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Technical paper

Operational experiences with the EuroLoop Liquid Hydrocarbon Flow Facility

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Abstract

The operational experiences obtained during the calibration of several types of liquid flow meter clearly demonstrate EuroLoop's ability to test the viscosity dependent performance of these instruments. The temperature as observed during a series of successive runs recorded at a constant flow rate, demonstrates a stability that is a factor 50 better than originally specified.

Extension of a previous intercomparison between the EuroLoop and Trapil facilities using an 8" 7 path ultrasonic transfer flow meter and EuroLoop's small prover [2] was extended using the big prover. All 19 results match a normalized deviation $E_n < 1$. For 16 results $E_n < 0.5$.

Sample analysis performed at two independent laboratories as part of EuroLoop's metrological maintenance, reveals a significant viscosity difference for the lowest and highest viscosity liquids. The density of the samples agrees within their mutual uncertainties, which is important for mass flow measurements.

1. Introduction

For most types of liquid flow meters for custody transfer purposes like ultrasonic flow meters, turbine meters and coriolis flow meters, the performance is depending on the Reynolds number dependent velocity profile or on the liquid viscosity directly. Also the C_d factor of Dp devices like orifices, nozzles and Venturis, is depending on the Reynolds number and therefore on the viscosity as well.

The EuroLoop Liquid Hydrocarbon Flow Facility operates on three different liquid viscosities – 1, 10 and 100 mm^2/s (centi-Stokes, cSt) – covering a large range of Reynolds numbers (approximately $1 \cdot 10^3$ – $4 \cdot 10^6$). The rationale behind the construction of EuroLoop is that calibration of a flow meter using different liquid viscosities gives the user of the meter insight on the viscosity dependent performance of the meter. For the manufacturer this knowledge enables him to compensate for the different flow profiles or different viscosities in the meter electronics. In addition EuroLoop can operate at a very constant liquid temperature which will keep the viscosity constant as well. This is extremely important for the calibration of turbine meters, where the calibration needs to be performed with a constant viscosity over the entire range of flow rates.

NMi EuroLoop operates the facility and is responsible for the metrological performance. The design of the facility was described earlier [2]. Accreditation is in the process of being acquired [1] and the first round robin tests have been performed [2]. All calibration certificates are issued by NMi EuroLoop. Maintenance is done by Krohne, the designer and constructor of the facility. The actual specifications of the facility are shown in the table below.
After years of construction and testing the current paper gives an anthology of operational experiences obtained during calibrations using the EuroLoop Liquid Hydrocarbon Flow Facility and its metrological maintenance.

Table 1: Specifications of the EuroLoop Liquid Hydrocarbon Flow Facility

	Small circuits	Large circuits
Flow	10 – 1 200 m^3/h	30 – 5 000 m^3/h
Dimensions of meters	4" – 12" (100 – 300 mm)	12" – 30" (300 – 750 mm)
Flanges and pressure classes	ANSI 150, PN 10	ANSI 150, PN 10
Kinematic viscosity	1, 10, 100 mm^2/s (cSt)	1, 10, 100 mm^2/s (cSt)
Temperature stability	Better than 0.1 °C	Better than 0.1 °C
Maximum back pressure	12 bar(g)	12 bar(g)
Overall uncertainty volume by piston / master	0.02% / 0.06%	0.02% / 0.06%
Overall uncertainty mass by piston / master	0.04% / 0.07%	0.04% / 0.07%

2. Description of facility

Each circuit, schematically displayed in Fig. 1, is split between a small and a large diameter loop. The temperature increase, resulting from the work exerted on the liquid by the pumps, is reduced by a cooling system using water. A back pressure of 6 – 9 bar(g) avoids cavitation in the liquid. If necessary, e.g. during the calibration of Venturi tubes, the back pressure can increased to 12 bar(g) to avoid cavitation in the throat of the Venturi. In that case operation has to be performed with great caution as safety valves open at 12.5 bar.
The primary references for calibration consist of a large piston prover and a small piston prover, which are both operated on all three liquids. The secondary references are master meters, which is a combination of an upstream monitoring full bore and downstream reduced bore ultrasonic meter.
The temperature in each circuit is monitored by fast ultrasonic sensors that measure the average temperature in a cross section of the pipe without disrupting the flow pattern. The ultrasonic temperature sensor is combined with an upstream pressure transmitter and a downstream Pt100. If the liquid properties change the readings of the ultrasonic temperature measurement and the Pt100 will start to deviate. In this way the operator is triggered to have the liquids analyzed again. In addition the operator has a diagnostic tool for checking the liquid homogeneity.

