ENSURING OF MILKING EQUIPMENT WASHING LIQUID OPERATION TEMPERATURE

J. Priekulis, V. Zujs, U. Iljins

Latvia University of Agriculture

ABSTRACT. *The article presents mathematical substantiation of heat leak from the washing liquid circulating in the milking equipment. In addition, the possibilities of reducing this leak have been investigated by covering the milk and washing liquid pipes with heat insulation material.*

It has been stated that in a barn where milking equipment for milking 100 cows in milk pipe is installed, the washing liquid loses approximately 60% of heat flowing through the milk and washing liquid pipes.

If the milk and washing liquid pipes are covered with heat insulation material the heat leak through these units will only be in the amount of 26% calculating from the total leak.

Methods and appropriate software have been developed for determination of the final temperature of the milking equipment washing liquid.

Keywords: *milking equipment, washing liquid, heat leak, ensuring of liquid temperature, heat insulation, mathematical substantiation.*

Introduction

In Latvia, the use of cold barns where cows are handled loose and milked in a separate parlour is becoming more widespread. Nevertheless, in winter time the ambient air temperature in such barns is lower (Priekulis *et al*., 2005). Therefore, while washing the milking equipment, the washing liquid cools faster and the recommended operational temperature norms are violated.

Similar problems can occur in warmed barns where cows are tied and milked in the milk pipeline as the length of the milk pipeline used in them usually reaches 100–150 m.

To eliminate this drawback, the washing liquid that circulates in the milking equipment is heated not only before usage but also during circulation. But it is related with additional consumption of energy. Therefore, the aim of our investigation was to determine the possibilities of ensuring the washing liquid operation temperature by covering the milk and washing liquid pipes with heat insulation material (Priekulis *et al*., 2005).

Material and Methods

The way of circulation of the washing liquid in the milking equipment can be roughly divided into four different stages (Figure 1):

I – milk line,
II – milk collection unit and washing liquid tank,
III – milking machines,
IV – washing liquid pipes (excluding the milking machines).

In milk and washing liquid pipes, transfer of heat from the washing liquid to the surrounding environment occurs through cylindrical surfaces, but in other cases through surfaces of indefinite shape. Therefore, this transfer of heat cannot be determined only theoretically but for this reason also experimental research is necessary.

Generally, the cooling of the washing liquid is characterized by the following equation (Treibus, 1970; Nagla *et al.*, 1982):

$$T_b = T_g + \left(T_i - T_g\right) \cdot e^{-\frac{t}{\tau}}, \qquad (1)$$

where: T_b – washing liquid final temperature, °C;
T_g – ambient air temperature, °C;
T_i – washing liquid initial temperature after heating the surface, °C;
t – time of taking measurements, s;
τ – time constant where the washing liquid temperature changes e times, s.

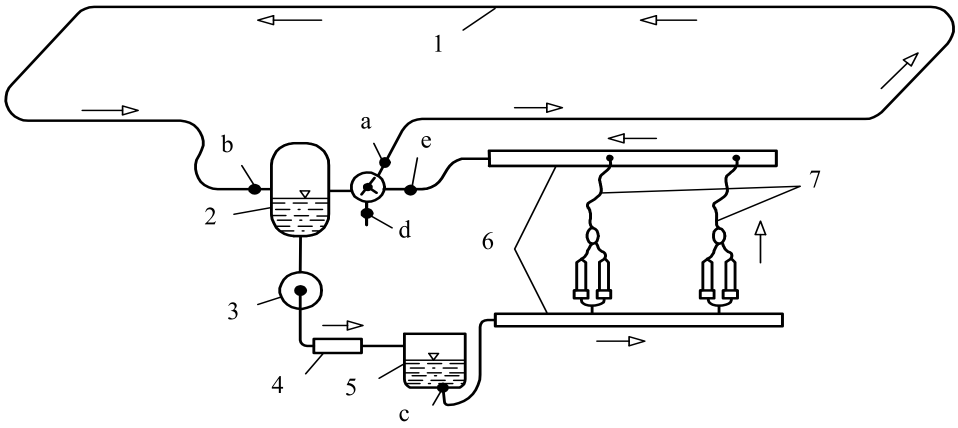

Figure 1. Distribution of the washing liquid flow through separate milking equipment stages: 1 – milk line; 2 – milk collector; 3 – milk pump; 4 – milk filter; 5 – washing liquid tank; 6 – washing liquid pipes; 7 – milking machines; a-b – I stage; b-c – II stage; III – stage; c-a – IV stage

