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11133 Interstate 45 S Suite O
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(713) 242-1190

# MEASUREMENT OF LIQUEFIED PETROLEUM GASES (LPGs)

**Class 2470.1**

Paul Mullen
Sr. Measurement Specialist
Enterprise Products
1100 Louisiana
Houston, Texas USA

## Introduction

Liquefied Petroleum Gas (LPG) is defined as "butane, propane or other light ends separated from natural gas or crude oil by fractionation or other processes". At atmospheric pressure, LPG's revert to the gaseous state.

This paper is intended to provide an overview of metering systems used for the volumetric measurement of LPG's. Operational experiences with measurement systems that degrade the performance of these systems will be addressed. It includes information for turbine and positive displacement meters used in volumetric measurement systems. The basic calculations and industry standards covering volumetric measurement will also be covered.

## Measurement Systems Design Considerations

Measurement systems for volumetric measurement employ basic measurement systems design criteria, including the use of strainers, flow conditioning, turbine or positive displacement meters, temperature and pressure measuring devices, electronic flow computers, densitometers, provers and pressure/flow regulating devices.

When reviewing an existing metering system, the piping layout and measurement system and controls must be inspected, with particular attention to flow conditioning. Upstream and downstream processes and controls need to be reviewed. Location of the product pumps in relation to the measurement equipment (or other potential sources of vibration or pulsation) should be addressed. Any bypasses around the metering system should be eliminated. The overall condition of the equipment should be observed.

## Meter Selection

The primary measuring devices such as turbine meters or positive displacement meters have inherent operating requirements which will, when taken into consideration, provide accurate measurement. The operational requirements will be different for each manufacturer and type of meter used.

When using a turbine or positive displacement meter for LPG measurement, it is important to consider the following:

1. The type of liquid the meter will measure, i.e. viscosity, specific gravity, vapor pressure and the corrosive nature of the liquid.
2. The range of operating flow rates and whether the flow will be continuous or intermittent.
3. Meter performance characteristics, i.e. linearity, repeatability, etc.
4. Range of operating pressures and maximum allowable pressure loss through the meter.
5. Temperature range in which the meter will operate.
6. Space available for meter installation.

## Turbine Meters

Turbine meters require some form of electronics for readouts and corrections. As they are susceptible to swirl and distorted flow profiles, some form of flow conditioning is required. Turbine meters do not respond well to pressure pulsations or excessive surges. API MPMS Chapter 5, Section 3, recommends 10-pipe diameter of straight pipe with flow conditioning upstream of the turbine meter as well as 5-pipe diameters of straight pipe downstream of the meter. Turbine meters also require sufficient backpressure to avoid cavitation. They routinely require a strainer upstream to protect the meter from debris.

Turbine meters have a stated linearity of +/- .02% to +/- .25% with typically a 10 to 1 turndown ratio. The turbine meter should also demonstrate the ability to reproduce the same meter factor when proved under similar flowing conditions. The meter factor should repeat within +/- .02%. Some turbine meter manufacturers have stated application requirements associated with low-density products such as LPG. Adjustments to the normal minimum and maximum flow rates should be shifted upward as described within the manufacturer's specifications. A turbine meter should never be operated above the manufacturer's extended maximum flow rate range.

Some turbine meter manufacturers claim to have developed turbine meters specifically designed for low-density products.

Turbine meters are also sensitive to changes in flow rate, density and viscosity. Although they are capable of measuring accurately, the meter's performance must be established with respect to those changes. Typically, turbine meters in LPG service do not demonstrate the stated manufacturer's linearity under normal flowing conditions within the specified flow range of the meter. Therefore, consideration should be given to reducing the turndown ratio to allow operation of the turbine meter within an acceptable linearity range developed within your operating parameters.

Generally, linearity is lost at low flow rates. For example, a given manufacturer's turbine meter may demonstrate significant meter factor shifts throughout its stated minimum to maximum flow rate range. Developing a meter factor curve will demonstrate the meter's performance at various flow rates. One may find that the meter operates within +/- .25% at flow rates in the upper 70% of the normal maximum flow rate. Using this example, a decision not to operate the meter within the first 30% of the flow rate range may be made. A turbine meter with a flow rate range of 500 to 5000 BPH would be operated at a minimum flow rate of approximately 1350 BPH. The meter would actually have an absolute minimum flow rate of 820 BPH, adjusted for low density liquids. The need to analyze the true operating characteristics of the meter under flowing conditions is essential in determining the operational limits necessary to achieve accurate measurement.