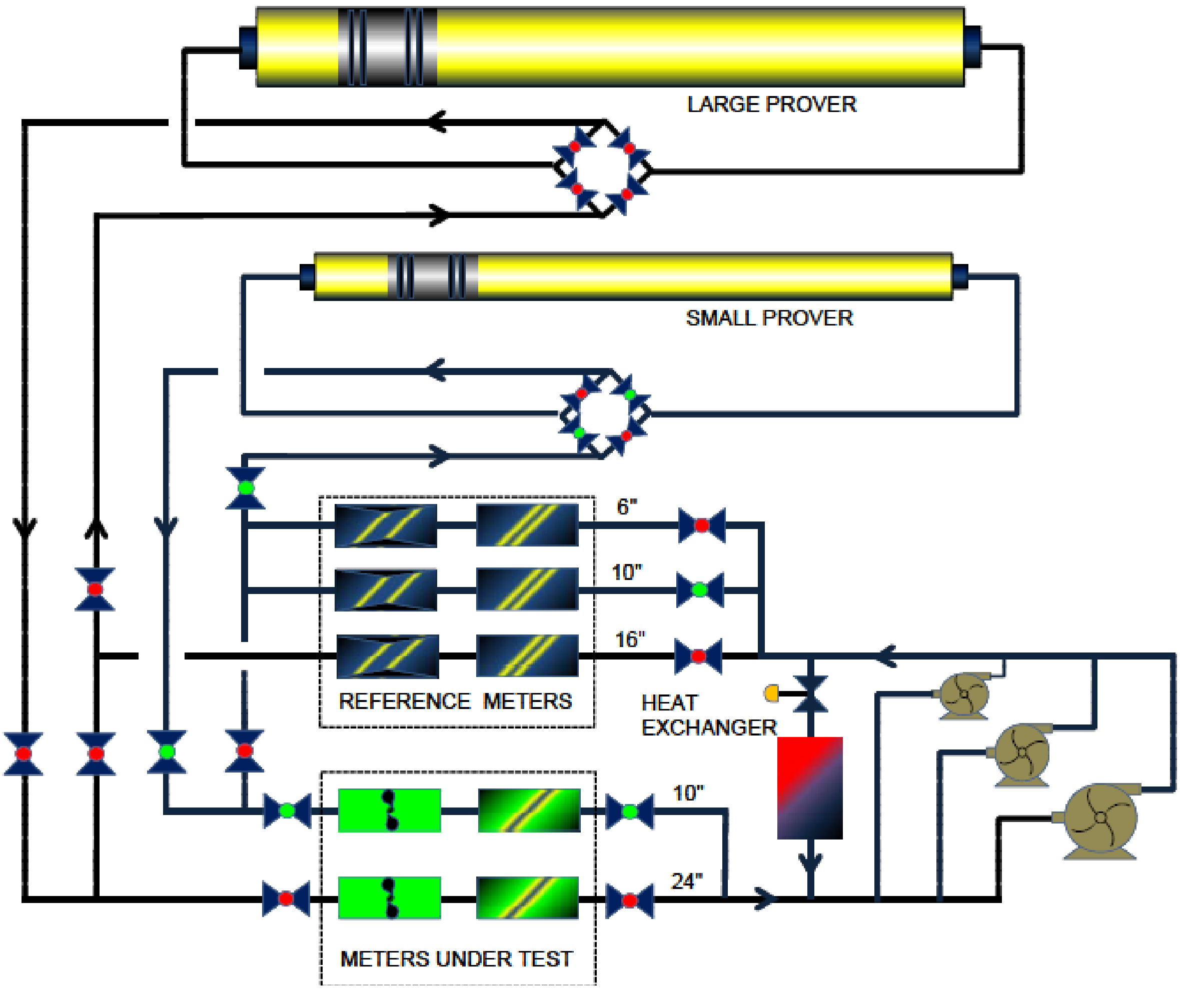

Fig. 1:. Schematic drawing of the EuroLoop Liquid Hydrocarbon Flow Facility. One circuit is shown, the others are identical. The piston provers are shared by all three circuits.

