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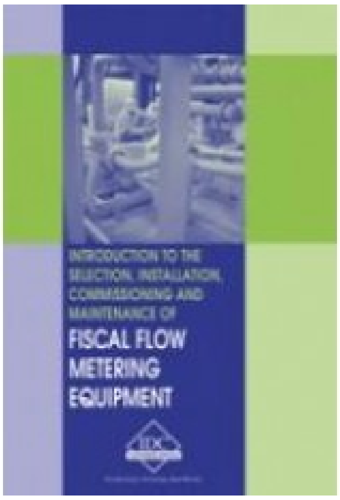
FA-E - Introduction to the Selection, Installation, Commissioning and Maintenance of Fiscal Flow and Metering Equipment



Price: $65.95

Ex Tax: $59.95

Short Description

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1 Introduction to Fiscal Metering

1.1 Introduction

A Fiscal metering system essentially is a supervisory system for liquid and gas flow measurement. The system may communicate with flow computers. Fiscal measurement is also referred to as custody transfer measurement. By definition, *custody transfer* refers to the fiscal measurement, which is used to determine the quantity and financial value of a petroleum product transaction (delivery). The Custody Transfer requirements can be of two types:

Legal

This is defined by Weights and Measures (W&M) or defined by jurisdiction in the country in which sale is conducted. To facilitate fair trade, various W&M codes and regulations control the wholesale and retail trade requirements. The regulations and accuracy requirements vary widely between countries and commodities, but they all have one common characteristic – traceability. The validation process is always defined by a procedure where the duty meter is compared to a standard that is traceable to the legal metrology agency of the respective region. To handle volume flow-rates under 2,800l/m (750gpm), wholesale and retail trade meters are normally smaller (4” and under).

Standards

Accuracy of the Custody Transfer measurement must be at the highest level, as even a small error in measurement can amount to a large financial difference. Because of the critical nature of these measurements, many standards have been developed and adopted by the petroleum companies around the world to meet the industry's needs. American Petroleum Industry (API), International Standards Organization (ISO), American Gas Association (AGA), Petroleum Measurement Standards, OIML standards, American society of Mechanical Engineers (ASME), American National Standard Institute (ANSI), API Manual of petroleum Measurement (API MPMS), etc. are some of the standards followed by industries. These standards are discussed in later chapters.

1.1.1 Meter Selection

The selection of a specific meter type depends on its application. In some applications, a specific type is preferred, whilst in others any meter type would perform quite satisfactorily.

All meter installations must meet certain fundamental requirements. These include accurate proving facilities; adequate protective devices such as strainers, relief valves, and air or vapor eliminators, and dependable pressure and flow controls. In addition, accurate instrumentation for measuring the physical properties of the flowing fluid, such as temperature, density, etc. is also required. Furthermore, physical conditions during normal metering operations (and proving of the meter) must also be identical.

When selecting a meter and its auxiliary equipment, the following should be considered:

- Flow range and whether flow is intermittent or continuous.
- Maximum operating pressure and maximum permissible differential pressure.
- Type of liquid and it's characteristics.
- Temperature range and accuracy of temperature compensation.
- Type of volume registration device.
- Accuracy required.
- Type and method of proving required.
- Applicability of auxiliary meter registration equipment.
- Maintenance requirements.
- Foreign matter in fluid streams.
- Installation space available.

1.1.2 Types of Meters

Flowmeters are used to measure the flow of air, fluids and gas. Most of the meters measure volume of the material. Some measure the speed, whilst others measure the mass of the materials. Flowmeters are often used to infer mass flow through calculations made by them in conjunction with flow monitoring instruments, after taking various flow measurements such as absolute pressure, differential pressure, viscosity and temperature. Most flowmeters consist of three parts, namely i) the primary device, ii) the transducer and iii) the transmitter, all combined into one instrument.

Flowmeters can broadly be classified as:

- Positive Displacement Meters
- Inferential Meters
- Oscillatory Flowmeters
- Differential Pressure Meters
- Variable Area Meters
- Electromagnetic Flowmeters
- Ultrasonic Flowmeters
- Mass Flow Measurement
- Open Channel Flow Measurement.

The above mentioned flowmeters are individually discussed in detail, in further chapters.

