Publishable Summary for 16ENG09 LNGIII
Metrological support for LNG and LBG as transport fuel

Overview

The overall aim of this project is to enable the large scale roll-out of liquefied natural gas (LNG) and liquefied biogas (LBG) as a transport fuel. However, an essential part of this is the development of measurement traceability for large scale LNG custody transfer applications. The custody transfer measurements of flow and composition need to be underpinned with a clear and traceable metrological infrastructure, and properties which are important for fuel usage, i.e. the density and the methane number (MN) need to be assessed.

To address this, this project will combine expertise from industry, instrument manufacturers and research institutes in order to establish the necessary test facilities and validation methods. The outcomes of the project will also be implemented in relevant written standards to enable and promote the use of LNG and LBG as a transport fuel.

Need

As addressed in the "Clean Power for Transport package", the utilisation of LNG and LBG as transport fuels constitutes one of the pillars of the European clean fuel strategy. The current alternatives to diesel are limited therefore LNG and LBG are particularly suited for long-distance road and water transport. LNG implementation would enable the stringent pollutant emission limits of future EURO VI standards to be met more cost-efficiently as compared to conventional fuels. Furthermore, the results of recent emission tests for many diesel engines are being questioned. In addition to this, engines running on LNG produce far less noise than diesel-operated engines and therefore trucks running on LNG are becoming the preferred choice for deliveries in urban areas. LNG is also an attractive fuel to meet the new limits for sulphur content in marine fuels and for nitrogen oxides (NOx)-emissions from marine engines.

However, the large scale roll-out of LNG and LBG as a transport fuel requires reliable determination of the amount, composition and physical properties of the cryogenic fuel; and although substantial progress has been made over the past few years, several issues still need to be resolved, such as:

Refuelling/bunkering:

A calibration facility for LNG flow measurements is currently being constructed at the Rotterdam Port area in the Netherlands. This facility will be operational in 2017 and provides an excellent platform for testing and validation of LNG flow metering technologies suitable for refuelling and bunkering applications. Validation under "optimal" conditions will be performed within the currently ongoing EMRP JRP ENG60 LNG II. However, the effect of parameters encountered in practical applications, such as, flow disturbances, the presence of a second phase, the meter insulation and the meter inclination on the calibration performance and the measurement uncertainty still need to be assessed.

Composition, density and particles:

The composition of LNG, and consequently the energy content and other physical properties of LNG, varies from source to source. Furthermore, the LNG composition in LNG carriers and storage tanks typically changes over time through a process known as "ageing"; which means that the LNG composition gets richer in heavier components. Therefore, reference methods and standards that regulate physical and chemical measurements to accurately define LNG/LBG mixtures are urgently needed. Furthermore, it is essential to have in place cost-effective (in-line) sensors for density and composition for use at the point of need to monitor the quality of the LNG.

LNG produced from LBG can contain small particles which affect engine performance over time. Moreover, silicon dioxide particles can be formed through the combustion of siloxanes present in biogas. Therefore, the presence and the source and nature of the particles in LBG also needs to be known in order to be able to decide the service intervals and the type of particle filters to be used at fuelling stations.

Engine performance:

In order to operate an engine in the most efficient way, it should be run as close as possible to its knocking point i.e. the point during the engine combustion where part of the fuel spontaneously ignites ahead of the flame front and burns in an uncontrolled manner. The MN, together with the engine type and the operational conditions, determines the knocking point. Consequently, in order to run an engine at its most efficient setting, the MN needs to be determined using highly accurate methods which are yet to be developed.

Depending on the combustion process, part of the methane (CH_4) may not burn in the engine and thus can be released to the atmosphere (also known as methane slip (MS)). Thus, for economic and environmental reasons (i.e. CH_4 is an important greenhouse gas), engine performance needs to be carefully monitored and managed (e.g. with validated sensors and algorithms) in order to increase the combustion efficiency and minimise MS.

Objectives

The overall aim of this project is to enable the large scale roll-out of LNG and LBG as a transport fuel. Therefore the specific objectives are:

1. To reduce the onsite flow measurement uncertainty for small- and mid-scale LNG applications to the level comparable to conventional fuels (0.5 %). To include a systematic assessment of the impact of flow disturbances, multi-phase flow and the impact of meter insulation and inclination.
2. To undertake a technical feasibility study to develop an LNG flow calibration facility for flow rates typically encountered in small- and mid-scale applications (400 m^3/h ~ 1000 m^3/h). The Calibration and Measurement Capability (CMC) of this facility should be low enough to at least meet the current International Legal Metrology Organisation (OIML) recommendations (1.5 %), but ultimately the uncertainty should be comparable to the one for conventional fluids i.e. (0.5 %). Furthermore, to assess whether the (on-site) measurement uncertainty can be reduced using a cryogenic piston prover.
3. To develop and validate a reference liquefaction technique (small scale liquefier) for the validation of LBG and LNG sampling and composition measurement systems.
4. To improve methods and (in-line) sensors for cost-effective measurement of the gas composition, methane number (MN) and methane slip (MS). In particular to: i) develop an SI-traceable density calibration method; ii) validate cost effective (in-line) density sensors; iii) validate sensors for composition and MN to enable real-time engine management, engine performance and the measurement of MS; iv) validate the existing MN algorithm from JRP ENG60 and reaction kinetics through full scale truck experiments; v) assess the source, content and potential impact of particles, particularly in LBG fuels.
5. To facilitate the take-up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (ISO, CEN) and end-users (transport and energy sectors). In particular to: i) input to an ISO standard for cryogenic flow metering, including recommendations on water calibration transferability; ii) input to an ISO standard for the calculation of the MN and iii) implement relevant results from the three LNG projects (EMRP JRPs ENG03 and ENG60 and this project) in the International Group of Liquefied Natural Gas Importers (GIIGNL) handbook for LNG custody transfer.

Progress beyond the state of the art & expected results

For billing purposes and to fulfil custody transfer regulations, the amount of LNG in terms of volume flow rate (m^3/h) has to be determined. In combination with the density, the amount of LNG in terms of mass flow rate should also be calculated, and through measuring the composition, the energy content per mass unit can be calculated. Therefore, improving these measurements and reducing their measurement uncertainty is a major goal of this project.

In EMRP JRP ENG60 LNG II, a mid-scale calibration facility for LNG for characterising and calibrating meters is being developed and constructed for LNG volume flow rates up to 200 m^3/h. This project will develop this midscale calibration facility to include a design and feasibility study for LNG volume flow rates up to 1000 m^3/h, to cover the full range of refuelling and bunkering applications. Extending the operational range with respect to the volume flow rate from 200 m^3/h to 1000 m^3/h for LNG is unprecedented and the target relative uncertainty of the calibration facility is 0.5 %, which meets market demands.

The targeted relative uncertainty of the flow meter calibrations is approximately 0.5 %, which is comparable to what is currently known for conventional fuels. However, this uncertainty is based on measurements carried out under “ideal” conditions. Therefore, a systematic assessment of the influence of various parameters, such as: flow disturbances, the presence of a second phase, meter insulation and meter inclination need to be performed to fully understand on-site measurement conditions, which is beyond the current state-of-the-art for measurements under cryogenic conditions. Measurements will also be conducted with “classical” flow metering techniques, such as Coriolis meters and Ultrasonic Flow Meters (USM), as well as with alternative techniques like Laser Doppler Velocimetry (LDV) and Electrical Capacitance Tomography (ECT).

The composition of LNG, and consequently the energy content and other physical properties, varies depending on the origin of the LNG. Furthermore, the LNG composition in carriers and storage tanks changes over time through a process known as “ageing”; whereby the LNG gets richer in heavier components. The composition of LNG is usually analysed by Gas Chromatography (GC) and Raman Spectroscopy. However, both analytical techniques need metrologically traceable LNG reference standards for calibration, which do not currently exist. Therefore, the project will design and construct a liquefier for the production of LNG reference standards with accurately determined compositions, based on synthetic natural gas mixtures. This liquefier will also be used to validate the LNG composition measurement standard currently being developed in EMRP JRP ENG60 LNG II.

The density of LNG is usually calculated based on its composition and an equation of state. However, in the absence of an accurate composition measurement, the LNG density is also commonly, but roughly determined, by the Coriolis meter or USM used for flow rate measurements. Thus this project will develop novel sensors (using LDV and ECT) for the measurement of LNG density and the combination of density and speed of sound (SoS) measurements in order to improve the accuracy and reduce the measurement uncertainty of LNG density measurements. To be able to provide data for performance testing, LNG reference densities will be measured using the LNG densitometer developed in the two preceding EMRP JRPs ENG03 and ENG60, and detailed metrological protocols for the calibration, the use and the uncertainty estimation of industrial measurements will be developed. The project also aims to improve the uncertainty of LNG density measurements to that targeted for flow measurements i.e. 0.5 %.

When LNG is used as a transport fuel in combustion engines, the MN must be accurately known to enable optimal engine performance. However, currently no harmonised method for the determination of the LNG MN exists. A novel algorithm to calculate the MN from the LNG composition was developed in EMRP JRP ENG60 LNG II and the results will be disseminated to ISO/TC 193 as a working draft for eventual publication as a standardised method for MN calculation. The composition of LNG also changes during storage or transport, therefore “smart low-cost” sensors need to be developed to monitor the MN at the point of use, so that engines equipped with intelligent motor management systems can then be tuned to the actual MN to maximise their performance. If undertaken, this will have both economic and environmental advantages by increasing engine efficiency, lowering fuel consumption and reducing the amount of unburned CH_4 (an important greenhouse gas) into the atmosphere, (a phenomenon known as MS), as well as decreasing particulate formation from over-fuelling due to incorrect MN determination.

