Legal Metrology Control of a Liquefied Petroleum Gas Transfer Standard and Field Practice

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Abstract

The paper presents construction, metrological testing and field practice of a Liquefied Petroleum Gas (LPG) transfer standard (TS). This meter package was tested first with water as working medium and re-tested with propane and butane at the National Measurement Institute of Australia (NMIA). The rational is that NMIs maintaining LPG legal measurement infrastructure could simplify the traceability method by utilizing water as test medium while keeping the same accuracy. In addition, the meter package is intended to replace the conventional gravimetric approach, which requires tedious in-situ testing process for a LPG fuel dispenser. The project is supported by Asia Pacific Metrology Program (APMP) Technical Committee Initiative fund.

Introduction

According to the statistics of the World Liquefied Petroleum Gas Association [1], a minimum of 200 million tons of liquefied petroleum gas (LPG) per year have been used worldwide. The usage in LPG automobile sector was 22 million tons in 2010. Although the number of automobiles using LPG in Taiwan is only 22,000 units, with 56 LPG stations exist [2], it is the duty of legal metrology agency to safeguard the custody transfer process and guarantee fair trade. Because the accuracy of LPG fuel dispensers is of high consumer interests, periodic examinations are conducted by authorities from Bureau of Standards, Metrology and Inspection (BSMI). International LPG fuel dispenser verification codes include the gravimetric method and the master meter method. Currently, the method used in Taiwan is the gravimetric [3], which requires heavy equipment, such as density measuring device, weight scales, and steel bottles. These lead to complex operation and low efficiency. Therefore, this study evaluates the feasibility of using the convenient master meter method to verify LPG fuel dispensers.

Standard flow meters generally employed in the master meter method include a positive displacement flow meter and Coriolis flow meter. Positive displacement flow meters measure volume directly, with a measurement performance closely correlated to medium characteristics. To ensure the precision of the PD type transfer meter, the standard system correction must use LPG as the test medium. Currently, no LPG standard calibration facility can be used to conduct traceability measurements in Taiwan.

A Coriolis flow meter is suitable for measuring various fluids and is able to directly measure fluid mass and density, which can be converted to a test fluid volume easily. Thus, if a LPG primary standard system is not available, the Coriolis flow meter is an optimal alternative as a standard flow meter, which gets around the real flow traceability issue.

Supported by the Asia Pacific Metrology Program (APMP) Technical Committee Initiative project, the Center for Measurement Standards conducted a series of studies on the Coriolis flow meter, including: pressure effect tests, density accuracy verification, comparison tests at the National Measurement Institute of Australia (NMIA) with propane and butane. While at the National Measurement Laboratory, performance tests with water were conducted, to justify the traceability scheme.

Additionally, both the Coriolis flow package and the gravimetric apparatus were used concurrently at an LPG fuel dispenser site to conduct verification tests. The results showed consistency of both methods satisfying legal metrology regulation in Taiwan.

Instrument Specifications and Uncertainty

According to the International Organization for Legal Metrology R117 [4], which specifies requirements for LPG testing equipment, the expanded uncertainty of the standard equipment used to test LPG fuel dispensers cannot exceed one-third of the maximum permissible error for testing. In Taiwan, legal metrology testing specification, namely CNMV 201 for the LPG dispenser, provides a permissible error of ±1.0 %. Thus, the expanded uncertainty for standard equipment must be lower than or equal to 0.3 %. The testing technique specification shows that the volume measurement of the gravimetric method is determined by a formula used to calculate the weight and density measurement. The density is measured using the standard established based on the measurement specifications CNS 2748 [5] and CNS 12953 [6]. After the measured density was converted to a density value at 15 °C, the relative testing error was calculated using (1):

$$E_R = I \times [1 + \beta (P_l - P_e)] \times \frac{d_e}{W} - 1 \qquad (1)$$

where E_R represents the relative error of the tested LPG fuel dispenser, I is the indicated volume of the tested LPG fuel dispenser, W is the mass of the tested LPG, d_e is the density of LPG in equilibrium passing through the LPG fuel dispenser at 15 °C, P_l represents the pressure of LPG passing through the LPG fuel dispenser, P_e represents the pressure of LPG in equilibrium passing through the LPG fuel dispenser, and β is the coefficient of compressibility for LPG.

