Evaluation of measurement uncertainty in transferred LNG volume to or from a ship tank

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Focus in this presentation

Report:

Evaluation uncertainty in transferred LNG volume

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- The need for a common metrological language and understanding and methodology for uncertainty assessment.
- Some reflections to the different types of tanks, level gauging equipment, trim/list measurements etc.
- The users need for understanding their measurement system and its use.
- Traceability in metrology for custody transfer
- Some significant differences between applied systems
- Visualization of significant contributions to the combined uncertainty
- Propagation of uncertainty trough correct models (model functions)
- Uncertainty in estimated unloaded volume from a complete vessel

Tank level gauging of LNG – a challenging metrological task

The measurements should be transparent and have a high degree of confidence for all parties involved. The measurement result should be reported with a measurement value and the associated expanded measurement uncertainty.

(Un)Loaded volume of LNG = $v_{LNG} \pm U_{v,LNG}$

The measurement result should be reported in a way that give trust that all relevant input quantities are identified and included in the result reported.

Important:

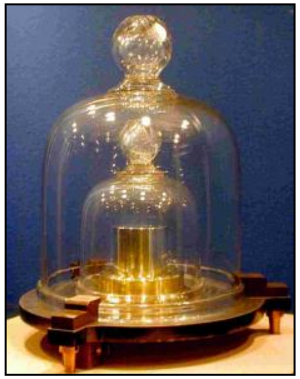
- ***This result should clearly be based on the actual measuring method and system in use.***
- ***The results should include all relevant influences and operational effects and be corrected for known systematic errors.***

Metrology terms according to the international vocabulary on metrology OK

(VIM available at www.BIPM.ORG)

Metrological traceability (VIM 2.43):

- Obtained through an unbroken chain of calibrations to a common reference system for all measurements.
- The references are normally maintained by national metrology institutes or BIPM



Metrology terms according to the international vocabulary on metrology OK

(VIM available at www.BIPM.ORG)

Calibration (VIM 2.39):

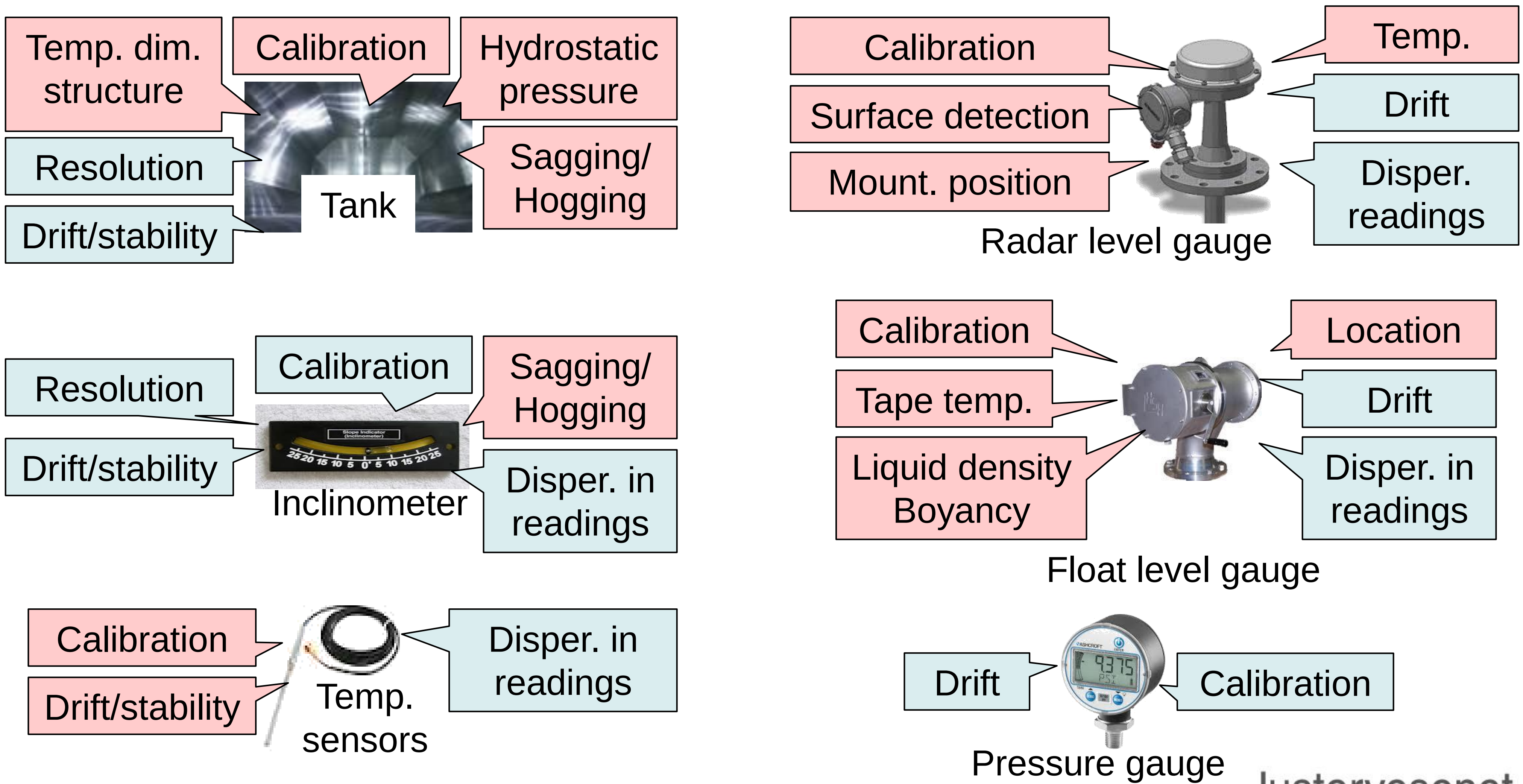
A calibration is the comparison of an instrument with a metrological reference to establish the value of the instrument. In this way a common reference system is secured.

