Report EUROMET project No 547 - Measuring systems for milk - calibration with water and milk

Purpose:
In many European countries measuring systems for milk are subject to pattern approval and to initial and subsequent verification; some calibration bodies use water and some use milk as the test liquid. Although water as the test liquid for the calibration has obvious commercial and practical advantages, the measurement results of milk in service may vary from the calibration with water.

The project should therefore examine the error curve-shift between the calibration by water and by milk leading to the conditions under which it would be admissible to substitute milk by water.
Remark:
It must be born in mind that the actual test liquid has a strong influence on the performance of the gas separator (air can easily be extracted from water but not from milk). So, when testing the whole measuring system one test run at the minimum must be conducted with milk to make allowance for the influence of the gas separator.

The above examination was foreseen for 4 types of meters ($Q_{max} \leq 500$ l/min):
Coriolis, Vortex, MID (electromagnetic meter), PD meter (i.e. rotating piston meter).
These meters should be tested at first under reference conditions on a water test rig and afterwards on a test installation using milk and then additionally installed in a given MS (e.g. installed on a road tanker), also using milk and water as test liquid.

Inquiry of the actual metrological measurement practice
Prior to any measurements, the BEV started with an inquiry of the actual metrological measurement practice in other European countries in order to get information if the proposed project programme was useful. The answers are summarized in the following table.

Country	A	D	CH	N	I	DK	CR
legally relevant	yes	yes	Yes	yes	Yes	yes	yes
Measuring instrument	MS	MS	MS, balances	MS	MS, milk churns, capacity measures	MS	MS, milk churns
type approval of meter	yes	EU: yes, mechan. meters: no	Yes	yes	Yes	yes	yes
type of meter	MID PD (rot. piston) PD (oval wheel ---	MID PD (rot. Piston) PD (oval wheel) Coriolis	MID PD (rot. Piston) Coriolis	MID PD (rot. Piston)	MID	MID PD (rot. piston) PD (oval wheel) Coriolis	MID PD (rot. piston) PD (oval wheel)
period of validity of meter approval	∞	∞	∞	10 years	∞	∞	10 years
recorded data at reception	Identity, date, volume ---	Identity, date, volume ---	Identity, date, volume, temp.	Identity, date, volume, temp.-range	no information received	no information received	Identity, date, volume, temp.
Recording media	printer, memory	printer, memory	printer, memory		no information received	printer, memory	printer, memory
type approval of MS	yes	yes	No	yes	no information received	no	yes
manufacturer of MS	Jansky, Schwarte	Jansky, Schwarte	Jansky	no information received	no information received	no information received	Jansky, Schwarte, Magyar, Diessel
period of validity of MS approval	∞	∞	not applicable	10 years	no information received	not applicable	10 years
verification by	verification officer	verification officer	verification officer	verification officer	no information received	accredi-tated lab	verification officer
test liquid at verification	Milk	Milk	milk	milk	no information received	water	milk or water
period of validity of verification	2 years	1 year	1 year	1 year	no information received	1 year	2 years
Metrological requirements	national (≅ EU)	national (≅ EU)	national	OIML R117	OIML R117	national	OIML R117
max. permissable error	± 0,5 %	± 0,5 %	± 0,5 %	± 0,5 %	+ 0,3 % – 0,2 %	± 0,5 %	± 0,5 %

First step of examination - test of meters by water

The first step of the project was to test the 4 kind of meters on the test rig with water.
During the tests it turned out that the performance of the Vortex meter even under reference conditions was so discouraging (unacceptable repeatability, unacceptable influences of upstream flow geometry), that we decided not to continue our investigations with this type of meter.

The test results for the remaining 3 types of meters (PD: rotating piston meter by Diessel / Coriolis: Endress & Hauser Promass 63 / MID: Process Data PD 340) are given for each meter in the 3 attached diagrams.
The error F is defined as usual by "indication of meter minus true value".
The error F was plotted against flow rate Q but not against Reynolds number Re. By doing so, the F/Q-diagrams appear more clear.