For the gravimetric method, it uses a scale that is accurate to within 0.01 kg. The hydrometer used for density measurement provides accuracy to 1 kg/m^3 and the thermometer provides accuracy to 1 °C. The collected LPG mass was approximately 11 kg, with density at 540 kg/m^3, and fluid temperature around 25 °C. The measurement uncertainty values of weight, density, and temperature influence on density were 0.1 %, 0.2 %, and 0.2 %, respectively. Based on the given information, the combined uncertainty of the gravimetric method approximated to 0.3 %.

For the master meter method, a Micro Motion Elite type Coriolis flow meter was used to measure the volume and density of LPG. A set of pressure gauges were installed at the inlet (upstream) of the flow meter, and a pressure gauge and a thermometer were installed at the outlet (downstream), as shown in Fig. 1. After testing the LPG fuel dispenser, the measured mass, density, temperature, and pressure values could be converted to those obtained at 15 °C to determine the density and thus, the volume at this temperature. The calculation procedure is shown in Fig. 2, which depicts the calculation of standard volume $V_{REF,15}$ as follows:

$$V_{REF,15} = \frac{M_{mm} \times MF}{\rho(15, P_{FD})} \qquad (2)$$

where

$$\rho(15, P_{FD}) = \rho(T_{mm}, P_{FD}) \times (1 + C_{tl} \times (T_{mm} - T_{15})) \times (1 - C_{pl} \times (P_{mm} - P_{FD})) \qquad (3)$$

$V_{REF,15}$ is the standard volume of LPG at 15 °C; M_{mm} is the measured mass; MF (meter factor) is the flow meter coefficient; $\rho(15,P_{FD})$ represents the converted density value of LPG under the pressure of the LPG fuel dispenser at 15 °C; P_{FD} is the internal pressure of the LPG fuel dispenser; T_{mm} is the fluid temperature of the Coriolis flow meter; P_{mm} is the fluid pressure of the Coriolis flow meter; and C_{tl} and C_{pl} represent the LPG coefficients of expansion and compressibility, respectively. Those two values are approximately 0.003/°C and 0.00054/bar, at room temperature and under operating pressure. Therefore, if the accuracy of the thermometer and pressure gauge is better than 0.1 °C and 0.1 bar, the influence on LPG volume measurement can be reduced to lower than 0.03 %.

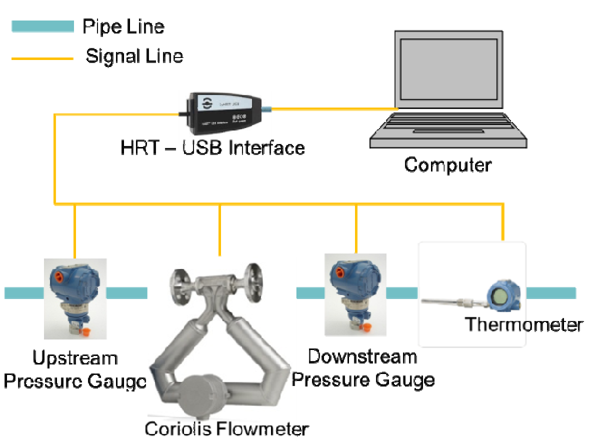

Fig. 1 Configuration of a Mass meter package

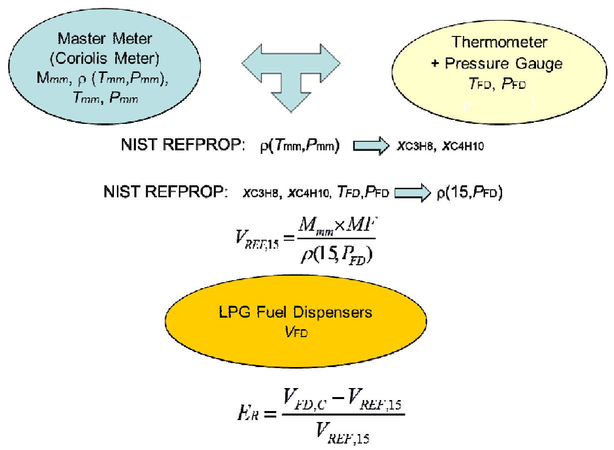

Fig. 2 Calculation procedure for relative errors of the standard meter in LPG fuel dispensers

