A NEW FACILITY FOR CALIBRATION OF FLOW METERS FOR COOLING APPLICATIONS

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ABSTRACT

A new test set-up for calibration of flow meters used in cooling applications has been established at Danish Technological Institute. The calibration set-up is based on reference metering with a Coriolis type flow meter. It consists of a closed conduit by means of a piping system for circulating a coolant mixture (e.g. 60/40 ethylene glycol/water mixture)in series through the reference flow meter and the meter under test. The coolant mixture is cooled through a pipe-in-pipe exchanger using CO_2 as refrigerant.Traceability of the reference flow meter is realized by means of a weighing system, which is also a part of the facility, so that the reference flow meter can be calibrated on a running basis. The facility is designed for a media temperature ranging from -20 °C to 20 °C and a flow range up to 30 m³/h.

BACKGROUND

Flow meters are used for a various of applications and purposes all over in the industry. Although the meters are used with a wide range of operating conditions and various fluids, calibration facilities are limited to a confined number of fluids and temperature conditions. Frequently, flow meters used in the processing industry are calibrated in water and used e.g. with coolant mixtures in cooling applications and refrigeration equipment without using any correction for the different usage.

In order to test and calibrate flow meters used in cooling applications where the refrigerant is a mixture of water and ethylene glycol *Danish Technological Institute* has established a new test set-up for calibration of these flow meters. This paper describes the concept of the new test rig and evaluates the uncertainties of the facility.

MATERIALS AND METHODS

Setup

Calibrations of flow meters in the new test setup are based on reference flow metering, where the reference meter is a Coriolis flow meter. The measuring principle of the Coriolis flow meter is based on the mass flow through the meter and not as it is the case for a lot of other principles the fluid velocity and hence the volume flow. This makes the Coriolis meter robust as a reference meter as it is not sensitive to density changes and flow profile of the fluid. In addition the Coriolis flow meter is not very sensitive to flow disturbances as for instance bends etc.

The test rig consists of a closed conduit by means of a piping system and a pump for circulating the refrigerant (e.g. 60/40 ethylene glycol/water mixture) through a reference flow meter (Coriolis) and the meters-under-test, which are the meters to be calibrated, see figure 1 for more details. By comparing flow rates on the reference flow meter, which has an known uncertainty and the meter-under-test this meter can be calibrated with a given uncertainty. The facility is designed for a calibration temperature range from -20 °C to 20 °C, a flow range up to 30 m³/h and for DN50 flow meters.

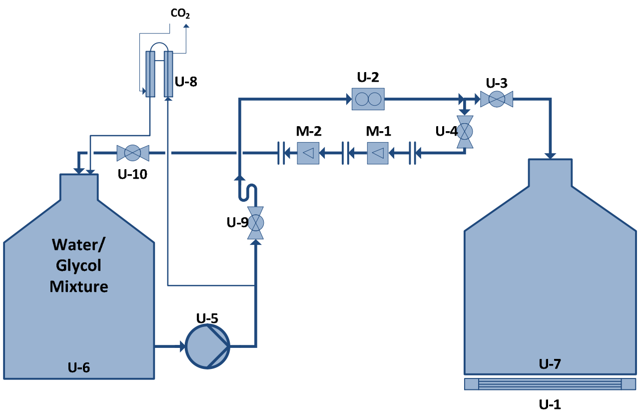

Figure 1: *Schematic drawing of the new test rig, where U-6 is the storage tank for storing the coolant mixture, U-8 is the heat exchanger for cooling down the coolant mixture with CO_2 as refrigerant, U-2 is the reference meter (Coriolis type), U-1 is the scale used to weigh the mass in the weighing tank U-7, U-3 and U-4 is used to shift the flow of the coolant mixture from the circulating system to the weighing tank, U-5 is the pump to generate the flow of the coolant mixture and the flow through the heat exchanger, and M-1 and M-2 is flow meters under test or calibration.*

The coolant mixture used in the test rig for calibration is stored in a 1 m³ storage tank and circulated by the pump through a close conduit, where the meters-under-test are mounted, see figure 1. The conduit returns the flow to the storage tank making it a closed loop.

In order to cool down the coolant mixture a secondary piping system circulates coolant mixture through a pipe-in-pipe heat exchanger using CO_2 as refrigerant and return the cooled mixture to the tank keeping the temperature in the tank at a certain level.

