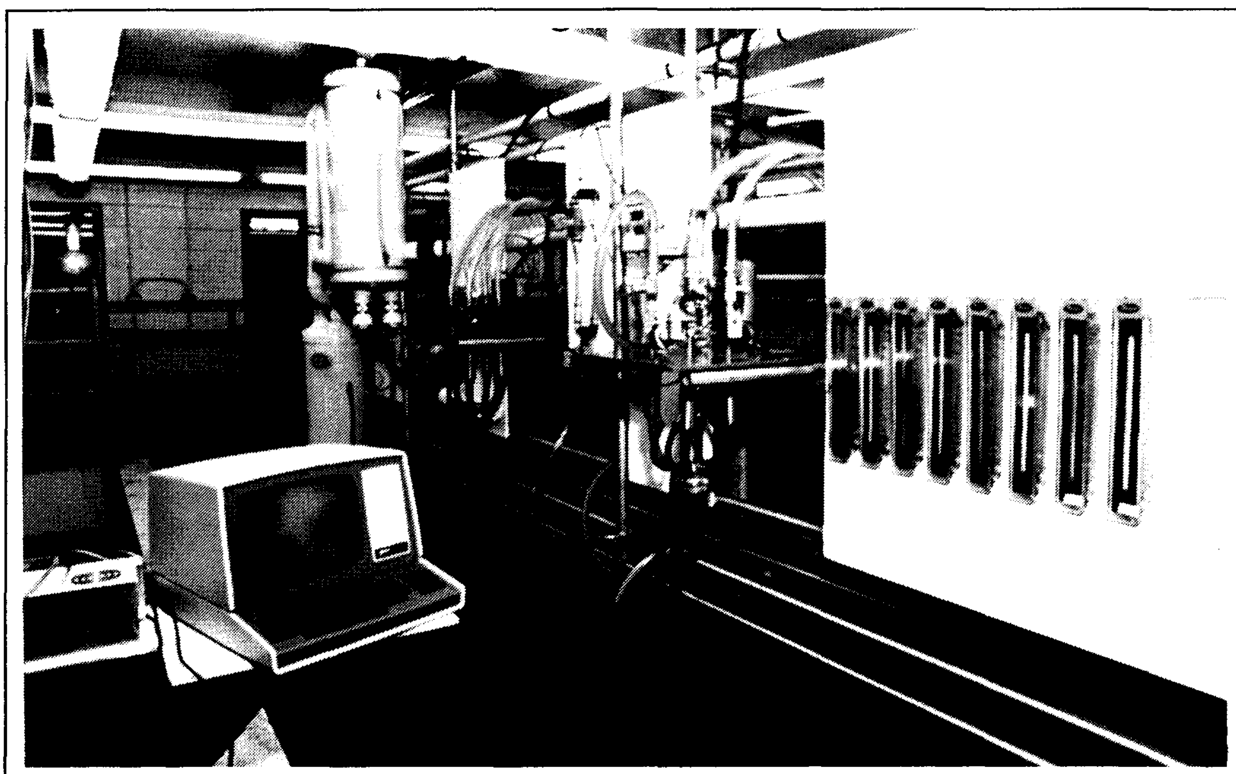

Figure 1. The "mechanical cow" data acquisition system is shown in the lower left corner. Water flow rotometers for unit 1 are shown at the extreme right, and unit 1 with individual water flow control is adjacent to the rotometers. Unit 2 is further back and adjacent to the closed circuit water circulation system simulating internal udder pressure (2 vertical tanks). Note the stainless steel milk pipelines, one below the milking units, the other above the fluorescent lights.

The University of Minnesota has initiated an interdisciplinary research thrust involving Agricultural Engineering, Animal Science and Veterinary Medicine.[1,2] The goal of this research is to develop and/or refine methodologies for suppressing losses in milk production caused by mastitis infections. To facilitate this research a **"Milking Equipment System Analysis"** test unit (MESA) was considered an essential research tool. The test unit is comprised of a conventional milking system, a "mechanical cow" to physically simulate the milk flow from cows, and a data acquisition system to monitor the milking system and milk flow.