The calculation formula of the standard volume $V_{REF,15}$ shows that expanded uncertainty comprises of flow meter characteristics and various types of measurement uncertainty, including meter traceability, density, and corrections for pressure and temperature. Based on these constraints, the Micro Motion Elite sensor and Model 2400S transmitter were used for mass and density measurements. The maximum measurable mass flow rate of the flow meter is 6800 kg/h. The accuracy of mass and volume flow rates is ±0.05 %. The density measurement accuracy reached to ±0.2 kg/m^3, and a pressure gauge with a ±0.02 bar accuracy and a thermometer with a ±0.1 °C accuracy were integrated into the flow meter package. With the above meter and secondary instruments, and with 0.03 % measurement uncertainty from the water flow standard calibration facility, the package provides an initial estimation of a combined uncertainty of smaller than 0.2 %.

Standard Meter Traceability and Verification

To confirm the influence of pressure, density, and different fluid medium on the standard meter, some tests were conducted and described below.

Pressure Effect Testing

To understand the pressure effect on the Coriolis flow meter, the water flow standard calibration facility was operated under pressure at 0.2, 9, and 12 bars, to test at five different flow rates under each pressure setting. To maintain 12 or 9 bars test pressure, a high-pressure pump was installed upstream of the Coriolis meter. The system configuration is shown in Fig. 3.

For each pressure test, five flow rate points at 10, 20, 30, 40, 50 kg/min were tested. The results of the comparison tests are shown in Fig. 4 using the flow meter coefficient MF as parameter.

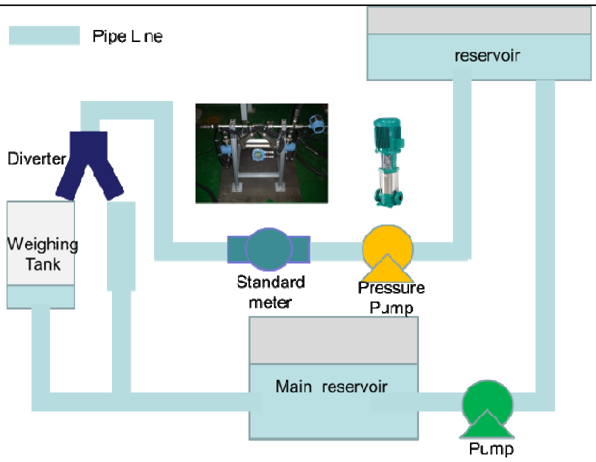

Fig. 3 Configuration of water flow standard system

In Fig. 4, values marked with *MF* represent the mean measurements. The error bar corresponds to uncertainty measured at a 95 % confidence level. The maximum difference between the measured *MF* values under differing pressure was 0.02 %. The results showed that the measurement difference under varying pressure was not significant. The expanded uncertainty of 0.2 % that was required for measuring the difference under varying pressure had only an influence of one-tenth. However, including this difference into the uncertainty evaluation satisfies the testing equipment specification requirements. Therefore, the pressure effect can be disregarded when testing the LPG fuel dispenser with a Coriolis flow meter, which was tested and traceable to a water flow standard system.

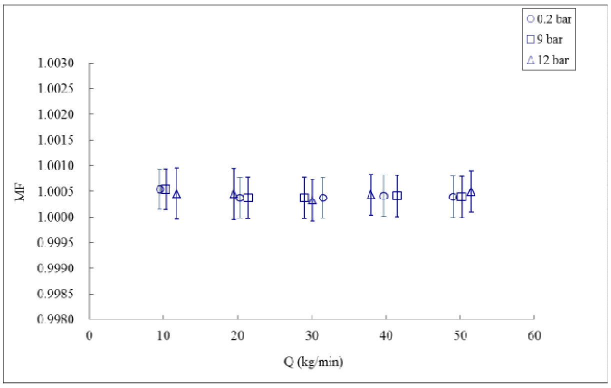

Fig. 4 Comparison of different pressure effects on the water flow standard calibration facility

