THE DESIGNING OF SMALL AND MEDIUM SIZED MILKING MACHINES FOR DAIRY SHEEP

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Abstract

Basically, the ISO standard 5707 (Milking machines installations: construction and performance) applies to milking machines for small ruminants for qualitative and quantitative requirements that are similar for dairy cattle such as vacuum regulation, sizing airlines, vacuum gages and receiver. Specific quantitative requirements for sheep were introduced by a group of experts within the International Dairy Federation (I.D.F.) and published in a bulletin in March 2002.

New recommendations, especially for vacuum pump capacity and effective reserve, are now available. For ewes, they take into account the type of cluster used, the number of operators with the type of machine (bucket or milkline) and the number of units. Vacuum pump capacity is also calculated referring to air used during the cleaning process (only for machine with milkline). Furthermore, regulation must be well adjusted in order to maintain a stable vacuum within the plant at every moment of milking.

Pulsation characteristics are important for ewes because they have a direct influence on stimulation of milk let-down. The best pulsation rate should be 150-180 cycles/min and a pulsator ratio of 50%.

Sizing milklines is similar to cows but taking into account the particular milk kinetics of the East-Friesian ewes and the type of cluster used.

Finally, recent recordings of vacuum beyond the teat and in the claw (or SMT) and of liner movements presented in this document can be useful for helping farmers in their choice of new equipment.

Résumé


Les recommandations spécifiques pour les brebis portent d’abord sur la détermination de la capacité de la pompe à vide et la notion de Réserve Réelle. Pour les brebis, et contrairement aux vaches, elle est fonction, du type de faisceau trayeur utilisé et du nombre de trayeurs, mais aussi du type de machine (pots à terre ou lactoduc) et du nombre de postes de traite. La capacité de la pompe à vide doit aussi tenir compte des besoins en air pendant la phase de nettoyage (uniquement pour les installations avec lactoduc). De plus, la régulation du vide doit être assurée dans les meilleures conditions afin de permettre un vide le plus stable possible pendant la traite dans toute l’installation.
Les caractéristiques de pulsation chez les brebis sont les suivantes : 150 à 180 cycles/min avec un rapport de 50%. Elles ont une influence directe sur la stimulation de l’éjection du lait.

La détermination du diamètre intérieur du lactoduc est basée sur le même principe que pour les vaches en tenant compte des cinétiques d’émission du lait des brebis et en particulier celle de la race East-Friesian et également du type de faisceau trayeur utilisé.

Enfin, le choix du faisceau trayeur (griffe et manchon trayeur) est abordé à travers des récents enregistrements réalisés en laboratoire tenant en compte l’évolution du niveau de vide sous le trayon et les mouvements du manchon pendant la traite.

**Introduction**

A milking machine is an assembly of different components which have to work together in the best conditions in order to produce a milk of high quality and to secure udder health of milked animals.

Ewes, like other species such as cows and goats, are milked with a specific machine which applies vacuum (under atmospheric pressure) under the teat in order to open the streak canal through which flows the milk held in the cistern of the gland.

Every component of the milking machine must be figured taking into account different parameters such as: the breed and milk ability of animals, anatomy and physiology of udders, special needs of ewes, skill of operators, etc.

This document attempts to give an overview of the design of a milking machine for ewes. The main parameters such as determination of the vacuum pump capacity with the right effective reserve (ER), sizing milklines and some considerations regarding clusters were discussed in an international group of experts and published in a bulletin of the International Dairy Federation (IDF).

Other results coming from our own researches and field observations are also described and explained because they are useful to have a better understanding of how the milking machine works and its main effects on animals.
The Main Components of a Milking Machine

They are described in figure 1 (bucket milking machine) and in figure 2 (milkline milking machine).

Figure 1. Example of a bucket milking machine (from ISO 3918)

1. Vacuum pump  
2. Airline  
3. Interceptor  
4. Regulator  
5. Vacuum gauge  
6. Vacuum tap  
7. Vacuum tube  
8. Pulsator  
9. Bucket  
10. Long pulse tube  
11. Long milk tube  
12. Claw  
13. Teatcups
Effective Reserve and Vacuum Pump Capacity

The effective reserve (ER) can be defined as an indication of the reserve airflow capacity actually available to maintain the vacuum within 2 kPa when air is accidentally admitted during milking. It is assumed that a vacuum drop of 2 kPa has little or no effect on milking performance.

It is also the difference between the vacuum pump capacity and the air consumption of the different components of the milking machine as shown in figure 3.
When ER is too small, vacuum stability within the machine is not maintained, leading to large vacuum drops which can damage udders and teats. Old Irish studies showed a negative effect on dairy cattle, but there is no reason that this physical phenomena doesn’t lead to the same conclusion for ewes.

ER for sheep is figured taking into account the type of cluster used, the number of milkers and milking practices in this species.

Four main types of clusters are marketed:

- conventional clusters (similar to those used for cows) without automatic shut-off device at the claw,
- conventional clusters with automatic shut-off,
- non-conventional cluster with automatic teatcup valves.
- non-conventional cluster with automatic teatcup valves with automatic teatcup removers.

For more than 15 years, manufacturers have been selling special clusters (non-conventional clusters) including a device called “automatic teatcup valve” which opens for vacuum to the liner when the teatcup is attached and automatically shuts off when the teatcup is detached or the unit falls off. This kind of cluster prevents air entering into the milking plant during handling units in order to maintain a good vacuum stability.

We consider that using clusters with automatic teatcup valves provides nearly the same milking conditions as those for cows when the milker works carefully during unit attachment and detachment. Then, effective reserve for dairy sheep should be relatively similar to the effective reserve for cows taking into account that claws and liners are different, the volume beyond the teat is smaller, and the frequency of liner slips and fall-offs is certainly higher. With this kind of cluster, the intake of air is reduced to a minimum but, when idle, they may need extra air for
working: 20 up to 50 l/min, depending on the model. This amount of extra air must be stated by
the manufacturer.

