Two methods for measuring large volume of LNG: Ultrasonic Flow Meters vs. Custody Transfer Handbook

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SUMMARY

Currently, the determination of LNG volume transferred between an LNG carrier and the Terminal is based on ship's instruments by using level gauges and calibration tables. Procedures are included in *LNG Custody Transfer Handbook.* Another alternative to measure volume transferred can be the utilization of the ultrasonic flow meter technology (USM), specially designed for cryogenic temperatures.

Enagás has carried out a pilot project, located in its regasification terminal in Cartagena, to assess the feasibility of the LNG volume determination by USM, compared with the volume determined by ship's devices. The USM employed has a dual chordal path design (*36*") and it is placed in the inlet pipe of a 150 000 cubic meter storage tank. The flow meter has been calibrated with water, traceable to NMi-VSL. The flow measurements have correction for temperature and Reynolds number. This flow meter is not intended as fiscal metering but for control purposes only.

The suitable scenario for the study has been achieved in twelve LNG unloadings. All comparisons have been satisfactory, obtaining a maximum volume difference of 0.5 %. Results from comparison between static and dynamic LNG quantity metering systems (LNG carrier devices vs USM) let us say that, taking into account the uncertainty of each system, measurements are statistically comparable.

For the purposes of *Custody Transfer,* USM should be supported by the following:

- Reduction of the meter uncertainty to the same order than the uncertainty in the tank gauging systems.
- Synchronism between the LNG carrier (un)loading and the USM measurement, which might lead to a review of the operative current procedures.

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1. BACKGROUND

Currently, the determination of LNG volume transferred between an LNG carrier and the Terminal is based on ship's instruments by using level gauges and calibration tables. Two sets of measurements are required, an initial one before opening (un)loading and a final one closing custody transfer. The difference between the larger and the smaller volume represents the volume of liquid transferred. Procedures are included in *LNG Custody Transfer Handbook (CTH) [1].*

One alternative to measure volume transferred, not contemplated in *CTH*, is the utilization of dynamic flow rate measurement, for example using ultrasonic flow meters (USM) specially designed for cryogenic temperatures, located in the LNG transfer pipe (in jetty).

The alternative method could supply important information for the LNG plants, in order to check (compare) the LNG volume quantities stated by the ship reports. However, the new method should be tested and proved as equivalent method to the level measurement.

Between 2011 and 2013, within the frame of the Program *"Metrology for LNG"*, Enagás has been involved in a project to evaluate the comparison between the two methods. The facilities of the LNG terminal of Enagás in Cartagena (Spain) have participated allowing the measurements with an USM, installed in the loading pipe of a terminal tank, and supplying the records of level in LNG carriers and terminal tanks.

2. OBJECTIVE OF THE STUDY

The objective of the study was the comparison of two measurement techniques, in order to evaluate the compatibility of dynamic vs. static techniques for the LNG volume calculations, so as to both methods can be recognised in *CTH* and used as equivalents in (un)loadings. Moreover, USM measurements have been also compared with the terminal tank.

3. INSTRUMENTATION DESCRIPTION

The three volume measurement systems studied are detailed below.

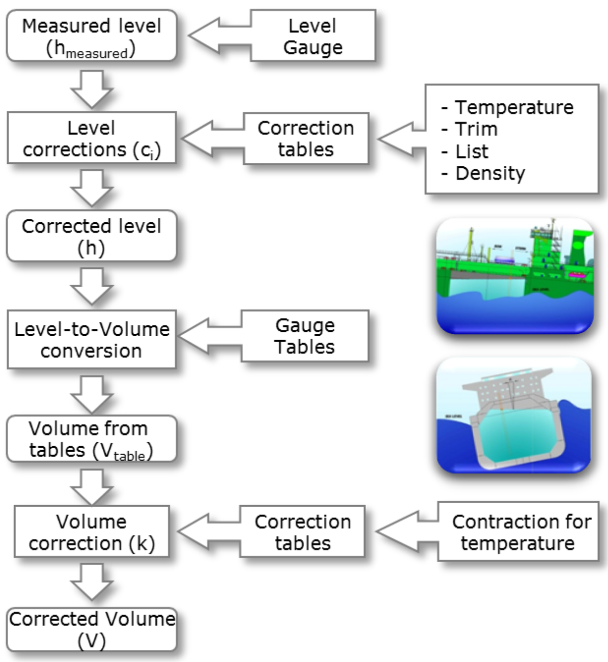
3.1. LNG CARRIER

The standard method chosen for measuring the volume of LNG transferred is based on the LNG carrier's instruments, mainly the use of level gauges and calibration tables, as described in *CTH*.