Density Measurement

The volume measurement from a Coriolis flow meter can be determined by converting the measured mass with its self-measured density. To confirm the accuracy of density measurement, reference liquids with an uncertainty of less than 0.02 kg/m^3 was acquired from PTB, to achieve traceability for Anton Paar DMA 4500 density meter, with a measurement uncertainty of less than 0.04 kg/m^3. Subsequently, Exxsol DSP 80/100 and deionized (DI) water, which have an approximate density to LPG, were used as the testing fluids. The density measurement values of the fluids under normal pressure were measured with both the Coriolis flow meter and the density standard meter and then compared. After measuring the density values of Exxsol DSP 80/100 and DI water at different temperatures using the Anton Paar DMA 4500, the resulting temperature and density data were calculated using regression curve estimation. The density values of Exxsol DSP 80/100 and DI water at varying temperatures were then measured using the Coriolis flow meter. The density values measured by the Coriolis flow meter and the regression curve estimation values were then compared under the same temperature.

The density testing results are shown in Fig. 5. The three marked measurements points are the means of the relative errors (E_R) between the Coriolis flow meter density measurement value (D_m) and the calculated regression curve value (D_s) of the density standard meter at the same temperature, as depicted in equation (4):

$$E_R = \frac{D_m - D_s}{D_s} \quad (4)$$

Fig. 5 shows that regardless of the fluid (DI water or Exxsol DSP 80/100), the relative error between measurements by the Coriolis flow meter and the density standard meter was within ±0.01 % and the measurement uncertainty was less than 0.02 %. The results show that the density measurement capability of the Coriolis flow meter meets the specification of ±0.2 kg/m^3, which is the density measurement accuracy of the standard meter.

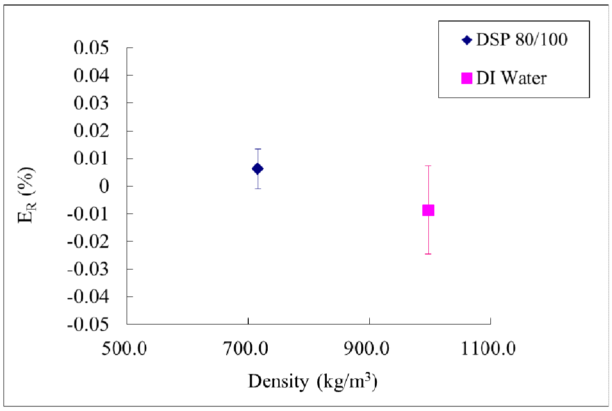

Fig. 5 Density measurement difference between the density standard meter and the Coriolis flow meter

Testing and comparison of various media including water, propane, and butane

In addition to testing the transfer package at CMS water flow facility, it was sent to NMIA to conduct measurement testing with propane and butane to verify the influence of different media. Fig. 6 shows the LPG standard calibration facility of NMIA. The primary component of the system is a compact prover with a standard capacity of 40 L. Propane and butane were pumped separately using a large or small pump depending on the flow rate. Combined with downstream flow regulator with a bypass line, flowrate and pressure can be adjusted and the maximum flowrate of 1700 L/min can be reached. The volumes of propane and butane were measured at 15 °C, which was used as the reference temperature. Before the volume at the reference temperature could be inferred, researchers need to extract samples from the system pipeline and fill into a specific container for temperature and pressure measurements. Subsequently, density at the reference temperature can be calculated. Finally, the meter factor (*MF*) of the standard meter under various test conditions were obtained through calculation. The testing conditions are presented in Table1.

Table 1 Propane and butane test conditions

Fluid medium	Propane					Butane				
Pressure (bar)	12					9				
Flow rate (kg/min)	10	20	30	40	50	10	20	30	40	50

Fig. 6 NMIA LPG standard calibration facility comparison and testing site

Test results of propane and butane are shown in Fig. 7. The error bar indicates the expanded uncertainty at a 95 % confidence level. The *MF* values demonstrated a difference between 0.00 % and 0.06 %. The expanded uncertainty of the LPG standard calibration facility is 0.03 %. Based on the precondition of a 0.025 % uncertainty regarding the Coriolis flow meter repeatability, the results showed that the difference between the use of propane and butane is not significant.