Each calibration starts with the specification of the calibration set-up. For the small circuits 24 meter straight length is available, for the large circuits 28 meter is available. In each configuration sufficient length is planned behind flow disturbances, like reducers or expanders. Before the start of the calibration all air and vapours are eliminated from the circuits and leak tests are performed. The liquid is homogenized, which is tested by the ultrasonic temperature measurements in the circuits. The last step in the preparation is an integrity check of the system. For each calibration there is a choice to use only the master meters as reference, or to use both master meters and piston prover. The latter option guaranties a substantially lower uncertainty, but requires more time.
The calibration itself starts with temperature equalization by circulating the liquid at a flowrate above 0.5 Q_{max}. The calibration flow rates and repeats can be performed according to API MPMS, OIML R117 or client wishes.

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3. Traceability

The traceability of the EuroLoop Liquid Hydrocarbon Flow Facility is schematically shown in Fig. 2. The piston provers are directly traceable to length, the master meters are traceable to the piston provers and the meter under test is traceable to either the master meters or the piston provers. A more elaborate description on the traceability of EuroLoop was discussed in an earlier paper [2].

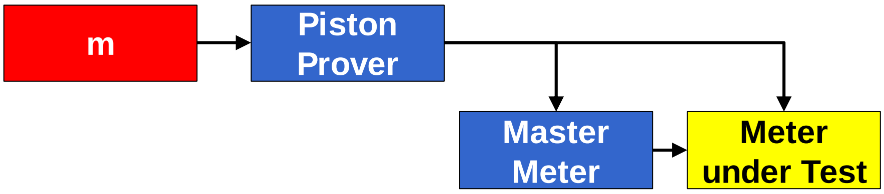

Fig. 2: Traceability chain of the EuroLoop Liquid Hydrocarbon Flow Facility.

4. Metrological maintenance

Part of the metrological maintenance is the regular determination of the density and the kinematic viscosity of all three liquids. The density and kinematic viscosity are obtained from analyzing samples from the test fluids. For this purpose we use two labs. A test laboratory is located close to EuroLoop and performs routine tests according to the appropriate ASTM standards [3][4]. Test results are available with 24 hours. The lab has an ISO 9001 certificate but does not hold an ISO 17025 accreditation. The calibration laboratory holds and ISO 17025 accreditation for viscosity, however the accredited density is outside the range we need at EuroLoop. This lab is further away and delivery times are between one and three weeks. Both laboratories obtain their traceability from reference liquids that are externally purchased from an ISO 17025 accredited laboratory.
EuroLoop needs results fast and also needs an ISO 17025 accredited lab. For that reason a small proficiency test (PT) was organized between both labs to verify if they produce equivalent results.. The liquids were circulated in the test sections in order to homogenize them. Then samples were taken and for each liquid two bottles were filled directly after each other. The samples were labelled and send to the labs. Lab A analyzed the sample at 10, 20 and 30°C. Due to time constraints Lab B could perform the analysis at 20 and 30°C only. Results were returned by calibration certificates and are graphically displayed in Fig. 3. The upper graphs show the results of the analysis. In order to distinguish the results of both labs the results of Lab A were plotted at the nominal temperature minus 0.5°C and for Lab B at the nominal temperature plus 0.5°C. The date of the analysis is shown in the legend of the graph. On the scale used, all results look identical.

In order to compare results between laboratories the so-called normalized deviation E_n is used, which is defined as:

$$E_n = \sqrt{\frac{(e_1 - e_2)^2}{U_1^2 + U_2^2}} \tag{1}$$

This is the ratio of the difference between two results and the uncertainty of the difference. If the difference of two measurement results is smaller than the uncertainty of the difference, i.e. $E_n \leq 1$, results are in agreement. When the uncertainties have a coverage factor of $k = 2$, the confidence level of this assessment is at least 95.4%.

