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MEASUREMENT OF PETROLEUM ON BOARD MARINE VESSELS
Class: 2310.1

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INTRODUCTION

At present, the quantity of pressurized light hydrocarbon liquids in a marine custody transfer is often determined by shipboard measurement. Specifically, the quantity onboard is measured by tank gauging, either automatically or manually, depending on the technology of measurement used, and the contractual agreement. Where a terminal has no custody transfer quality flow metering system to load a pressurized marine vessel, shipboard measurement is usually used for the bill of lading.

Unlike crude oil and refined products, calculation of the quantity on board a pressurized marine vessel and in shore tank will take into consideration of the vapor. For some cargoes, such as liquefied petroleum gas (LPG), propane (C3) and Butane (C4), which are kept at a higher pressure without fully refrigeration, the quantity of the vapor could account for more than a few percent of the total cargo transferred.

If the cargo is refrigerated, corrections to raw measurement value will be required for the shrinkage effect. The ullage/level measurement may also need correction, depending on the type of measurement technology used.

What also makes pressurized marine transfer different from crude oil and refined products is that mass, rather than standard volume is often used in the quantity calculation.

For cargo reconciliation, the quantity transferred from a marine vessel, or in some cases, a floating storage offloading (FSO), or a floating production storage offloading (FPSO), is compared against the receiver's own measurement, which is either a shore tank, or an export tanker. A FSO or FPSO is considered "shore," where today the quantity is often measured by automatic tank gauging. In contrast, a small pressurized, river barge is often measured manually. In any case, the method is called for in the contractual agreement.

Industry Measurement Standards

Several standards have been published in the American Petroleum Institute's (API) Manual of Petroleum Measurement Standards (MPMs). Some of these standards are:

Chapter 3.5	Standard Practice for Level Measurement of Light Hydrocarbon Liquids Onboard Marine Vessels by Automatic Tank Gauging
Chapter 7	Temperature Determination
Chapter 8	Sampling
Chapter 9.2	Standard Test Method for Density or Relative Density of Light Hydrocarbons by Pressure Hydrometer
Chapter 11.2.4	Temperature Correction for the Volume of NGL and LPG, Tables 23E, 24E, 53E, 54E, 59E and 60E
Chapter 11.5.1 to 11.5.3	Density/Weight/Volume Intra-conversion Tables
Chapter 17.10.2	Measurement of Refrigerate and/or Pressurized Cargoes on Board Marine Gas Carriers, Part 2—Liquefied Petroleum and Chemical Gases

At present, some of the API standards are under revision.
Sampling and testing often follow the procedures by the American Standards for Testing and Materials (ASTM) and Gas Processors Association (GPA), such as:

ASTM D 1265	Standard Practice for Sampling Liquefied Petroleum (LP) Gases (Manual Method)
ASTM D 2163	Standard Test Method for Determination of Hydrocarbons in Liquefied Petroleum (LP) Gases and Propane/Propene Mixtures by Gas Chromatography
ASTM D 3700	Standard Practice for Obtaining LPG Samples Using a Floating Piston Cylinder
GPA 2145	Physical Constants for Hydrocarbons & Other Compounds of Interest to the Natural Gas Industry

Other test methods for quality of the cargo are not listed here. Other standards published by the International Organization of Standards (ISO) also address these topics.

Measurement Equipment and Methods

Measurement of pressurized marine cargo usually involves determination of the quantity of the liquid, and the quantity of vapor. The total quantity, in weigh or mass, is the sum of them. If static measurement is chosen, the tank gauging method will require level, temperature of liquid, and plus pressure, molecular weight or density of the vapor.

- liquid level;
- average temperature of the liquid;
- average temperature of the vapor;
- pressure of the vapor space in the tank;
- volume of vapor in the tank;
- compositions of liquid and vapor;
- densities for liquid and vapor.

Other information such as list/trim and shrinkage factor is also needed to make corrections to measurements device readings. The measurement technology of each these categories are described in the following tables.

Table 1 Measurement Equipment for Pressurized Barges

	Automatic Measurement	Manual Measurement
Level	Magnetic ATG	Slip tube[1]
Liquid Temperature	Single or multiple point RTDs	Portable electronic thermometer or fixed thermometer/sensor
Vapor Pressure	Pressure gauge/transmitter	Pressure gauge
Sampling	Manual Sampling with cylinder	Manual Sampling with cylinder
Density	Manual testing of sample	Manual testing of sample

Note:
1. Use of slip tube is restrictive in some areas due to environmental regulation.