Note:

- Adjustment should not be confused with calibration. The confusing term “self-calibration” should never be used as it violate the understanding of the need for traceable measurements
- Calibrations will normally be repeated to obtain knowledge of the stability of the instrument in use. Information on stability may alternatively be obtained based on other identical instruments use under the same conditions.
- Measuring instruments should always be maintained in according to planned interval based on knowledge of the instruments stability.

Some relevant input quantities for tank based measurements

An overview of relevant input quantities is given. Red color indicates that they may significantly influence the measurement of transferred volume.



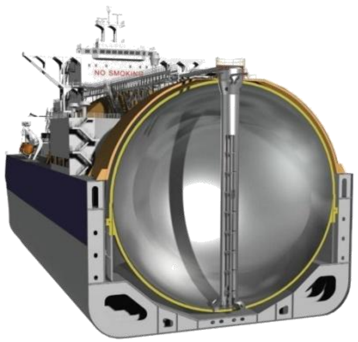
Stability in tank dimensions – what do we know?


Ref: www.worldwideflood.com

Input quantities related to possible changes in size and shape of tanks should have a high focus related to potential impact:

- **Recalibration** of ship tanks only done after repair / changes of dead volume. The work of NBS (LNG Measurements, NBSIR 85-3028) seems to be the most significant work done on the stability of ship tanks of different types. Available validations will increase transparency and document uncertainty estimates.

- Results of relevant **inter-comparisons** between calibration suppliers for gauge tables will demonstrate a common reference level and give increased confidence in gauge tables.


Ref: www.tu.no

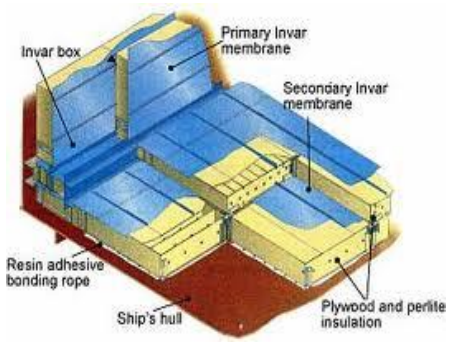
- Thermal deformation, loading pressure and sagging/hogging will change the dimensions of the tank dependant on type of tank.