Installation conditions at BEV

The MID and the PD were installed in the test rig in series, at first the MID with its inlet pipe (length 500 mm, diameter 50 mm, same as the MID). The straight outlet pipe, length 300 mm and diameter 50 mm, was connected to the PD.
The Coriolis was tested separately by mounting it appropriately on a support according to the manufacturer´s instructions and connecting inlet and outlet to the test rig by rigid hoses.
The zero adjustment was done prior to measurements and only once for the whole project.

Test method at BEV

Start/stop-method. Water supply by a centrifugal pump. Setting of flow rate prior to test runs without any alteration of flow rate during test runs.
Constancy of flow rate: $\leq$ 0,5 l/min
Constancy of temperature during the test series: < 0,5 K.
Flow rates (l/min): 500, 350, 150, 80, 50; 3 test runs at each flow rate; measured quantities approximately 500 l at each test run.
2 series of measurements, one with cold water and one with warm water in order to calculate the thermal expansion coefficient of the meters.

Assessment of thermal expansion coefficient of meters

From the BEV cold water curve (blue curve "BEV, w, 8 °C, pump") and the BEV warm water curve (red curve "BEV, w, 30 °C / 50 °C, pump") of each diagram the thermal coefficient of expansion was calculated in order to reduce all curves to 8 °C.
Besides, it is interesting to look at the sign of the temperature coefficient of the various meters:
The coefficient of the PD and the MID is negative (errors tend to minus with increasing temperatures), while the coefficient of the Coriolis is positive (errors tend to plus with increasing temperatures).

Second step of examination - test of meters by milk

The meters were transferred to a dairy*) in order to test them with milk, but under similar conditions as at the BEV.

Conditions in the dairy:

Liquid supply by a (strongly pulsating) centrifugal pump with a maximum flow rate of 350 l/min (the installation of the Coriolis reduced this flow rate to approx. 300 l/min), refrigerated raw milk kept constant at 6,5 °C, 500 l-calibrated standard capacity measure of stainless steel (calibration by the BEV).
Temperature of pumped water: 8 °C
temperature of water from the pipe: 13 °C
temperature of raw milk: 6,5 °C

viscosity of raw milk at 6,5 °C $\approx$ 3,3 $mm^2 . s^{-1}$

Remark:
The calibration of the standard capacity measure refers to the liquid "water". In order to make allowance for the measurement of other liquids than water, e.g. milk, the BEV had formerly performed a test series in order to assess the influence of the surface wetting for other liquids than water thus yielding for milk a wetting of plus $\approx$ 200 ml against water for a 500 l-standard capacity measure (water $\approx$ 20 ml). This wetting correction for milk has been considered in our calculations of the actual volume of the standard capacity measure.

Installation conditions at dairy

At the outlet of the centrifugal pump a non-return valve. The MID, the PD and the Coriolis installed in series, at first the MID with its inlet pipe. Outlet pipe of the MID coupled to the PD (same inlet and outlet pipe as in the BEV). The PD was connected to the Coriolis by a rigid hose. For the Coriolis the same support was used as in the BEV. The outlet of the Coriolis was equipped with a mechanical valve (for the set of flow rate) and then coupled to a rigid hose with a mechanical valve at its end (as the transfer point) delivering the liquid into the standard capacity tank.

Test method at dairy

Start/stop-method. Supply by a centrifugal pump. Set of flow rate during the start phase of each test run by the mechanical valve without any further alteration during test run. Stability of temperature during test runs < 0,5 K.
Prior the each measurement the hoses were pressurized by the pump with the transfer point kept closed and the flow rate control valve (partly) open: Then reset of meter indications resp. reading of indication of Coriolis; then opening transfer point and set of flow rate control valve.
At the end of each test run closure of transfer point and afterwards stop of pump and reading of meter indications.

Flow rates (l/min): 350 (PD and MID only), 300, 150, 80, 50; measured quantities 500 l at each test run.
In order to see if there is any difference between the test results at the BEV and at the dairy we first performed the test runs with pumped water (2 test runs at each flow rate). As we recognized differences of a magnitude of up to 0,1 % (for the PD at Qmin of up to 0,2 %) (we attributed this difference to the influence of the pulsating pump at the dairy), we also tried to perform tests with water supply from the pipe (2 test runs at each flow rate, but maximum attainable flow rate only 150 l/min).
After that we continued with milk (3 test runs at each flow rate).