**Positive Displacement Meters**

Positive displacement meters (PD) are suitable for the measurement of LPG's. They also require some form of electronics for readouts and corrections. They are not susceptible to swirl, but can be affected by pressure pulsation or excessive surges. PD meters do not require flow conditioning. They do require sufficient backpressure to avoid cavitation. A strainer should be installed upstream to prevent damage to meter internals. Refer to API MPMS Chapter 5, Section 2, to obtaining guidelines for accurate measurement and maximum service life.

A PD meter can offer excellent accuracy, repeatability and reliability metering LPG's with varying densities and viscosities over a broad range of flow rates Be aware that PD meters typically have limitations on applications with extremely dry liquids, such as LPG's. PD meters can employ special trim and bearings, which are suited for LPG measurement.

PD meters have a low tolerance to liquids containing solid particles. These particles wear away the meters internal parts and measuring chambers and/or rotors.

System flow rate limits should be known to insure a meter with sufficient rangeability is installed to handle both the maximum and minimum required flow rates. Excessively low rates tend to under-register flow, as slippage increases, and excessive high flow rate will increase wear. A meter should operate optimally at or greater than
50% of the stated maximum flow rate. Typically the PD meter installation requires less space and shorter meter run lengths.

## Flow Conditioning

Enough cannot be said about flow profile conditioning with respect to turbine meter installations. Flow profiles can greatly affect meter performance. There are several ways systems upstream of the meter run can impact measurement. Pressure regulating valves can cause flow profiles that will change with every movement of the valves trim. Certain piping configurations can produce swirl and profile distortions, such as two elbows out of plane. Flow profile problems caused by reducers can be eliminated with the use of concentric reducers' instead eccentric reducers

It is not recommended to install a prover upstream of the meter. Flow through the prover will create a different flow profile, as compared to when the flow is bypassing the prover. The meter factor developed will be different from the meter factor that would be developed with the prover bypassed or with the prover installed downstream of the meter.

Another common source of flow profile distortion is gaskets having a smaller I.D. than the meter and/or meter run. Flanges misaligned produce similar types of disturbances.

Flow conditioning problems can be greatly reduced by eliminating as many potential sources of flow profile distortion as possible. Having as many upstream unobstructed pipe diameters as possible, along with the use of flow conditioning devices such as the FMC High Performance Flow Conditioner, CPA Straight Plates or GFC's will greatly reduce the effects of flow profile distortion.

## Strainers

A strainer installed upstream of the metering equipment will protect the meter from foreign object damage. Strainers should be selected to provide a minimum of a 6:1 ratio of the basket open area to the meter I.D. to prevent excessive pressure drops. The system should be equipped with a differential pressure indicator to allow you to determine when the strainer needs cleaning.

## Product Contamination

Contamination produced by over-lubricating valves, lubricant leakage from product pumps or from pipeline rouge may be deposited on the critical surfaces of a meter. While contaminants on bearing surfaces may slow or even stop the blade rotation of a turbine or PD meter, coated blades may actually cause indicated flow to increase.

## Pumping Equipment

A problem related to pumping equipment, which can be severe when associated with positive displacement pumps, is the pulsation they produce. Pulsating or cyclical flow generally causes turbine meters to over-spin more than under-spin, causing metered volumes to be too high. PD meters are not affected by pulsation to as significant a degree. Measurement equipment such as densitometers may be very susceptible to errors relating to pulsation if the frequency is near the operating frequency of the densitometer or a multiple (harmonic) of that frequency.

## Back Pressure

The need for a backpressure control valve downstream of the meter skid is essential for high vapor pressure LPG products, since it prevents the product from flashing to the vapor phase. We generally try to maintain line pressure in the metering system at a minimum of 1.25 times the vapor pressure of the product. For LPG's, the definition of standard pressure is the equilibrium vapor pressure of that liquid at its flowing temperature. There are a variety of laboratory methods which measure vapor pressures. Vapor pressure can be calculated from compositional analysis, such as that obtained from chromatographic analysis. Vapor pressure is an "absolute pressure"; so 14.7 psi must be added to the pressure gauge reading (psig) to obtain the equivalent absolute pressure (psia).