Considering that the distance of the circulation of the washing liquid can be divided into separate stages, the time constant is characterized by the following equation (Zujs, 2005):

$$\tau = \frac{\sum_i c_i \cdot M_i}{\sum_i K_i} = \frac{c_u \cdot M_u + c_I \cdot m_I \cdot L_I + c_{II} \cdot M_{II} + c_{III} \cdot m_{III} \cdot n_{III} + c_{IV} \cdot m_{IV} \cdot L_{IV}}{k_I \cdot L_I + K_{II} + k_{III} \cdot n_{III} + k_{IV} \cdot L_{IV}}, \quad (2)$$

where: c_i – specific heat capacity of the washing liquid and stage i, kJ kg^{-1} K^{-1};
M_i – total mass of the washing liquid and stage i, kg;
K_i – heat transfer coefficient of stage i, W K^{-1};
c_u – washing liquid heat capacity, kJ kg^{-1} K^{-1};
M_u – washing liquid total mass, kg;
c_I – milk line specific heat capacity, kJ kg^{-1} K^{-1};
m_I – milk line one meter mass, kg;
c_{II} – total specific heat capacity of the milk collecting unit and the washing liquid tank, kJ kg^{-1} K^{-1};
M_{II} – total mass of milk collection unit and washing liquid tank, kg;
c_{III} – specific heat capacity of the milking machines, kJ kg^{-1} K^{-1};
m_{III} – mass of one milking machine, kg;
c_{IV} – specific heat capacity of washing liquid pipes, kJ kg^{-1} K^{-1};
m_{IV} – one meter mass of the washing liquid pipe, kg;
k_I – milk line heat transfer coefficient, W m^{-1} K^{-1};
L_I – length of the milk line, m;
K_{II} – total heat transfer coefficient of the milk collection unit and the washing liquid tank, W gab^{-1} K^{-1};
k_{III} – heat transfer coefficient of the milking machines, W gab^{-1} K^{-1};
n_{III} – number of milking machines, pcs;
k_{IV} – heat transfer coefficient of the washing liquid pipes, W m^{-1} K^{-1};
L_{IV} – length of the washing liquid pipes, m.

If the milk and washing liquid pipes of the milking equipment are covered with heat insulation material, the time constant can be calculated according to a similar equation:

$$\tau' = \frac{\sum_i c_i \cdot M_i}{\sum_i K_i} =$$

$$= \frac{c_u \cdot M_u + c_I \cdot m_I \cdot L_I + c'_I \cdot m'_I \cdot L_I + c_{II} \cdot M_{II} + c_{III} \cdot m_{III} \cdot n_{III} + c_{IV} \cdot m_{IV} \cdot L_{IV} + c'_{IV} \cdot m_{IV} \cdot L_{IV}}{k'_I \cdot L_I + K_{II} + k_{III} \cdot n_{III} + k_{IV} \cdot L_{IV}}$$

where: c'_I – specific heat capacity of milk line heat insulation material, kJ kg^{-1} K^{-1};
m'_I – milk line heat insulation one meter mass, kg;
k'_{IV} – washing liquid pipe heat insulation material heat transfer coefficient, W m^{-1} K^{-1};
k'_I – milk line heat insulation material heat transfer coefficient, W m^{-1} K^{-1};
c'_{IV} – washing liquid pipe heat insulation material specific heat capacity, kJ kg^{-1} K^{-1};
m'_{IV} – washing liquid pipe heat insulation material one meter mass, kg.

