Final Publishable Summary Report for ENG03 LNG
Metrology for Liquefied Natural Gas (LNG)

Background

The overall objective of the research project was to make a big step towards a significant reduction of uncertainty (by a factor two) in the determination of transferred energy in LNG for billing purposes. This requires improved measurements in the so called custody transfer process that is when ownership of LNG is transferred from one organisation to other. The project supported both traditional and innovative measurement methods by developing a metrological framework consisting of test & calibration standards together with the written standards and guidelines.

Need for the project

An improved infrastructure for LNG is one of the priorities of the EC integrated energy policy, motivated by the need to ensure a more diversified and secure energy supply and fair and open trade in natural gas. The growing importance of the LNG market has created an urgent need to build a metrological infrastructure to provide industry and society with accurate and reliable LNG measurements.

At the time the project was started there was no clear view on the total measurement uncertainty for the delivered energy of LNG. While the main referenced industry standard claimed a total measurement uncertainty for delivered energy of about 0.5%, a more realistic estimate was 1% or more. This results in financial risks that are in some cases not recognized and at any rate too high. One (ship) carrier load of LNG can be as valuable as 50 million euro and even an optimistic estimate of uncertainty represents a financial risk of 400 k€. A single large production facility may thus be exposed to this on a daily basis.

Delivered energy is measured indirectly by measurements of LNG volume, LNG composition and LNG density. Therefore the project sought to assess the real uncertainties in the determination of these parameters based on sound metrological principles and then to reduce these uncertainties by developing measurement standards, methods and procedures. The objective of the project was to provide a clear estimate of the uncertainty in practice and to make a big step towards reducing it by at least a factor two.

Flow metering in general is a more accurate method for measuring transferred volume or mass of liquids than the on-ship level gauging method currently in use (i.e.measuring the height of the LNG in tanks) but the lack of test and calibration standards for LNG flow meters is hindering their introduction to the market. Therefore the project sought to establish a system of traceable flow measurement in conditions relevant to the LNG industry with a key parameter being a system that provides accurate measurements at -163 °C (the temperature that LNG is stored and transported at).

Another important source of uncertainty is the sampling and vaporization of LNG prior to analysing the composition. In particular, the industry view is that the current ISO standard (ISO 8943) on sampling of LNG falls short of providing practical guidance with regards to the demands and uncertainties involved in sampling of cryogenic fuels.

The density of LNG is calculated on the basis of the measured composition, temperature and pressure. New and more accurate density reference data need to be produced in order to validate the many available density calculation methods that are based on very old reference data.

EMRP European Metrology Research Programme ▶ Programme of EURAMET

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LNG transfer contracts refer to written standards and/or guidelines and therefore a key route to improving the accuracy of custody transfer is the incorporation of improved measurement methods and traceability to national measurement standards in the relevant standards to ensure their implementation.

Scientific and technical objectives

The specific objectives of this project are summarised as following:

1. Developing traceability for LNG flow meters
2. Testing and evaluating LNG quantity metering systems
3. Improving LNG composition measurement systems
4. Reducing uncertainties in LNG density and calorific value calculations
5. Contributing to measurement guidelines, written standards and legal metrology

The first four objectives focused on developing a better understanding of, and a reduction in, measurement uncertainties in the LNG custody transfer while the fifth ensured the new measurement standards, methods and procedures will be incorporated in the relevant standards and industry guidance documents and implemented, in time, by the LNG industry.

Results

The project resulted in a better understanding of uncertainties using current measurement techniques. The estimated total measurement uncertainty on energy of about 1% is confirmed. An exact figure can not be provided as the project demonstrated that this must be determined on a case by case basis and because some potential uncertainty sources are not quantified today. The project has resulted in the development of calibrations standards that can be used to support new measurement techniques and improve calculation methods. The target of reducing the total measurement uncertainty by a factor two remains in range and will be further pursued in the Metrology for LNG II project that started in June 2014.

1. Developing traceability for LNG flow meters

The first objective was focused on developing primary standards for flow measurements of LNG. At the start of this project there existed no LNG flow calibration facility working at -163 °C anywhere in the world. The approach for achieving the first objective started with the development by VSL of a flow calibration standard with top-class accuracy (target level 0.05%) up to 25 m^3/h and operational with LNG at -163 °C.

The standard (size of a sea-container) was built and first tested in 2010 with liquid nitrogen. Over time, a number of revisions have been implemented to improve the measurement uncertainty. Finally the system was installed at Gasunie peakshaver (LNG site) to operate and validate the performance with real LNG.

The claimed measurement uncertainty (CMC) of the combined flow standard and flow meter under test over the flow range lies between 0.12 - 0.15% and can be improved to 0.10% with relatively simple measures. This is a factor of two higher than the original target but is still sufficiently low to calibrate flow meters at an uncertainty level competitive with tank level measurements.

Subsequently a number of commercial coriolis type flow meters were tested with the system. The results varied and showed meter deviations between 0.1% up to 0.5% and in one case even 6% (due to a faulty meter).