Determination of the volume transferred requires two sets of measurements, an initial one before starting loading or unloading and a final one at the end of the procedure. These are called the opening and closing custody transfer surveys (CTS) respectively. The difference between the two resulting LNG volumes represents the volume of liquid transferred.

The total LNG volume of the LNG carrier is obtained from the liquid level of each tank, using a level gauge. This measured level should be corrected, depending on the type of gauge. Once the corrected level is determined, the volume is obtained from the gauge tables, which relate the height of the liquid to the volume contained in each tank. In some type of tanks and in case the liquid temperature differs from the reference temperature of the gauge tables, it is necessary to correct the volume due to the expansion/contraction of the tank wall (see procedure scheme in Figure 1).

Figure 1: Measurement of LNG volume in a ship's tank

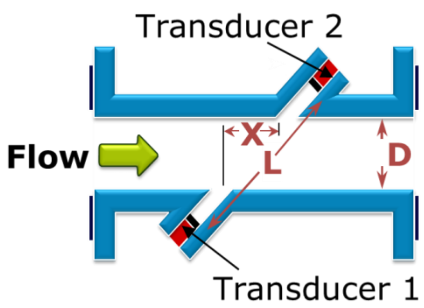


The uncertainty of the volume measurement in the ship's tanks depends on the instrumentation of each LNG carrier. In general, the (un)loading volume uncertainty can vary from 0.20 % to 0.55 % (k=2).

3.2. ULTRASONIC FLOW METER

The USM are based in the measurement of the propagation time of acoustic waves in a system in movement (see Figure 2). For that purpose, the transit time of the pulse propagating into the direction of the flow is measured, from transducer 1 to transducer 2 (T_{12}). Next, the transit time of the pulse propagating against the direction of the flow is measured, from transducer 2 to 1 (T_{21}).

Figure 2: USM system



Once the two transit times, T_{12} and T_{21}, are obtained and the distances X and L are accurately known, the velocity of the fluid V along the path 1-2 can be determined by using the following equation:

$$V = \frac{L^2}{2X}\left(\frac{T_{21}-T_{12}}{T_{21}\cdot T_{12}}\right) \qquad \textit{(Equation 1)}$$

Finally, taking into account fluidynamic corrections, the flow Q is obtained from the average velocity (of one or several paths) and the transversal area of the pipe:

$$Q = \overline{V} \cdot A \qquad \textit{(Equation 2)}$$

The USM used in the project (see Figure 3) has been calibrated with water, following the procedure traceable to NMi-VSL standards. The flow measurements have correction for temperature and Reynolds number to account for the differences in fluid viscosity. Figure 4 summarizes its main operative characteristics.

Figure 3: USM located in Cartagena terminal

Figure 4: Flowmeter characteristics

Design	Dual chordal path
Diameter	36”
Velocity range	0…20 m/s
Temperature range	-170…600 ºC

Calibration uncertainty reported by the manufacturer is 2.19 % (*k*=2).

3.3. TERMINAL TANKS

The system for the volume determination in onshore tanks is similar to the one in offshore tanks (LNG carrier). The main difference comes from level corrections, as trim and list do not affect to onshore tanks.

Figure 5 shows the characteristics of the volume measurement in the terminal tank used in the present study.

Figure 5: Terminal tank characteristics

Level	***Gauge***	Float type
	Range	0…37 m
	Uncertainty	2.31 mm (*k*=2)
Tempe rature	***Gauge***	PT-100
	Range	-200…70 ºC
	Uncertainty	0.12 ºC (*k*=2)
Tank table uncertainty		0.1 % (*k*=2)

The volume uncertainty of the studied tank is approximately 0.14 % (*k*=2).

4. COMPARISON CONDITIONS

The LNG volume obtained from the different measurement systems employed has been compared using the following equation:

$$Difference = \frac{V_{USM} - V_{TANK}}{V_{TANK}} \qquad \text{(Equation 3)}$$

where

Difference	from the compared measurement systems, expressed as %.
V_{USM}	volume determined by the USM, in m^3.
V_{TANK}	denote the volume of the ship's tanks or terminal tank, depending on the comparison, in m^3.