With conventional clusters (similar to claw used for cows) without automatic shut-off valves
in the milking unit as defined in ISO 3918, the risk is very high that milkers do not shut off the
vacuum at the liner when they attach and when they detach clusters from udders. In this case, ER
should compensate at least for the total air admission of a fully open cluster, which has been
evaluated at 600 litres/minute (21.2 cfm). In these conditions, and unlike dairy cows, the air
admission during unit attachment depends particularly on the number of milkers because there is
risk that different milkers may generate the same fault at the same time.

With conventional clusters with automatic shut-off valves, it is possible for the milker to work
more carefully when using this device. Then the air admission during attachment, which also
depends on the number of milkers (more risks than for cows especially during attachments),
should be similar to transient air entering into an installation for cows used by a normal operator.

The installation shall have a minimum ER determined in accordance with table 1. For each
kind of cluster, ER also depends on the type of installation (pipeline or bucket) and of the number
of units.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Minimum effective reserve (^{a}), in l/min of free air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pipelines</td>
</tr>
<tr>
<td>( n )</td>
<td></td>
</tr>
<tr>
<td>( n \leq 10 )</td>
<td>200 + 20n + nE</td>
</tr>
<tr>
<td>( &gt; 10 )</td>
<td>400 + 10(n - 10) + nE</td>
</tr>
<tr>
<td>Non-conventional cluster with automatic teatcup valve and automatic teatcup removal</td>
<td></td>
</tr>
<tr>
<td>( n \leq 10 )</td>
<td>200 + 20n</td>
</tr>
<tr>
<td>( &gt; 10 )</td>
<td>400 + 10(n - 10)</td>
</tr>
<tr>
<td>Conventional cluster without automatic shut-off valve</td>
<td></td>
</tr>
<tr>
<td>( n \leq 10 )</td>
<td>200 + 20n + 400M</td>
</tr>
<tr>
<td>( &gt; 10 )</td>
<td>400 + 10(n - 10) + 400M</td>
</tr>
<tr>
<td>Conventional cluster with automatic shut-off valve</td>
<td></td>
</tr>
<tr>
<td>( n \leq 10 )</td>
<td>200 + 20n + 200M</td>
</tr>
<tr>
<td>( &gt; 10 )</td>
<td>400 + 10(n - 10) + 200M</td>
</tr>
</tbody>
</table>

\(^{a}\) Plus additional for ancillary equipment.
E = extra air needed for clusters equipped with automatic teatcup valves. M = number of milkers. n = number of units.
Tables 2 to 5 give some examples of ER for small and medium sized installations according to formulas given in table 1.

### Table 2. Minimum effective reserve for milking, in l/min of free air: conventional clusters without automatic shut-off at the claw (in cfm)

<table>
<thead>
<tr>
<th>No units</th>
<th>Pipeline milking machines</th>
<th>Bucket milking machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 milker</td>
<td>2 milkers</td>
</tr>
<tr>
<td></td>
<td>1 milker</td>
<td>2 milkers</td>
</tr>
<tr>
<td>2</td>
<td>640 (22.6)</td>
<td>1040 (36.7)</td>
</tr>
<tr>
<td></td>
<td>340 (12.0)</td>
<td>540 (19.1)</td>
</tr>
<tr>
<td>3</td>
<td>660 (23.2)</td>
<td>1060 (37.5)</td>
</tr>
<tr>
<td></td>
<td>360 (12.7)</td>
<td>560 (19.8)</td>
</tr>
<tr>
<td>4</td>
<td>680 (24.0)</td>
<td>1080 (38.2)</td>
</tr>
<tr>
<td></td>
<td>380 (13.4)</td>
<td>580 (20.5)</td>
</tr>
<tr>
<td>6</td>
<td>720 (25.4)</td>
<td>1120 (39.6)</td>
</tr>
<tr>
<td>8</td>
<td>760 (26.9)</td>
<td>1160 (41.0)</td>
</tr>
<tr>
<td>10</td>
<td>800 (28.3)</td>
<td>1200 (42.4)</td>
</tr>
<tr>
<td>12</td>
<td>820 (29.0)</td>
<td>1220 (43.1)</td>
</tr>
<tr>
<td>16</td>
<td>860 (30.4)</td>
<td>1260 (44.5)</td>
</tr>
</tbody>
</table>

### Table 3. Minimum effective reserve for milking, in l/min of free air: conventional clusters with automatic shut-off at the claw (in cfm)

<table>
<thead>
<tr>
<th>No units</th>
<th>Pipeline milking machines</th>
<th>Bucket milking machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 milker</td>
<td>2 milkers</td>
</tr>
<tr>
<td></td>
<td>1 milker</td>
<td>2 milkers</td>
</tr>
<tr>
<td>2</td>
<td>440 (15.5)</td>
<td>640 (22.6)</td>
</tr>
<tr>
<td></td>
<td>240 (8.5)</td>
<td>340 (12.0)</td>
</tr>
<tr>
<td>3</td>
<td>460 (16.3)</td>
<td>660 (23.3)</td>
</tr>
<tr>
<td></td>
<td>260 (9.2)</td>
<td>360 (12.7)</td>
</tr>
<tr>
<td>4</td>
<td>480 (17.0)</td>
<td>680 (24.0)</td>
</tr>
<tr>
<td></td>
<td>280 (9.9)</td>
<td>380 (13.4)</td>
</tr>
<tr>
<td>6</td>
<td>520 (18.4)</td>
<td>720 (25.4)</td>
</tr>
<tr>
<td></td>
<td>320 (11.3)</td>
<td>420 (14.8)</td>
</tr>
<tr>
<td>8</td>
<td>560 (19.8)</td>
<td>760 (26.9)</td>
</tr>
<tr>
<td></td>
<td>360 (12.7)</td>
<td>460 (16.3)</td>
</tr>
<tr>
<td>10</td>
<td>600 (21.2)</td>
<td>800 (28.3)</td>
</tr>
<tr>
<td></td>
<td>400 (14.1)</td>
<td>500 (17.7)</td>
</tr>
<tr>
<td>12</td>
<td>620 (21.9)</td>
<td>820 (29.0)</td>
</tr>
<tr>
<td></td>
<td>420 (14.8)</td>
<td>520 (18.4)</td>
</tr>
<tr>
<td>16</td>
<td>660 (23.3)</td>
<td>860 (30.4)</td>
</tr>
<tr>
<td></td>
<td>460 (16.3)</td>
<td>560 (19.8)</td>
</tr>
</tbody>
</table>