Flowmeters are useful in a variety of fields because of their varied uses. In general, they are used in many industrial applications for flow measurements, in order to assist in determining profit gain or loss. Various industries that benefit from the use of flowmeters include the automotive industry, petroleum and gas industries, utility services, HVAC, food processing and raw materials industry.

Pressure Gauges or Transmitters: An accurate pressure determination is required since the measured liquid is always metered at a pressure higher than atmospheric pressure (one standard atmosphere) and is in a compressed form. A compressibility factor must be established and applied to the metered volume.

Temperature Transmitters and Devices: Liquid is generally measured at some temperature other than base 60°F. In order to correct the volume to a net 60°F volume, a volume correction must be made. This can either be done manually, or in a (flow) computer or else directly at the meter. An additional thermo-well is normally installed adjacent to the transmitter, to allow periodic checks to be made.

Pulse Generating Device: A pulsing device, connected directly to the meter, is required for transmitting the metered volume and for proving the accuracy of the meter. The pulse rate varies with meter size and type. Typically, this may be anything between 1,000 to 8,400 pulses/bbl (Barrel) for PD (Positive Displacement) meters, and 500 to 1,000 pulses/bbl for turbine meters.

Registering Devices: Typically, this device is either a mechanical or electronic totalizer. A local register must be provided, to show gross readings. Measurement Row Computers are mostly utilized to accumulate not only the pulses but also the temperature and pressure variables, and in some systems the flowing real time density.

Pulsation Dampers: Meters located in line with positive displacement pumps should use a dampening device to eliminate the effects of pulsations. The typical device usually consists of an appendage to the pipeline, which has an inflatable bag inside, that is pre-charged with nitrogen.

Air Eliminators: Air or vapor eliminators should be installed preceding the meter, since large compressed volumes will tend to expand through the meter causing over-speed and serious damage. An air eliminator is usually an enlarged section of pipe or vessel that is vented and provided with a level control device.

Back Pressure Control: Some installations require a method of controlling backpressure on the meter at a level sufficiently high enough, to prevent vaporization across the meter. API MPMS recommends that the backpressure be equal to or greater than twice the pressure drop across the meter at maximum flowing conditions plus 1.25 times the equilibrium vapor pressure at flowing temperature.

Master meters are utilized from time to time in specific applications. Meters that are used to measure liquids of different densities, viscosities or other characteristics, which may affect meter slippage or volume corrections, should have meter factors developed for each type of fluid. Additionally, as meters are subject to varying rates of flow, they should be proved at a sufficient number of points This will allow for a performance curve to be obtained, and this will, in turn, allow for an appropriate meter factor to be selected from the curve. For all practical purposes, a change of 15% from the base-rate, is considered to be sufficient change to warrant multiple proving.

Although there are a number of prover types and a variety of proving techniques, the functionality of all the provers remains the same. The basic concept of pipe provers is to accumulate the registration of the meter during a time when the displacer moves through a pipe of known volume. This known volume is referred to as the calibrated section and is precisely defined by the detector switches. As the displacer passes the detector switch, it activates the prover counter to commence collecting the pulses generated by the meter.When the displacer activates the second detector, the counter stops it’s accumulation of pulses. Adjusting the total pulses by the meter’s K-factor yields the meter's indicated volume, which can then be compared to the provers known volume. This ratio yields the meter factor for the given meter.

Prover Calibration: The known volume of the prover calibrated section must be precisely determined. This calibration process, for pipe provers, is known as a waterdraw calibration. Tank provers are calibrated utilizing a similar process known as water-fill method. Using precisely calibrated test measurements, the prover is calibrated in a manner similar to proving a meter.

As water is circulated through the prover, it moves the displacer. When the displacer activates the first detector, a solenoid valve is typically activated and the fluid is displaced from the prover into the Test Measure, stopping when the second detector is activated. The process is repeated until a repeatability criterion is met. The volume recorded from these calibration runs is corrected to base conditions and then related to the volume of the calibrated section. This volume at base conditions is called the Prover Base Volume, and becomes the basis for the meter proving process. The process of calibration, i.e. the “waterdraw" is covered in the API MPMS standard Chapter 4, section 7 under the heading "Field Standard Test Measures." A new standard, API MPMS, is covered in Chapter 4, section 9 under the heading "Prover Calibration".