Moreover, the compatibility index (E_n) has been obtained from equation 4. Statistically two measurements are comparable if $E_n \leq 1$.

$$E_n = \frac{|V_{USM} - V_{TANK}|}{\sqrt{U^2(V_{USM}) + U^2(V_{TANK})}} \qquad \text{(Equation 4)}$$

where

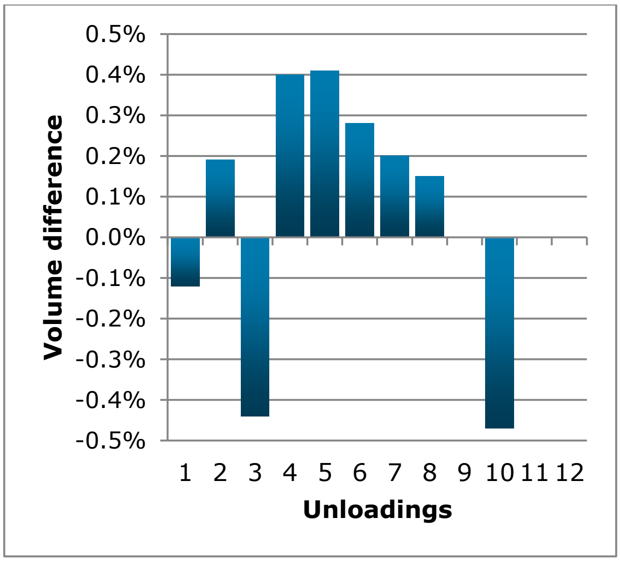
V	volume, in m^3.
$U(V)$	expanded uncertainty of the volume, in m^3.

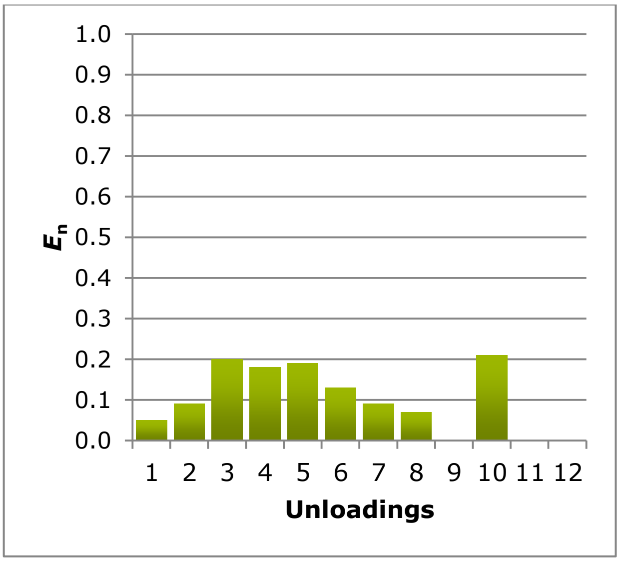
5. RESULTS OF MEASUREMENT SYSTEMS COMPARISON

Data from 2011 to 2013 have been collected. However, the suitable scenario for the comparison has been achieved only in twelve unloadings, due to the location of USM (placed in the inlet of storage tank instead of the jetty) and the particular operative conditions.

Following figures show volume difference and the compatibility index for the comparison of the USM with the terminal tank (Figure 6) and the LNG carrier (Figure 7).