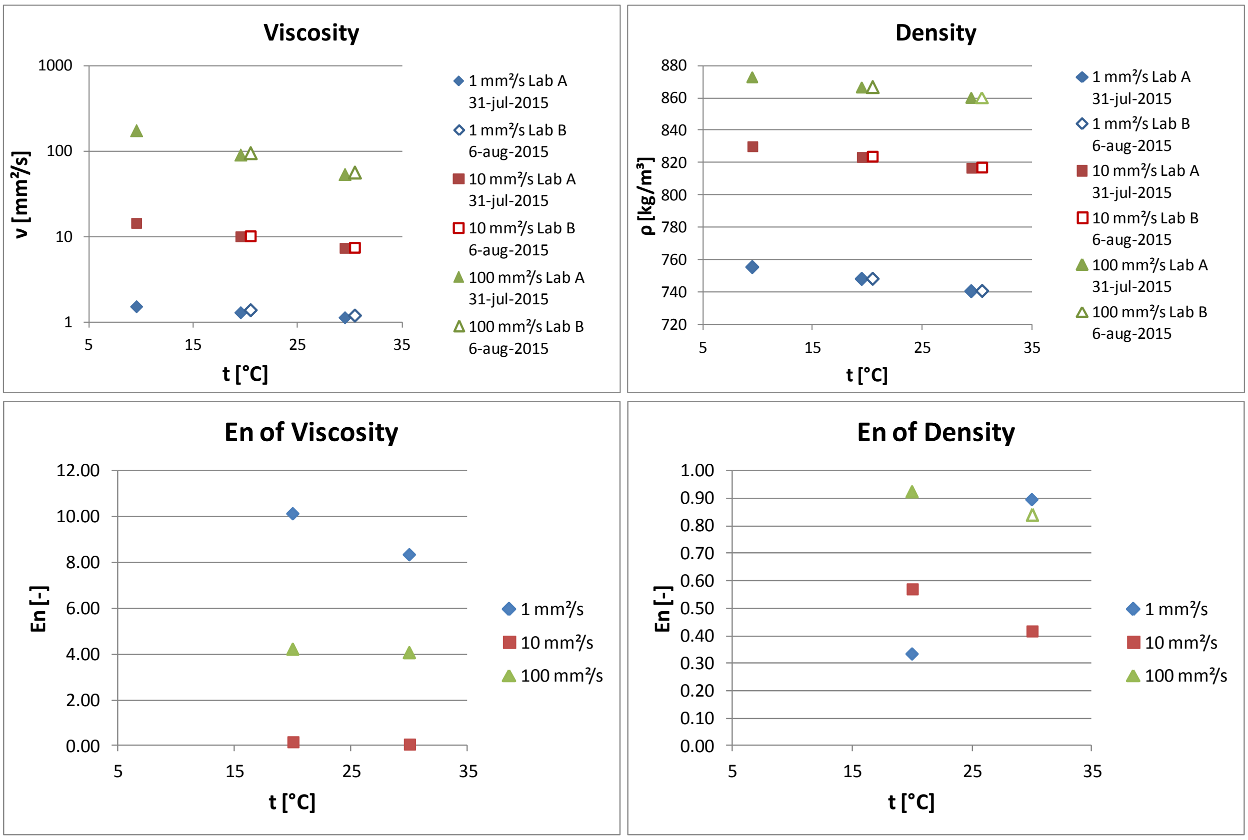

Fig. 3: Proficiency test results for kinematic viscosity [mm^2/s] (left hand side) and density (right hand side) of EuroLoop's three hydrocarbon liquids. The upper graphs show the results of the analysis, where the viscosities are plotted on a logarithmic scale. The lower graphs depict the normalized differences.

In the lower part of Fig. 3 the E_n values are plotted. For the density all E_n values are less than 1, which means the labs agree. For the viscosities the results for the 10 mm^2/s liquid agree very well. The results for the other liquids differ significantly. The laboratories were asked for clarification but have not responded so far.

The agreement of the density results is important for the comparison of a mass flow meter with a volume reference. For the uncertainty of the density the root-sum-square value of both labs are taken, i.e. 0.025%.
In the viscosity comparisons the 10 cSt results are extremely well in agreement and for this reason the differences observed for the other liquids are remarkable. For the 1 cSt liquid $E_n = 10$, which means a difference in the measured viscosities of 7%, too much for comparing facilities that operate on different liquid viscosities. The viscosity values obtained at the accredited lab will be used for reference. EuroLoop will use a 1% uncertainty for all liquid viscosities and corresponding Reynolds numbers.
Further steps will be taken which will include a critical evaluation of our own sampling procedures, a repetition of the comparison to see if differences are consistent over time, looking for laboratories that have a relevant ISO 17025 accreditation and supplier audits that will focus on the details of the measurement processes for density and viscosity.