Table 2 Measurement Equipment for Ocean-going Carriers and FSO/FPSOs

	Automatic Measurement	Manual Measurement	Notes
Level	Microwave (radar)[1], Servo-operated, Magnetic, Magneto-strictive ATG, Hydrostatic tank gauge (HTG), or hybrid tank measurement system (HTMS)[2]	N/A	1. Filtering /averaging can be accomplished in some electronic gauges. 2. HTG and HTMS can provide mass of tank content.
Liquid / Vapor Temperature	Multi-point RTD based Automatic tank thermometer (ATT)	N/A	
Vapor Pressure	Pressure gauge/transmitter – standalone, or as part of the ATG	N/A	
Sampling	Automatic or Manual Sampling	N/A	
Density	Manual testing of sample		In-tank density available if HTG or HTMS is used.

It should also be noted that two separate sets of measurement sensors are required for ocean-going pressurized marine carriers, and for FSO/FPSOs, as specified in industry standards. One of them is designated as the primary and the other as secondary or backup.

Calibration of Measurement Equipment

Automatic tank gauging equipment should have been calibrated, and those used onboard are often certified by the party performing calibration, or witnessing the calibration. The measurement devices should meet their respective tolerance specified in the API (or ISO) standards. Some of these standards are listed in this paper.

Due to the difficulty to verify some automatic measurement devices by manual method using a portable electronic gauging device, therefore it is important that the calibration prior to use be carried out, and the documentation provides adequate information that the measurement devices meet the tolerance in the calibration.

Calibration and Certification - Prior to Initial Use and Afterward

The measurement equipment used in custody transfer should be calibrated by the manufacturer at the factory, or a test facility prior to delivery. The equipment and system should be verified, and re-calibrated as applicable there, to ensure the expected accuracy is maintained after installation.

Calibration should cover the local and remote readout and data transmission to ensure the equipment which may be components of the measurement sub-system(s) deliver the specified accuracy. Calibration (and re-calibration) should be performed by a qualified technician and witnessed by an independent inspector. Upon successful calibration, the results should be certified by the party witnessing the calibration and a certificate of calibration issued. Refer to the respective standards for the method and procedure.

Subsequently, these measurement equipment and systems should be re-calibrated and re-certified on a periodic basis, subject to contractual and/ or regulatory requirements.

The computer system, if used to directly communicate with measurement devices (sensors) and is used in the calculation of bill of lading quantity should be tested and certified prior to initial use, and re-certified when modification or repairs are carried out and which affect the accuracy of the measurement data, including tank capacity tables used in the calculation of the cargo quantity in custody transfer application.

Calculation of quantity by a standard-alone computer should be verified for the calculations used, to comply with agreed method, and procedure in the standards.

Frequency of Re-calibration and Re-certification

The frequency of periodic accuracy verification of the measurement equipment is sometimes agreed among the parties to the sales and purchase contract of liquefied gases, and may be subject to national or local regulations and applicable API or ISO standards. For ocean-going carriers, periodic verification is typically scheduled to coincide with classification society inspections. The frequency should also take into consideration recommendations by the equipment manufacturer.

Re-calibration and re-certification is normally carried out while the vessel is at the shipyard for dry docking, although in some uncommon cases, a measurement device could be re-calibrated in the interim by a qualified third party (i.e., manufacturer or an independent calibration agency) after de-gassing a cargo tank.

The installation of a new automatic tank gauge (ATG) or automatic tank gauging system may also require adjustments to the tank capacity table, or the determination of a correction factor to account for a different gauge reference height. Pressure transmitters can be calibrated if verification indicates that they are operating outside of tolerance, however, temperature sensors cannot normally be adjusted.

Verification of Measurement Equipment between Dry Dockings

In addition to calibration during each dry docking, all measurement equipment used in custody transfer should be checked before use at each loading or discharge to ensure they are in good working condition.

The comparison of the primary and secondary measurement equipment within a tank should be performed as one means of verification. The results of this comparison should be recorded and tracked by the vessel operator.

Other equipment may be verified while the vessel is in service. For example, pressure sensor/ transmitters may be verified against a reference standard device. Trim/list gauges, such as inclinometers, or draft gauges (if used for level corrections) may be verified/calibrated at even keel by comparison to manual draft measurements or other equivalent procedure.

Where equipment is suspect or has failed, secondary measurement equipment should be used in their place until such time as the equipment is repaired or verified to be in good working order. Measurement equipment that has been shown to be faulty when verified during normal operation should be replaced prior to next custody transfer if practical, or at the next dry docking.

Where the measurement equipment can be verified against a known value, the results of this verification should be recorded and tracked. If the primary measurement system is found to be out

of calibration, use of the secondary measurement system should be considered in accordance with contractual agreement.