Impact

Impact on industrial and other user communities

The knowledge and measurement results gained by this project will be shared through the project’s stakeholder board that has already been established in EMRP JRPs ENG03 and ENG60. It currently has 25 members from industry such as instrument manufacturers. Such results will include the mid-scale flow calibration facility (flow rates between 100 m^3/h – 400 m^3/h) developed by this project and the preceding LNG projects, which will enable the generation of knowledge on the behaviour of flow measurement instruments under cryogenic conditions, i.e. as they occur during LNG metering. This project will also undertake a feasibility study for a calibration facility for higher flow rates (400 m^3/h – 1000 m^3/hr) which is important for flow meter end-users who will be able to determine whether ship bunkering could be calibrated with the required metrological traceability and uncertainty.

The project will also develop a validated technique for flow measurement based on LDV which will enable equipment manufacturers to develop flow meters on this measurement principle. As well as a good practice guide for filter weighing and the sampling of particulates at LNG/LBG refuelling stations. This good practice guide will enable operators to apply good practice in particulate content measurements, thus improving their measurement performance and consequently, supporting a reduction in the maintenance costs of refuelling stations with respect to the filter replacements.

Further to this, the project will develop and test better MN sensors and detectors, which will have a significant impact on engine manufacturers who will implement this technology as well as the commercial development of LNG as a bunkering fuel. MN specification is necessary in new supply contracts for LNG as a bunkering fuel, however no reliable or common method currently exists to calculate MN which creates a legal liability for suppliers. This is particularly important in cases where the MN is around the limit value of the specification because, depending on the calculation method, the MN either complies with the specification or it does not.

Impact on the metrology and scientific communities

The primary flow measurement standard for LNG that was constructed and validated in EMRP JRP ENG03 will form the basis of the new mid-scale calibration facility to be developed in this project. This facility will be made accessible to the scientific community, e.g., equipment manufacturers for calibration, studying dynamic effects in flow measurement, and offers unique opportunities to advance science in metering cryogenic hydrocarbon fluids, including and beyond LNG and LBG.

The primary standards for the composition of LNG developed by this project will be made available to stakeholders by providing services to the scientific community, including the assessment of commercial LNG samplers, Raman analysers, and densimeters. The provision of (by liquefying) synthetic gas mixtures of known “LNG type” compositions will provide unique metrological traceability and a direct connection with the existing measurement infrastructure for natural gas.

The enhanced equation of state for LNG density and the MN algorithm developed in EMRP JRP ENG60 will be transferred into practical tools for the calibration and checking of commercially available sensors and/or on-line analytical techniques.

The results from this project will be presented at approximately 15 external conferences and at 3 new project workshops (including 2 training sessions) and there will be at least 10 peer reviewed papers. Results will also be shared with the metrological community through the project website (www.lngmetrology.info).

Impact on relevant standards

The project studies a number of properties of LNG, such as flow, composition, density, particles and methane number. For all aspects, the results will be shared with relevant ISO, CEN and OIML technical committees as well as with important user groups such as GIIGNL to advance international standards and guidelines. Examples include ISO/TC 28 SC5 Measurement of refrigerated hydrocarbon and non-petroleum based liquefied gaseous fuels in order to contribute to ISO 10976 sections 5.7 and 6.4 on dynamic flow measurements. ISO/TC 28 Petroleum and related products, fuels and lubricants from natural or synthetic sources and ISO/TC 193 Natural gas in order to contribute to a revision of ISO/TR22302. CEN/TC 234 WG11 Gas Quality in order to provide input to the 2019 revision of EN 16726 (determination of the Methane Number). Partners NEL and RUB will also disseminate the outcomes of EMRP JRPs ENG03 LNG and ENG60 LNG II and this project to GIIGNL in order to contribute to an update of the latest version of the GIIGNL handbook.

Wider impact of the project

This project will support the large-scale use of LNG and LBG as a transport fuel. Thereby making a significant contribution to the European “Clean Transport Fuel Strategy” [1] which aims to reduce the emissions of greenhouse gases, nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particles. LNG fuelled truck engines produce around 25 % less carbon dioxide (CO_2) compared to diesel engines and 85 % less NO_x. Furthermore, they produce less noise and thus are the preferred option for deliveries in urban areas and city centres, especially in the early morning or late at night (when avoiding peak traffic).

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2017, 36 months</td></tr>
<tr><td colspan="3">Coordinator:
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<tr><td>Internal Funded Partners:
1 Cesame, France
2 CMI, Czech Republic
3 INRIM, Italy
4 JV, Norway
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6 NPL, United Kingdom
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