So, in our case the total expression of the washing liquid cooling mathematical model will be as follows:

$$T_b = T_g + \left(T_i - T_g\right) \cdot e^{-\frac{t \cdot \left(k_I \cdot L_I + K_{II} + k_{III} \cdot n_{III} + k_{IV} \cdot L_{IV}\right)}{c_u \cdot M_u + c_I \cdot m_I \cdot L_I + c_{II} \cdot M_{II} + c_{III} \cdot m_{III} \cdot n_{III} + c_{IV} \cdot m_{IV} \cdot L_{IV}}} . \quad (4)$$

But when covering the milk and washing liquid pipe with heat insulation material layer,

$$T_b' = T_g + \left(T_i' - T_g\right) \cdot e^{-\frac{t \cdot \left(k_I' \cdot L_I + K_{II} + k_{III} \cdot n_{III} + k_{IV}' \cdot L_{IV}\right)}{c_u \cdot M_u + c_I \cdot m_I \cdot L_I + c_I' \cdot m_I' \cdot L_I + c_{II} \cdot M_{II} + c_{III} \cdot m_{III} \cdot n_{III} + c_{IV} \cdot m_{IV} \cdot L_{IV} + c_{IV}' \cdot m_{IV}' \cdot L_{IV}}} . \quad (5)$$

In turn, the milk line heat insulation material heat transfer coefficient can be found according to the equation:

$$k_I' = \frac{\left(c_u \cdot M_u + c_I \cdot m_I \cdot L_I\right) \cdot \ln\left(\frac{T_i' - T_g}{T_b' - T_g}\right)}{L_I \cdot t} . \quad (6)$$

In order to experimentally evaluate the speed of the washing liquid cooling in the milking equipment pipes, the time constant τ can be used, expressed from the formula (1)

$$\tau = \frac{t}{\ln \frac{T_i - T_g}{T_b - T_g}} \quad \text{and} \quad \tau' = \frac{t}{\ln \frac{T_i - T_g}{T_b' - T_g}} . \quad (7, 8)$$

Where the formula 7 is useful for the milking equipment without heating the corresponding pipes, formula 8 can be used for the milk and washing liquid pipes that are covered with heat insulation.

Relating one time constant towards the other, it is possible to determine the coefficient δ that characterizes the influence of the heat insulation:

$$\delta = \frac{\tau}{\tau'} = \frac{\ln \frac{T_i - T_g}{T_b' - T_g}}{\ln \frac{T_i - T_g}{T_b - T_g}} . \quad (9)$$

From the T'_b, the correlation is obtained:

$$T_b' = T_g + \left(T_b - T_g\right) \cdot \left(\frac{T_b - T_g}{T_i - T_g}\right)^{\delta - 1} , \quad (10)$$

Thus, knowing the value of the coefficient δ stated experimentally the final temperature of the washing liquid which can be calculated according to the formula (10) T'_b, *i.e.*, the temperature of this liquid after flowing through such milking equipment stages that are covered with heat insulation material.

The changes in the temperature of the washing liquid in circulating flow were investigated experimentally at the Scientific Laboratory of Milk Production Machinery and Technology at the Institute of Agricultural Machinery of the Latvia University of Agriculture. The milking equipment ADM – 8A laboratory stand completed with a 14 m long milk line and three milking machines was used in the research.

In the experimental research, the following was measured: temperature of the washing liquid T_i; temperature in the laboratory T_g; intensity of the washing liquid through flow.

In order to control the temperatures, digital thermometers with precision ±0.3 °C of the company "Baltic Instruments Ltd." were used. The length of every experiment was 1 h but temperature measurements were taken with a 60 s long interval.

The experiments were carried out in four stages, including each time certain stages of the milking equipment.

In the first experiment only the milk collection unit was included. Therefore, the passage of the washing liquid ran as follows: from the washing liquid tank through a rubber pipeline to the milk collector, through the milk pump and the milk filter, and back to the washing liquid tank.

In the second stage of the experiment, the milk line was added to the run of the washing liquid.

In the third stage of the experiment, the milking machines were joined to the flow of the washing liquid as well.

In the fourth stage of the experiment, the first experiment was repeated, joining the washing liquid pipes in addition.

For every stage of the experiment, the equation of cooling the washing liquid was developed (Table 1). Using these equations as well as the results obtained in the experiments, the numerical values of the heat transition coefficient were calculated.