### Table 4. Minimum effective reserve for milking, in l/min of free air: non-conventional clusters with automatic teatcup valves (examples with extra air of 20 l/min (0.7 cfm) and 40 l/min (10.4 cfm)) (in cfm)

<table>
<thead>
<tr>
<th>No units</th>
<th>Pipeline milking machines</th>
<th>Bucket milking machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extra air 20 l/min</td>
<td>Extra air 40 l/min</td>
</tr>
<tr>
<td></td>
<td>Extra air 20 l/min</td>
<td>Extra air 40 l/min</td>
</tr>
<tr>
<td>2</td>
<td>280 (9.9)</td>
<td>320 (11.3)</td>
</tr>
<tr>
<td></td>
<td>180 (6.4)</td>
<td>220 (7.8)</td>
</tr>
<tr>
<td>3</td>
<td>320 (11.3)</td>
<td>380 (13.4)</td>
</tr>
<tr>
<td></td>
<td>220 (7.8)</td>
<td>280 (9.9)</td>
</tr>
<tr>
<td>4</td>
<td>360 (12.7)</td>
<td>440 (15.5)</td>
</tr>
<tr>
<td></td>
<td>260 (9.2)</td>
<td>340 (12.0)</td>
</tr>
<tr>
<td>6</td>
<td>440 (15.5)</td>
<td>560 (19.8)</td>
</tr>
<tr>
<td>8</td>
<td>520 (18.4)</td>
<td>680 (24.0)</td>
</tr>
<tr>
<td>10</td>
<td>600 (21.2)</td>
<td>800 (28.3)</td>
</tr>
<tr>
<td>12</td>
<td>660 (23.3)</td>
<td>900 (31.8)</td>
</tr>
<tr>
<td>16</td>
<td>780 (27.6)</td>
<td>1100 (38.9)</td>
</tr>
</tbody>
</table>
Table 5. Minimum effective reserve for milking, in l/min of free air: non conventional clusters with automatic teatcup valves and automatic cluster removal.

<table>
<thead>
<tr>
<th>no units Pipeline milking machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>16</td>
</tr>
</tbody>
</table>

Influence of altitude

For installations at altitudes of less than or equal to 300 metres, an atmospheric pressure of 100 kPa shall be assumed for calculating effective reserve. To fulfill the requirements at altitudes higher than 300 meters, a vacuum pump with increased capacity shall be installed. Table 6 gives standard atmospheric pressure and correction factors at various altitudes.

Table 6: Standard atmospheric pressure (p\textsubscript{s}), and correction factor H for a vacuum level of the pump of (kPa) (example)

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Atm press.</th>
<th>Correction factor H for a vacuum level of the pump of (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-300</td>
<td>100</td>
<td>.67 .68 .69 .70 .71 .73 .74 .75 .77 .78 .78 .80 .82 .83</td>
</tr>
<tr>
<td>300-700</td>
<td>95</td>
<td>.68 .70 .71 .72 .74 .75 .77 .78 .80 .82 .84 .86 .88 .90 .87</td>
</tr>
<tr>
<td>700-1200</td>
<td>90</td>
<td>.71 .72 .73 .75 .77 .78 .80 .82 .84 .86 .88 .90 .92 .94 .97</td>
</tr>
<tr>
<td>1200-1700</td>
<td>85</td>
<td>.73 .75 .76 .78 .80 .82 .84 .86 .88 .91 .93 .96 .99 .98</td>
</tr>
</tbody>
</table>

For example, if a milking plant for dairy sheep is to be installed at 1000 meters (3280 feet) above the sea level with a vacuum pump working at 40 kPa (12 inches Hg) (1200 l/min (42.4 cfm) of capacity at 50 kPa (15 inches Hg) at the sea level), the real capacity of the pump at 1500 meters height and 40 kPa will be 1200/0.88 = 1364 l/min (48.2 cfm).

Air used for cleaning

Milklines are usually cleaned by a mixture of air and cleaning solution transported and agitated by the vacuum difference to achieve effective cleaning by slugs with a speed of 7 m/s to 10 m/s.

Where washing systems rely on high pump capacity to achieve the air speed necessary to produce slugs for washing as shown in figure 4, this capacity, Q\textsubscript{clean}, is dependent on the following parameters:

- internal diameter of the pipe,
- air and slug speed in the milk tube,
- actual atmospheric pressure during the test,
- vacuum level when washing the plant.

Figure 4. Principle of cleaning of a milkline in a milking machine.
Because of the low vacuum milking level, milking installations for small ruminants with milklines can be washed at a higher vacuum level to ensure a better turbulence of the cleaning solution through the installation. For example, it is recommended to install the milking machine with two regulators: one is adjusted to work at 36 kPa (10.8 inches Hg) during milking (working vacuum) and the other is adjusted at a higher vacuum level and works only during cleaning within the range of 45-50 kPa (12.6-15 inches Hg).

The quantity of air required for cleaning shall be estimated by referring to table 7.

Table 7. Air used for cleaning in litres/minute (at a speed of 8 m/s and atmospheric pressure of 100 kPa)

<table>
<thead>
<tr>
<th>Vacuum level (kPa)</th>
<th>Internal diameter (mm)</th>
<th>38 (1.5’’)</th>
<th>40 (1.6’’)</th>
<th>48 (1.9’’)</th>
<th>50 (2’’)</th>
<th>60 (2.4’’)</th>
<th>73(2.9’’)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td></td>
<td>348</td>
<td>386</td>
<td>556</td>
<td>603</td>
<td>869</td>
<td>1285</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>338</td>
<td>374</td>
<td>539</td>
<td>584</td>
<td>841</td>
<td>1245</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>327</td>
<td>362</td>
<td>521</td>
<td>565</td>
<td>814</td>
<td>1205</td>
</tr>
<tr>
<td>42</td>
<td></td>
<td>316</td>
<td>350</td>
<td>504</td>
<td>547</td>
<td>787</td>
<td>1165</td>
</tr>
</tbody>
</table>

For example, air used for cleaning a milking plant equipped with a milkline of 50 mm internal diameter (2’’) and working (during cleaning) at 42 kPa (12.6 inches Hg) is 547 l/min (19.3 cfm) at the sea level and 100 kPa atmospheric pressure.