A well instrumented milking system and mechanical cow afford several advantages for conducting research on milking units and milking systems compared with research using actual cows. A mechanical cow can be adjusted to obtain controlled and repeatable milk flow rates and remove variability inherent in normal cow milking (i.e., changing flow rates during milking, different flow rates between morning and evening milkings, changing milk production over a lactation). Numerous tests can be run on a mechanical cow and replicated in a single day without concern about running out of cows to milk.

SYSTEM DESIGN CHARACTERISTICS

MESA was constructed in order to conduct extensive research on the influence of milking system design and operation on milking performance and incidence of mastitic infections. MESA is comprised of three interrelated systems, namely: a) the milking machine system; b) a simulated milk flow system (i.e., mechanical cow); and c) a data acquisition and analysis system.

The **milking machine system** is an Alpha-Laval parlor system with a 60 ASME standard CFM rotary vane vacuum pump. The pulsation and milk line components were designed and built to easily adjust individually or collectively the following independent variables: a) pulsation type—alternate vs. simultaneous; b) pulsation rate—60 vs. 50 c/min; c) pulsation ratio—50:50, 60:40, 70:30; d) milk pipeline height—low vs. high; e) milk pipeline diameter—1.5, 2.0 and 3.0 in.; f) vacuum reserve capacity—0 to 42.4 CFM; and g) vacuum level—12.4 to 14.8 in.

The **mechanical cow** is a closed circuit water circulation system that simulates milk flow from 1 to 12 cows. Two of the milking units are equipped with artificial teats built: a) to allow a predetermined flow of water while milked with the milking machines; and b) to measure the pressure at teat-end. A milk ejection pressure is generated with a head pressure tank having a constant head of about 3 in. Excess water overflows into the water reserve tank, which also receives all water milked through the milking system, and is pumped back into the head pressure tank.

The **data acquisition and analysis** system is based on a 14-bit Measurement Technology MT1000 controller programmed in Turbo Pascal. With its direct memory access features, data is collected from each of 7 channels for 15 seconds at a rate of 200 readings per channel per second.

Five vacuum transducers were installed in MESA. They have a sensing rate of 0 to 29.8 in., accurate to 0.03 in., and a time constant of 1 ms. Two transducers measure the vacuum at teat-end of the left front and right rear teats of Unit 1. The other transducers measure vacuum in the claw on Unit 1, in the milkline and in the vacuum distribution tank.

Volumetric water flow through each teat in Unit 1 and simultaneously through all 4 teats in Unit 2 are set by use of needle valves and measured visually by rotometers. Water flow through any one of these pathways, usually the left front teat of Unit 1, is measured and recorded electronically (channel 6) by the use of a turbine flowmeter.

A mass flow transducer is available to measure air flow through different portions of the vacuum system. Results are recorded electronically (channel 7). The transducer is frequently used to measure the volume of air admitted purposefully to study the effect of unintentional air admissions on machine milking performance.

Preliminary tests have focused on the identification of factors and conditions that increase the potential for creating **reverse vacuum differences (RVD's)**. An RVD is when there is a higher vacuum in the teat-end than in the claw. Typically, an RVD is further defined by requiring the teat-end vacuum to exceed the claw vacuum by at least 0.5 kPa (0.15 in.) for a minimum of 0.025 s. In analyzing data associated with low milk flow (near end-of-milking) an RVD may be defined at 0.25 kPa (0.07 in.) for 0.005 s.

RESULTS AND CONCLUSIONS UTILIZING MESA

AVERAGE VS. HIGH FLOW RATE COWS

Description of cow	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
1. Average flow	5.6	10.2	13.5	13.9	.028
2. High flow	10.9	8.7	13.5	190.0	.085

Conclusions:

1. High flow rate cows (10.9 lb/min) lower the vacuum at teat end and in the claw by 15% from that with average flow rate cows (5.6 lb/min) across all treatments.
2. Vacuum in the milkline and in the distribution tank (13.5 inches) was unaffected by flow rate.
3. Reverse vacuum difference (RVD's), defined as a higher vacuum at teat end than in the claw by at least .15 inch for .025 seconds, increases from about 14 per quarter per minute for average milk flow cows to 190 per quarter per minute for high flow rate cows. Furthermore, there is a threefold increase in the area (magnitude x duration) of each RVD in the high flow cows.