Checking of Measurement Equipment by Independent Inspector

Prior to and during a custody transfer that involves independent cargo inspector, the inspector appointed by the involved parties should inspect the measurement equipment to ensure that they are fully functional, and should identify any deficiencies. The independent cargo inspector should also review the vessel's records to determine whether the calibration certificates are valid and current.

Exceptions and malfunction of measurement equipment, if any, prior to and during a custody transfer should be immediately reported to the vessel operator and the involved parties promptly notified. Upon specific request, onboard testing, checks or verification may be carried out on measurement devices in question, and the results should be documented.

Marine Vessel vs. Shore Tanks

While many in the loss control of marine transfer of crude oil and refined products use a tolerance of 0.3 to 0.5%, for ship-shore or outturn, the tolerance for pressurized liquids marine transfer is different. At present, the tolerances of LPG and chemical gas marine transfers are established as a matter of company procedure. The tolerance established by some of the operators ranges from 0.5 to 1 % for large tankers and ocean-going carriers, and in FSO/FPSO export transfers. A higher tolerance is not uncommon for transfers that involve smaller LPG tankers and river barges.

When tank gauging is performed both on the marine carrier and onshore tanks, opening gauging and closing gauge reading should be taken in static conditions. Tank heel quantity and quality (e.g., density,..) would need to be determined, so that the liquid loaded does not lead to an off-spec incident.

If a flow metering system (using a coriolis mass flow meter, or a volumetric meter with in-line densitometer) is used to load a pressurized marine vessel, three figures can be compared at the loading terminal: shore tank drop, meter totalizer quantity, and marine cargo tank rise. The measured quantities, in mass, should be within a pre-determined tolerance, which is established based on the measurement equipment and method.

Calculation of tank quantity should be performed in accordance to industry standards, such as those by API, ASTM, GPA or ISO. Examples of calculation forms are shown in Figure 1 (for marine vessels) and 2 (for shore tanks).

Figure 1 Pressurized Marine Vessel Measurement Report

VESSEL MEASUREMENT REPORT

	Vessel			Product				Date/Time
	Terminal			Client				
	Port			Operation				

	Tank no.		1	1 S	1	2 S	1	3 S
	Capacity	m^3						
	Cap. Shrinkage							
	Corr. Capacity	m^3						
	Pressure (gauge)	kPa						
	Temperature	°C						
V	Volume	m^3						
A	Shrinkage							
P	Corr. Volume	m^3						
O	% Product							
R	Vapor Volume	m^3						
	Vapor Density	kg/m^3						
	Mass	MT						
	Temperature	°C						
L	Corr. Ull / Inn	mm						
I	Volume	m^3						
Q	Shrinkage							
U	Corr. Volume	m^3						
I	VCF (CTL)							
D	Volume	m^3						
	Density at 15 °C	kg/m^3						
	Mass	MT						
	Total Mass	MT						

Atm. Pressure (abs)	kPa	
Draft Forward	M	
Draft Aft	M	
List	Degrees	
Trim	Degrees	
Molecular Weight		
Shore Line Condition		
Density Source		
Vapor		Ideal Gas
Liquid (VCF)		Table 54E

In Air		**In Vacuum**	
Total on board		Total on board	
Metric Tons		Metric Tons	
Long Tons		Long Tons	
Short Tons		Short Tons	
Pounds		Pounds	

Figure 2 Pressured Shore Tank Measurement Report

			Open	Close
	100% Capacity	m^3		
	Cap. Shrinkage Factor			
	Corrected Capacity	m^3		
V	Pressure (gauge)	kPa		
A	Temperature	°C		
P	Volume	m^3		
O	Shrinkage Factor			
R	Corrected Volume	m^3		
	% Product			
	Vapor Volume	m^3		
	Vapor Molecular Weight			
	Vapor Density	kg/m^3		
	Mass	MT		
	Temperature	°C		
	Corrected Level	mm		
L	Volume	m^3		
I	Shrinkage Factor			
Q	Corrected Volume	m^3		
U	Volume Correction Factor			
I	Volume	m^3		
D	Density at 15 °C	kg/m^3		
	Mass	MT		
	Total Mass	MT		
	In Air		**In Vacuum**	
	Total on board		Total on board	
	Metric Tons		Metric Tons	
	Long Tons		Long Tons	
	Short Tons		Short Tons	
	Pounds		Pounds	

Conclusion

Marine custody transfer of pressurized liquids often involves static measurement by tank gauging. Both the liquid and vapor in a tank must be measured and calculated and the weight/mass be determined. In refrigerated applications, further correction could be required for the shrinkage of tank capacity and level measurement. Ship/shore reconciliation should be performed but due to the process conditions and limitations of measurement, the tolerance today is less stringent as compared to that used today on crude oil. With better accuracy of measurement technology, and calibration, the tolerance could be improved.