When estimating the vacuum pump capacity of a given plant, the higher value between ER or air used for cleaning will be chosen.

Vacuum pump capacity

The vacuum pump should be capable of withdrawing all air from the milking plant whether it is introduced by different components such as pulsators, regulator, units, or milkers when handling units, and its capacity must be sufficient so that the vacuum drop in the receiver (or close to the receiver) does not exceed 2 kPa during the course of normal milking, including teatcup attachment and removal and liner slips.

The capacity of a vacuum pump is estimated taking into account ER and air demand for cleaning, maximum tolerated consumption of the different components of the milking machine and the eventual correction for altitude.
**First example**: estimation of a vacuum pump capacity for a bucket milking machine installed at 200 meters above the sea level:

a) machine with 2 double buckets with 4 conventional units without automatic shut-off at the claw,
   b) one milker,
   c) working vacuum level: 36 kPa (10.8 inches Hg),
   d) air admission in the clusters: 8 l/min (0.3 cfm),
   e) number of pneumatic pulsators: 2,
   f) air consumption for each pulsators: 35 l/min (1.6 cfm),
   g) buckets and units hand cleaned.

1 - According to table 1, the effective reserve capacity for milking will be:

\[ 100 \text{ l/min} + (20 \times 4) \text{ l/min} + 200 \text{ l/min} = 380 \text{ l/min} \text{ (13.4 cfm)} \]

2 – Because of hand cleaning, no special air used for cleaning is required,

3 - Air consumption for the milking units (air admission and pulsators will be: (8 x 4) l/min +(35 x 2) l/min = 102 l/min (3.6 cfm).

4 - Total air demand during milking will be: 380 l/min + 102 l/min = 482 l/min (17.0 cfm).

5 - Regulation loss is 10 % of the manual reserve. The effective reserve was 380 l/min and is smaller than the manual reserve. Consequently:

   Manual reserve = 380 l/min \times 100/(100-10) = 422 l/min (14.9 cfm)
   regulation loss 422 l/min \times 10/100 = 42 l/min (1.5 cfm)
   total: 482 l/min + 42 l/min = 524 l/min (18.5 cfm)

10 - Leakage into the airlines are equal to 5 % of the pump capacity, that is vacuum system leakage: 524 l/min \times 5/100-5) = 27 l/min (0.9 cfm)

   total: 524 l/min + 27 l/min = 551 l/min (19.5 cfm)

11 - With a pressure drop of 3 kPa between pump and measuring point the vacuum level at the pump will be: 36 kPa + 3 kPa = 39 kPa (11.7 inches Hg)

   551 l/min (19.5 cfm) is the pump capacity at its working vacuum level (39 kPa or 11.7 inches Hg))

   Table 6 gives a correction factor of 0.78 for a vacuum of 39 kPa for an atmospheric pressure of 100 kPa and a vacuum level of 50 kPa at 200 meters high:

   The nominal pump capacity will be: 551 l/min \times 0.78 = 430 l/min (15.2 cfm).

**Second example**: milking parlour with 12 units, automatic teatcup valves, valve located at 1000 m above the sea level;

a) one milker,
   b) working vacuum level: 38 kPa (11.4 inches Hg),
   c) milkline internal diameter: 48 mm (1.9’’),
   d) air admission in the clusters: 8 l/min (0.3 cfm),
   e) extra air needed at clusters: 20 l/min (0.7 cfm),
   f) number of pulsators: 6,
   g) air consumption for each pulsators: 25 l/min (0.9 cfm),
   h) vacuum level for cleaning: 50 kPa (15 inches Hg)
1 - According to table 1 the effective reserve capacity for milking will be:
   \[ 400 \text{ l/min} + (10 \times 2) \text{ l/min} + (12 \times 20) \text{ l/min} = 660 \text{ l/min} (23.3 \text{ cfm}) \]

2 - According to table 7 the air demand for cleaning at 50 kPa for a milkline of 48 mm internal diameter and at an altitude of 1000 m should be 386 \text{ l/min} (13.6 \text{ cfm}) which is lower than the effective reserve for milking.

3 - Air consumption for the milking units (air admission and pulsators will be:
   \[ (8 \times 12) \text{ l/min} + (25 \times 6) \text{ l/min} = 246 \text{ l/min} (8.7 \text{ cfm}) \]

4 - Total air demand during milking will be: 660 \text{ l/min} + 246 \text{ l/min} = 906 \text{ l/min} (32.0 \text{ cfm})

5 - Total air demand during cleaning will be: 434 \text{ l/min} + 246 \text{ l/min} = 680 \text{ l/min} (24.0 \text{ cfm})

6 - In this example the capacity for milking is larger and therefore shall be taken as a basis for the pump dimensioning.

7 - Leakage into the milk system: 10 \text{ l/min} + (2 \times 12) \text{ l/min} = 34 \text{ l/min} (1.2 \text{ cfm})

8 - Total: 906 \text{ l/min} + 34 \text{ l/min} = 940 \text{ l/min} (33.2 \text{ cfm})

9 - Regulation loss is 10 % of the manual reserve. The effective reserve was 660 \text{ l/min} (23.3 cfm) and is smaller than the manual reserve. Consequently:
   - Manual reserve = 660 \text{ l/min} \times \frac{100}{100-10} = 733 \text{ l/min} (25.9 \text{ cfm})
   - regulation loss 733 \text{ l/min} \times \frac{10}{100} = 73 \text{ l/min} (2.6 \text{ cfm})
   - total: 940 \text{ l/min} + 73 \text{ l/min} = 1013 \text{ l/min} (35.8 \text{ cfm}).