Temperature effects on tank volume

Temperature effects on the ship tanks should be addressed according to their construction and material used.

Membrane tanks

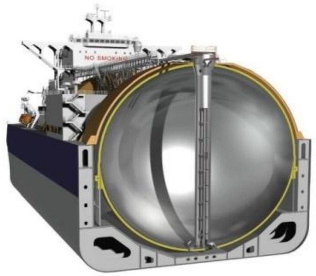
- Thermal barrier between the LNG/NG and supporting structure.
- Supporting structure expected to stabilize at a temperature close to the temperature of ballast water.
- Gauge tables for membrane tanks use 20 °C as ref. temperature



Ref: www.twi.co.uk

Moss tanks

- Tanks are self support around equator.
- Isolated is outside the dimensional structure so that the change in the volume relates to the int. temperature (liquid/vapor).
- The reference temperature for the gauge table is -160 °C.


Ref: www.tu.no

Level gauging

A multitude of influences related to level gauging should be identified and accounted for:

- Level gauges will measure height with reference to top of tank. Thermal or mechanical changes may change the height of tank affecting this reference level.
- Thermal effects on level gauge from interior temperature (liquid/vapor) must be corrected for. Errors from these effect will be correlated to errors related to the thermal changes of top reference level on tank.
- Calibration methods for different level gauges must be identified, and they should be made according to expected drift of instrument.
- Primary and secondary level gauge should not serve as reference for each other.
- Significant deviations of reading of primary and secondary level gauge should abandon measurements

Sensitivity of errors in level measurements and trim/list as a function of level

The inclinometer may in some situations be critical for the correct measurement of loaded / unloaded volume.

- The sensor should be mounted / corrected to the horizontal plane defined for the tank gauge table. It should be emphasized that it should indicate the trim and list for the specific tank being filled or emptied.

- Sagging/hogging may introduce errors between reference plane for tank and mounting position of inclinometer.

- Calibration, resolution and repeatability of readings may be relevant to the uncertainty analysis.

- The sensitivity of an error in the inclinometer reading will significantly be influence by the operating situation .

Ref: www.directindustry.com

Uncertainty assessment

Some important precondition for the uncertainty assessment:

- The propagation of uncertainty is only possible if there is a defined model function or the sensitivity in the result (output quantity) for a given input quantity is given. The model will normally depend on the method.

- The uncertainty calculation is done related to one specific operating state. Relative uncertainties can only be combined directly if the model function is built up by multiplications/divisions. This is not the case for model functions related to tank gauging of LNG.

- The input quantities and their uncertainty estimates should be related to the operation conditions, the actual instruments used and operational procedures.

- Significant correlations between input quantities should be accounted for.

A measurement model is needed

For each tank gauging system a mathematical models must be identified. The model should be used for calculating the volume given estimates for all “input quantities”

- Readings (often the mean of repeated readings)
- Corrections from last calibrations and drift
- Corrections due to thermal, mechanical or constructional effects
- Requirements for maximum list and trim during loading and stabilizing time
- Corrections for non reference conditions like for the temperature in the supporting structure of a membrane tank
- …

Detailed model functions depend on each type of system. They are not given in the “Custody Tranfere Handbook” given by GIIGNL. Below som functions used for propagating uncertaint in the project :

$$V = (V_{table} + c_V) \cdot C_{tank,t}(T) \cdot C_{tank,p}(p) \qquad c_V = \Delta V_{saggingHogging} + \Delta V_{Hydrostatic} + \Delta V_{Drift}$$

$$h = h_{ind} \cdot C_{gauge,T}(T_{gauge}) \cdot C_{gauge,p}(p_{gauge}) + \Delta h_{trim} + \Delta h_{list} + \Delta h_{\rho} + \Delta h_{comp} + \Delta h_{cal} + \Delta h_{drift}$$

Sensitivity coefficients in the measurement method must be known

The sensitivity coefficients are given by the model function and the estimates for the input quantities.