A comparison of the primary flow standard with a weigh bridge test in Norway showed that these are both valid approaches in the sense that they can produce consistent results.

A design specification document has been drafted, including an indication of expected uncertainty, for a LNG flow standard that can go up to 200 m^3/h, 10 ton/h and that will be traceable to the primary standard. A novel cryogenic flow metering technology, Laser Doppler Velocimetry (LDV), was explored as an alternative to ultrasonic and Coriolis flow metering. A prototype LDV (Laser Doppler Velocimetry) flow metering standard has been built and tested by CESAME at different air flows and pressures. The study found that it is feasible to realise a cryogenic LDV with a relative accuracy on volume flow of better than 0.2%.

The results above have led to the first step (primary LNG flow standard) in developing traceability for LNG flow meters. The primary flow standard will need to be integrated in the future planned LNG calibration facility to provide calibration services to industry. This metrological framework will make it possible for LNG flow metering to become an accepted method with a clear potential to reduce measurement uncertainties and simpler operations. The availability of certified LNG flow meters will be also very important for the development of LNG as transport fuel. This new market is expected to become a huge economic factor in Europe and will have positive effects on the environment.

2. *Testing and evaluating LNG quantity metering systems*

The second objective aimed to test and evaluate flow metering measurement (dynamic) methods against the static measurement methods (ship tank gauging, weighbridge methods) typically used in the LNG industry in order to validate and demonstrate the potential of flow based methods.

It included the establishment of the real uncertainty for (state of the art) ship-based tank-gauging methods by performing a comprehensive metrological study (desktop based and using real data and experience from industry). No final conclusions about the level of uncertainty regarding LNG (un)loadings have been drawn although there are strong indications that the uncertainty figures commonly used by the industry for transferred volume are somewhat underestimated. The actual uncertainty depends on the circumstances and should be determined on a case by case basis, but typically will be 0.5% or higher. More in-depth research into some sources of uncertainty is recommended.

The measurement performance of tank gauging and flow metering systems was compared by designing and performing in-field testing and reviewing test results from other pilot studies. A field test was conducted in Norway, in which flow metering and weigh bridge methods were compared. The observed difference between the weighbridge and the flow meter methods was 0.2% with a standard deviation of 0.06%.

Results of comparisons between ship based tank measurements and ultrasonic flow meters at an Enagas LNG terminal show that the results are consistent with the claimed uncertainties.

A cryogenic test rig has been built by NEL for small flow meters and a complete test programme was executed to look at the effects of cryogenic media on instruments. The information and experience gathered from this work will be fed into the design of the future mid and large scale flow facilities.

Objective data and reports with uncertainty assessments and comparisons of the static and dynamic quantity measurement methods will offer the industry the opportunity to make better informed decisions about implementing either method. The preliminary conclusion of the work is that flow metering has the promise of delivering lower uncertainties than tank level gauging and that so far the flow metering method shows results that are consistent with the current practice of tank level gauging.

3. *Improving LNG composition measurement systems*

In order to improve LNG composition measurements the third objective focused on the performance of different sampling systems was assessed by reviewing design principles and by analysing real data provided by industry. A report has been finalised containing a review of current state of the art and detailed description of all elements used in LNG sampling systems. The report also covers uncertainties associated with sampling and data analysis. The report can be used by industry to review and approve their measurement installations and will also be used as input to develop a calibration standard and concept in the follow up project.

An alternative optical method (Raman spectroscopy) for determining the LNG composition directly in the LNG pipeline has been compared with sampling based methods. Elengy completed a report about a Raman spectroscopy system tested at the LNG Everett (Boston) terminal. This report has been reviewed by VSL. It concluded that there is a lack of experimental data to demonstrate the performance of Raman spectroscopy compared to traditional methods in absolute terms. It recommended that the Raman analyser method be validated in the laboratory.

These reports provide an overview of the current state-of-the-art in LNG composition methods and offer industry the ability to make well informed decisions on the preferred method. It also provides a starting point for the improvement of methods and the development of a reference standard to validate LNG composition methods.

4. Reducing uncertainties in LNG density and calorific value calculations

The fourth objective was to develop laboratory based systems to measure the density of LNG with improved accuracy.

An advanced primary LNG densitometer system has been designed and realised at the Ruhr university Bochum to produce new reference data with very low uncertainty. The reference data will be used to validate and recommend or improve equations of state that are used to calculate the density. This new densimeter covers the range from 10 kg/m3 to 1000 kg/m3, Measurements can be carried out in a temperature range from 90 K to 290 K at pressures up to 8 MPa. The Archimedes (buoyancy) principle is applied by utilizing a single-sinker system incorporating a magnetic suspension coupling. The goal was to obtain density directly (without the need for calibration fluids) with an expanded uncertainty (k = 2) of 0.02 % for density. Due to unexpected decomposition effects only part of the new reference data is considered valid. The measured data (expanded uncertainty between 0.06 and 0.08%) agreed better with the revised Klosek McKinley (within maximum 0.08 %) than with the GERG-2008 Equations of State. Due to the lack of a sufficient amount of valid new reference data this is considered a preliminary check rather than a validation.

