World's first LNG research and calibration facility

P. Lucas[1], O. Büker[2], A. Kenbar[3], H. Kolbjørnsen[4], K. Rasmussen[5], G. Rathwell[6], M. Safonova[7], K. Stolt[2], M. P. van der Beek[1]

[1]*VSL Dutch Metrology Institute, Delft, The Netherlands*
[2]*SP Technical Research Institute of Sweden, Borås, Sweden*
[3]*NEL, Glasgow, Scotland*
[4]*Justervesenet, Kjeller, Norway*
[5]*FORCE Technology, Designated Institute, Bröndby, Denmark*
[6]*OGM, Ely, United Kingdom*
[7]*IMS, Moscow, Russia*

E-mail (Peter Lucas): plucas@vsl.nl

Abstract

A Liquefied Natural Gas (LNG) flowmeter research and calibration facility is being built in Rotterdam by the Dutch metrology institute VSL. This cryogenic test loop will also be used to test and develop LNG analysers, new technologies and devices for measurement of LNG physical properties. The facility will consist of a Primary Standard Loop (PSL) that can measure the mass of LNG flows traceable to the International Kilogram standard in Paris. The primary standard is capable of flow measurements up to 25 m^3/hr. A second Midscale Standard Loop (MSL) will measure volumetric flow rate of up to 200 m^3/h, expandable to at least 400 m^3/h in the future. The Midscale standard is traceable to the PSL and scales the flowrate up using bootstrapping techniques. This paper describes the combined PSL and MSL facility, its objectives, and accomplishments to date.

1. Introduction

LNG is seen as a cleaner alternative to conventional fuels such as diesel because it contributes to significant reductions in CO_2, NO_x and SO_x emissions and noise. In addition to these environmental benefits, LNG is perceived as an important transition fuel, of which the infrastructure can be used for the roll-out of bio-LNG.

Reliable, accurate and commonly agreed measurement methods are a first requirement for trading of goods and related services. For existing transport fuels, a well established infrastructure for measurements of quantity and quality of the fuel is already in place. However, in the case of LNG as a transport fuel, there is no commonly agreed measurement practice and the metrological framework is still under development. Note, for the large scale LNG distribution chain there is a commonly agreed measurement practice as described in various ISO standards and the GIIGNL "Custody transfer handbook" [2], however the lack of large scale primary calibration facilities means these measurements are not traceable to a primary standard compared to other conventional fuels such as oil.

Therefore, type approval and calibration of individual LNG flow meters are currently based on calibrations with water corrected to cryogenic conditions backed up by limited test data from small scale testing with liquid nitrogen. There is a concern that this approach is not sufficiently accurate and requires further validation and improvement.

LNG is composed of various components which together determine the energy content. It is known that LNG can vary significantly in its composition, and thus energy content, depending on its origin and the production method. In addition, during storage and transport, the "LNG ageing" phenomenon contributes to change in its composition. It is therefore important to have accurate (and cost-effective) LNG composition measurements throughout the whole chain, in order to track the energy value, and also emissions of greenhouse gas to the environment.

In order to tackle the measurement challenges associated with the LNG quantity and quality, VSL and its partners are working on two calibration and research facilities; a small Primary Standard Loop (PSL) with a capacity from 0 to 25 m^3/h, and a larger Mid-Scale Loop (MSL), traceable to the PSL, with a capacity of 200 m^3/h (1600 kg/min), expandable to at least 400 m^3/h (but within the scope of a separate project). The MSL will also incorporate a composition standard based on ISO EN 12838. The PSL has been developed in earlier research projects, however is currently being upgraded to reduce the measurement uncertainty to achieve a target of 0.10% for mass flowrate. For the MSL the uncertainty target for mass flow measurement is 0.15.

In 2014 the MSL project started and currently the detailed design is approaching completion. It is scheduled to have the facility constructed by October 2016. Thereafter the commissioning and functionality testing will begin.

Upon completion of functionality testing, the facility will be used to study the performance of LNG flow meters and sampling systems. One of the key objectives is to investigate how water-based calibrations compare to LNG flow calibrations. Earlier we have performed a preliminary investigation into this aspect for small (0 to 25 m^3/h) LNG flow meters using the Primary Standard Loop. Although these results were promising, they may not be representative for larger flow meters.