Test results
Differences cold water BEV – cold water dairy:
BEV cold water curve is blue "BEV, w, 8 °C, pump".
Dairy cold water curve is dotted blue "dairy, w, 8 °C, pump".

Deviations of up to 0,1 % occurred (for the PD at Qmin up to 0,2 %). For the PD and the Coriolis both cold water curves are nearly equal in shape, what might be able to be explained, because flow turbulences should not influence both types of meters, whereas for the MID the deviation might be attributed to different flow profiles between the measurements at the BEV and at the dairy.
The deviations seem to be systematic which could direct to a systematic difference in volume between the BEV measure and the dairy measure (most points of BEV cold water curve higher than dairy cold water curve). But contrary to that, the brown curve (water from pipe "dairy, w, 8 °C, pipe") representing a smooth supply of liquid (no pessure strokes) does not show any systematic trend. Unfortunately, this brown curve could not be extended to more than 150 l/min because of the limited capacity of the pipe.

But, whichever cold water curve is taken as the basis for the comparison with the milk curve, there are significant deviations between water and milk (see below).

Differences water – milk
The dairy cold water curve is the dotted blue “dairy, w, 8 °C, pump”.
The dairy milk curve is the dashed green “dairy, m1-2 / m3, 8 °C, pump”.
3 test series were performed.

The first and the second set of measurements showed good coincidence (“dairy, m1-2, 8 °C, pump”), but the third set did not fit (“dairy, m3, 8 °C, pump”).
The cause of the deviation of set 3 was certainly the quality of the milk:
whereas during set 1 and 2 the milk was homogenous and showed little foam and separation of fat, during set 3 the milk became “ready” (air mixed in the liquid, milk not homogenous any more, supply tank with a thick upper layer of fat).
The deviations of set 3 are up to 0,25 %. So it is advisable for milk measurements to use roughly fresh milk and to pay attention to the homogeneity and to the separation of fat. The separation of fat is a strong indication that the milk shall not be used for measurements any more.
Besides, it is interesting, that the error shift of set 3 is negative for all three meters. The interpretation could be that air bubbles (which were certainly present in the milk for set 3) might have been compressed by the pump and the meters, but then were de-pressurized in the standard capacity measure thus giving apparently an increase of volume (we have already observed this effect when testing air separators by the injection of air under pressure).

So, for the comparison between water and milk, set 1 and set 2 are used only.

What did we expect from the different meters and what was actually measured?

PD:
Because of the higher viscosity of milk (3,3 $mm^2.s^{-1}$; water ≈ 1 $mm^2.s^{-1}$) the milk curve was expected to be somewhat higher than the water curve and should tend to minus at a lower flow rate than the water curve.
This prognosis was fulfilled, but among all types of tested meters its milk curve has shown the maximum difference against water (BEV test rig or dairy test installation) (up to + 0,4 %).
We have no interpretation for this large deviation (our first explanation was that the motion of the rotating piston follows the strokes of the pulsating pump thus giving an additional acceleration of the piston and an overestimation of the volume, especially at high flow rates, but this effect should have also occurred with pumped water, but which was not the case).
After the dairy the meter was tested once more in cold water at the BEV and showed no agreement with the first BEV-measurements at all (dashed yellow “BEVpost, w, 8 °C, pump”).
(To be sure, we did the tests once more on an other test rig, but the test results did not yield any significant improvement of this shift).
The deviations are of such magnitude that make questionable any statement on the difference between the water curve and the milk curve. For the moment, this shift is not quite understandable, because the PD was tested in series with the MID, and contrary to the PD the MID repeated well (see below). But what we had done quite after the end of the milk measurements was to rinse the meter with hot water in an assembled condition so that the hot water might have perhaps enlarged plastic rotating parts. These enlarged plastic parts might have been rubbed off mechanically during the re-measurements with water at the BEV, thus resulting in a smoother rotation and in a shift of the error curve to higher values. But this is a very vague theory.

MID:
Because the MID is said to be independent of viscosity and the upstream flow conditions were supposed to be the same for milk and water, no significant difference between the water curve and the milk curve was expected.
This became true for the dairy cold water curve and the milk curve (deviations ≤ 0,05 %). The coincidences were not so convincing for the BEV cold water curve and the dairy milk curve (deviations up to 0,1 %), maybe because of installation effects.

