Measurements of vacuum stability conditions in mid-level and low-level milking units

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Summary

The vacuum applied to the teat end when the milking liner is open has a major influence on the efficiency of milk extraction. In present study the vacuum levels and vacuum fluctuations were recorded on a milk flow simulator with mid-level and in a low-level milking units. Tests were carried out on six cluster types in mid-level system, with three water flows 4, 6, 8 litres / min; a pulsation rate of 60 cycles / min; three pulsator ratios 60, 64 and 68%, two pulsation phases simultaneous-1 and alternate-2 and with 13.5 and 16mm i.d long milk tubes. Four of the six clusters were evaluated in a low-level system. Large differences in liner open vacuum were recorded for milking units that gave similar vacuum losses measured over complete pulsation cycles. By increasing the LMT internal diameter the liner open vacuum was increased. For both types of milking unit the losses in vacuum when the liner was open were lower with wide bore tapered liners than with narrow bore liners ($p<0.001$). Simultaneous pulsation gave lower vacuum losses than alternate pulsation in all cases except in a low-level milking unit fitted with a cluster with a large claw with angled entry nozzles. With simultaneous pulsation and a wide bore tapered liner an increase in claw volume reduced the liner open vacuum at the three water flows ($p<0.001$). The lowest level of vacuum fluctuations was recorded with narrow bore liners in conjunction with alternate pulsation. There was a good correlation between liner open vacuum and flow rate through the artificial udder.

Key words: *Milking machine, vacuum, simulator.*

Introduction

Generally most modern parlour milking systems have large bore milk pipelines and the vacuum variations or losses in the milk pipelines are low. The main vacuum losses occur from frictional losses in the connecting system from the teat to the milk pipeline during milk flow, in commercial milking on farms these losses are difficult to measure as the flow through individual liners is not known. For this reason the losses in vacuum in milking systems are usually measured in laboratories where water is used instead of milk and the flow conditions from the teat are simulated by inserting artificial teats into the liners and water flow is controlled. Nordegren (1980), Osteras (1980), Woyke (1993), Wiercioch (1994), Luczycka (1993) and Stewart (1997), developed milk flow simulators for recording vacuum losses.

Operating vacuum should be related to the liner open vacuum and not as is common practice to the mean vacuum measured over complete pulsation cycles. While most milking machine manufacturers supply milking systems that give minimum fluctuations during the full liner movement cycles the alternative design approach of reducing vacuum losses when the liner is open and allowing vacuum drops to occur during liner closure can give satisfactory milking characteristics with specific liner designs (O'Callaghan, 1997). It is important that drops in vacuum during liner closure do not cause liner slippage, the milking cluster should be designed to avoid excessive teat penetration into the liner and liner movement curve should follow the pulsation curve. The objective of the present study was to investigate the vacuum stability conditions in mid-level and low–level milking systems using different designs of milking clusters.

Materials and methods

Tests were carried out with a new design of flow simulator (O' Callaghan, 1997). The opening on the artificial teat was placed in the plane of collapse of the liner and the collapsed liner discontinued the flow of water. The maximum, minimum and mean value of vacuum level in a full pulsation cycle and during the four phases of a pulsation cycle was also computed for each measurement sensor.

Tests were carried out on mid-level and a low-level milking systems with six and four designs of milking unit respectively, with three water flows 4, 6.8 litres / min; a pulsation rate of 60 cycles / min; three pulsator ratios 60, 64 and 68% and two pulsation phases simultaneous and alternate. For the mid-level milking system each claw was connected to a 48.5 mm milk pipeline, the milk lift of 1.4 metres and a system vacuum level of 50 kPa were used. With the low-level milking unit a long milk tube with a bore of 16mm and 0.8 m long was used, this was connected to a 20 litre receiver vessel located 300 mm below the claw. The mean vacuum in this receiver was set at 40 kPa.

Table 1. Details of milking units used for mid-level (cluster 1-6) and low-level (cluster 1,4,5,6) tests.