10 - Leakage into the airlines are equal to 5 % of the pump capacity, that is vacuum system leakage: 1013 \text{ l/min} \times \frac{5}{100-5} = 53 \text{ l/min} (1.9 \text{ cfm})

11 - With a pressure drop of 3 kPa between pump and measuring point the vacuum level at the pump will be: 38 kPa + 3 kPa = 41 kPa (12.3 inches Hg).

1066 \text{ l/min} (37.7 \text{ cfm}) is the vacuum pump capacity at its working vacuum.

Correction for the higher altitude in accordance with table 6 for the altitude of 1000 m and a vacuum of 41 kPa will give a correction factor of 0.90 for an atmospheric pressure of 100 kPa and a vacuum level of 50 kPa.

The nominal pump capacity is: 1066 \text{ l/min} \times 0.9 = 959\text{l/min} (33.9 \text{ cfm})

**Regulation**

The regulator is one of the main parts of a milking machine. Its role is to keep the vacuum level constant within the range of 2 kPa during the course of normal milking, including teatcup attachment and removal, liner slips or teatcups falls-off for at least 99% of the milking time.

Self controlled regulators are good devices and easily fulfil the requirements. They only have to be maintained in good order by good maintenance.

A regulator has to be sensitive (<<1 kPa). Sensitivity of the regulator is the difference of working vacuum when the machine is working with no milking unit connected, and all units
connected. A lower sensitivity can lead to a higher and/or unstable working vacuum which has bad effects on udder health and teat end conditions.

A high regulation loss (air flow through the regulator when it normally would be closed) indicates some problems of connection or leakages between the regulator and the receiver. This issue leads to higher irregular fluctuations in the long milk tube as shown on figure 5.

Figure 5. Irregular vacuum fluctuations in the Long Milk Tube (LMT) and near the regulator (Vr) with (a) and without (b) regulation loss when a large amount of air suddenly enters into the installation.

Irregular fluctuations simultaneously occur under the teat. When associated with large cyclic variations which can be generated by some clusters and/or in certain conditions, it is a real source of udder infections as it has been shown for dairy cattle for more than 35 years. (Nyhan, 1968; Thiel et al, 1973; Bramley, 1991). In addition, large irregular fluctuations may decrease vacuum under the teat which can lead to liner slips and impacts of infected droplets of milk on the teat end; providing another source of infection. (Thiel et al. 1969; Le Du, 1977; Thompson et Pearson, 1979; O’Shea et al, 1984; Bramley, 1991).

Too much regulator leakage means that the regulator is open when it should be closed. That leads to an unstable vacuum and milking troubles as described above. This is often due to bad maintenance of the regulator.

Vacuum level of a given installation has to be adjusted taking into account different parameters such as:
- milking ability of ewes
- type of liner and cluster
- skill of the operator (s)
- type of milking machine (bucket, low or high milkline).

Too high vacuum can lead to poor teat end conditions and udder infections, more stripping but faster milking. Too low of vacuum results in a milking duration increase, and more liner slips.
and fall-offs can be observed. Then, it is easy to understand that the best vacuum for a given installation is a compromise between all these parameters.

Usually, the following vacuum levels are advised:

- 34-38 kPa (10.2-11.4 inches Hg) for buckets and low milklines
- 38-40 kPa (11.4-12 inches Hg) for high line milklines.

**Pulsation System**

**Type of pulsators**

2 types of pulsators are used: pneumatic and electronic.

Pneumatic pulsators are traditionally used in very small plants with buckets, for example. They are very simple devices only working with vacuum. However, their characteristics, especially pulsation rate, are vacuum sensitive. For example if the regulator fails or if the farmer wants to change the working vacuum, pulsation rate will also change. Pulsator ratio is also affected but in a smaller proportion.

The main drawback of pneumatic pulsators is a tendency for failure due to worn pieces and moisture. A French study (Sauvée et al, 1998) showed that less than three months after having being checked and adjusted, more than half of them were still out of order. That means that pneumatic pulsators have to be checked very often (every month for example) and maintained in a good order by at least cleaning filters and changing worn components. The risk of failure increases when feeding ewes during milking due to dust generated by concentrate foodstuffs falling down into mangers. In this case, cleaning and maintenance have to be reinforced.

Electronic pulsators are now used in milking parlours. They have two main components: a pulsation generator which is an electric and electronic device that sends electric signals to an electric relay or a pulsator. Generally, in dairy sheep milking machines, one relay or pulsator is used for two units. Electronic pulsators are more reliable because pulsation rate doesn’t change with vacuum and is stable. Obviously, pulsator ratio can also fail if relays are not clean enough. However, the above mentioned French study showed that most electronic pulsators were still working well 18 months after their last adjustment. Unfortunately, they are more expensive, but they lead to more relaxed milking conditions both for milkers and animals.

So, it is recommended to use electronic pulsation instead of a pneumatic one, especially in milking parlours.

In dairy sheep milking machines, pulsators used are simultaneous pulsators. That means that each half udder is at the same time in the suckling phase and in the rest phase (figure 6).
Recent researches (Billon et al., 2004) showed that there are no technical reasons for using alternate pulsation for dairy ewes with modern clusters and liners (similar average, minimum and maximum teat end vacuum and similar movement of the liner) (figure 7). The only reason for choosing alternate pulsation in dairy sheep milking machines should be when using very small clusters with small internal diameter of the short milk tubes in order to avoid claw flooding by dividing the milk flow rate by 2.

In milking parlours, it is recommended that filtered atmospheric air be used for the pulsators in order to maintain clean relays for the longest time as possible. The air filter should be installed
in a place where it cannot be contaminated with dust coming from forage or other goods that can taint dairy products.