Table 1. Mathematical equations of the washing liquid cooling for separate milking equipment stages

Stages of the experiment	Parameter to be determined	Mathematical model
1.	K_{II}	$T_{II} = T_g + (T_i - T_g) \cdot e^{-\frac{t \cdot K_{II}}{c_u \cdot M_u + c_{II} \cdot M_{II}}}$. (11)
2.	k_I	$T_{I;II} = T_g + (T_i - T_g) \cdot e^{-\frac{t \cdot (k_I \cdot L_I + K_{II})}{c_u \cdot M_u + c_I \cdot m_I \cdot L_I + c_{II} \cdot M_{II}}}$. (12)
3.	k_{III}	$T_{II;III} = T_g + (T_i - T_g) \cdot e^{-\frac{t \cdot (K_{II} + k_{III} \cdot n_{III})}{c_u \cdot M_u + c_{II} \cdot M_{II} + c_{III} \cdot m_{III} \cdot n_{III}}}$. (13)
4.	k_{IV}	$T_{II;IV} = T_g + (T_i - T_g) \cdot e^{-\frac{t \cdot (K_{II} + k_{IV} \cdot L_{IV})}{c_u \cdot M_u + c_{II} \cdot M_{II} + c_{IV} \cdot m_{IV} \cdot L_{IV}}}$. (14)

For determining the heat insulation influence coefficient *δ,* a unit of the milk line made of stainless steel that is used in the equipment of the company "Larta 1" was used. The length of this line was 12 m, the outer diameter was 42 mm, the thickness of the wall 1.2 mm. One end of the pipe was closed with a thick cork but the pipe itself was fastened with the open end upwards.

The experiment was carried out in several rounds. In the first round the milk pipe had no heat insulation but in the second round it was covered with a 7 mm thick foam polyethylene heat insulation material, and in the third round with a 30 mm thick stone wool insulation and aluminium foil cover.

At the beginning of each experiment, the pipe was filled (up to the top) with hot water the temperature of which was 90 °C. Considering that at the beginning the material of the pipe was warming, the measurements were started when the temperature of water decreased to 50 °C.

The experiments lasted for two hours every 15 minutes, recording the changes of the washing liquid temperature. In turn, it was tried to keep the ambient temperature constant (16.5 °C).

As a result of the experiment, data was obtained on the dynamics of the changes of the water temperature in the corresponding period of time. For the evaluation of the speed of liquid cooling, the time constant *τ* was calculated. After that also the heat insulation influence coefficient *δ* was calculated. For all kinds of calculations, corresponding computer software was elaborated.

Using the mathematical model (5) mathematical expressions for the calculation of the final temperature of the washing liquid for every stage of the milking equipment using warmed milk and washing liquid pipes were developed.

Also the pipe heating economic calculations have been done using general methods for this reason (Priekulis *et al*., 2000).

Results and Discussion

The experimentally obtained changes of the washing liquid temperature depending on the length of the liquid circulation are shown in Figure 2.

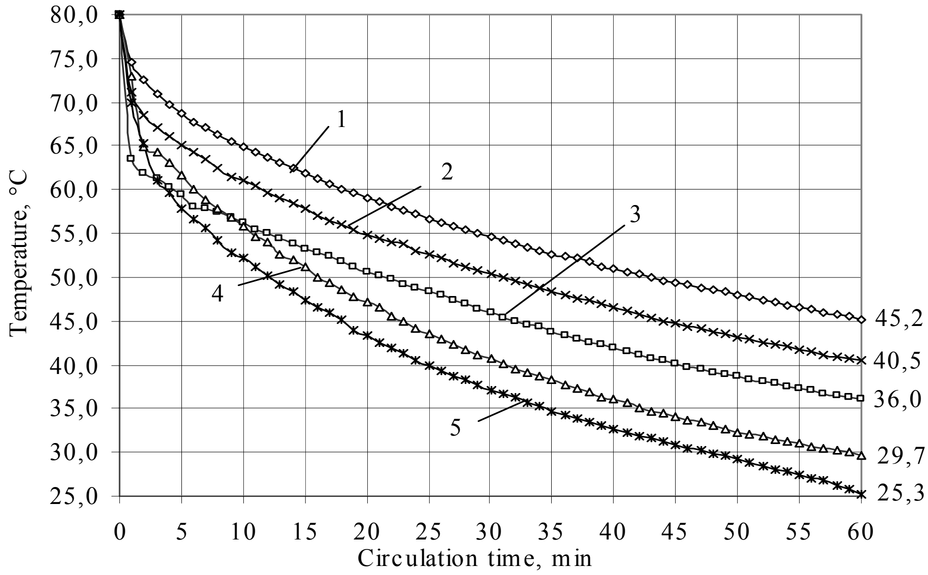

Figure 2. Washing liquid temperature changes depending on the time of washing the milking equipment (heat insulation is not used in this case): 1 – in the II stage of the milking equipment T_{II}, °C; 2 – II and in stage IV $T_{II;IV}$, °C; 3 – in stages II and I $T_{II;I}$, °C; 4 – in stages II and III $T_{II;III}$, °C; 5 – in the milking equipment $T(t)$, °C (determination coefficients R^2 change in the frame from 0.96 to 0.97)