If product is allowed to flash, the meters may over-spin and the temperature of the flowing stream will decrease significantly. Flow indications will increase dramatically and may even result in damage to the metering system's primary element. Flashing impacts density measurement as well. Sample flow through a densitometer from a flashing LPG stream will not be representative of the stream. Likewise, the density indications during flashing will be erratic and inaccurate. If flashing occurs, almost every component of the metering system can be affected. Backpressure must be maintained well above the vapor pressure of the product at flowing conditions.

**Flow Computers**

The use of electronic flow computers have made vast improvements in measurement throughout the industry over the last decade and have become the most accepted method of determining net standard volumes. However, the incorrect use of these devices can contribute to inaccurate measurement. Each flow computer has its individual requirements for installation, wiring, setups and programming.

One cause of measurement inaccuracies is the setup/programming of the flow computer. Flow computers require that their setup/programming be such that they meet the requirements of the products being measured. The incorrect application of volume correction tables, conversion factors and/or input assignments will cause errors. Be sure to review the setup/programming of each flow computer to insure accuracy. API MPMS, Chapter 21*, "Flow Measurement Using Electronic Metering Systems*" should be reviewed for guidelines associated with electronic measuring equipment.

**Meter Proving**

When the meter is proved, a meter factor is developed to correct the apparent metered volume to actual volume at operating conditions. A meter factor is defined as the ratio of the actual volume determined by the prover to the apparent volume registered by the meter. Meter proving is discussed in detail in API MPMS, Chapter 4, "*Proving Systems*".

The prover and prover connections should be installed downstream of the meter. Valves associated with meter proving system must provide block and bleed capability to ensure that no flow is bypassing the prover, or that no leakage is occurring during proving operations.

When performing a meter proving, many corrections to the prover itself must be made to ensure uniformity with industry standards and most of all accuracy. The following is a list of the corrections that are made when accurately proving a LPG meter.

1. "CTSP" Correction for the effects of temperature on steel. These corrections are made for the effects of temperature on the steel components used in the construction of the prover's calibrated section.

2. Cubical Coefficient of Thermal Expansion – Corrects prover volume for the operating temperature of the calibrated section.

3. Coefficient of Linear Thermal Expansion - (Small volume prover) - Corrects prover volume for the operating temperature of the invar/switch rod assembly.

4. Modulus of Elasticity - These corrections are made for the effects of pressure on the steel components used in the construction of the prover's calibrated section.

5. "CTL" Correction for the effect of temperature on liquid density.

6. "CPL" Correction for the compressibility of the liquid density. With LPG the equilibrium vapor pressure is applied here.

Take the time necessary to insure that the proper correction factors have been applied with respect to the types of metal used in the construction of the prover.

Before the proving runs are made, ensure that product has been flowing through the prover long enough to allow temperatures throughout the system to stabilize. Remember that the proving system must be stable, i.e., stable flow rates, temperatures and pressures, if you expect to get acceptable runs of repeatability.

When using a SVP's consideration should be given to the distance between the prover and the meter. LPG's are compressible and become very sponge when given an area the will allow for product compression when the piston launches. This compression can cause a pressure shock wave to travel form the prover back to the meter causing instability in the flowing stream. Best practice is to install the prover as close to the meter as possible.

The prover must be carefully inspected and be in perfect working order. An external visual inspection should verify that the prover is free of physical damage such as dents that could affect the calibrated volume. Detector switches should be sealed, indicating that they have not been tampered with. Any associated proving equipment should be mechanically sound and without defect.

With pipe provers using spheres, the sphere must be inflated to the proper size and be free of cuts and gouges. LPG is considered a dry product that provides little or no lubrication to equipment in the system. For that reason, observe the system while the sphere or piston is moving through the calibrated section to ensure that there isn't excessive vibration. The sphere/piston should move smoothly. For example, if the sphere is too tight (over- inflated) and begins to vibrate while in the calibrated section, repeatability will be poor. An undersized sphere or leaking piston may allow flow to bypass and give false flow and volume indications. Verify the integrity of the 4- way valve or plunger seal.

A scheduled leak test should be performed periodically to verify the integrity of the seals of small volume provers. As with sphere provers, the operation of the plunger through the calibrated section of the prover should be smooth with no excessive vibration.

Should the detector switches need to be adjusted or replaced, a review of your companies policy, contractual agreements, and API requirements should be made to determine if a prover recalibration is required. Some companies require the prover be calibrated anytime a detector is repaired and/or replaced if used in custody transfer.

