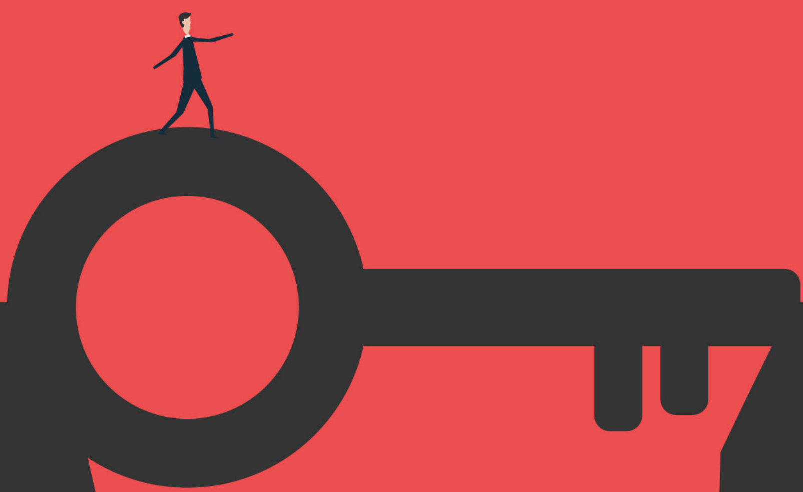
Calibration is the key

Dean Standiford, VSL, the Netherlands, explains how insulating a flowmeter can affect the flowmeter temperature measurement value and how this can affect the mass flow output.



LNG has traditionally been used to transport natural gas across the world to supply areas where it is not readily available. This is achieved using LNG carrier ships that are designed for cryogenic storage and with specific volumes based on the level of LNG in the storage tanks. Transport companies make level measurements after loading the ship with LNG and again when the LNG is unloaded. The difference between these two measurements is the total volume of LNG transferred which is used in the final energy calculation. There are many corrections made to each measurement in this process to obtain the corrected volume.

Correction tables for list and trim of the ship are used for the level measurements. Gauge tables are used to convert the level measurements to volume and LNG fluid properties are used to obtain the corrected volume. This is all applied twice, once during loading and once during unloading, to obtain the final transferred volume. Transferring a full load of LNG (typically approximately 150 000 m^3) creates a large difference in the beginning and ending measurements, which allows the measurements and correction errors to be less precise without any commercial impact.

The transition to clean energy has been driving the demand for LNG into new markets such as marine bunkering and land-based mid to small scale LNG trade. The transition of LNG into these new markets where smaller amounts of LNG is being transferred and measured has prompted a transition to new measurement methods utilising existing measurement technologies such as inline dynamic mass flow measurement. According to the latest edition of the GIIGNL LNG Custody Transfer Handbook 6th Edition 2021, "LNG flow metering using mass flow (Coriolis) meters and/or volumetric (ultrasonic) flowmeters is gradually being introduced into applications of LNG fiscal measurement in small scale operations."

Dynamic mass flow measurement is standard practice for most liquids in custody transfer following OIML R-117, "Dynamic measuring systems for liquids other than water" and OIML R-81, "Dynamic measuring devices and systems for cryogenic liquids". These standards describe the term 'influence quantity' as, "a quantity that is not the subject of the measurement but that can influence the value of the measurand…" noted as being relevant to electronic measuring systems. This article will discuss the flowmeter temperature measurement as an influence quantity that is relevant when using a Coriolis flowmeter for inline dynamic mass flow measurement. Specifically, how insulating the flowmeter can affect the flowmeter temperature measurement value and how this can affect the mass flow output.

Coriolis flowmeters

Coriolis flowmeters measure the Coriolis effect induced by fluid flowing through one or more tube(s) vibrating at their natural bending frequency. The fluid flow through the tubes causes the vibrating tubes to twist at their natural twist frequency. The vibrating and twist frequencies are influenced by the stiffness of the tube's material, and the stiffness of the tube's material is influenced by the tube's temperature.