From Figure 2 it can be seen that at the beginning of every experiment there occurs a fast decline in the temperature of the washing liquid, but after approximately five minutes the process stabilizes. It can be explained with the heating of the separate parts of the milking equipment along which the washing liquid flows. This amount of heat that is consumed for heating of the parts of the milking equipment can be characterized by the equation:

$$\Delta Q = \sum c_i \cdot M_i \cdot (T_i - T_g) = c_{\bar{u}} \cdot M_{\bar{u}} \cdot (T_0 - T_i), \quad (15)$$

where: ΔQ – amount of heat for warming separate parts of the milking equipment, kJ K^{-1};
T_0 – washing liquid initial temperature, °C.

From the previous equation, the initial temperature T_i of the washing liquid after heating the equipment surfaces can be expressed:

$$T_i = \frac{c_u \cdot M_u \cdot T_0 + \sum c_i \cdot M_i \cdot T_g}{\sum c_i \cdot M_i + c_u \cdot M_u}. \quad (16)$$

Using the theoretical correlations and our experimentally obtained data as well as the information from the Internet [http://www.likumi.lv], the numerical values of the heat transition coefficients k_i were calculated (Table 2).

Table 2. Heat transition coefficients for separate milking equipment stages

Experiment stages	Coefficient		
	symbol	measuring unit	numerical value
1.	K_{II}	$W \cdot K^{-1}$	22.68
2.	k_I	$W \cdot K^{-1} m^{-1}$	0.66
3.	k_{III}	$W \cdot K^{-1} gab^{-1}$	11.96
4.	k_{IV}	$W \cdot K^{1} m^{-1}$	0.77

The experimentally obtained water cooling characteristic curves are shown in Figure 3.

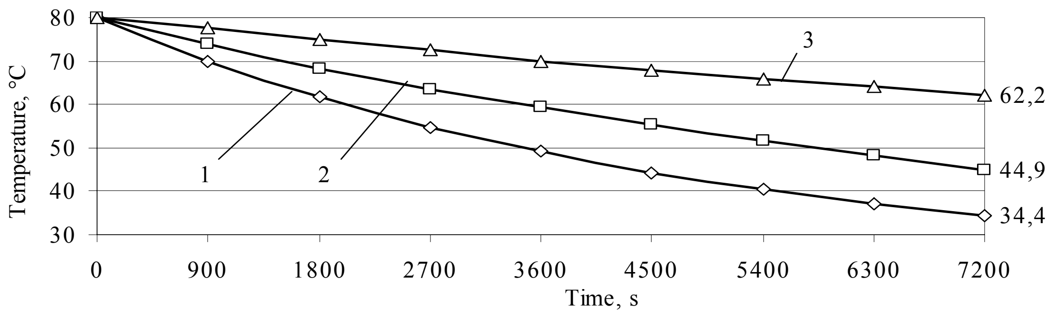

Figure 3. The dynamics of cooling water in the pipeline stage without heat insulation or with using heat insulation: 1 – water temperature changes without heat insulation, °C; 2 – water temperature changes, using foam polyethylene heat insulation, °C; 3 – water temperature changes using stone wool heat insulation, °C

Note: in all experiments the heat measurement determination coefficient R^2 = 0.9

The results of the experimental research including also the calculated parameters are summarized in Table 3.

Table 3. Heat insulation influence investigation results

Parameters to determine	Research versions		
	Without heat insulation	With foam polyethylene insulation	With stone wool and aluminium foil insulation
τ, s	5690		
τ', s		8953	22081
δ'		0.636	0.261
T_b, °C	34.4		
T'_b, °C		44.9	62.2

If no heat insulation was used, the liquid temperature during the experiment declined from 80.0 to 34.4 °C, but using a pipe covered with heat insulation material, the liquid final temperatures were respectively 44.9 and 62.2 °C, *i.e.*, by 10.5 and 27.8 °C higher. In turn, the liquid cooling time constants τ' in these cases were 5690, 8953 and 22081s, respectively. Therefore, while using foam polyethylene heat insulation, the liquid cooling time constant τ' increased by 36.4%, but, using stone wool heat insulation that is covered with aluminium foil, the time constant τ' increased by 74.2%. The corresponding heat insulation influence coefficient δ in these cases was 0.636 and 0.261, respectively.