1½-INCH HIGH LINE VS. 2-INCH LOW LINE SYSTEMS

Description of milkline	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows					
2-inch low line	5.7	11.4	13.5	17.8	.028
1½-inch high line	5.5	9.0	13.4	10.1	.027
High flow rate cows					
2-inch low line	11.8	10.1	13.5	202.9	.071
1½-inch high line	10.0	7.2	13.5	77.1	.102

Conclusions:

1. Cluster vacuum drops from milkline vacuum by 2.1 to 3.4 inches in 2-inch low line systems; and from 4.4 to 6.3 inches in 1½-inch high line systems.
2. Milk flow rate in high line systems is 97% of the low line results with average milk flow rate cows, 85% in high flow rate cows.
3. Although Reverse Vacuum Differentials with 1½-inch high line systems occur less often than with 2-inch low line systems, it appears there may be an offsetting increase in the area per occurrence.

LINE DIAMETER VS. LINE HEIGHT

Description of milkline	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Milkline diameter				
2-inch	11.8	13.8	121.25	.049
1½-inch	11.8	13.8	116.00	.052
Milkline height				
Low	13.1	13.7	129.75	.050
High	10.5	13.7	107.50	.050

Conclusions:

1. Milkline diameter had no effect on cluster vacuum, milkline vacuum, or number and size of RVD's.
2. High level milkline resulted in a 20% drop in cluster vacuum and a 17% drop in the number of RVD's. Milkline vacuum and size of RVD's were unaffected.

MILKLINE CONFIGURATION

Description of milkline	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Looped	10.4	14.2	12.3	129.50	.078
Dead-ended					
Away from unit 1	10.3	14.4	12.2	118.25	.076
Close to unit 1	10.3	14.7	11.8	106.75	.077

Conclusion:

Cows milked close to the dead-ended line have a lowered and more variable cluster vacuum.

MILKLINE OPENING

Description of milkline opening	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Top	6.7	14.2	14.6	29.33	.025
Side	6.7	14.3	14.6	4.67	.007
Bottom	6.6	14.1	14.6	25.33	.028

Conclusions:

1. Milkline bibs opening into the bottom of the milkline result in a slightly lowered and more variable cluster vacuum.
2. Note: From a milk quality standpoint, the opening should always be on the top side of the milkline.

HIGH VS. LOW VACUUM RESERVE

Description of vacuum reserve	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows					
High reserve (5.3 cfm/unit)	5.6	10.2	13.5	14.6	.028
Low reserve (1.3 cfm/unit)	5.6	10.2	13.4	13.3	.028
High flow rate cows					
High reserve	10.9	8.7	13.6	187.3	.078
Low reserve	10.9	8.6	13.5	192.8	.093

Conclusions:

1. As long as the vacuum reserve is sufficient to compensate for any air leaks that occur, low reserve has no apparent influence on milk flow rate cluster vacuum, milkline vacuum or reverse vacuum difference.
2. Note: Previous work indicates more vacuum reserve is required for adequate system cleaning than for operating the milking machine.

HIGH VS. LOW VACUUM SETTING

Description of vacuum level	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows					
High vacuum (14.8 in.)	5.7	11.2	14.6	19.6	.029
Low vacuum (12.4 in.)	5.5	9.2	12.3	8.2	.025
High flow rate cows					
High vacuum	11.1	9.5	14.7	168.8	.072
Low vacuum	10.7	7.8	12.3	199.3	.103

Conclusions:

1. Vacuum level has only a small effect on milk flow rate (3 and 4% decline from low level vacuum for average and high flow rate cows, respectively).
2. The ratio of cluster to milkline vacuum is influenced much more by milk flow rate of cows (76 vs. 64% for average and high flow rate cows, respectively) than by vacuum level settings.