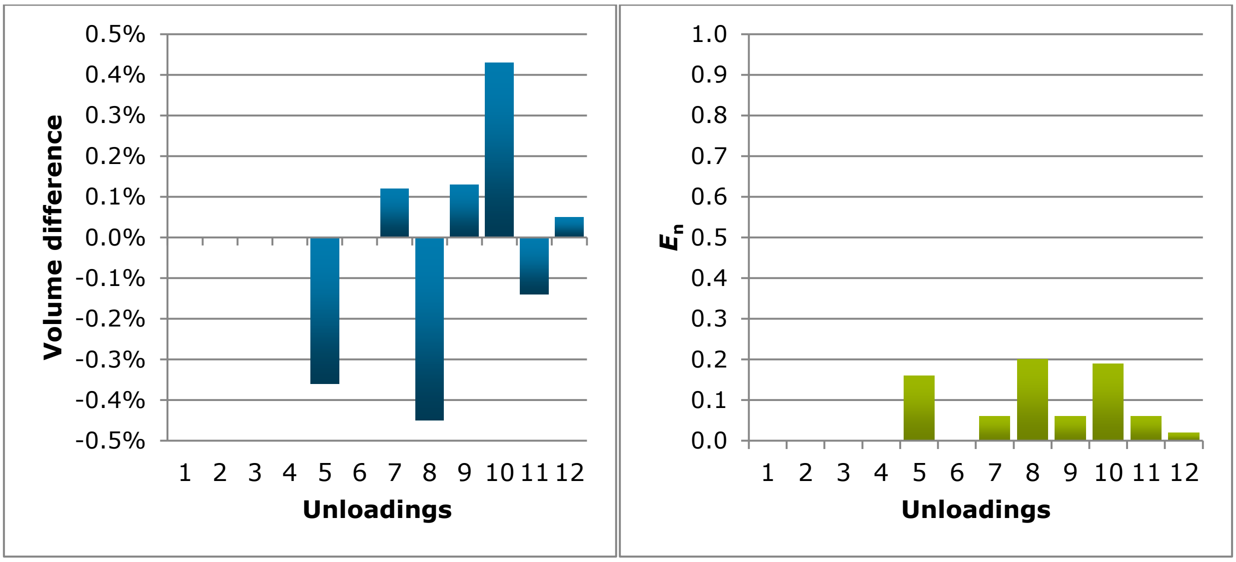
Figure 6: Comparison USM – terminal tank





Note: There were signal reception problems in three unloadings, so the comparisons were not possible.

Figure 7: Comparison USM – LNG carrier



Note: Only in seven unloadings, the whole cargo was transferred to the tank with USM. In the other five cases, the LNG was unloaded into several terminal tanks and not all the cargo passed through the USM.

As it can be seen, all volume differences are less than ± 0.5 %. Moreover, all measurements are statistically comparable, as $E_n < 1$ in all comparisons.

These compatibility indices have been calculated taking into account that the uncertainty of the USM volume is greater than 2 %, as the flowmeter is designed for control purposes and not for Custody Transfer. In case a USM suitable for Custody Transfer had been used, with an uncertainty of about 0.5 %, the above E_n values would slightly increase but would remain lower than 1.

Similar studies have been carried out by the company CAMERON [3], demonstrating as well the validity of ultrasonic flowmeters for this purpose. These studies were located in an LNG terminal in Alaska in 2007 and were corroborated from 2009 with more than twenty USMs in RasGas facilities in Qatar. In this case, the USMs were specially designed for Custody Transfer to be used in LNG transferences between different LNG producers and were calibrated with water (VSL-NMi certified procedure).

Note: As uncertainties of current procedure with water can still be reduced, in 2010 a group of NMI's joined in the frame of an European Research project "Metrology for LNG", as part of the European Metrology Research Program (EMRP).

As results, a primary calibration standard up to 25 m^3/h (calibrated with LNG at -163 ºC) has been developed and validated. Currently, a second step is ongoing to develop a new calibration test rig which should raise the range at least up to 200 m^3/h with an option to extend it up to 400 m^3/h, and traceable to primary LNG mass flow standard developed in the former step.

6. CONCLUSIONS

From obtained results, it can be concluded that the dynamic measure of LNG volume using USM is comparable with the officially recognized method of static measure in ship's tanks, both technically and statistically.

The suitable location for the USM to be used in Custody Transfer would be in the jetty, upstream the header to distribute GNL to different tanks, instead of the current location in the input pipe of one tank.

The validity of the USM measure should be supported by the following:

- Reduction of the USM uncertainty, similar to uncertainty of static measurement in LNG carriers, by improving the USM technology and the metrological traceability.
- Synchronism between the LNG carrier unloading and the USM measurement, which could lead to a revision of the current operative procedures.

7. REFERENCES & BIBLIOGRAPHY

[1] *LNG Custody Transfer Handbook*, 3.01 edition, GIIGNL.

[2] ISO 13528:2005: *Statistical methods for use in proficiency testing by interlaboratory comparisons*

[3] Stuart, Christie et al. “Operational experience with ultrasonic meters for allocation measurement of LNG”, Proceedings of LNG 17 Conference, Houston (USA), April 2013.