1.1.3 Fiscal Metering Functions

The following list indicates the functions of a fiscal metering system.An example of a fiscal metering system is shown in figure 1.1.

- Flow computer communication.
- Computation of totals and average values.
- Providing the main operator interface to the metering system.
- Handling batch set-up and reporting.
- Flow scheduling between individual metering lines.
- Proving set-up and termination, including proving report, and acceptance of computed K-factors.
- Control sampling of produced oil.
- Setting of manual base density value.
- Printing reports.
- Indicating fixed values.

1.1.4 Metering Points

- Oil transfer to off-loading vessels
- High pressure flare gas
- Low pressure flare gas
- Fuel gas consumption.

Figure 1.1

Fiscal metering system

1.2 Custody Transfer Metering

A custody transfer or fiscal metering system produces very accurate results, if the equipment is selected carefully, and if the operators understand how the meter's performance can be affected by changes in flow conditions as well as other variables.

Custody metering is an essential tool for the profitable operation of offshore platforms.

1.2.1 Why Metering Matters?

Custody transfer metering is very important, from a cost saving perspective. If a typical offshore oil production facility produces 150,000 bpd (barrels per day) and incurs a random $5 barrel extraction cost, an under-reading error of 0.5% in flow can lose about $1.3m in a year, assuming an oil price of $35 a barrel., Bear in mind that a custody metering station only costs around $1m. At $50 a barrel—the price at the time of writing—that loss, or potential saving, amounts to $2.25m.

The primary reason for offshore metering is security. One can be sure of the output of a facility, if the meter is at source. It is possible to offload crude by shuttle tanker to a shore terminal for custody metering. However, in practice, this opens the way to disagreements with production partners and the tax authorities, over issues such as 'bill of lading'.

1.2.2 Fiscal, Custody and Allocation

The terms 'fiscal' and 'custody' are essentially interchangeable although, technically, fiscal means 'concerned with government finance and policy' and custody means 'safekeeping or guardianship'. Neither fiscal nor custody defines a level of metering accuracy, although both are taken to mean the best accuracy in normal oil field practice.

Metering performance is expressed as the total uncertainty of the flow-rate measurement. In Russia, a massbased oil flow measurement is generally preferred; whereas in the UK, volume metering is favored. Either is acceptable, provided the necessary corrections for density, water and sediment quantity are properly addressed.

In the UK, the Department of Trade and Industry (DTi) have supplied metering guidelines to offshore operators and licensees since the early 1970s, and defined the following 'measurement approaches'. Measurement approaches are summarized in Table 1.1.

Allocation measurement refers to continuous measurement, by which a quantity of hydrocarbon, metered to Custody Transfer standard is attributed to different sources.

Table 1.1

Measurement approaches

Approach	**Typical Uncertainty in Mass Flow-rate Measurement (%)**	
	Liquid	Gas
Custody Transfer	0.25	1.0
Custody Transfer (Non-Petroleum Revenue Tax)	0.25 - 1.0	--
Allocation	0.5 – 5	2 – 5
Well Test	10	
Multiphase Metering	10 – 20	

Space and Weight

Early offshore platforms were converted to drilling rigs, where space and weight were severely constrained. The Argyll oil meter skid was based on typical early offshore meter stations, and was simply a cut-down version of its land-based predecessor.

Moving away from PD (positive Displacement) meters was the most significant change, despite their excellent accuracy of ±0.15%. This was as a result of them being too large, heavy, and susceptible to internal damage.

In the 1960s, a Dr.Potter patented a turbine principle meter to handle high fuel flow-rates. The 'Pottermeter' became the workhorse of offshore metering with a long-life, low-drag hydrodynamic thrust bearing and 0.25% linearity. Later helical bladed rotor designs handled wider viscosity ranges, with a premium linearity of ±0.15%.

These meters 'infer' the volume flow-rate by removing a little kinetic energy from the liquid to spin the turbine in a fairly linear relationship to flow-rate. Whatever the design, they are susceptible to changes in the oil character (viscosity) and therefore require regular proving or calibration, under real operating conditions.

Ball Provers

A 'ball' or 'pipe prover' is the conventional proving device for most turbine and PD meters.