Cluster	Liner	Claw vol.	SMT diam.	Bore(upper)	Bore(lower)
1	Wide bore - tapered.	150	8.5	31.5	20
2	Wide bore - tapered.	150	13.5	31.5	20
3	Wide bore - tapered.	420	13.5	31.5	20
4	Wide bore - tapered.	420	8.5	31.5	20
5	Narrow bore.	323	11.1	22.0	19.5
6	Narrow bore.	275	12	25.0	21.0

Results and discussion

The overall effects of cluster type, long milk tube (LMT) internal diameter, water flow, pulsation pattern and pulsator ratio on liner open vacuum are presented in table 2. Increasing the long milk tube to 16mm from 13.5 mm increased the liner open vacuum. Also simultaneous pulsation-1 gave higher liner open vacuum than alternate pulsation –2. The interactions between cluster type, pulsation phase and flow for liner open vacuum is presented in Table 3. For the six cluster types the liner open vacuum was significantly higher with simultaneous than with alternate pulsation. An increase in the diameter of the short milk tube (SMT) from 8.5 mm to 13.5 mm for cluster 1 had a minimal affect on the liner open vacuum. With simultaneous pulsation and a wide bore tapered liner increasing the claw volume reduced the liner open vacuum at the three water flows. The data indicates that level of liner open vacuum is affected by flow and the measurement can be a useful indicator of flow capacity of a milking unit in association with other measurements.

Table 2. Effects of cluster type, long milk tube internal diameter, water flow, pulsation pattern and pulsator ratio on liner open vacuum in a mid-level milking unit.

Cluster	1	2	3	4	5	6	s.e.d
	42.2	41.2	40.0	40.1	38.4	40.4	0.10
LMT (i.d bore)	13.5	16.0					
	38.9	42.1					0.06
Flow (l/min)	0.0	4.0	6.0	8			
	47.6	41.2	38.2	34.9			0.09
Pulsation phase	1.0	2.0					
	42.2	38.8					0.06
Pulsator ratio %	60.0	64	68.0				
	40.5	40.4	40.5				0.08

Table 3. Liner open vacuum - clusters x pulsation x flow interactions for a mid-level milking unit.

Cluster	Flow (l/min) Pulsation	0		4		6		8		s.e.d
		1	2	1	2	1	2	1	2	0.30
1		48.5	48.2	46.3	39.8	44.3	36.0	41.8	32.6	
2		48.4	48.3	45.0	40.5	42.9	36.6	40.0	33.5	
3		47.4	48.0	42.7	39.2	39.5	35.5	35.6	31.7	
4		47.5	47.6	42.8	39.2	39.9	35.9	36.1	31.7	
5		46.2	47.0	38.7	38.3	37.1	34.1	34.1	31.9	
6		47.2	47.0	42.9	39.3	40.2	35.9	37.7	32.5	

The interaction between cluster type, pulsation and flow and mean and minimum vacuum measured over a complete pulsation cycle are shown in Table 4 and Table 5 respectively. Again the mean and minimum vacuum was reduced with increases in water flow rate. The differences in mean vacuum measured over complete pulsation cycles were small in practical terms for the six clusters with either simultaneous or alternate pulsation. Measurements of minimum vacuum over a full cycle differ considerably with cluster type and also are influenced by flow rate. With the wide bore tapered liner a increase in the diameter of either the short milk tube (SMT) above 8.5mm or the claw volume above 150ml increased the minimum vacuum. The low minimum vacuum recorded with a wide bore taper liner used in clusters 1 to 4 when the liner was closed does not affect the frequency of liner slips or milking characteristics (O'Callaghan, 1989, 2000). Alternate pulsation gave higher minimum vacuum than simultaneous pulsation for the six clusters. However there is a definite advantage in using simultaneous pulsation with the six cluster types for a milk extraction perspective.

Table 4. Mean vacuum over full cycle - cluster x pulsation x flow interaction for a mid-level milking unit.

Cluster	Flow (l/min) Pulsation	0		4		6		8		s.e.d
		1	2	1	2	1	2	1	2	0.24
1		47.9	48.0	37.9	39.2	35.0	35.1	32.3	31.1	
2		48.0	47.8	39.0	40.2	36.0	36.6	32.9	33.5	
3		47.4	47.8	38.7	39.1	34.9	35.4	30.9	31.7	
4		47.6	47.6	38.2	39.1	34.6	35.4	30.9	31.1	
5		47.0	47.0	38.5	38.5	35.3	34.2	32.0	31.3	
6		47.4	46.9	38.6	39.2	35.6	35.7	32.7	32.3	

Table 5. Minimum vacuum in full cycle - cluster x pulsation x flow interaction for a mid-level milking unit.

Cluster	Flow (l/min) Pulsation	0		4		6		8		s.e.d
		1	2	1	2	1	2	1	2	0.60
1		38.0	44.0	14.4	25.5	12.2	19.3	10.4	14.6	
2		39.1	43.9	22.5	36.5	18.9	32.5	15.5	28.9	
3		41.1	45.0	27.6	36.0	23.0	32.0	19.1	27.9	
4		41.7	44.9	22.2	33.2	17.9	26.9	15.2	19.6	
5		43.3	43.7	30.4	34.5	25.2	27.7	21.8	23.1	
6		41.4	44.0	27.8	36.4	24.4	32.5	20.9	28.2	

The vacuum fluctuation or the difference between the maximum and the minimum vacuum over a complete pulsation cycle is presented in Table 6. With simultaneous pulsation the vacuum fluctuations did not increase progressively with flow. With alternate pulsation the vacuum fluctuation increased with flow, the relationship was however not linear. Rating of clusters for flow capacity based on vacuum fluctuation is of limited value.