**Pulsation rate**

A survey carried out by the International Dairy federation (I.D.F.) in 1998 showed that pulsation rate for dairy sheep is usually in the range from 90 to 180 cycles/min. A lot of studies showed that a high pulsation rate is necessary to obtain the most milk during the shortest milking time. For example, Le Du (1981) showed that a pulsation rate of 180 cycles/min leads to a shorter machine on time, more fat content, similar machine yield and more total milk due to more stripping milk and obviously greater stripping time. However, this study was carried out at a 44 kPa vacuum level in high line parlour; it is likely the main cause of a higher level of stripping.

French field experiences confirm everyday that a high pulsation rate leads to better milking conditions and not necessarily to a higher amount of stripping milk which depends both on the shape of the udder and on the teats location on the udder.

In addition, a fast pulsation rate leads to better teat end conditions (Marnet et al., 2002) (figure 8).

![Figure 8. Relationship between teat end conditions and pulsation rate and working vacuum level](image_url)

More recent field observations in France on different breeds showed that pulsation rate should not be less than 150 cycles per minute. 180 cycles/min should be the pulsation rate for high yielding ewes such as the Lacaune breed.

When checking, the pulsation rate must not deviate by more than 5% from the values given by the installer. It is easy to check the pulsation rate with the thumb into the mouthpiece chamber
during half a minute or one minute. If the number of massages during one minute shows a higher deviation than 5% from the initial value, the pulsators must, at least, be cleaned. If no amelioration occurs after cleaning, the pulsators must be checked by the dealer.

**Pulsator ratio**

Traditionally, pulsator ratio used in milking machines for sheep is 50%. A pulsator ratio of 60% is possible. In certain cases a higher ratio improves the pulsation curve and movements of the liner, especially when the liner is open leading to a quicker milking.

When checking, the pulsator ratio must not differ more than ±5 units of percentage from the values given by the installer. In addition, pulsator ratios of all pulsators of an installation must not vary from each other by more than 5 units of percentage, and, in case of alternate pulsation, the two teatcups may not vary from each other by more than 5%.

Because it is more difficult to check the ratio without special tools and recording devices, it is recommended that the dealer check every pulsator at least once a year and more often for pneumatic devices.

**Pulsation phases**

Right now, there is no evidence, and no scientific proof, of effects of pulsation phases on milking and udder health for dairy sheep. More research is needed.

**Milk System**

**Minimum internal diameter of milklines**

Ideally in a milkline, milk should flow in the lower part of the pipeline with a clear continuous space above for the much larger volume of air to pass over it. This flow condition is known as stratified flow. In practice, flow typically varies between stratified flow and slug flow. Slug flow occurs whenever slugs of milk fill the entire cross-section of the milkline. Slug flow conditions in the milkline almost always induce transient vacuum drops greater than 2 kPa. Chronic slugging in the milkline is likely to have almost the same effect on milking performance and milk quality as raising the milkline height by about 300 mm to 500 mm, i.e., slower milking and more liner slips (because of lower minimum liner vacuum), and higher acid degree values. Milkline vacuum almost always remains stable within ±2 kPa of the receiver vacuum under stratified flow conditions. Therefore, the limit of 2 kPa essentially means that stratified flow should be the normal flow condition in the milkline.

Experimental laboratory studies have been carried out to determine the maximum milk flow rate to ensure that stratified flow is the normal flow condition during dairy cattle milking. There is apparently no reason why equations figured for cattle should not apply to small ruminants if the ratio between steady air flow and milk flow is chosen according to real milking conditions of these
species. For example, with dairy cattle, the experimental data were based on a ratio of 10 l/min (0.35 cfm) steady air flow at the unit per 4.5 l/min liquid per unit, i.e. a ratio of 2.2.

However, the problem is more difficult with small ruminants because maximum flow rate can vary between between breeds. Thus, it is suggested that equations referring to dairy cattle (ISO 5707) for three different ratios based on 8 l/min (0.28 cfm) steady air per unit (refer to the paragraph related to air vent and leakage at the unit) and three milk flow rates apply: 0.8 l/min for species and breeds with low maximum milk flow rates (Lacaune and Manech breeds for example), 1.3 l/min for species and breeds with medium maximum milk flow rates (Manchega, Churra and Laxta breeds for example), and 2.7 l/min for species and breeds with high maximum milk flow rates (Sardinian breed for example). Referring to the results of McKusick et al. (2002), a milk ejection curve for East Friesian ewes in Wisconsin is similar to the one for medium maximum milk flow rate such as Manchega, Chura or Laxta breeds (average parameters: maximum flow rate - 1.24 l/min, milk flow latency - 13.1 seconds, machine milking time - 105.9 seconds) (figure 9).

Figure 9. Typical milk flow rate curves for sheep

Maximum milk flow in the milkline can be predicted from the milk flow curves taking into account the breed and the average attachment rate. Then it is possible to figure the maximum milk flow per slope to ensure that stratified flow is the normal condition during milking. The calculated milk flow must be less (or at least equal) to the predicted milk flow in the milkline.

Tables 8 shows examples of the predicted maximum milk flow rate of a group of sheep with maximum milk flow rates of 0.8 and 1.3 l/min and for units attached at intervals of 5 and 10 seconds which are common milking routines for small ruminants.
Table 8: Maximum predicted milk flow rate in litres/minute in milklines for sheep

<table>
<thead>
<tr>
<th>No units</th>
<th>6</th>
<th>10</th>
<th>12</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attach' rate (s)</td>
<td>Maximum flow rate : 0.8 l/min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.8</td>
<td>7.3</td>
<td>8.2</td>
<td>9.0</td>
</tr>
<tr>
<td>10</td>
<td>4.1</td>
<td>4.6</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>Maximum flow rate : 1.3 l/min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7.1</td>
<td>9.1</td>
<td>9.6</td>
<td>10.0</td>
</tr>
<tr>
<td>10</td>
<td>4.9</td>
<td>5.2</td>
<td>5.2</td>
<td>5.2</td>
</tr>
</tbody>
</table>

The main parameters for sizing milklines are the following:
- type of cluster and transient air when handling for each kind of cluster,
- slope of the milkline,
- configuration of the milkline (looped or dead-ended),
- attachment rate,
- maximum predicted milk flow rate.