NO VS. HIGH CONSTANT AIR LEAK

Description of air leak	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows					
No air leak (0 cfm/min)	6.0	12.2	13.5	25.0	.004
Large air leak (8.33 cfm/min)	5.3	8.2	13.4	2.9	.026
High flow rate cows					
No air leak	12.2	11.4	13.6	199.6	.064
Large air leak	9.6	5.9	13.5	180.4	.109

Conclusions:

1. A large air leak in the cluster lowers milk flow rate in average and high milk flow rate cows by 11 and 22%, respectively.
2. A large air leak in the cluster lowers cluster vacuum in average and high flow rate cows by 33 and 48%, respectively.
3. Note: Cluster vacuum of less than 7.0 inches, depending on the type of liner and liner/shell combination, may result in an inadequate massage of the teat end.
4. Large air leaks reduce the frequency of RVD's occurring, but each RVD occurrence has an increased area associated with it.

ALTERNATE VS. SIMULTANEOUS PULSATION

Type of pulsation	Actual flow rate (lb/min)	Claw vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows				
Alternate	6.6	14.2	91.8	.042
Simultaneous	6.7	14.2	126.5	.042
High flow rate cows				
Alternate	16.3	13.9	155.8	.230
Simultaneous	16.3	13.9	222.2	.254

Conclusion:

Alternate pulsation has little or no influence on average claw vacuum or milk flow rate. It does, however, result in fewer RVD's.

60 VS. 50 PULSATION RATE

Pulsation rate	Actual flow rate (lb/min)	Claw vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows				
60/min	6.7	14.2	107.1	.039
50/min	6.6	14.2	111.2	.044
High flow rate cows				
60/min	16.4	13.8	199.7	.209
50/min	16.1	13.9	158.3	.276

Conclusion:

Pulsation rate of 60 per min, vs. 50 per min, has little influence on vacuum level within the cluster. It may speed milk flow rate, particularly during peak flow.

MILK:REST RATIO

Milk:rest ratio	Actual flow rate (lb/min)	Claw vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
Average flow rate cows				
70/30	7.4	14.2	138.4	.049
60/40	6.7	14.3	103.0	.042
50/50	5.9	14.3	86.0	.035
High flow rate cows				
70/30	18.6	13.8	215.8	.254
60/40	16.2	13.9	190.5	.238
50/50	14.1	13.9	130.8	.235

Conclusion:

Increased milk:rest ratios (i.e., 70:30) result in significantly faster milkout and an increase in the number of RVD's.

PULSATION COMBINATIONS, RANKED BY FLOW RATE

Pulsation Type	Pulsation Rate	Pulsation Ratio	Achieved flow rate (lb/min)	% of slowest combination	Reverse vacuum diff. (RVD) No. per quarter per min	Rank	Area per occurrence (kPa x sec)	Rank
Simul.	60	70/30	13.22	135.3	191.3	1	.177	2
Alt.	50	70/30	12.96	132.7	154.8	6	.137	7
Alt.	60	70/30	12.94	132.4	181.5	3	.100	11
Simul.	50	70/30	12.77	130.7	180.8	4	.193	1
Simul.	60	60/40	11.64	119.1	182.5	2	.129	8
Alt.	60	60/40*	11.41	116.8	125.5	8	.116	10
Simul.	50	60/40	11.38	116.5	175.3	5	.154	5
Alt.	50	60/40	11.34	116.1	102.8	9	.161	4
Alt.	60	50/50	10.14	103.8	92.0	11	.128	9
Simul.	60	50/50	10.10	103.4	146.5	7	.095	12
Alt.	50	50/50	10.03	102.7	85.3	12	.175	3
Simul.	50	50/50	9.77	100.0	109.8	10	.141	6

*Reference system.

Conclusions:

1. If fast milkout is a goal, a pulsation system combining simultaneous pulsation, 60 cycles/min, and 70:30 milk:rest ratio is the combination of choice.
2. Conversely, slower milkout occurs with 50:50 milk:rest ratios, 50 cycles/min, and either alternate or simultaneous pulsation.
3. Combinations that result in faster milkout result in more RVD's occurring.