Generally the claw and teat-end vacuum during the liner open phase were similar. Analogue plots of teat-end and claw vacuum indicate differences particularly during the liner closing phase of the pulsation waveform. The maximum and minimum readings of claw and teat-end vacuum do not always occur simultaneously and the potential for reverse flow requires analysis of synchronised values of teat-end and claw vacuum.

Table 6. Vacuum fluctuation in a full cycle - cluster x pulsation x flow interaction for a mid-level milking unit.

Cluster	Flow (l/min) Pulsation	0		4		6		8		s.e.d
		1	2	1	2	1	2	1	2	0.70
1		13.0	6.5	37.3	21.4	37.0	25.6	37.8	28.2	
2		11.8	6.2	28.2	10.0	29.0	11.5	29.0.	13.0	
3		8.7	4.5	18.9	8.2	19.8	8.6	19.7	10.1	
4		8.3	4.5	24.2	11.5	25.4	14.9	24.2	19.1	
5		6.2	5.3	15.7	8.9	18.4	12.9	19.8	15.0	
6		8.6	5.2	18.1	7.9	18.4	8.9	19.4	10.3	

For low level milking units the losses in liner open vacuum were lower with clusters 1, 4 and 6 with simultaneous compared to alternate pulsation (Table 7). These differences were not evident from measurements of vacuum over full pulsation cycles (Table 8). The claw in cluster 4 had angled milk nozzles and gave less vacuum loss with alternate pulsation than with simultaneous. Generally vacuum losses were low with the four clusters for low-level tests. The low minimum vacuum and large vacuum fluctuation recorded with wide bore tapered liner in cluster 1 and 4 were due to the large volume change during liner closure (Table 9 and 10). The high levels of liner open vacuum that occur with simultaneous pulsation are due to the peak in vacuum during liner opening particularly with wide bore tapered liners.

Table 7. Liner open vacuum - clusters x pulsation x flow interactions for a low - level milking unit.

	Flow (l/min)	0		4		6		8		s.e.d
Cluster	Pulsation	1	2	1	2	1	2	1	2	0.21
1		39.5	39.0	39.2	36.8	38.6	34.8	37.5	33.3	
4		39.0	38.9	37.4	36.5	37.5	35.8	36.4	33.9	
5		39.1	39.4	37.0	38.1	35.8	37.5	34.9	37.5	
6		39.0	38.7	37.0	36.7	36.6	35.3	36.0	34.2	

Table 8. Mean vacuum over full cycle - cluster x pulsation x flow interaction for a low - level milking unit.

	Flow (l/min)	0		4		6		8		s.e.d
Cluster	Pulsation	1	2	1	2	1	2	1	2	0.19
1		39.6	38.9	36.4	36.4	34.9	34.9	33.2	33.6	
4		39.1	38.9	36.7	36.4	35.0	35.2	33.4	33.7	
5		39.3	39.3	37.6	37.1	36.6	36.3	35.8	35.9	
6		39.1	38.6	36.3	36.0	34.8	34.8	33.8	33.8	

Table 9. Minimum vacuum in full cycle - cluster x pulsation x flow interaction for a low-level milking unit.

	Flow (l/min)	0		4		6		8		s.e.d
Cluster	Pulsation	1	2	1	2	1	2	1	2	0.45
1		37.6	36.8	21.4	24.7	18.7	23.0	16.2	21.3	
4		37.4	37.3	26.6	27.7	20.4	24.7	18.0	22.9	
5		38.4	37.9	32.7	31.5	30.0	28.4	28.3	27.0	
6		37.0	36.6	28.2	31.9	24.5	30.4	22.6	29.5	

Table 10. Vacuum fluctuation in a full cycle - cluster x pulsation x flow interaction for a low-level milking unit.

Cluster	Flow (l/min) Pulsation	0		4		6		8		s.e.d
		1	2	1	2	1	2	1	2	0.61
1		3.0	2.8	21.4	16.9	24.4	18.7	27.0	21.0	
4		2.4	2.3	14.8	13.8	20.8	17.4	23.1	18.9	
5		1.6	2.0	8.8	8.6	11.9	12.0	13.4	13.4	
6		2.8	2.9	11.9	7.0	15.8	7.9	17.5	7.9	

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