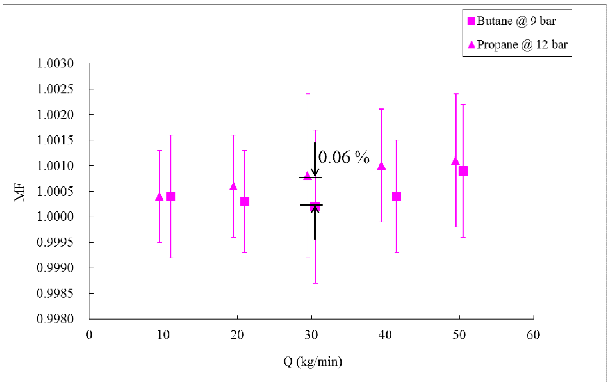

Fig. 7 *MF* measurement differences between propane and butane in the NMIA LPG standard calibration facility

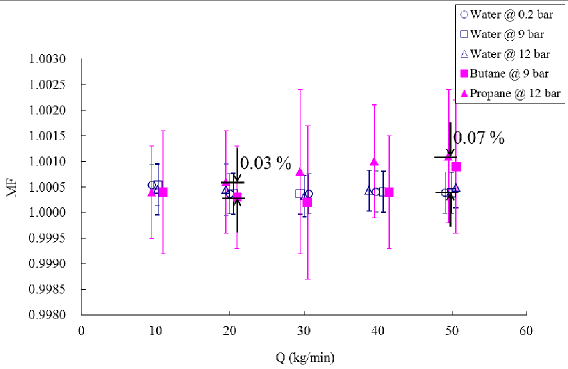

Fig. 8 Comparison of water, propane, and butane *MF* measurement results

By comparing the *MF* measurement results of different media, the differences between using water and LPG as the operating fluid in the Coriolis flow meter were further clarified. Fig. 8 shows that when the testing flow rate was smaller than 20 kg/min, the difference was less than 0.03 %. However, when the testing flow rate exceeded 30 kg/min, the maximum difference was 0.07 %. This indicates that using the Coriolis flow meter with 0.05 % accuracy for on-site calibration of LPG dispensers has small measurement differences, regardless of the testing media (i.e., water or LPG). Therefore, using the Coriolis mass meter to calibrate the LPG fuel dispenser with traceability to the water flow standard facility satisfied the legal metrology regulation that an uncertainty below 0.3 % would be assured.

On-Site Testing and Results

The purpose of on-site testing the LPG fuel dispenser was to confirm the appropriateness of TS before any recommendation made to BSMI. Thus, comparing the test results of the existing test method and proposed method was necessary. The current test method for the LPG fuel dispenser employs gravimetric analysis, which measures the LPG density and filled weight of the LPG steel bottle and converts the measurements to a saturated LPG volume at 15 °C. After cleaning a steel bottle prior to conducting the measurement, LPG was pumped into a transparent and high pressure container that included a specific gravity meter and thermometer for measuring the LPG density and temperature. A temperature and density conversion table was referenced, and the measured density and temperature data were then converted to the LPG density equilibrium to that passing through the LPG fuel dispenser at a reference temperature of 15 °C.

After the LPG density value was obtained, the LPG fuel dispenser was tested. The empty steel bottle was measured before it was filled with LPG fluid. After connecting the LPG machine nozzle to the steel bottle, a full flow rate of approximately 38 L/min and a one-third flow rate of approximately 20 L/min were used to inject 20 L of LPG into a steel bottle. The LPG mass was then weighed and relative errors were calculated using equation (1).

Before testing LPG flow with a standard meter, the inlet of the standard meter should be connected to the LPG fuel dispenser and the outlet to a recycle pipeline. This enabled the measured LPG fluid to flow back into the storage tank. The connection configuration of the transfer package is shown in Fig. 9. Before formal testing, all valves were completely opened to ensure the LPG was operational and confirm that the standard meter was filled with LPG before measurement commenced. During testing, two conditions were used: a full flow rate of approximately 28 L/min and a flow rate of 20 L/min. The two flow rates correspond to collected volumes of 20 L and 50 L, respectively. The testing conditions of the gravimetric method and master meter method are shown in Table 2.