At regular intervals, the interior of the sphere type prover must be inspected. The calibrated section must be clean, coated and smooth with no pits, deep scratches, dents, deposits or other apparent problems. With pipe provers, special attention should be paid to the elbows to insure that no mandrel marks or gouges are present due to the milling of the elbow.

As noted above, many things can go wrong with a proving system that will result in unacceptable meter repeatability or linearity. Don't assume that the meter's inability to be linear or repeatable is the fault of the proving system. Worn or defective meters or an improper installation may also be the culprit. Other problems related to proving systems not mentioned above may be:

1. Leaking four-way valves on bi-directional provers.
2. Four-way valve actuating too slowly. The sphere contacts the first detector switch before the four-way valve is completely sealed.
3. Leaking valves associated with parallel meter runs.
4. Meter pulse counter or accumulators malfunctions.
5. Detector switches not properly installed or not operating correctly. This could cause actuation due to vibration as the sphere approaches the switch.
6. Problems related to the mechanical and electrical integrity of the various components.
7. Metered flow bypassing the prover, such as when the sample source for the sampler or densitometer is between the meter and the prover and the low-pressure return is downstream of the prover.
8. The need for the prover to be insulated. If the temperature between the meter and the prover is subjected to drastic changes during the proving process, insulating the meter and prover may be required to achieve accurate meter provings.

Another area for inaccuracies related to meter proving is when a meter is proved at a flow rate other than that at which it is currently being operated. Meter proving should be performed at the current flowing rate and not allow flow to be changed during proving runs. An example of this is with parallel meter runs, where each meter is flowing at an equal flow rate, but when one of the meters is switched into the prover, the flow rates of the two meters become unequal. Flow rate deviations between the two meter runs can be on the order of a few hundred barrels per hour. Every effort should be made to keep the system operating at current flowing conditions.

When meters when proved demonstrate greater than +/- 0.25% linearity over the manufacturer's stated flow rate range, the need to develop meter factors for multiple flow rate ranges may be necessary. For a particular meter that demonstrates a linearity of +/- 0.50%, the need to develop a meter factor curve would provide the information necessary to determine the flow rate range that would apply to a given meter factor.

**Density Measurement**

The density of the fluid at flowing conditions is measured by a densitorneter in gm/cc. Choosing the right densitometer for LPG measurement is important, but as important is the fact that the densitometer must be installed correctly to insure the accurate measurement of the density. The Densitometer becomes a primary measurement device in the measurement of LPG's. Densitometers should be installed and calibrated per API MPMS, Chapter 14, "*Natural Gas Fluid Measurement*".

Densitometers should be placed on a regular routine calibration schedule. The most common type of densitometer being used today is the vibrating tube type densitometer, which measures the changes in the frequency of vibration as the density within the tube changes. Density measuring systems consist of a densitometer and electronics that measure the frequency output by the densitometer. Many times a flow computer is used for this purpose. Attention must be paid to the programming of the calibration constants, obtained from the densitometer's calibration certificate, into the flow computer or frequency-measuring device. Incorrect densitometer constants will cause density calculation errors.

Accurate flowing density temperature measurement is important to calculate the density correctly. Some units provide an installed RTD. The RTD is attached to the vibrating tube that permits the connection of the RTD to an electronic measuring device, such as a flow computer. Others provide a 4-20 ma signal representative of temperature, which must also be sent to a flow computer. A means of verifying the density temperature at the densitometer is necessary for determining if the density temperature measured by the flow computer is correct. The devices that receive the frequency and temperature signal from the densitometer converts those signal to a density that represents the flowing stream.

A densitometers sample loop should be designed using pitot tubes, orifice plate, pumps or other means to drive flow through the sample loop. Ensure that flashing does not occur due to excessive pressure drop across the sample loop. If the sample loop is short, well insulated and protected from excessive vibration and pulsation, it will provide a reliable means of delivering a representative sample to the densitometer. Densitometers should be installed as recommended by the manufacturer's guidelines for flow rate, densitometer mounting, wiring, etc. Should fouling occur, the densitometer would have to be cleaned to obtain accurate measurements.

The densitometer should also be proved on-line under actual operating conditions using a pycnometer. When the densitometer is proved, a Density Meter Factor (DMF) is developed and is multiplied times the apparent density (registered by the densitometer) to obtain the actual density. The Density Meter Factor is defined as the ratio of the actual density determined by the pycnometer to the apparent density registered by the densitometer.