PRELIMINARY DATA UTILIZING MESA

REGULATOR COMPARISON

Item	Modern	Weighted arm	Oil bath
Regulator sensitivity test	109.7	34.7	35.0
Change in vacuum from intentional air leak:	% drop		
Distribution tank	0.6	1.8	3.7
Milkline	0.9	2.1	4.0
Claw	1.0	2.5	4.8
Quarter 1	1.0	2.5	4.8
Quarter 4	1.0	2.5	4.8

Preliminary finding:

Vacuum levels and milk flow rate could not be compared, since initial vacuum levels varied. The number and magnitude of RVD's appeared to be similar.

LINER COMPARISONS

Liner	Actual flow rate (lb/min)	Cluster vacuum (inches)	Milkline vacuum (inches)	Reverse vac. diff. (RVD) No. per quarter per min	Reverse vac. diff. (RVD) Area per occurrence (kPa x sec)
1. Demonstration liner	6.2	12.3	14.7	176	.053
2. Reference liner	6.1	12.4	14.7	40	.028
3. No. 2, w 18-gage needle	6.7	14.2	14.8	0	0
4. S liner	6.2	12.3	14.7	0	0
5. Z liner	6.7	14.3	14.8	0	0

Preliminary findings:

1. Liner differences result in varying vacuum levels, flow rate and RVD's.
2. Preliminary results suggest that increased diameter of the short milk tube and/or addition of intentional air inlet into the short milk tube results in reduced RVD's.

ORGANISM TRANSFER UTILIZING MESA

Preliminary studies have been undertaken to determine the number and magnitude of RVD's required to transfer mastitis causing organisms from one teat to another within the clusters. Streptococcus agalactia was used because it is a common mastitis pathogen that is easily identified by differential media. Procedures have been developed to: a) prepare culture solutions; b) introduce organisms by injection in liner 3 (left rear); c) recover organisms on sterile filter paper attached to other artificial teats within the cluster; and d) identify and count the number of organisms transferred.

Flow Rate From 3 Quarters (lbs/min)	Unintentional Air Slip (cfm)	Organism Transfer (log_10 scores)	Flow Rate Means (log_10 scores)
<1.1	0	4.54	
	1.2	5.61	5.16[a]
	2.4	5.31	
6.6	0	2.24*	
	1.2	3.90	2.80[b]
	2.4	2.28	
13.2	0	4.21	
	1.2	3.15	3.80[b]
	2.4	4.04	

* Reference system.

[a,b] Means with different superscripts differ, $P < .10$

Preliminary findings:

1. Very preliminary results suggest that when compared with reference system, organism transfer increases: a) 100-fold when milking rate is low and no unintentional air slips occur; and b) 1,000-fold when end-of-milkout is combined with unintentional air slips.
2. There is a tendency (10-fold increase) for an increase in organism transfer when milk flow rate increases from medium (6.6 lb/min) to high (13.2 lb/min).
3. More research is needed to confirm these preliminary findings. However, these results do suggest that the most critical stages in the milking process during which time the occurrences of air slips should be prevented are: a) immediately after unit attachment, and b) near completion of machine milking.

DYNAMIC ANALYSIS OF VACUUM MILKING SYSTEMS

Results obtained and reported in this section utilized five Setra model 204 vacuum transducers installed in the existing Alfa-Laval parlor milking system at the University of Minnesota. The milking parlor was a 10-unit (5 per side) herringbone system with 3-inch milklines, 2-inch pulsator lines, and an 80 CFM (ASME standard) rotary vane vacuum pump. There were two vacuum reserve tanks, one near the vacuum pump (4.2 ft^3) and a distribution tank (5.6 ft^3) 6 ft. from the milk receiver tank. The pulsation system had a 60:40 milk:rest ratio, alternating pulsation, 60 cycles/min., with each side of the parlor having a 90° phase difference. Some results were obtained utilizing mathematical modeling.