5. Calibration experiences

Now the facility is operational we are acquiring experience with the different types of flow meters. The examples shown comprise two turbine meters in series, two different coriolis meters and an ultrasonic meter. All results are anonimized unless the owner has given us explicit consent to mention details of the meters.

5.1 Turbine meters

The two 16" turbine meters were calibrated in series. Both meters were configured with a pipe bundle 20D upstream of the meter. The schematic setup is displayed in Fig. 4. The meters are red, the inlet pipe with the flow conditioners is yellow and the flow conditioners are white. Below the spools the length of each section is indicated. Above the spool the pipe number are written.

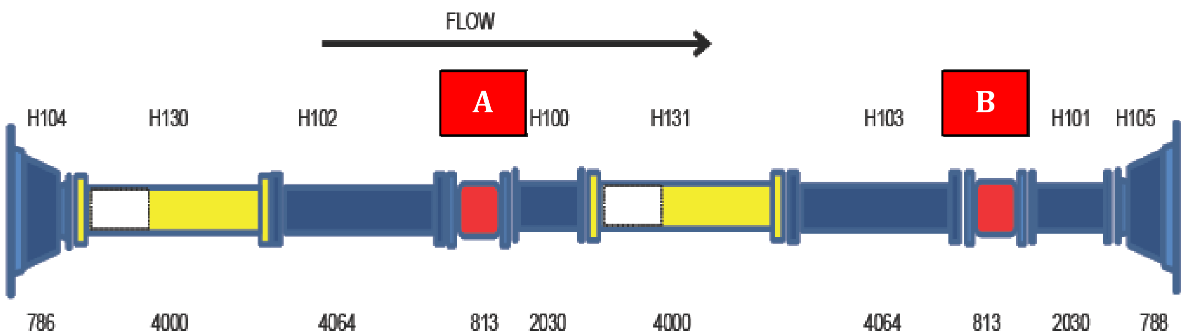

Fig. 4: Schematic configuration of the calibration setup of two 16" turbine meters.

The meters were calibrated with the 10 cSt liquid, however due to elevated temperature of 25.9 °C the effective kinematic viscosity was 7.88 mm^2/s. The as-found results of the calibrations are shown in Fig. 5. The deviation of both meters is in the range of -0.15% and 0.00%. Both meters show a relatively flat curve in the lower operating range. Between 60% and 100% of Q_{max} one meter raises while the other curve drops. The meters have been sent back to the manufacturer for furter examination.
One of the observations made during the calibrations is that the temperature variation during a series of succesive repeats at one specific flow rate is very low. The double standard deviation equals $2s(t)$=0.002°C, which corresponds to a viscosity stability of better than $4{\cdot}10^{-4}$ mm^2/s. Both values are less than the calibration uncertainty of the quantities. The temperature stability appears to be a factor 50 better than the design specification in Table 1, which is beyond expectation. Despite this impressive result the uncertainty analysis will be based on a temperature repeatability (2s) of 0.05°C.