The structure of this paper is as follows. Section 2 provides details on the PSL water-based calibration and shows some early results. Section 3 will discuss the design of the new PSL and MSL LNG research and calibration facility. Finally, Section 4 discusses future plans and expected progress.

2. Extrapolation from water based calibration

Current industry practice is to calibrate LNG flow meters with water at ambient conditions and then transfer this calibration to cryogenic conditions by applying corrections. For ultrasonic flow meters, several corrections are involved. However for Coriolis flow meters it was found that the water calibration can be transferred successfully so long the non linear dependence of the Young's Modulus of stainless steel elasticity against temperature is taken in to consideration. However, this was only demonstrated for flow meters of 2 inch in size. An example of the well-known relationship of Young's modulus versus temperature is shown in Figure 1 for three types of stainless steel. More recent estimates of the Young's module are available, however it is unknown which estimates have been used to determine the correction factors (typically confidential information). The correction factors are normally based on some polynomial fit against temperature which is fairly linear to temperatures down to about 150 K. For lower temperatures, the Young's modulus is clearly nonlinear. An additional uncertainty source may be that not all relevant physics are captured within this temperature correction model and therefore further check and validation of this approach is essential.

In earlier work, VSL, NEL and JV have investigated the accuracy of the extrapolation models for small flow meters. In table 1 the test flow meters with their specifications are shown (all are 2" CMF flow meters of which 3 have a twin-bent configuration and 1 has a twin straight tube configuration). In Table 2 the test conditions are shown.

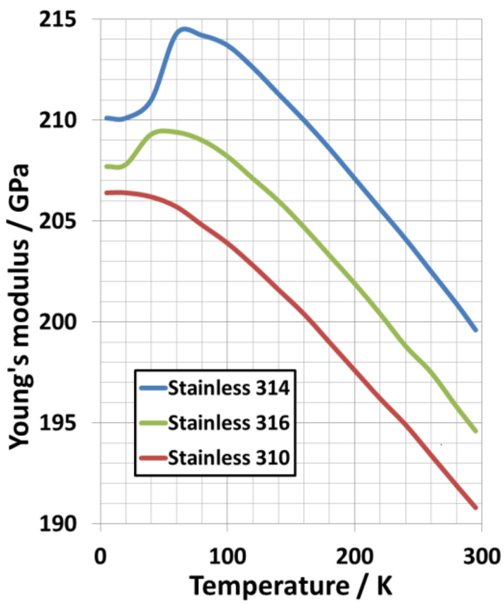

Figure 1: Young's Modulus of three types of stainless steel, taken from [4].

Table 1: Specifications flow meters A, B, C and D.

Test flow meter	Meter flow range [kg/s]	T range [ºC]	Claimed accuracy [%]	Zero point stability [kg/s]
A	1 to 24	-240 to 204	within ±0.35	<0.002
B	1 to 13	-240 to 200	within ±0.30	<0.001
C	1 to 24	-240 to 204	within ±0.35	<0.002
D	1 to 9	-180 to 230	within ±0.20	<0.001

Table 2: Test conditions flow meters A, B, C and D.

Test flow meter	Meter flow range [kg/s] & (Institute)	Liquid Nitrogen flow range, [kg/s] & (Institute)	LNG flow range, [kg/s] & (Institute)
A	1 to 12 (VSL)	1 to 9 (NIST) 1 to 5 (VSL)	1 to 4.7 (VSL)
B	1 to 4 (third party)	Not tested	1 to 4.7 (VSL)
C	1 to 16.4 (JV)	Not tested	4.3 (JV) 1 to 4 (VSL)
D	1 to 9 (NEL)	1 to 9 (NIST)	1 to 4 (VSL)

The following procedure was used to test the flow meter. The flow meter zero was set for the current testing conditions (ambient or cryogenic). This was achieved by closing the two valves upstream and downstream of the flow meter for a short time to avoid any liquid boiling. No further change was made to its value during subsequent tests. However, for flow meter D, the zero was set for ambient conditions. At cryogenic conditions, the zero value was monitored and recorded before and after each test in order to measure its shift from the stored value. Note, the various procedures for zeroing the meter together with the zero stability may attribute to a small discrepancy for low flow rates (worst case scenario is 0.10 % for 1 kg/s). It was observed that the zero stability was much better for LNG than for Liquid Nitrogen (LIN). It is yet unknown whether this is a property of the flow meter or caused by the conditions. The measurements with LNG were conducted during winter whereas the measurements with LIN where conducted in summer. Consequently, the temperature gradient for the LIN measurements was significantly larger than for the LNG measurements.