The designed air flow conditions are based on a steady air admission of 8 l/min (0.3 cfm) through air vents and constant leaks at the cluster, plus intermittent air flows associated with attachment, liner slips and removal.

The proposed guidelines for transient air must be consistent with the other requirements and particularly with the ER calculation and are the following:

1- for conventional clusters without automatic shut-off valve: 400 l/min (14.1 cfm) for intermittent air flow into a dead-ended line, or 200 l/min (7.1 cfm) per slope for a looped milk line
2- for conventional clusters with automatic shut-off valve: 200 l/min (7.1 cfm) for intermittent air flow into a dead-ended line, or 100 l/min (3.5 cfm) per slope for a looped milk line
3- for non-conventional clusters (with automatic teatcup valves): 50 l/min (1.8 cfm) for intermittent air flow into a dead-ended line, or 25 l/min (0.9 cfm) per slope for a looped milk line

A special Excel sheet was made in order to facilitate calculations. See example below (figure 10).
Table 9 gives an example of the maximal number of units per slope for East Friesian ewes (dmax = 1.3 l/min) and a milkline of 48.5 mm (2’’) internal diameter at an attachment rate of 5 s.

Table 9: Maximal number of units per slope for ewes with dmax = 1.3 l/min and a milkline of 48.5 mm (2’’) internal diameter and an interval attachment of 5 s.

<table>
<thead>
<tr>
<th>Type of Cluster</th>
<th>Looped milklines (dead-ended milklines)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>slope (%)</td>
</tr>
<tr>
<td></td>
<td>0.5  1.0  1.5  2.0</td>
</tr>
<tr>
<td>Conventional without automatic shut-off</td>
<td>3 (2)  9 (3)  * (7)  * (*)</td>
</tr>
<tr>
<td>Conventional with automatic shut-off</td>
<td>5 (3)  * (9)  * (<em>)  * (</em>)</td>
</tr>
<tr>
<td>Non conventional with automatic teatcups valves</td>
<td>4 (<em>)  9 (</em>)  * (<em>)  * (</em>)</td>
</tr>
</tbody>
</table>

* = unlimited number of milking units

For other calculations (i.e. different attachment rates, other diameters,…), use the Excel sheet.
Cluster Assembly

Long milk tube

The long milk tube can have a large effect on vacuum fluctuations under the teat. To minimize this issue, its internal diameter must be greater than 12.5 mm (or at least equal). When using a high level milkline, and because of the column of milk to be lifted from the claw to the milkline, the internal diameter of the long milk tube shall be less than 14.5 mm (or at least equal).

When using low level milkline, length of the long milk tube must be as short as possible without a bend in order to avoid milk being lifted into the milkline.

Short milk tube

To reduce the likelihood of milk plugs in the short milk tube and reverse flow and/or impacts against the teat, it is recommended to use a short milk tube with internal diameter of at least 9 mm.

Claw

Clusters used in milking machines for sheep have a claw of 50-100 cc, but some of them are only made with tubes of stainless steel, or plastic, as a Y shape. This kind of claw can milk ewes while maintaining desired vacuum only if the internal diameter of the short milk tubes (SMT) is at least 9 mm and if the air vent is in good order. Then the bowl is not necessary.

Conventional clusters can be equipped with an automatic shut-off device at the claw. With such a device, it is easier for the operator to limit air entering into the installation during detachments and when going from one animal to another. It also shuts off the vacuum when the cluster falls off onto the platform. Obviously, it leads to less air into the plant and less bacteria in the milk. At least, an easy-to-use clamp should be installed on the long milk tube.

Air vent and leakage

An air vent at the cluster is necessary in order to avoid flooded claws and/or slugs in short milk tubes. With clusters including a liner with an elbow and a long short milk tube (25 up to 30 cm -10 to 12 inches-), it is recommended to locate the air vent at each teatcup just above or at the elbow leads for a better milking, better draining of tubes and claws (Le Du, 1981) (table 10) and less vacuum fluctuations under teats.
Table 10. Influence of the place of air vent on milking

<table>
<thead>
<tr>
<th>Air vent</th>
<th>Total Milk</th>
<th>Stripping milk</th>
<th>Machine Milking time</th>
<th>Average flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the claw</td>
<td>756</td>
<td>94.5</td>
<td>91</td>
<td>436.1</td>
</tr>
<tr>
<td>At the claw AND at the bend</td>
<td>771</td>
<td>84.1</td>
<td>85.1</td>
<td>484.3</td>
</tr>
<tr>
<td>Stat</td>
<td>NS</td>
<td>**</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

The total air intake per cluster from the air vent and air leakage (conventional clusters) must not exceed 8 l/min (0.28 cfm) and must allow at least 4 l/min of free air (0.14 cfm) at the nominal working vacuum level. That means that a constant effort of the operator has to be done in order to maintain the air vent free of dust and moisture.

In conventional clusters, a maximum of 2 l/min at the shut-off device is tolerated.

Liner

The liner is one of the most important components of a milking machine, yet this is relatively unknown. The main characteristics of a liner should be the following:
- quick and gently milking of every animal,
- limiting stripping,
- limiting liner slips and avoiding fall-off,
- limited influence on somatic cells count (SCC) and clinical mastitis,
- limited influence on free fatty acids (FFA).

Le Du (1981) showed that liners made of silicone produced the same amount of stripping milk compared with liners made with rubber. Another study by the same author compared 4 liners, the characteristics of which are shown in table 11. This study was performed on Lacaune ewes with a lowline milking machine working at 36 kPa (10.8 inches Hg), a pulsation rate of 172 cycles/min, and a pulsator ratio of 50%.