After the dairy the meter was tested once more in cold water at the BEV and showed a good agreement with the first measurements (dashed yellow “BEVpost, w, 8 °C, pump”).

Coriolis:
Because the Coriolis is said to be independent of the medium, its viscosity, the flow conditions upstream of the meter, etc, no significant difference between the cold water curve (BEV or dairy) and the milk curve was expected.
This could not be verified (deviations in the mean ± 0,1 %, but reaching 0,3 % in the vicinity of Qmin). The reason for this difference cannot be the strongly pulsating pump because the dairy cold water curve is quite the same as the BEV water curve. It might be the medium itself which is not a physically homogenous liquid. So, further testing is necessary.

After the dairy the meter was tested once more in cold water at the BEV and showed a good agreement with the first measurements (dashed yellow “BEVpost, w, 8 °C, pump”).

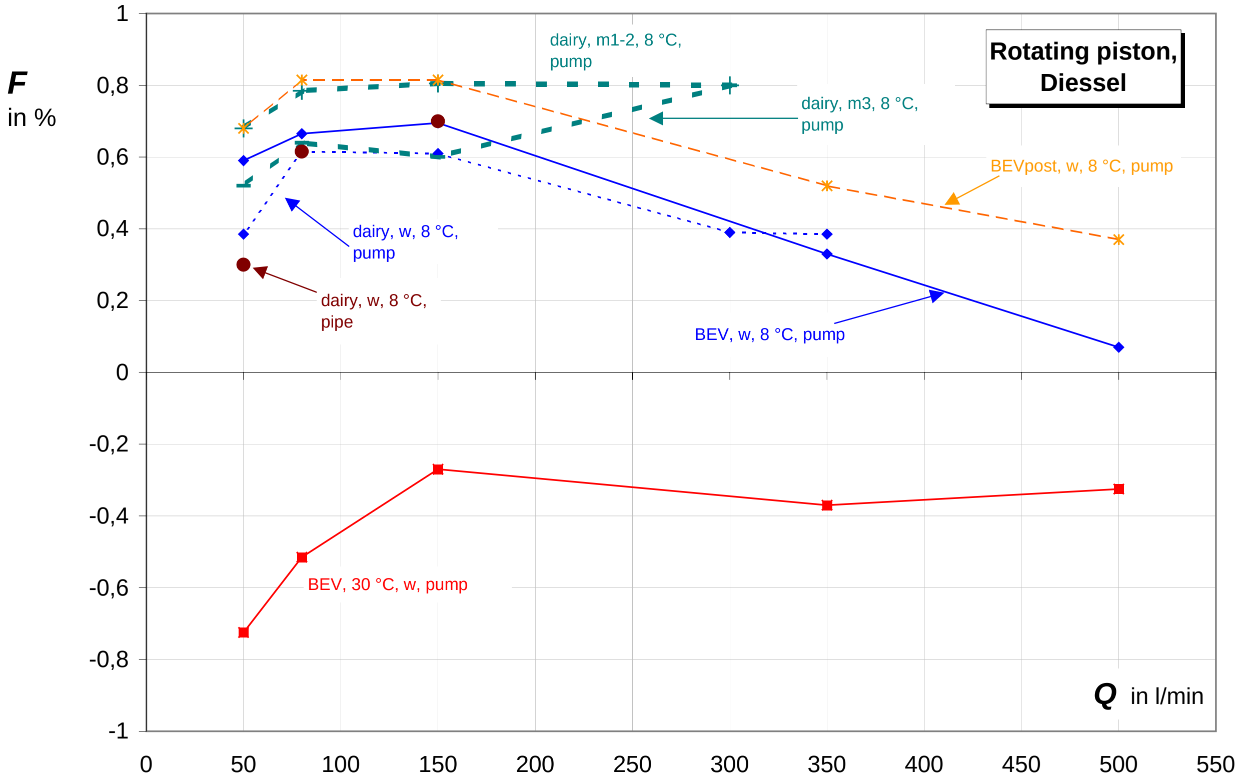
Summary

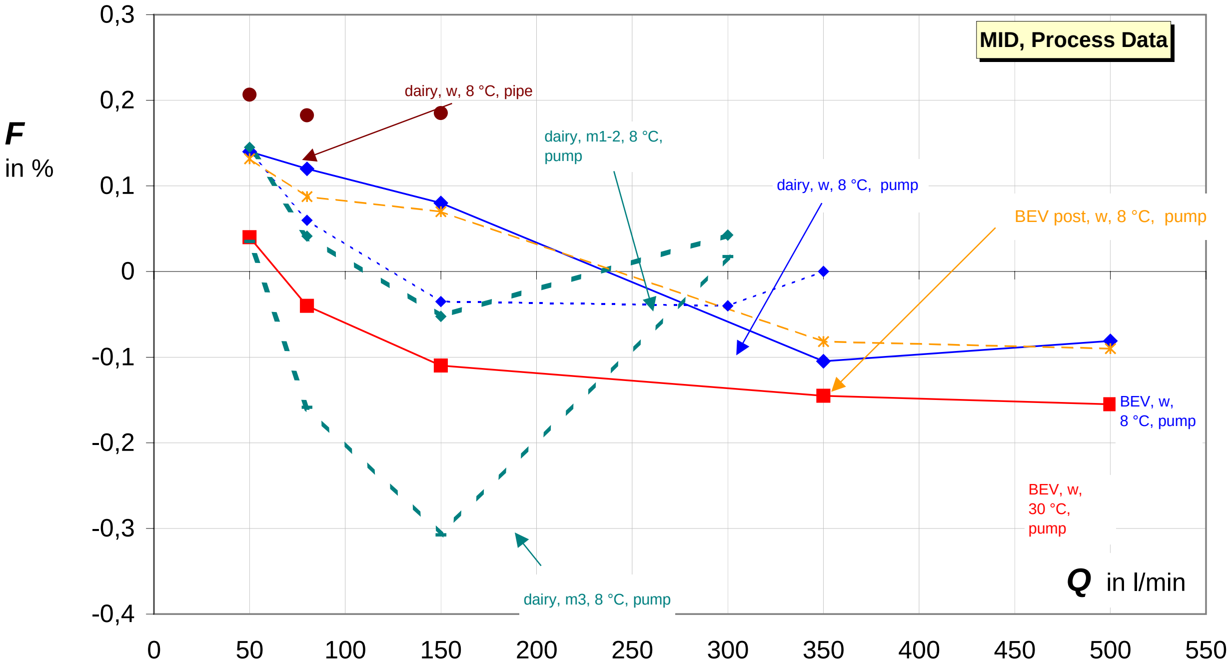
The purpose of this project, namely to achieve a definite general statement concerning the error curve-shift between the calibration of meters by water and by milk, leading to the conditions under which it would be admissible to substitute milk by water, were not achieved by the performed tests. Further testing seems to be necessary to get more consistent results.

Nevertheless, there are some remarkable test results as a by-product:
- Deviations for the reported measurement range (50 l/min to 300 l/min) of the error curves between a (reference) water test rig and a simple installation device for milk have been less than 0,1% for the MID, less than 0,3 % for the Coriolis and less than 0,4 % for PD.
- The viscosity of milk shifts the error curve of PD to positive values, but has no significant systematic influence upon MID and Coriolis.
- Installation effects seem to be more critical for MID than for PD and Coriolis. Especially, the kind of liquid supply (pump / pipe) is less significant for Coriolis.
- The good quality of milk (homogeneity, no separation of fat, no air mixed in the liquid) is of crucial importance to gain good measurement results.

Remark:
It was also one of the targets of the project to install the meters in a measuring system (road tanker) and to check them there with water and with milk. But first, during the tests in the dairy there was no time for that testing and second, the actual measurement results were not so convincing. Therefore, further tests of the meters only – especially with a larger measurement range (up to 600 l/min ?) - seem to have priority over the test in a road tanker.

*) Federal Dairy Institute at A-3261 Steinakirchen am Forst, Wolfpassing 1.
At this place we want to gratefully acknowledge the support by this institute, especially by its head Ing.Vogelauer and his colleague Ing. Hart, in the shape of the necessary installations, knowledge, milk and coffee.