For water, the meters were calibrated between 10 % and 50 % of full scale (100 % for flow meter D). For LIN, flow meter A has been calibrated up to 40 % and flow meter D up to 100 % of full scale. For LNG, flow meters A and C have been calibrated up to 20 % and for flow meter B and D up to 36 % and 44 % respectively.

The measured values of mass flow rate, density and temperature from the flow meter were collected in addition to the reference flow rates and physical property data from the calibration rigs. There were no statistical evaluations done to observe any pressure, temperature or thermal cycling dependencies. The results from LNG and LIN tests are given in Figures 2 and 3 respectively. These figures show the deviation of measured mass flowrate by the meters from the gravimetric reference measurement.

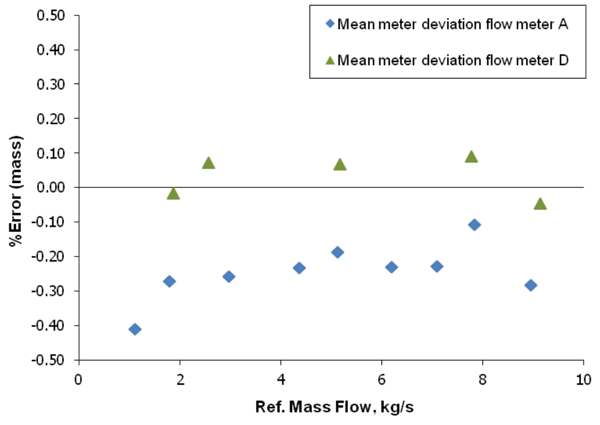

Figure 2: All meter deviations for meters calibrated with Liquid Nitrogen (LIN).

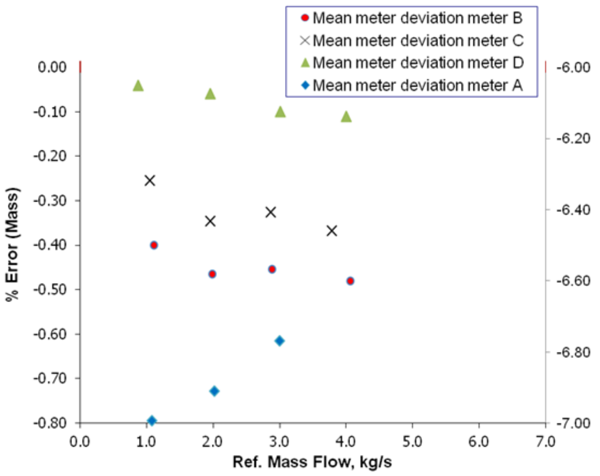

Figure 3: All meter deviations for meters calibrated LNG. Deviations for flow meter A are shown on the right axis. The errors for meters B, C and D are given on the left axis, the error for meter A is given on the right axis.

These results reveal that measurements of liquid Nitrogen flow can be achieved within the manufactures accuracy claims. Figure 3 shows the results obtained for all meters that have been calibrated with LNG. Although the accuracy claims in general was met for the meters tested, note that these claims are quite a bit relaxed compared to accuracy claims for water calibrations; i.e. for water the specified accuracy is typically around 0.10 %, whereas for cryogenic calibrations it is typically around 0.30 %.

The deviations found for the measurements of liquid natural gas are somewhat larger than found for liquid Nitrogen (despite the better zero point stability), especially for flow meter A. The deviations for flow meter A and B are outside the accuracy specifications. An explanation could be that the cryogenic correction models have so far been tuned for water and liquid Nitrogen. Nevertheless, the cryogenic correction models decrease the deviation to (almost) acceptable levels. However, note that all flow meter deviations are negative, i.e. all flow meters under read (without the cryogenic correction factor the flow meters can under or over read). Because flow meters A to D use different correction models (different polynomials in temperature), part of these deviations may be attributed to the various models used. In technical report [3] the full results are shown and discussed.