Model equations and uncertainty budget

Different parameters affect both the results of reference flow meter calibration and calibration of the meters-under-test. In order to assess and shed light on the uncertainty elements and their contribution to the total uncertainty of the system an uncertainty budget is made. In the following are listed the main parameters that influences the calibration results:

- During calibration of reference flow meter the weighing tank (U-7) is filled with cold coolant mixture giving rise to some condensed water or ice on the outside of the weighing tank, which originates from the humidity in the surrounding air. The water is condensed due the low temperature of the fluid inside the tank. This extra mass of the weighing tank as water or ice sticks to the outside of the tank affects the correctness of the weighing.
- The scale itself has an error at different load situations, which means that there is a deviation between the acquired read out and the actual weight. This error can be accounted for by a correction equation, which can be derived by calibration of the scale using calibrated weights.
- The measured mass of the coolant mixture collected in the weighing tank has to be corrected for the buoyancy effect created by the displacement of air by the coolant mixture in the weighing tank.

Reference flow meter calibration: Traceability of the reference flow meter is realised by means of a weighing system, which is an integrated part of the facility. This means that the reference flow meter can be calibrated on a running basis e.g. for different temperatures etc. Calibration of the reference flow meter is realised by shifting the position of the three-way valve so the coolant mixture is pumped directly from the storage tank to the weighing tank through the reference flow meter. The reference flow meter then aggregates the mass of coolant which flows through it. When the flow is stopped the aggregated value for the reference flow meter can be compared to the weight of the coolant in the storage tank measured on the scale corrected for certain parameters. The “quality” of this calibration can be assessed using an uncertainty budget, described in more details below.

Calibration of the reference flow meter entails a comparison between the aggregated mass measured by the reference meter and the mass collected in the weighing tank, denoted $M_{weighing}$. The correct mass $M_{weighing}$ is not the value acquired directly from the scale itself, as mentioned it has to be corrected for various influencing parameters.

The model equation including the correction parameters for $M_{weighing}$ is showed below

$$M_{weighing} = (M_{scale} + \delta M_{corr} + \delta M_{ice} + \delta B)\ [Kg]$$

where M_{scale} is the read out on the display of the scale, δM_{corr} is the correction of the scales found during calibration, δM_{ice} is the extra weight due to condensed water (ice) on the outside of the weighing tank, δB is the correction for the buoyancy due to the displacement of air as the weighing tank has got filled with coolant mixture The scale (U1) was calibrated using known and calibrated weights. The correction δM_{corr} for the scale was found during the calibration of the scale by linear regression of the calibration points. δM_{corr} is the specified by the following equation :

$$\delta M_{corr} = K \cdot M_{scale}$$

where M_{scale} is the measured weight acquired from scale and K is a constant found by regression. The value of K was found to be 0.00033 with a standard error of $2.2277 \cdot 10^{-5}$.

The correction value δB is calculated as follows:

$$\delta B = \left(M_{scale} \cdot \frac{1 - \frac{\rho_{air}}{\rho_{Weights}}}{1 - \frac{\rho_{air}}{\rho_{coolant}}} \right) - M_{scale} [kg]$$

where ρ_{air}, $\rho_{veights}$, and $\rho_{coolant}$ are the densities of air, weights used during calibration of the scale, and the coolant mixture respectively. As δB is a function of both air and coolant mixture densities it is also sensitive to temperature, humidity, and air pressure.

The density of air is found by the following equation:

$$\rho_{air} = \frac{0.348444 \cdot p - h \cdot (0.00252 \cdot t - 0.020582)}{276.15 + t}$$

Where p is the atmospheric pressure in mbar, h is the air humidity in per cent and t is the air temperature in degrees Celcius.

Density $\rho_{coolant}$ of the coolant mixture is found in table 1 below:

Temp.	Ethylene Glycol mixture (% volume)						
(°C)	25	30	40	50	60	65	100
-40	-	-	-	-	1.12	1.13	-
-17,8	-		1.08	1.10	1.11	1.12	-
4,4	1.048	1.057	1.07	1.088	1.1	1.11	-
26,7	1.04	1.048	1.06	1.077	1.09	1.095	-