Table 11. Characteristics of studied liners

<table>
<thead>
<tr>
<th>Liner Parameter</th>
<th>Ref</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouthpiece lip ID (mm)</td>
<td>20</td>
<td>22</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Barrel ID (mm) (top)</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Barrel ID (mm) (bottom)</td>
<td>19</td>
<td>19</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Buckling pressure (kPa)</td>
<td>10.7</td>
<td>10</td>
<td>10</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Results show that for Lacaune ewes, and likely for ewes with similar milking ability and udder and teats morphology, a good liner has a mouthpiece lip diameter not greater than 19 mm, a tapered and smooth barrel (table 12). The lowest amount of milk during stripping was obtained with two different liners, one with a tapered barrel and the other with a larger bore. That is consistent with other studies carried out on cows. Machine-on time was the lowest when the liner bore was not too high (around 19 mm) or tapered. Liner B gave the best compromise between all
requirements and objectives mentioned earlier. In addition, the better teat end conditions after the 48 days of experimentation lead to the conclusion that a soft liner with a low buckling pressure (7-8 kPa) is likely interesting. However, too low buckling pressure as liner C in the experiment seems to indicate too weak of material because early distorted mouthpiece lips were observed.

| Table 12. Milking characteristics of different studied liners (Lacaune breed) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Liner   | Total milk yield (ml) | Stripping yield (ml) | Stripping yield (%) | Machine milking time (s) | Average milk flow rate (l/min) | Number of fall-off (%) | Number of slipping (%) |
| Ref 1708 | 232 | 13.8 | 246 | 386 |
| Ref 1720 | 236 | 13.8 | 251 | 377 |
| Ref 1749 | 224 | 12.8 | 244 | 400 | 0.69<sup>b</sup> | 2.31<sup>a</sup> |
| A 1625 | 282<sup>a</sup> | 17.7 | 260<sup>a</sup> | 338<sup>a</sup> | 4.86<sup>c</sup> | 2.99<sup>b</sup> |
| B 1622 | 209<sup>b</sup> | 13.2 | 242<sup>b</sup> | 378<sup>b</sup> | 0.35<sup>a</sup> | 2.50<sup>a</sup> |
| C 1643 | 203<sup>b</sup> | 12.5 | 254<sup>b</sup> | 368<sup>b</sup> | 1.18<sup>b</sup> | 2.01<sup>a</sup> |
| Stat | NS | P<0.001 | NS | P<0.001 | P<0.001 | P<0.001 |

<sup>a,b,c</sup>: values with the same letter in the same column do not differ statistically.

To conclude, a good liner should have the following characteristics:
- made in silicone and soft,
- with a narrow mouthpiece lip (not greater than 19 mm)
- with a narrow bore or tapered barrel,
- with an air vent at the bend of the short milk tube,
- and not too expansive!!.

The choice of a cluster

It is always very difficult to choose the right cluster able to milk rapidly and gently the total number of ewes in a given flock with only a few risks to udder health and with good utilization of labour. Quick and gentle milking will be especially managed by choosing the right vacuum level and the better pulsation characteristics (see previous paragraph).

Following are the main properties of a good cluster:
- good handling in order to guarantee good working conditions but also to limit air admission into the installation during attachments and detachments. Clusters with automatic teatcups valves are surely the best solution but conventional clusters can be appropriate if operators work carefully. In this case, an automatic shut-off device will be a good assistant. These solutions limit impacts of milk droplets against teat ends which are well known to be a major factor of introduction of pathogens into the streak canal during milking.
- Good vacuum stability under the teat during milking. That means that vacuum drops due to milk flow through the cluster must be as low as possible and both vacuum under the teat and vacuum at the milk outlet of the claw have to be the most similar as possible as shown on figure 11.
In some cases, the minimum vacuum under the teat can dramatically decrease principally due to a too small of diameter of the short milk tube (figure 12). In extreme situations this phenomena can lead to liner slips and fall-off which are a source of unstable vacuum and of impacts.

When the cluster is not appropriate and especially when the free volume under the teat is too small due, for example, to flooding, minimum vacuum under the teat decreases as mentioned just above. In addition, maximum vacuum, which occurs when the liner is opening raises to a higher level then the nominal vacuum and a higher level than the vacuum within the claw at the same time. Then, milk which was flowing from the teat (top) to the claw (bottom) is re-suckled from the claw (or the SMT) to the teat. That is what specialists call “reverse flow”. Teats are washed by milk and bacteria living on udder’s skin can be deposit all around the extremity of the steak.
canal, ready to be introduced during milking or at the end of milking just before the canal is completely closed (figure 13).

Figure 13. Vacuum and liner movements in two clusters with a flooded claw or SMT (LL, 36 kPa and 1.5 l/min milk flow rate)

- In addition with dimensional aspects mentioned in the previous paragraph, movements of the liner are very important. Despite the high pulsation rate, we can observe a real ‘suckling’ phase when the liner is completely open and a real ‘rest’ phase with the liner is collapsed (see figures 11 to 13). Obviously, duration of these phases vary from liner to liner. Laboratory recordings with 8 different kinds of clusters, now used for sheep worldwide, showed that the duration of the ‘suckling’ phase varied from 62 up to 111 ms, and the duration of the ‘rest’ phase varied between 73 and 167 ms. That shows that for several liners the ‘rest’ phase is longer that the ‘suckling’ phase. More research is needed in order to define what should be the best duration.

- Finally, recent studies show that some clusters are less dependant than others on milk flow. Figures 14 show two examples of evolution of the average vacuum under the teat of two clusters in high and low milklines. When the average vacuum under the teat is practically constant, that means that every ewe can be milked at the same vacuum level at each moment of milking. Obviously, more research is also needed in order to ensure that constant vacuum conditions during milking of ewes are absolutely necessary.

Figure 14. Average vacuum under the teat in relationship with milk flow rate
and type of milkline

Conclusion

A milking machine must be properly sized, taking into account both animals and operator(s). Each component of the machine is important, and all of them must perfectly work together in order to avoid milk quality issues and udder health troubles. The milker must not believe that the biggest is the best: for example, bigger vacuum pump or larger milkline internal diameter than needed are obviously more expensive when buying but also when working: higher energy, water and hygiene products consumption.

In addition, a bad operator will automatically lead to bad milking and bad results. Efforts should be done by farmers in milking routine so that they try to limit overmilking, for example and for maintenance of the main components such as the vacuum pump, the regulator and pulsators.

References