As mentioned earlier, these results are for 2” flow meters. It is well-known that larger Coriolis flow meters can exhibit quite different behaviour. Hence, further research is required to investigate the suitability of the correction models for the more common larger flow rates which is why the extended mid-scale facility is being built.

3. LNG research and calibration facility

3.1 Specifications

The facility will be a closed loop system to calibrate LNG flow meters as well as sampling systems. The range of the facility will be 5-200 m^3/h, with the possibility to increase to at least 400 m^3/h, depending on customer demand. The operational line pressure is up to 10 Bar(g). A standard for composition measurements, taking ISO EN 12838 into account, will be realized for calibration of sampling systems.

The following uncertainties are aimed for:

- Uncertainty in mass flow reference value (equivalent to 5 to 200 m^3/h): < 0.15 % of reading over the full range of which 0.10 % is due the PSL.
- Uncertainty in volume flow reference value (5 to 200 m^3/h): < 0.20 % over the full range of which 0.15 % is due the PSL and 0.10 % due to the density determination.
- Uncertainty in density (357 to 438 kg/m^3): < 0.10 % due to pressure, temperature and composition uncertainty.

– Uncertainty in temperature (-165 to -120 °C): < 0.10 °C. Resolution minimal 0.02 °C, including representatives, primary calibration etc.
– Uncertainty in pressure (0 – 10 barg): < 0.2 bar. Resolution minimal 0.05 bar.

The LNG will be kept subcooled using LIN based heat exchangers. The calibration of all meters is done using the flying start stop method and/or a static start/stop test where the reference is the sum of multiple Coriolis mass flow meters. These flow meters have a maximum flow rate of 50 m^3/h each and can be used in parallel to achieve the maximum flow rate of 200 m^3/h. For the potential future expansion additional flow meters in parallel will be realized. These meters are called the working standards and are traceable to two master Coriolos flow meters. These master meters are in turn traceable to the PSL.

3.2 Design
The LNG research and calibration facility consists of the following main elements:
– Primary standard loop (PSL);
– LIN and LNG vessels;
– LNG pumps;
– Heat exchangers;
– Master meters;
– Meter-under-Test (MuT) runs;
– Working standards.

Calibration of a specific meter will be performed against the working standards. The working standards are traceable to the master meters, which in turn are traceable to the PSL. Both the master meters and the working standards are contained in a cryogenic box that is insulated to minimize heat gain. This box is referred to as the Meter Cold Box.

In Figures 4 to 6 the LNG research and calibration facility is shown. Figure 4 shows the process units in the facility; Figure 5 shows the Meter Cold Box, and the MuT, whereas Figure 6 is a sketch of a working standard within the cold box. Figure 7 finally gives a sketch of the PSL.

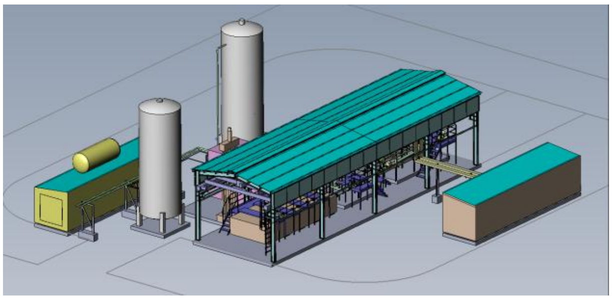

Figure 4: Overview of the complete facility. The left most building is the primary standard, next to it are the LNG and LIN storage tanks. The building in the middle contains the meter runs as well as the master meters and working standards (Figure 5 gives a close up). The building on the right is the control room.

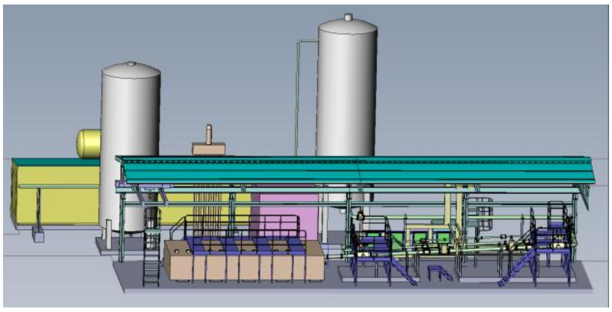

Figure 5: Master Meter Cold Box, The MuT meter runs, master meters and working standards. The Master meters are installed in a cold box (brown box on the left). The MuT meter runs are to the right of the cold box.