A summary of results and conclusions are as follows:

1. Vacuum pump capacity has little effect on reducing cyclic vacuum variation caused by pulsation. Increased vacuum pump capacity can, however, reduce vacuum variation caused by unit fall-off or other irregular air leaks.
2. In this study, each pulsator and claw air bleed used approximately 2.1 and 0.6 CFM (ASME standard) of air, respectively. Further, the maximum air flow occurring from a unit fall-off approached 24 CFM. In developing a recommended vacuum pump size, one may choose to add 20% to the required capacity to allow for future deterioration in vacuum pump performance. Thus, the following equation is recommended:

   ((3 CFM/unit x No. units) + 24 CFM) x 1.2 = Total CFM

   Example for a 10 unit parlor: 3 CFM x 10 units = 30 + 24 = 54 x 1.2 = 65 CFM

3. A large capacity vacuum reserve tank can reduce peak cyclic vacuum variation but becomes impractical due to the size required. Two vacuum reserve tanks located some distance apart are a better configuration than a single large tank to filter air disturbances that cause cyclic vacuum fluctuations.
4. Large capacity vacuum reserve tanks have no effect on reducing sudden vacuum drops (variation) due to unit fall-off or other sudden irregular air leaks.
5. Increased pipeline sizes have little influence on reducing the effect of pulsation on air leaks caused by unit fall-off. Modern milking system pipelines are oversized—thus, serving only to increase the amount of hot water and chemicals needed to properly clean the system.

6. Milk flow plus air bleeding are the most significant factors causing cyclic vacuum drop and variation in liners (1.5 to 2.0 inches overall drop and 1.5 to 2.0 inches peak-to-peak variation). The inertia and resistance associated with milk flow have a two-fold effect: a) causing vacuum to drop and to vary inside the liners, which is undesirable; and b) suppressing fluctuations going from milk line to liners, which is desirable.
7. Unit attachment, unit fall-off or an air slip in one liner can severely affect vacuum levels (nearly 12 inches in this parlor) inside other liners on the same claw on an irregular basis; reverse vacuum differences are likely when these events occur.

SUMMARY

While milking machines are often assumed to be the cause of mastitis, this research has shown that two other associated factors are of primary importance in influencing machine function, namely: rate of milk flow (cow factor) and unintentional (irregular) air admissions (human factor and/or cow factor).

Milking machine components or settings causing decreased cluster (teats cups and claw) vacuum and lowered milk flow rate when all other variables are held constant are summarized in the following table. Most of them are relatively unimportant when compared with cow and human factors.

Reverse vacuum differences (RVD's), defined as having a higher vacuum at the teat end than in the claw, are assumed to be a primary cause for spreading mastitis organisms from one teat cup to another. This research has shown that the overriding factor for increasing the frequency of RVD's is a marked increase in milk flow rate, resulting in flooding of the teat cups. Preliminary tests involving the transfer of mastitis causing organisms (Strep. ag) introduced in one teat cup suggest that many more organisms are transferred to other teat cups within the cluster when milk flow is low (near the end of milking) and few or no RVD's are recorded.

Future research utilizing the mechanical cow known as MESA (Milking Equipment System Analysis) should focus on the cluster, especially liner and shell design, diameter of short tubes and long milk hoses, and claw design.

Change from reference system	Cluster vacuum, % decrease	Milking rate, % decrease	No. of RVD's % increase	No. of RVD's % decrease
1. Constant air leak, 0 to 8.3 CFM	33	12		88
2. Low line to high line	20	4		17
3. Vacuum level, 14.8 to 12.4	18	4		58
4. Milk flow rate, 5.6 to 10.9 lb/min.	15	—	1367	
5. Milkline, looped to dead-end	5	1		18
6. Milkline entry, top to bottom	1	2		14
7. Pulsation ratio: 60:40 to 70:30	1	(+10)	34	
60:40 to 50:50	0	12		17
8. Vacuum reserve, 5.3 to 1.3 CFM/unit	0	0		9
9. Pulsation, alternate to simultaneous	0	(+2)	38	
10. Pulsation rate, 60 to 50/min.	0	2	4	

RELATED PUBLICATIONS

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