The measured Coriolis effect is used to calculate mass flow using a calibration constant. The calibration constant is typically determined while flowing ambient temperature water through the tubes in a laboratory calibration system. During use, the calibration constant is corrected for other fluid temperatures, usually within the flowmeter transmitter, using the difference between the current temperature and the initial calibration temperature. The correction is based on the change in stiffness of the material due to a change in temperature, or Young's modulus of elasticity. For 316 stainless steel this value is approximately 4% for every 100˚C, when derived in terms of mass flow error per ˚C.

Coriolis flowmeters measure the tubes' material temperature, not the fluid temperature, to correct the calibration constant. This is usually undertaken with a temperature sensor on the outside of the tubes, or on the flowmeter body close to the tubes. The temperature sensor relies on heat transfer properties between the fluid and the tubes' material to make an accurate measurement.

The heat transfer processes in cryogenics are essentially the same as for any engineering temperature range. Heat transfer at low temperatures is governed by the same three mechanisms present at ambient and elevated temperatures: conduction, convection, and radiation. However, due to the cryogenic condition of LNG there are other complications that lead to the inconsistency of the thermal properties, or mechanisms stated above. Within conduction, convection, and radiation are several variables contributing to these inconsistencies. Flowrate for conduction, ambient temperature for convection, and sunlight for radiation to name just a few. In addition, there is also the size of the flowmeter, tube geometry, installation location, and whether the flowmeter is insulated.

Figure 1. VSL's LNG mid scale loop calibration facility.

Figure 2. Flowmeter under test (MUT) section of VSL's LNG calibration facility.

An LNG calibration facility

In 2019, VSL commissioned the world's first SI-traceable mid scale LNG calibration facility utilising VSL's primary LNG mass flow standard that was realised in 2014. The combination of these two facilities (Figure 1) gives VSL the ability to provide calibrations and performance testing of LNG flowmeters at the end user's actual cryogenic conditions with a reference mass flow uncertainty of 0.17% (k=2).

VSL's mid scale loop runs LNG at flowrates from 4 m^3/h to 150 m^3/h (1800 kg/h to 67 500 kg/h) at approximately 5 bar (gauge) and -165˚C. The mid scale loop has two flow paths and can accommodate flowmeter line sizes from DN25 (1 in.) up to DN150 (6 in.) (Figure 2).

Figure 1 shows a large blue structure that covers the two flow paths, or flowmeter under test (MUT), sections shown in Figure 2. During calibrations, the structure prevents most of the rain and radiation effects from the sun, but the flowmeters are exposed to wind and humidity. On a flowmeter without insulation, wind and humidity can affect the amount of frost build-up on the flowmeter body. Frost builds up on the flowmeter body and acts as an insulating layer, reducing ambient temperature effects. However, the amount of frost build-up can be extremely variable depending on the current outside conditions which can impact the insulating properties of the frost layer.

Having performed multiple calibrations under cryogenic conditions, VSL has learned that both ultrasonic and Coriolis meters show a flow measurement bias when the meters are not insulated. Coriolis meters also indicate a bias in the flowmeter temperature measurement error when the flowmeter insulation is removed. This becomes an influence quantity as it affects the mass flow reading from the Coriolis sensor. The temperature measurement bias is consistent between line sizes and has an overall negative impact on the mass flow measurement error. The temperature measurement error and temperature stability are also impacted by flowrate. The largest deviations can be seen at the lowest flowrates where there is less heat transfer from the fluid and more convection from ambient heat sources. Low flowrates also lead to a much longer cool down period before measurements can be made with acceptable repeatability. However, the temperature measurement bias remains even with longer cool down periods.

Conclusion

As the transition to clean energy continues to drive the demand for LNG into new markets, it makes good business sense to utilise new measurement methods, such as inline dynamic mass flow measurement, to improve measurement accuracy during trade. However, cryogenic conditions are very different than reference temperature water used for most flowmeter calibrations, and a good understanding is required of all the influencing factors that are present.

The new mid scale LNG calibration facility, with its low mass flow uncertainty (0.17%, k=2), enables VSL to perform SI-traceable calibrations on cryogenic flowmeters that match the end user's process conditions. This leads to a better understanding of the cryogenic influence factors and an improved measurement accuracy in their installation. **LNG**