Comparing the final temperatures of the washing liquid T_b and T'_b that were obtained in laboratory experiments and as a result of calculations, the difference is only 0.25% (without heat insulation) and 3.21% (with heat insulation). It testifies that the methods of calculation of the milking equipment washing liquid cooling final temperatures elaborated by us are sufficiently exact.

These investigations also prove that by covering the milk and washing liquid pipes with heat insulation, it is possible to ensure sufficiently high washing liquid temperature during the whole time of its circulation without additional heating of the liquid. It is proved also by the distribution of the heat losses in the milk line stages in a barn with 100 cows that has been discussed in two cases when the milk and washing liquid pipes are without heat insulation and when these pipes are covered with a 30 mm thick stone wool layer (Table 4).

Table 4. Distribution of heat losses for differently equipped cow milking equipment with milk line

Milking equipment stages		Distribution of heat losses, %, with heat insulation	
No	Included parts	not used	used
1.	Milk line	56	24
2.	Milk collection unit and washing liquid tank	13	24
3.	Milking machines	27	50
4.	Washing liquid pipes	4	2
		100%	100%

As can be seen from this example, the use of milk and washing liquid pipes heated with stone wool, the heat losses through these pipes decrease from 65 to 24%, *i.e.*, more than two times.

Based on our theoretical research, software was developed by which it is possible to calculate the washing liquid final temperature in each definite case. This software is useful when the milk and washing liquid pipes do not have heat insulation or also in cases when they have heat insulating cover.

As our economic calculations show, the use of heat insulation is also economically profitable and pays back during 2–3 years.

Conclusions

1. The way of the washing liquid circulation in milking equipment can be divided into four different stages: I – milk line; II – milk collection unit and washing liquid tank; III – milking machines; IV – washing liquid pipes. In order to determine the washing liquid heat leak occurring during these stages, it is necessary to carry out not only theoretical but also experimental research. Cooling of the milking equipment washing liquid can be slowed down if the milk and washing liquid pipelines are covered with heat insulation. If, for instance, a 30 mm thick stone wool insulation is used that is additionally covered with aluminium foil cover then the washing liquid cooling time constant τ increases by 74% compared to a pipeline without heat insulation.
2. The milking equipment washing liquid final temperature depends on the definite situation and it can be calculated using the software developed by us. This software is useful also if the milk and washing liquid pipes are covered with heat insulation.
3. Using sufficiently effective heat insulation cover, it is possible to ensure that in the conditions of lowered ambient temperature (during winter) in cold barns as well as in heated barns with a long milk line it is not necessary to heat the washing liquid additionally. In such case the use of heat insulation is economically profitable and will pay back in 2–3 years.

References

http://www.likumi.lv – Regulation No. 495 of the Cabinet of the Republic of Latvia. – Inspected on 20 May, 2006.

Nagla, J., Saveļjevs, P., Cars, A. 1982. Heat Technological Calculations in Examples. – R.: Zvaigzne, p. 310 (in Latvian).

Priekulis J., Latvietis, J. 2005. Economic Evaluation of Usage of Cold Cowsheds in Latvia. LŽŪU mokslo darbai No 69 (22), Kaunas: Akademija, p. 89–94.

Priekulis, J., Strautnieks, N. 2000. Economic Evaluation of Agricultural Work Mechanisation. – Jelgava: LLU, p. 29 (in Latvian).

Priekulis, J., Zujs, V., Auziņš, V. Milking Equipment with Milk Pipeline. Latvian patent. Resolution from 20.04.2005.

Зуйс В., Приекулис Ю., Ильинс У. 2005. Разработка математической модели остывания моющей жидкости в доильных установках. – Proceedings of the International Scientific Conference "Agricultural engineering problems". Jelgava, c. 184–189.

Трейбус М. 1970. Термостатика и термодинамика. – М: Энергия, 502 с.