Table 1

Quantity	Value	Std. Uncertainty	Distribution	Sensitivity Coeff.	Uncertainty Cont.	Index
M_{scale}	250.0 kg	$5.77\cdot10^{-3}$ kg	rect	1.0	$5.8\cdot10^{-3}$	0,0%
δM_{ice}	0.0 kg	0.289 kg	rect	-1.0	0.29	99,6%
ρ_{air}	1.1885 kg/m³	0.0386 kg/m³				
$\rho_{weights}$	8000 kg/³					
$\rho_{coolant}$	1080 kg/³	54.0 kg/m³	normal	$-260\cdot10^{-6}$	-0.014	0.2 %
K	$330.0\cdot10^{-6}$	$22.3\cdot10^{-6}$	normal	250	$5.6\cdot10^{-3}$	0.0%
p	1013 mbar	28.9 mbar	rect	$240\cdot10^{-6}$	$6.9\cdot10^{-3}$	0.0%
h	50%rh	5.77%rh	rect			
t	20 °C	4.33 °C	rect	$-820\cdot10^{-6}$	$-3.5\cdot10^{-3}$	0.0%
$M_{weighing}$	**250.321 kg**	**Expanded uncertainty (k=2)**		**± 0.23%**		

Table 2, uncertainty budget for calibration of the reference flow meter.

Density of the steel weights used for calibration of the scale has a constant value of 8000 kg/m³.

Now the uncertainty of the individual parameters specified above can be examined in the uncertainty budget leading to the combined uncertainty of $M_{weighing}$.
Below are the uncertainty parameters and their distribution listed:

u(M_{scale}) = ± 0.01 kg (rectangular distribution)

u(p) = ± 50 mbar (rectangular distribution)

u(t) = ± 7,5 °C (rectangular distribution)

u(h) = ± 50 %rh (rectangular distribution)

u($\rho_{coolant}$) = ± 5 % (rectangular distribution)

the uncertainty of the parameters p,h and t are estimated relative high since there are no track record of neither air pressure, humidity, and nor air temperature in the laboratory where the test rig is located. The scale is not necessarily calibrated the same day as the reference flow meter, and therefore these three parameters can differ a lot between the two situations. However, the contribution of the three parameters to the total uncertainty budget is insignificantly.

Regarding the parameter $M_{ice,}$ a layer of 1 mm ice or condensed water that sticks to the weighing tank, which has an area of approximately 2 m², will add an additional weight of approximately 2 kg to the tank. The system has to be conditioned before calibration and the scale will be tared before measurement, so the value of M_{ice} is actually zero as it is zeroed out by the taration. However in order to calculate the total uncertainty of M_{scale} the uncertainty of M_{ice} must be included in the uncertainty budget. The uncertainty of M_{ice} is estimated to:

u(M_{ice}) = ± 0.5 kg (rectangular distribution)

In order to calculated the expanded uncertainty for calibration of the flow meter the GUM Workbench Pro © software was used. Below is the uncertainty budget specified for a given situation when calibrating the reference meter, where the mass of the coolant mixture in the weighing tank (M_{scale}) is read out to 250 kg. See the total uncertainty budget in table 2.

The reference flow meter can now be calibrated with an expanded uncertainty of 0.23 % as long as the weighing tank is filled with approximately 250 kg of coolant mixture. If one wishes to calibrate the reference meter with a low degree of filling of the weighing tank a new uncertainty budget has to be performed as some the parameters will change by a lower or higher degree of filling.

Flow meter-under-test calibration: Once the reference flow meter is calibrated the calibration of different flow meters can be performed by referring to the reference flow meter. The uncertainty elements, which are estimated to influence the total uncertainty budget of this approach are specified below:

- The uncertainty of the reference flow meter found during calibration as described in the section above.
- The density measurement of the reference flow meter used to convert the mass flow rate measured by the reference meter to volume flow rate, which is the most common measurement for most flow meters.
- Temperature stability of the coolant mixture during calibration.
- Flow rate stability in the conduit during calibration.
- Reading off the meter under test

As there is still some run-in to do on the test rig the uncertainty budget for the meters-under-test calibration is not yet completed, but the parameters listed above serves as a list of points to pay attention to when preparing the uncertainty budget.

Conclusion

Assessing the uncertainty budget for calibration of the reference flow meter turned out to give a relatively low expanded uncertainty of 0.23% when 250 kg of coolant is filled into the weighing tank. Hence, the calibration of the reference flow meter can be performed for different flow rates and temperatures in order to find the calibration curves for these different parameters. However, it is important to notice that this uncertainty of 0.23 % is only valid for approximately 250 kg in the weighing tank.

Calibration of the reference flow meter will be carried out in the near future, whereupon tests and calibrations of different flow meters will be carried out.