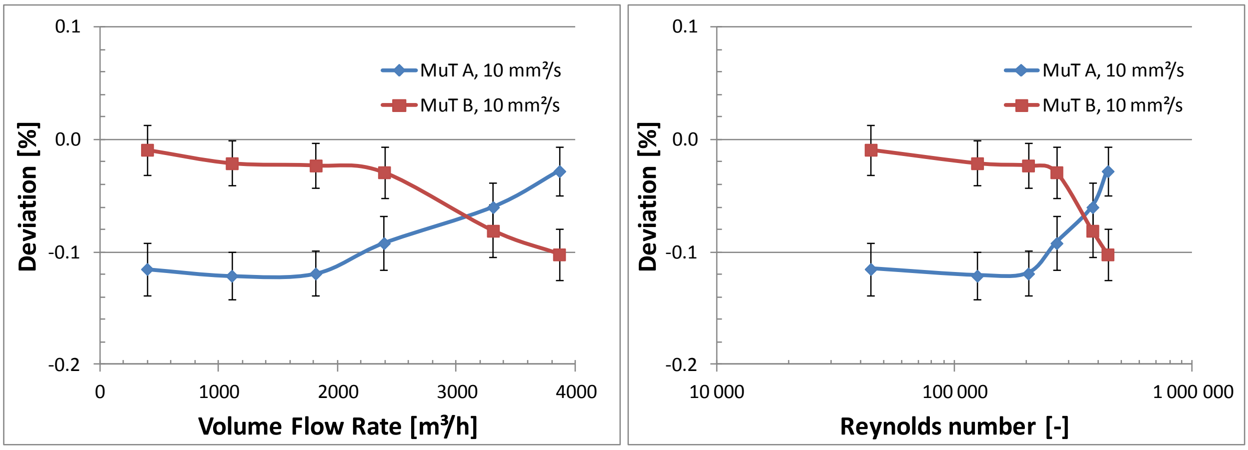

Fig. 5: As-found calibration results of two turbine meters A (in blue) and B (in red). The deviation is plotted as a function of the flow rate [m^3/h] (left) and the Reynolds number [-] (right).

5.2 Coriolis meters

An example of the calibration of a coriolis meter is shown in Fig. 6. The coriolis meter was calibrated using the piston prover as a reference. On the left hand side the deviation is plotted versus the mass flow rate, on the right hand side the deviation is plotted versus the Reynolds number. The error bars in both graphs indicate the expanded overall uncertainty ($k = 2$). All results range between -1.5% and +0.5%. In the left graph of Fig. 6 the viscosity dependency of the meter is clearly visible. The difference between the deviations at a specific flow rate exceeds the uncertainties and is therefore significant. The higher the viscosity the more the curve drops to minus at low flow rates. The right hand graph of Fig. 6 shows that the curves on the different product connect well in the overlapping Reynolds range. This knowledge allows the manufacturer to compensate for the Reynolds dependency.

For a different coriolis meter Fig. 7 shows an example what will happen if such compensation is in place. Here calibration results are plotted using a liquid with a nominal viscosity of 100 mm^2/s. The results are cumulated from runs performed on two dates. Where in Fig. 6 the results of a regular coriolis meter for the highest viscosity liquid range from -1.5% to 0.0%, the deviations for the viscosity compensated meter are between -0.2% to 0.05%. This is a reduction in the dispersion of the observed deviations with a factor six. Before putting out the flag, some remarks are to be made here. During the measurements the coriolis meter showed substantial variations of the viscosity indication while the actual viscosity was constant. Unfortunately, there was no opportunity to test the meter with other liquid viscosities. It would be interesting to test the meter with both lower and higher viscosities. And lastly the question is whether the viscosity compensation mechanism is influenced by other parameters or conditions.

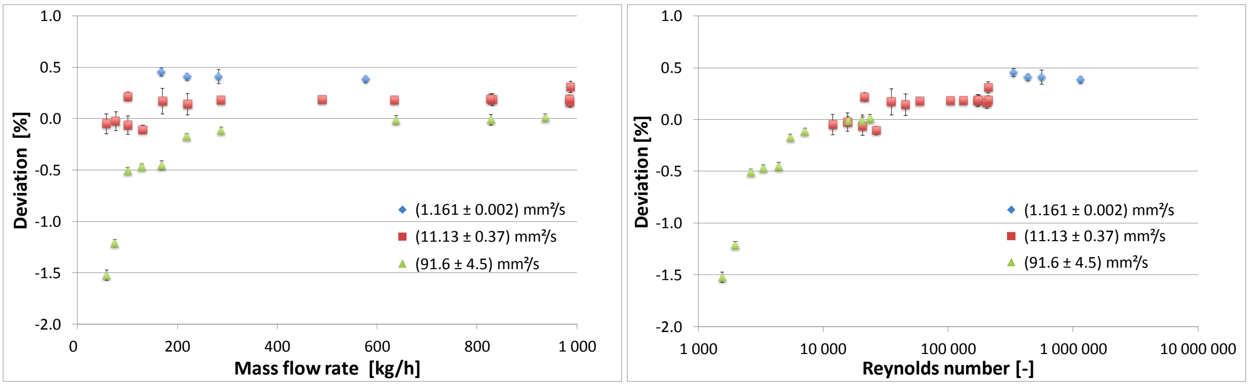

Fig. 6: Results of the calibration of a coriolis meter with three different viscosity liquids. The deviation [%] is plotted versus the mass flow rate [kg/h] (left graph) and versus the Reynolds number [-]. Error bars represent the overall expanded uncertainty.

