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LNG Mid-Scale Loop flow metering – Preliminary Test Results

M.D. Schakel[1], O. Kerkhof[2], M.P. van der Beek[3], P. van den Herik[2], R. van Hof[2], P. Lucas[4], S. Wulffers[2]

[1]VSL, mschakel@vsl.nl, Delft, The Netherlands
[2]VSL, Delft, The Netherlands
[3]Euroloop, Rotterdam, The Netherlands
[4]TNO, Delft, The Netherlands
E-mail (corresponding author): mschakel@vsl.nl

Abstract

The LNG Mid-Scale Loop (MSL) has been taken into use in 2019. Instead of making use of surrogate fluids, the facility will be able to perform calibrations with cryogenic liquid directly, and under actual operating conditions. Consequently, insight on surrogate-fluid calibration transferability will be obtained. The Cryogenic Research and Calibration facility allows for metrologically traceable cryogenic flow meter calibrations. At the time of writing, calibrations with liquid nitrogen (LiN) can be performed. By performing traceable calibrations with cryogenic liquids directly, market confidence in LNG custody transfer will be established which in turn allows the uptake of LNG on a larger scale. Notably, in addition to economic benefits of using LNG, the use of LNG as a transport fuel for trucks and ships has considerable environmental benefits. The Cryogenic Research and Calibration facility is based on a closed-loop system where cryogenic liquid is circulated. The cryogenic primary mass flow standard (PSL) is fully integrated into the facility. The target maximum flow rate of the facility is 200 m^3/h. A metrologically traceable LNG composition primary standard allows to calibrate alternative composition measurement systems. Thus, the facility provides the means to traceably calibrate flow meter and composition measurement systems with cryogenic liquid directly, which in turn allows the calibration of systems for measuring the quantity of LNG-energy transferred. This article will describe the facility, it's operating principles, preliminary test-results, and future plans. The facility allows for systematic research into flow meter performance in varied circumstances, such as the effects of flow-meter insulation, (upstream) flow disturbances, and multi-phase flow. Prototypes and models of cryogenic flow meters can be tested and calibrated in a metrologically traceable manner.

1. Introduction

Liquified Natural Gas (LNG) is traded between the exporter and the importer during custody transfer. Typical applications of LNG are (at the large scale) to regassify it and inject it into the gas grid, and (at the small to midscale) as a transport fuel. LNG is an alternative to pipeline gas, with strategic and, for long distances, economic benefits [1]. Further LNG has considerable environmental benefits. Engines running on LNG will meet the (new) limits set on NO_x and CO_2 emissions and produce less noise than diesel operated engines. LNG fuelled trucks are an alternative to diesel fuelled trucks for long-distance road freight transport. LNG shipments may overtake inter-regional pipeline shipments in the 2020s [2]. Clearly, the global trade in LNG is growing and there is a need for metrological infrastructure to facilitate it. The quantity of LNG traded is based on the amount of energy transferred [3]. To determine this amount, current practice is to measure the volume of LNG which, in combination with the mass density and the measurement of LNG composition, allows to compute the amount of energy transferred (see for example [3]).

One method to measure the volume is based on level gauges and calibration tables in the LNG carrier. Another method is to measure the flow when custody transfer takes place, such as when fuelling an LNG truck or in LNG ship bunkering. Typical instruments used in the second method are ultrasonic flow meters (USM) and Coriolis Mass Flow (CMF) meters. Currently, CMF meters are calibrated with water and interpolation methods are applied to compensate for temperature effects at cryogenic conditions when measuring LNG flow (see for example [4,5]). Clearly traceable calibrations with LNG will help to establish confidence in LNG flow metering and therefore in LNG custody transfer.

Within the European Metrology Research Programme (EMRP), the European Metrology Programme for Innovation and Research (EMPIR), and the “Regeling Nationale EZ subsidies” (Dutch Ministry of Economic Affairs and Climate Policy) research and innovation projects were undertaken to establish metrological infrastructure for LNG applications. In 2019 VSL completed the construction of the Cryogenic Research and Calibration facility to enable traceable cryogenic flow meter calibrations with a target maximum flow rate of 200 m^3/h and a target measurement uncertainty of 0.15% in mass flow rate (which equates to about 0.20% in volume flow rate). The facility will serve the needs of small-scale to mid-scale LNG flow meter calibrations. The LNG composition primary standard allows to calibrate alternative composition measurement systems as well. Thus, the facility provides the means to traceably calibrate flow meter and composition measurement systems, which in turn allows the calibration of the quantity of LNG-energy transferred in LNG trade.

An LNG roadmap is displayed in Figure 1. A primary standard was built in 2013 and documented [6]. It is now integrated into the Cryogenic Research and Calibration Facility, which was completed in 2019 and where this paper is about. The facility can, in principle, be expanded to larger flow rates (range 400 – 1000 m^3/h). The ultimate aim is to allow for traceable LNG flow meter calibrations at the large scale (10,000 m^3/h).