In parallel INRIM manufactured a pycnometer based system for LNG density measurements. Experiments were carried out to produce new density reference data. The results showed that the pycnometer set-up suffers from significant decomposition effects and no valid reference data was produced.

A comparison of thirteen density calculation methods has been made based on literature data. It was found that calculations of LNG calorific values at various reference conditions results in large differences with a significant financial impact.

Another set of calculations has shown that the calorific value of LNG in the liquid state (e.g. in a LNG tanker) is significantly higher (4%) than at standard conditions (e.g. at the terminal or pipeline). This equates to a reduction of 340 k€ (for a cargo of 150.000 m3 and LNG price of 2 ct/kWh) when LNG is vaporised to standard conditions. This is considered significant as it represents about 1.6% of cargo value.

This part of the project has led to a new density measurement system that can be used for research purposes to produce accurate reference density data. These data will lead to improved Equations of State to calculate the LNG density with much lower uncertainty, thereby improving the total measurement uncertainty on energy. The application for the first time of magnetic suspension coupling technology to densitometry in the cryogenic region led to unforeseen technical challenges. For this reason the uncertainty of the produced data is still a factor 3-4 higher than what was aimed for. The technological problems were solved after the project and the system will thus be available for further research and with improved measurement uncertainty.

The study on calculation methods and reference conditions provides greater transparency in the trade of LNG. Parties will be able to make better informed choices on the calculation method that they need to agree on.

5. Contributing to measurement guidelines, written standards and legal metrology

The fifth objective was to contribute to improvements and extensions of measurement guidelines and international standards. In existing documents the uncertainties are sometimes not well characterised, some technologies (LNG flow metering) are not yet described and in some cases insufficient guidance is provided to industry. All this will ensure that the newly created knowledge in this project concerning LNG measurement systems finds its way to the user community. Some meetings with important ISO committees, industrial stakeholder organisations and legal metrology organisations were held. All relevant groups and contact persons were identified and have been provided full access to the project reports and presentations. Input to the legal metrology framework has also been provided.

Two international workshops were held with more than 70 industrial attendants at each. Several other impact activities including the website, publications in key user journals and contributions to workshops and conferences have led to a group of nearly 300 followers of the project. A 2-day final conference was organised in October in Delft, the Netherlands. The program consisted of poster and oral presentations from the project partners as well as from industry. The conference was attended by 150 professionals from 25 different countries.

Impact

The primary flow standard is available at NMI level, this will serve as the starting point for providing traceability to industry. The primary density standard is available for producing reference density data for industry. This data can be used for validating or improving the equations of state that are used by industry to determine density and amount of energy transferred. This data can also be used to improve other equations of state used by industry to simulate and optimise LNG liquefaction processes. These capabilities will be developed further in the next project (Metrology for LNG II project) which will improve the accuracy of LNG measurements and endeavour to increase their uptake by the relevant communities.

This project has succeeded in the incorporation of a dynamic flow measurements section in the ISO10976 standard with a focus on process control measurements rather than custody transfer measurements. The project has however also resulted in a resolution adopted by ISO TC28 to form a new and joint working group for the creation of a dedicated ISO standard for LNG flow metering systems. Presentations and reports have been exchanged with ISO TC67/WG10 and ISO TC193, WELMEC WG10 and with the GIIGNL Technical Standing Group. New editions of the GIIGNL LNG custody transfer handbook, a key guidance document used by industry, will make reference and adopt the know-how created in the project.

In the longer term as the metrology capabilities are further developed and taken up by the LNG industry, the determination of transferred energy in LNG will improve, leading to reduced financial exposure and a more efficient and effective industry.

List of all publically available publications

- Richter, M.; Kleinrahm, R.; Span, R.; Schley, P., *A new apparatus for accurate measurements of the densities of Liquefied Natural Gas LNG*, Proceedings of the International Gas Union Research Conference, IGRC, Seoul, Republic of Korea, 2011
- Kerkhof, M. van der Beek, P. Lucas, M. Mirzaei et al., *LNG Calibration standards*, LNG17 conference paper, Houston, USA, April 2013
- Richter, M.; Kleinrahm, R.; Span, R., *Apparatus for Accurate (p,v,T,x) Measurements of Liquefied Natural Gas (LNG) based on a Single-Sinker Densimeter*, Journal of Chemical Thermodynamics, September 2013.
- Strzelecki, A.; Ouerdani, A.; Lehot, Y.; Vallet, J.P.; Windenberger, C., *LNG Flowrate measurement using Laser Doppler Velocimetry*, Proceedings of the 16th International Flow Measurement Conference, FLOMEKO 2013, Paris, France
- M. van der Beek, P. Lucas, O. Kerkhof, M. Mirzaei, G. Blom, *Validation of a primary LNG flow calibration standard*, Metrologia (accepted for publication, 2014)

Project start date and duration:	1 May 2011 duration 42 months
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