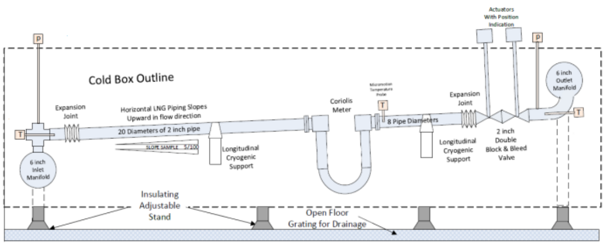

Figure 6: Sketch of the installation of one Master Meter within the Master Meter cold box. The whole line is slightly inclined to avoid entrapped gas pockets. The u-shaped object is the Coriolis flow meter, the brown boxes within the cold box are temperature transmitters whereas the brown boxes outside the cold box are pressure transmitters.

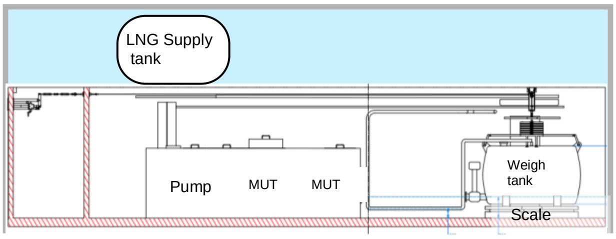

Figure 7: Sketch of the primary standard. Traceability is through the gravimetric method, hence LNG is pumped from the supply tank (top) through the MUT and then to the weighed tank (right).

4. Future work

Traceability and validation
The master flow meters of the LNG research and calibration facility are traceable to the PSL. Below are the options for calibrating the master meters:
- through a direct fluid connection with the primary standard. Hence, the LNG flows through the meter of the primary standard and then through the master meters. The flow meter of the primary standard is directly calibrated by a weighing scale. Hence, from all flow meters the PSL flow meter is the highest standard.
- installation of the master meter in the primary standard, or installation of the primary standard flow meter in the LNG research and calibration facility.

In [1] the PSL as well as its validation has been described. From the validation, it was found the calibration uncertainty of the primary standard is somewhat high due to parasitic forces on the balance (caused by a fixed fluid connection of the weighing tank). Therefore the primary standard will be upgraded with an automatic levelling system as well as a dry-break coupling. Additionally, the temperature measurements and the timing uncertainty will be reduced, aiming to reach a calibration uncertainty of 0.10 % in mass flow.

The validation of the LNG calibration and research facility aims at validating the uncertainty claim. Amongst others, the following are the uncertainty sources that will be assessed:

- Calibration uncertainty of the PSL.
- Dead (connecting) volume between the working standard and the meter under test. This uncertainty follows from the uncertainty in density and volume. The former is a combined effect of the uncertainty in pressure, temperature, composition and density model.
- Repeatability and zero drift of the reference Coriolis flow meters.

Validation of extrapolation models
After the metrological validation various flow meters will be assessed for their metering accuracy. This will reveal whether the water based extrapolation models are suitable or not for flow meters up to 4”. It is possible that the results will depend on flow meter model and make.

Impact flow disturbances
In addition to ‘regular’ LNG flow calibrations, it will also be investigated how various flow meters react to flow disturbances such as swirl and other installation effects.

Acknowledgement
The results described in this paper have been obtained with two research projects that have been funded by the EMRP. The EMRP is jointly funded by the European Commission and participating countries within Euramet and the European Union.

References

[1] Beek, M.P. van der, Lucas, P., Kerkhof, O., Mirzaei, M. and Blom, G. Results of the evaluation and preliminary validation of a primary LNG mass flow standard, Metrologia, 51, 2014
[2] GIIGNL, LNG Custody transfer handbook, fourth edition, version 4.00, 2015
[3] Kenbar, A., Lucas, P., Mortenson, T., Coriolis flow meters – Calibration approach for cryogenic applications, technical report, available online at: http://lngmetrology.info/publications
[4] Ledbetter, H., Stainless-steel elastic constants at low temperatures, Journal of Applied Physics., Vol. 52, No. 3, march 1981