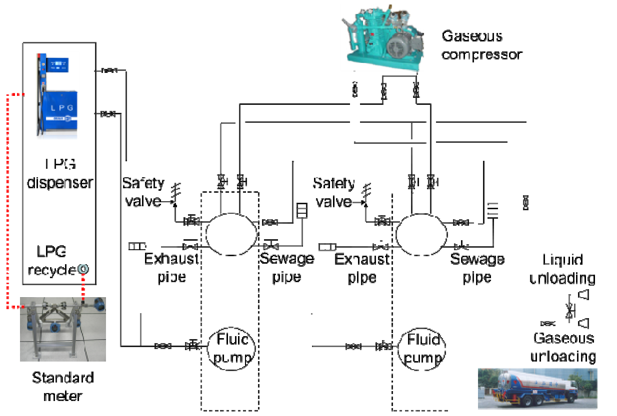

Fig. 9 Configuration of an LPG station and a standard meter

Table 2 Testing conditions for the LPG fuel dispensers

Method	Master meter method				Gravimetric method	
Flow rate (L/min)	28.3	20.3	27.8	19.3	37.8	20.1
Volume of collected (L)	20	50	20	50	20	20

The gravimetric method was used to test the LPG fuel dispenser, and weight, density, temperature, and pressure, were measured and calculated using (1) to obtain the relative errors of LPG fuel dispensers. The master meter method measured mass, density, temperature, and pressure, combined with the flow meter coefficient *MF* traceable to the water flow standard calibration facility. Subsequently, (2) was used to obtain the relative error of the LPG fuel dispenser after the standard volume was determined. Both testing methods converted the LPG to the same volume to calculate the relative error. However, the gravimetric method converted the LPG to the volume inside the steel bottle, whereas the master meter method converted the LPG to a volume, in identical flowing condition, to that of the LPG fuel dispenser. The test result calculations of the LPG fuel dispensers for both the gravimetric and master meter methods are shown in Fig. 10. The marked values of relative errors of the standard meter were the mean of three relative easurements. The error bar is the combined uncertainty of measurement and equipment at 95 % confidence level. By contrast, the marked values of the relative errors of the gravimetric method were determined by a single measurement. The error bar corresponds to the combined uncertainty of the gravimetric equipment.

Fig. 10 shows that using master meter method under differing flow rates and collection volumes, and relative error ranges from 0.36 % to 0.43 %, with a difference below 0.1 %. For gravimetric method, it is ranging from 0.42 % to 0.62 %. The results showed no significant differences between the standard meter measurements under differing flow rates and volumes of collection. In addition, the relative errors of LPG fuel dispenser based on the Coriolis meter method under different flow rates showed better performance.

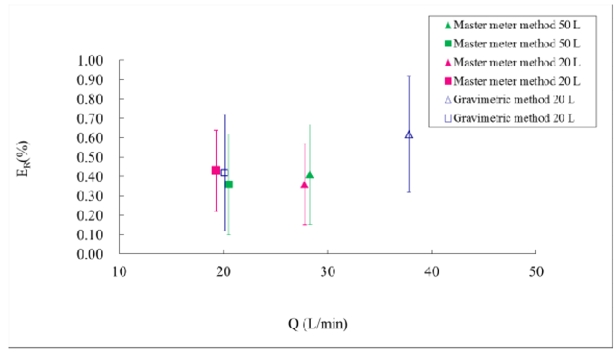

Fig. 10 Comparison of the relative errors of the LPG fuel dispenser tests

Conclusion

The test results were verified using gravimetric and master meter methods, and are summarized as follows:

- Through water flow standard calibration facility tests at 0.2, 9, and 12 bars, the results showed that the influence of pressure at Coriolis flow meter can be disregarded. Thus baseline calibrations were conducted under a normal pressure of 0.2 bars. After the traceability of density measurement was verified, the measurement accuracy of density by the Coriolis flow meter was ±0.2 kg/m^3.
- The NMIA tests verified that the differences in propane and butane measurements for the Coriolis flow meter were less than 0.06 %. Test results using water, propane, and butane as test medium, showed a maximum difference of 0.07 %. Therefore, a standard meter traceable to the water flow standard calibration facility is feasible to be used in the field, which meet the requirement that LPG test devices with an uncertainty of less than 0.3 %.
- One added uncertainty of the gravimetric method is that a small amount of LPG located between the LPG fuel dispenser and steel bottle valve could not be measured. This amount, which was not calculated, would have increased the measurement uncertainty. For the transfer meter package, under different flow rates or collected volumes, the results showed that the master meter has smaller measurement differences.

In summary, when the water flow standard calibration facility is used without increasing the operating fluid pressure, the Coriolis flow meter can be used for on-site verification of LPG fuel dispensers, with the uncertainty satisfying local legal metrology requirements.

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