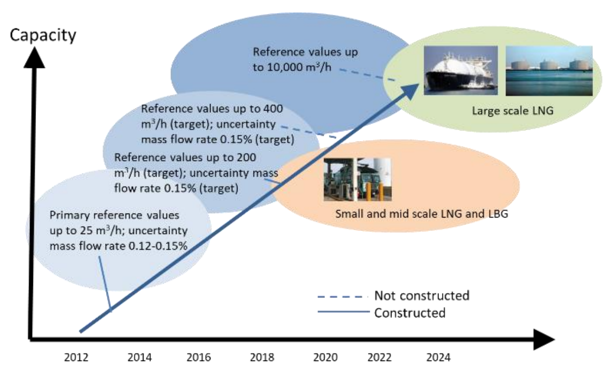

Figure 1: Roadmap for traceable LNG flow meter calibrations. LBG denotes liquified biogas.

Figure 2 shows the metrological traceability scheme for LNG composition, density, and flow, which are the inputs to compute the amount of LNG energy transferred on which LNG trade is based [3]. The composition analysers are made traceable by reference gases derived from primary standard mixtures. The reference gases are liquified by a liquefier. These liquids are used to calibrate the composition analyzers at the Cryogenic Research and Calibration facility. Pressure and temperature sensors embedded in the facility are made metrologically traceable by direct calibration with primary standards. Combining pressure, temperature, composition with an equation of state enables the LNG density to be computed. Mass and time are made metrologically traceable by the gravimetric mass flow primary standard which contains a weighing scale on which a cryostat-vessel rests. By combining the density with the mass flow the volume flow rate is computed.

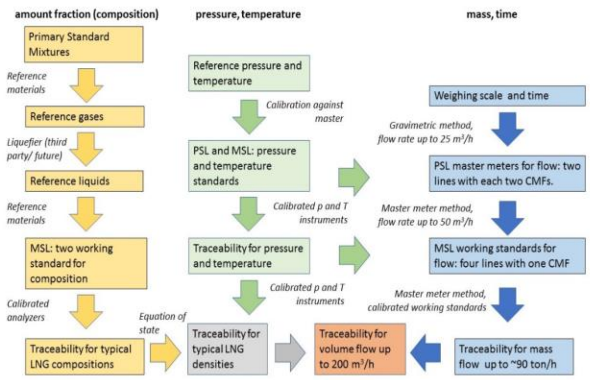

Figure 2: Metrological traceability scheme.

This paper will describe the main components of the Cryogenic Research and Calibration facility, the operating principles of the facility, preliminary test-results, and future plans. The facility allows for systematic research into flow meter performance in varied circumstances, such as the effects of flow-meter insulation, (upstream) flow disturbances, multi-phase flow, and variable subcooled conditions. Prototypes and models of cryogenic flow meters and cryogenic liquid composition analysers can be tested and calibrated in a metrologically traceable manner.

2. Cryogenic Research and Calibration facility components

Figure 3 shows an overview of the main components of the Cryogenic Research and Calibration facility.

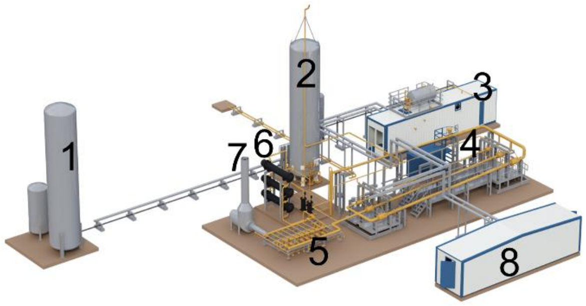

Figure 3: The Cryogenic Research and Calibration facility: 1) Liquid Nitrogen (LiN) storage tank, 2) cryogenic liquid storage tank, 3) primary Standard (PSL) for mass flow utilizing the gravimetric method to calibrate the Coriolis mass flow meters in the PSL, 4) Meter under Test (MuT) section, 5) working standards, a set of Coriolis mass flow meters, 6) heat exchangers and pumps, 7) Nitrogen (N_2-)warmer and 8) control room.

1) The LiN storage tank is used as supply of LiN. LiN is used for varied purposes such as liquid coolant, source for instrumentation nitrogen, source of purging gas, etc.
2) The cryogenic liquid storage tank is used to store the cryogenic liquid (for example LiN or LNG). Since the tank is a cryostat, the cryogenic liquid can be kept into the storage tank without it being converted to gas.
3) The Primary Standard Loop (PSL) is a gravimetric primary standard for mass flow which is used to provide metrological traceability for mass flow to the working standards of the MSL.
4) In the Meter-under-Test (MuT) section cryogenic flow meters can be calibrated.
5) MSL flow working standards. Figure 4 shows a picture of the four Coriolis mass flow meter working standards. The working standards are refrigerated with cold N_2-gas boiled off from the heat exchangers.