Ref:ntnu.no

Below are some examples on how sensitive coefficients relates to different operating situations like:

- Both for membrane and Moss type tanks, the liquid **surface** area of the liquid will decrease for low and high levels of LNG. This is especially the case for a spherical shaped tank. Partially loading/unloading will as a consequence have a higher combined uncertainty.

- Influences of deviations from “even keel” (zero trim and list) in level measurements caused by a horizontally location **not** in the center of the tank or with an angel to the horizontal plane, will be more significant as trim and list deviates from zero.

Correlation of input quantities

Input quantities may be correlated in some degree. This will influence the combined uncertainty. Positive correlation in input quantities which are added will increase the combined uncertainty.

JCGM 100:2008 (GUM 1995 with minor corrections)

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Paragraph 5.2.4 states that there may be significant correlation between two input quantities if the same measuring instrument, physical measurement standard, having a significant standard uncertainty is used in their determination.

Paragraph 5.2.5 states that correlations between input quantities should not be ignored if present and significant.

It may be difficult to evaluate the degree of correlation. Taking correlation into account in a conservative way is preferred.

Presentation of an uncertainty analysis

Given a model function an uncertainty analysis may be presented in a format like the below. This can be efficient for identifying and improving the measurement system / method.

Input quantety / parameter	Value	standard uncertainty	relative standard uncertainty	sensitivity	contribution
V_{table} (Trunc(h_{start}))	34000	68	0.20%	1	68.0
h_{start}	22.90	0.015	0.07%	-1273	-19.2
$\Delta V_{SaggingHogging,start}$	0	34	NA	1	34.0
$\Delta V_{Hydrostatic,start}$	0	34	NA	1	34.0
$\Delta V_{Table,drift,start}$	0	8.5	NA	1	8.5
V_{table} (Trunc(h_{stop}))	1600	3.2	0.20%	1	3.2
h_{stop}	0.15	0.0063	4.19%	-19	-0.1
$\Delta V_{SaggingHogging,stop}$	0	1.6	NA	1	1.6
$\Delta V_{Hydrostatic,stop}$	0	1.6	NA	1	1.6
$\Delta V_{Table,drift,stop}$	0	0.40	NA	1	0.4
$T_{tank,start}$ (°C)	20	10	50%	1	11.2
$T_{tank.stop}$ (°C)	20	10	50%	0	0.5
$T_{tank,ref}$ (°C)	20	1.0	5.0%	-1	-1.1
α	1.10E-05	0.00	5.0%	0	0.0
$V_{tank\ unloaded}$	**33242**			**$u_{Vloaded}$**	**87.97**
				$U_{V,loaded}$	**175.95**
				$U_{V,loaded}$*	**0.53%**

(Note: Values given as examples to clarify method)

Maintenance of each measurement system

Every measurement system needs skilled operators, following up and maintenance:

- There should be a clear understanding of the responsibility and needed competence for the LNG measurement system at each ship.

- An updated version of the uncertainty evaluation given in a easy readable format should be available for each loading/unloading. From this it should be possible to identify the most significant contributions to the actual measurement.

- The uncertainty budget and its estimates should be clearly linked to the actual system in use and the conditions during the measurement.

- The measurement result included the measurement uncertainty (95 % confidence) should be reported.

- Based on experience with each system it should be possible to improve measurements and reduce measurement uncertainty

Uncertainty in unloading a vessel

For unloading a vessel, the unloading volume of each tank is summed to a total:

- Same calibration reference, methods etc.
- Same operational /maintenance procedures
- Same environmental situation

Model function divided into two input summarized quantities for each tank. One summarize correlated input quantities and one uncorrelated input quantities.

$$V_{vessel} = V_{tank1,uncorr.} + V_{tank1,corr.} + V_{tank2,uncorr.} + V_{tank2,corr.} + V_{tank3,uncorr.} + V_{tank3,corr.} + V_{tank4,uncorr.} + V_{tank4,corr.} + V_{tank5,uncorr.} + V_{tank5,corr.}$$