The pycnometer is a calibrated sphere of known volume and weight. . To prove the densitometer, the pycnometer is connected in series or parallel with the densitometer. Product is allowed to flow through the pycnometer until the temperature is stable to within +/-0.2°F at all of the temperature measurement points in the sample loop. The pycnometer is then removed and weighed. Care must be taken to allow the pycnometer time to stabilize at flowing temperature and pressure before it is removed from the from the sample loop.

The pressure inside the pycnometer can increase rapidly due to the expanding liquid as the product warms and will eventually cause the rupture disc to fail, releasing product to the atmosphere. Atmospheric moisture may condense on the sphere, which will cause errors in the weighing. The new double walled pycnometers greatly reduce the problems associated with temperature by providing an effective layer of insulation in the evacuated space between the walls.

Always be careful while emptying a pycnometer. It must be vented in a safe area with no ignition sources. Make sure the pycnometer is designed to contain the highest operating pressure at your facility. The pycnometer and rupture disc should be rated for 1.5 times the maximum line pressure they will contain. Careful checks of the certified empty weight of the pycnometer will provide evidence of contaminants inside the pycnometer. Between provings, ensure the pycnometer is empty and clean. If you suspect that the pycnometer is contaminated internally, clean the pycnometer with solvent, and then dry it with very dry instrument air, helium or nitrogen. The empty weight must check out prior to every proving if your results are to be useful.

**Calibration and Verification Equipment**

The calibration and verification of measurement instrumentation and equipment is essential to accurate measurement. Routine verification and scheduled calibrations insure that measurement instrumentation and equipment is working correctly and accurately. The use of certified thermometers, pressure gauges and calibration equipment that is traceable to NIST (National Institute for Standards and Technology) is vitally important to insure that instrumentation and equipment used in the measurement of LPGs is accurate. All measurement devices should be re-certified at least once a year.

**Volumetric Measurement Correction Factors**

Volumetric measurement is a common method used for the Custody Transfer measurement of LPGs. This is generally an acceptable method for LPGs of a pure nature, where the physical property changes to temperature and pressure are known and can be predicted. When physical property changes to temperature and pressure are not known or cannot be accurately predicted, mass measurement is preferred. LPGs fall into both categories. Therefore LPGs are measured for custody transfer using both volumetric and mass measurement methods.

LPGs are very compressible and have a greater coefficient of expansion than heavier hydrocarbons. Accurate measurement of temperature, pressure and density is critical. If the LPG is of a pure nature and physical properties can be predicted, then the appropriate volume correction factors must be used to correct the measured volumes to base volumes at 60ºF and at saturation (equilibrium) pressure. Separate factors for Temperature (CTL) and Pressure (CPL / VCF) are used to make these corrections.

With the publication of GPA-TP27 (Tables 23E and 24E), as of September 1998, by the Gas Processors Association (GPA), ASTM and the American Petroleum Institute (API), any previous tables and/or standards published by either of GPA, ASTM and/or API should no longer be used.

GPA TP-27, TABLE 23E "*Correction for Observed Density to Relative Density at 60ºF/60ºF*" is used to calculate an observed density to a corresponding relative density at 60ºF/60ºF.

GPA TP-27, TABLE 24E "*Temperature Correction for the Volume of Light Hydrocarbons*" is used to calculate CTLs for a given relative density within a range of .3500 to .6880 at 60ºF, within a temperature range of from -50ºF to 200ºF at equilibrium.

API MPMS Chapter 11.2.2. "*Compressibility Factors for Hydrocarbons within .350 - .637 Relative Density (60ºF/60ºF) and -50ºF to 140ºF Metering Temperature*" is used to calculate CPL / VCF.

GPA TP-15, API MPMS Chapter 11, “*Physical Properties Data*”, is used to calculate the equilibrium vapor pressure using relative densities (60ºF/60ºF) and flowing temperatures.

**Conclusion**

Many factors must be considered during a review of LPG metering systems. Errors in metering, temperature, pressure or density will produce inaccurate measurement. The list continues, but hopefully we have reviewed some of the most frequent sources of poor performance for LPG systems. If the industry standard guidelines and the guidelines in this paper are followed, LPG metering systems should balance within +/- 0.25%. If they do not, detectable problems will exist in the systems.