Rotating piston, Diessel
F in %
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
-0,8
-1
0
50
100
150
200
250
300
350
400
450
500
550
Q in l/min
dairy, m1-2, 8 °C, pump
dairy, m3, 8 °C, pump
BEVpost, w, 8 °C, pump
dairy, w, 8 °C, pump
dairy, w, 8 °C, pipe
BEV, w, 8 °C, pump
BEV, 30 °C, w, pump


MID, Process Data
F in %
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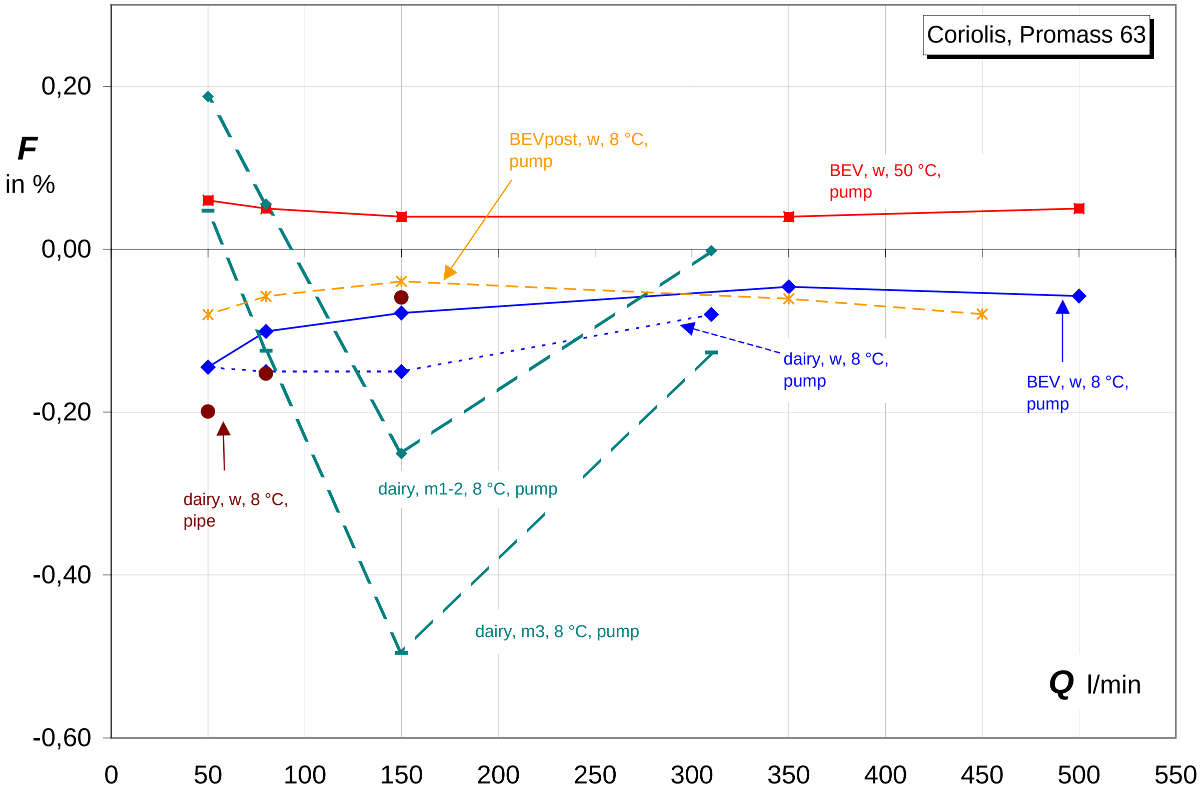
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
0
50
100
150
200
250
300
350
400
450
500
550
Q in l/min
dairy, w, 8 °C, pipe
dairy, m1-2, 8 °C, pump
dairy, w, 8 °C, pump
BEV post, w, 8 °C, pump
BEV, w, 8 °C, pump
BEV, w, 30 °C, pump
dairy, m3, 8 °C, pump


Coriolis, Promass 63
F
in %
0,20
0,00
-0,20
-0,40
-0,60
0
50
100
150
200
250
300
350
400
450
500
550
Q l/min
BEVpost, w, 8 °C, pump
BEV, w, 50 °C, pump
dairy, w, 8 °C, pump
BEV, w, 8 °C, pump
dairy, w, 8 °C, pipe
dairy, m1-2, 8 °C, pump
dairy, m3, 8 °C, pump