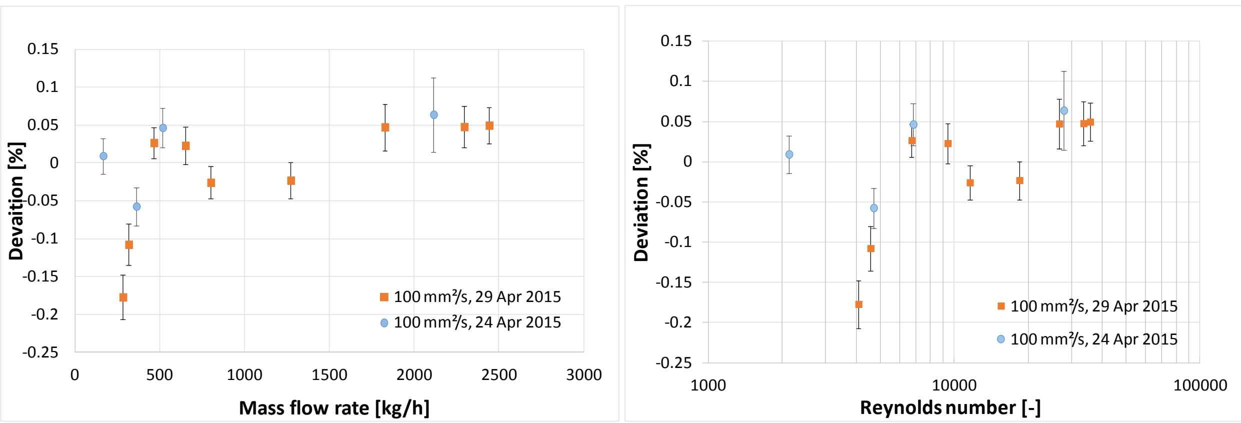

Fig. 7: Calibration results of a coriolis meter with viscosity compensation using a liquid with a nominal viscosity of 100 mm^2/s. The deviation [%] is plotted versus the mass flow rate [kg/h] (left graph) and versus the Reynolds number [-]. Error bars represent the overall expanded uncertainty.

5.3 Ultrasonic meters

For ultrasonic meters Reynolds-based profile corrections are already common practise. This makes the meter suitable for intercomparison exercises. In a previous paper [2] an intercomparison was described between the Trapil and EuroLoop facilities, in which only EurpLoop's small piston prover was used. At EuroLoop the calibrations were repeated with the big piston prover using a single meter (i.e. 8" Altosonic 5 NG meter s/n A14050085 – 19YA20901_2002) that was used in the previous experiment. The calibration results were compared with the previously obtained results at Trapil [2].
The left picture in Fig. 8 gives an overview of all calibration results obtained both at Trapil and at EuroLoop utilizing the big piston prover. All calibration results are found in a bandwidth of 0.2%, which is the result of the implementation of a profile correction algorithm. Error bars indicate the overall expanded uncertainties, black for Trapil's results and blue for EuroLoop's results. Uncertainties range between 0.03% and 0.11%, which is caused by differences in repeatability.

The agreement between Trapil and EuroLoop was evaluated using E_n defined in Eq. 1. The Trapil results were obtained at Reynolds numbers that differ from the Reynolds numbers of the EuroLoop results. In order to compare the results a linear interpolation was used to translate the observed deviations at Trapil and their uncertainties to the Reynolds numbers of the EuroLoop observations. In formula:

$$e = e_i + \frac{e_{i+1} - e_i}{Re_{i+1} - Re_i}(Re - Re_i), \quad U = U_i + \frac{U_{i+1} - U_i}{Re_{i+1} - Re_i}(Re - Re_i) \qquad (2)$$

in which Re is the Reynolds number of the observation at EuroLoop, Re_i and Re_{i+1} are the adjacent Reynolds numbers corresponding to the deviations e_i and e_{i+1} in Trapil, U_i and U_{i+1} are the expanded uncertainties corresponding to e_i and e_{i+1}.