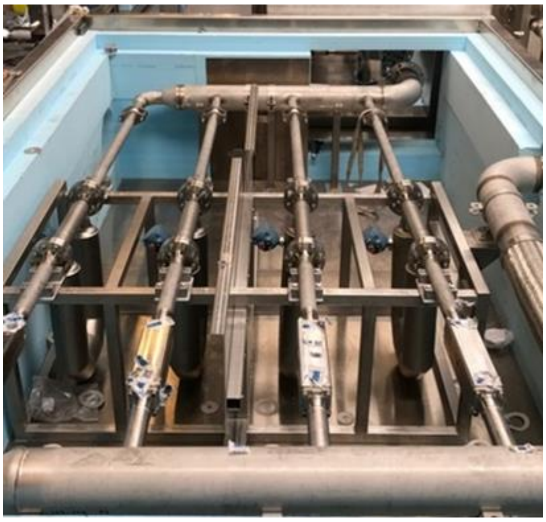

Figure 4: working standards, a set of Coriolis mass flow meters.

6) Pumps generate flow in the MSL by pumping the liquid from the cryogenic liquid storage tank through the MSL in which it is circulated in a loop. The heat exchangers refrigerate the cryogenic liquid below its boiling point to create a sub-cooled state of the cryogenic liquid. Figure 5 shows the pumps and Figure 6 shows the heat exchangers.

Figure 5: cryogenic pumps.

Figure 6: heat exchangers. LiN is guided past the cryogenic liquid to cool it down towards a sub-cooled state.

7) The N_2-warmer heats the relatively cold waste nitrogen released from the heat exchanger (boiled of nitrogen from the sub-cooling process) and guides the heated gas towards a safe point into the atmosphere.
8) The facility is operated from the control room.

3. Operating principles

The Cryogenic Research and Calibration facility is based on a closed-loop system where cryogenic liquid is pumped (Figure 3, item 6) from the cryogenic vessel (Figure 3, item 2) to the working standard Coriolis mass flow meters (Figure 3, item 5), then towards the Meter(s)-under-Test (Figure 3, item 4), and then recirculated by the pumps towards the working standards (Figure 3, item 5). LiN (Figure 3, item 1) is used to subcool the cryogenic liquid, which occurs in the heat exchanger (Figure 3, item 6). Subcooling avoids boiling and concomitant two-phase flow of the circulated cryogenic liquid. Heating of cryogenic liquid occurs due to the heat transfer from the air at ambient temperatures towards the cryogenic liquid at cryogenic temperatures. A composition measurement primary standard (not shown) is located downstream of the Meter(s)-under-Test. This is a logical place as it will be assured that their connections to the loop will not affect the flow profile in the flow metering loop.

The PSL (Figure 3, item 3) is fully integrated into the facility. It was modified with respect to an earlier version with the aims to reduce the measurement uncertainty, to integrate it into the MSL of the Cryogenic Research and Calibration Facility, and to improve the metrological robustness of the primary standard Coriolis mass flow meters. Metrologically traceable calibrations of Coriolis mass flow meters in the primary standard can be performed and used to transfer traceability towards the working standards of the MSL through a bootstrapping procedure. This procedure must be performed periodically (for example each year) and the flow loop will then be diverted from the MSL towards the PSL. After having (re)established the metrological traceability, the flow will be diverted back towards the MSL to perform traceable calibrations of Meter(s)-under-Test in a loop from the MSL working standards towards the Meter(s)-under-Test and then back to the working standards.

4. Preliminary test results

Stable flow rates with LiN have been achieved within the loop. This applies to flow from the pumps to the PSL and then towards the MSL as well as for the flow within the MSL. This is considerable better performance than initially expected, as the LiN is not actively cooled by another liquid coolant. This shows the high potential of the facility.

5. Future plans – A Cryogenic Field Laboratory

The facility was taken into use for metrologically traceable calibrations for LNG flow meter and LNG composition analysers. Naturally future plans are to flow LNG through the loop instead of LiN. This flow can be expanded to higher flow rates (range 400 – 1000 m^3/h) completely serving the full range of the small- to mid-scale LNG market for refuelling and bunkering applications.

The commissioning of the facility with LiN has provided further insights. The facility opens up possibilities for cryogenic research not limited to:

- Systematic research into flow meter performance in varied circumstances, such as the effects of flow-meter insulation, (upstream) flow disturbances, multi-phase flow, and variable subcooled conditions
- Research into improved accuracy and robustness of cryogenic temperature measurements
- Metrologically traceable calibrations of prototype cryogenic measuring devices for mass and volume flow, density, speed-of-sound, etc.
- Metrologically traceable calibrations of prototype cryogenic liquid composition measuring devices
- Cryogenic training for operators and metering experts
- Research on new cryogenic measurement methods
- Cryogenic equipment field testing

6. Conclusion

The LNG research and calibration facility was commissioned with LiN. Even with LiN stable flow rates can be achieved both in the PSL as in the MSL. As the LiN is not actively cooled by a liquid coolant, this implies that it will be easier to create stable flow with any cryogenic liquid with a boiling point higher than LiN (such as LNG). Thus, the facility provides the means to traceably calibrate flow meter and composition measurement systems with cryogenic liquid directly, which in turn allows the calibration of systems for measuring the quantity of LNG-energy transferred.

The LiN commissioning results indicate the high potential of the facility as a Cryogenic Field Laboratory for cryogenic research into fields not limited to flow, composition, temperature, pressure, alternative and surrogate cryogenic liquids.

7. Acknowledgements

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