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Uncertainty in unloading a vessel *(cont,)*

High degree of correlation for measurement of (un)loaded volume from/to a vessel

Input quantity				Uncertainty							Correlatiomatrix								
Input quantety	Estimated input		Distribution	Estimated standard uncertainty	Rel. Exp. uncertainty	Sensitivity	Contribution	Vtank1, corr.	Vtank1, uncorr.	Vtank2, corr.	Vtank2, uncorr.	Vtank3, corr.	Vtank3, uncorr.	Vtank4, corr.	Vtank4, uncorr.	Vtank5, corr.	Vtank5, uncorr.
$V_{tank1,corr.}$	26770	112	normal	56,22	0,43 %	1	56		0	1	0	1	0	1	0	1	0
$V_{tank1,uncorr.}$	0	20	normal	10,00		1	10	0		0	0	0	0	0	0	0	0
$V_{tank2,corr.}$	26770	112	normal	56,22	0,43 %	1	56	1	0		0	1	0	1	0	1	0
$V_{tank2,uncorr.}$	0	20	normal	10,00		1	10	0	0	0		0	0	0	0	0	0
$V_{tank3,corr.}$	26770	112	normal	56,22	0,43 %	1	56	1	0	1	0		0	1	0	1	0
$V_{tank3,uncorr.}$	0	20	normal	10,00		1	10	0	0	0	0	0		0	0	0	0
$V_{tank4,corr.}$	26770	112	normal	56,22	0,43 %	1	56	1	0	1	0	1	0		0	1	0
$V_{tank4,uncorr.}$	0	20	normal	10,00		1	10	0	0	0	0	0	0	0		0	0
$V_{tank5,corr.}$	26770	112	normal	56,22	0,43 %	1	56	1	0	1	0	1	0	1	0		0
$V_{tank5,uncorr.}$	0	20	normal	10,00		1	10	0	0	0	0	0	0	0	0	0	
V_{vessel}	133850					u_{Mlast}	282										
						U_{Mlast}	564										
						U_{Mlast}^{*}	0,42 %										

(Note: Values given as examples to clarify method)

Summary

Model functions reflecting the actual measurement method (tank, level gauge, relevant temperature measurements, trim/list measurement and errors related to traceability/calibrations should be maintained for each ship. The most significant contributions to the measurement uncertainty should be identified and if possible reduced.

Temperature effects caused by deviations from reference conditions for tank (interior or exterior) on tank volume, height of reference point for level gauge and the level gauge itself should be carefully accounted for with corrections and uncertainty estimates.

Errors in trim and list may significantly influence volume measurements dependant on operational conditions, type of tank and mounting position of sensor. Both errors and observed fluctuations should be accounted for in the uncertainty estimate. Care related to the mounting position, maintenance and calibration of the sensors for measurement of trim and list is important. Preferably it should be measured locally for each tank and synchronized with the level measurement.

Summary *(cont.)*

Correlation effects between input quantities, for instance related to corrections for temperature effects, must be accounted for. They may significantly increase or decrease the combined measurement uncertainty.

Data from validation or other investigations, can increase understanding of tank gauging of LNG volume significantly and should be shared to increase knowledge. It is a need for obtaining more information on stability of instruments/tank and influences. Comparable measurements systems will increase knowledge. Measurement comparisons made a

An updated version of the uncertainty evaluation given in a easy readable format should be available for each loading/unloading. The person responsible for the measurement system should use this tool to identify the most significant contributions to the actual measurement and if needed initiate improvements.

Summary *(cont.)*

Based on experience with each system it should be possible to improve measurements and reduce measurement uncertainty

Improvements in the calibration method for LNG tanks will contribute directly to reduced uncertainty. Intercomparissons should be performed to document these improvements.

More documentation of the stability of both membrane tanks and self supported spherical tanks would be preferable.

Identified known and systematic effects should be corrected for to reduce the uncertainty. This may relate to temperature effect and drift in measurement equipment.

Thank you for your attention!