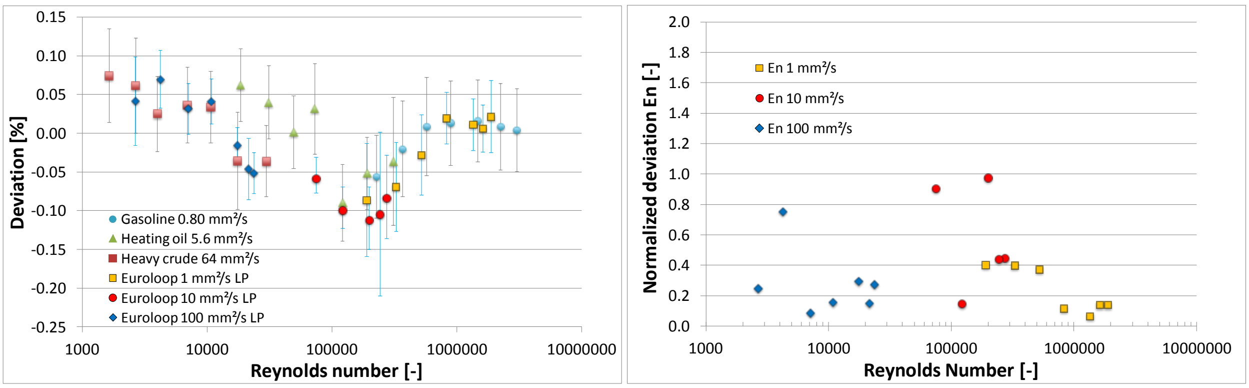

Fig. 8: Meter curves obtained at EuroLoop and Trapil for meter A (left). The deviation of the meter [%] is plotted versus the Reynolds number [-]. Error bars indicate the total uncertainty (k=2) of the measurement results. The grey and the blue bars are attached to Trapil and EuroLoop results respectively. On the right the normalized deviation E_n [-] is plotted versus the Reynolds number [-].

The E_n results are depicted in the right graph of Fig. 8. All 19 E_n values are less than 1, 16 E_n values are less than 0.5. These results mean that all Trapil and EuroLoop results agree with at least 95.4% confidence.

6. Conclusions

Now EuroLoop is fully operational the characteristics of the facilities can be compared with the specifications the facility was designed to. From the operational experiences described in the previous chapters to following conclusions can be drawn.

1. EuroLoop is very suitable to test the viscosity dependence of flow meters. Instruments with viscosity compensation installed can be calibrated and verified at EuroLoop leading to improved meter performance at lab conditions.
2. The temperature stability observed during a series of successive calibration runs at one specific flow rate appears to be much more constant than originally expected. Instead of 0.1°C double standard deviations of 0.002°C were observed. Despite this impressive result a temperature repeatability (2s) of 0.05°C will be used in the uncertainty analysis.
3. After earlier intercomparisons using the small piston prover [2], even better comparison results were obtained between Trapil and EuroLoop using the big piston prover. All observations have a normalized difference smaller than 1, which means that the results agree with more than 95.4% confidence. From the 19 observations, 16 had a normalized difference of smaller than 0.5.
4. Point of attention for the metrological maintenance is the analysis of liquid samples. Although traceability is in order, there is a significant difference between the two test and calibration laboratories for the lowest and highest viscosity liquids. The density of the samples agrees within their mutual uncertainties. Further steps will be necessary to resolve the differences.

7. References

[1] Jos van der Grinten, Bart van der Stap and André Boer (2015): Preparing the new EuroLoop liquid flow facility for accreditation, Lecture presented at the 3rd European Flow Measurement Workshop, 17-19 March 2015, Noordwijk, The Netherlands
[2] Jos van der Grinten, Bart van der Stap and Pico Brand (2015): Round robin testing for the new EuroLoop liquid flow facility, International Symposium for Fluid Flow Measurement, 14-17 April 2015, Arlington, Virginia, USA
[3] ASTM D 7042-14 (2014): Standard Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity), ASTM International, PA, USA
[4] ASTM D 4052-11 (2011): Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter, ASTM International, PA, USA