The procedure involves a plastic sphere being inflated with water, to create a close fit inside a pipe 'loop'. This is then pushed along by the oil flow in series with the meter under test, and passes 'sphere detectors' mounted in the pipe wall which initiate a timer with the start and finish of an accurately calibrated internal volume. Repeating the proving a number of times provide a highly accurate measurement of average flow-rate, that is used to calibrate the meter.

In the very early days of ball moving in the provers, there was only one direction of travel through the loop. The physical size and weight of the early ‘Uni-directional’ provers became problematic for offshore service, and therefore a ‘bi-directional’ prover was developed. Utilizing a four-way flow diverter valve, it allows the ball to travel in both directions, one after the other, combining the forward/reverse volumes to make a single proving ‘cycle’. This reduces the overall calibrated length of the provers, and limits possible hysteresis errors introduced by the sphere detectors.

In the mid 1980s, pulse interpolation techniques were developed for small volume piston provers. The procedure interpolates (estimates) the part of a full meter pulse that is inevitably ‘lost’, at the end of a displacer movement. This improvement is also now applied to ball provers.

Pulse interpolation is used by almost all new provers, to reduce the necessary calibrated volume. However, the reduction can only be made if the duty meters have a uniform pulse output per revolution. This is true of all turbine meters, unless they have been damaged in a way that decreases their intra-rotational linearity. This is not necessarily true for all PD meters, which utilize several different principles to achieve the swept volume per revolution.

Oil Proving and Calibration

‘New technology’ manufacturers are rightly proud of the inherent stability of Coriolis and Ultrasonic flowmeters. However, the reality is that even a bad flowmeter may be calibrated to be accurate at a single instance in time, at a well-controlled test laboratory. The real test occurs offshore, under real operating conditions, 365 days per year.

The industry needs to prove to itself, and government agencies, that the meters remain consistently sound between onshore laboratory calibrations. Good practice demands a dedicated prover to be installed for all offshore oil custody metering systems.

Ideally, a rotary inferred volume type meter should be proved by a different principle, such as a PD ball prover. It is very unlikely that both devices would be affected in the same way by an external upset, such as a sudden increase in product viscosity—this reduces the risks of so-called ‘common mode errors’ and is an important principle of good custody flow metering.

In ‘master metering’, the ball prover may be replaced with a transfer or master meter, of equal or better accuracy than the duty meters. To reduce its degradation, the master is normally kept isolated and protected from the main system. It is often the same type of meter as the duty meter, and is periodically returned to a laboratory for accurate recalibration.

As this method may suffer from the ‘common mode errors’ as stated above, they are best suited to a location or installation where the total rate of fluids metered, is small.

Small Volume Piston Provers

In this category, ‘small footprint’ units use machined solid pistons and cylinders, pulse interpolation, and optical position detectors to allow higher piston speeds, smaller swept volumes, and much greater turndown ratios, than pipe provers.

They are perceived as more complex than bi-directional provers and require some de-rating for use, with inferential pulse meters such as Coriolis and Ultrasonic flowmeters. These meters have a pulse train generated electronically from a processor, based upon many instantaneous ‘snapshots’ of the flow. This may lead to a ‘jumpy’ and over-responsive output, so some de-rating of the prover may be necessary. This amount depends on the size, configuration and manufacturing design of the prover and the meter under test.

New Meter Technologies - Coriolis Mass Meter

The first DTi approved mass metering system, for the UK North Sea, is believed to be the 1993 BP Forth Harding system, where there were potentially very high viscosity excursions up to 1800cP with wax and high acidity.

Extreme viscosity ruled out turbine meters. PD meters were considered vulnerable to the high acid content and local vibration, and hence the novel technique of coriolis mass metering was selected. There were high pressure drops during high viscosity but, crucially, the meters were not being damaged or degraded.

Good practice was observed by installing a permanent small volume piston prover on the package.

New Meter Technologies - Ultrasonic Flowmeters

Custody oil Ultrasonic flowmeters have been available since the mid 1990s, and in less than ten years they have become as much a standard feature as turbines.

On the Canadian Husky Oil White Rose FPSO (Floating Production, Storage and Off-take) there was insufficient space for a conventional multi stream turbine and bi-directional prover metering system, as well as a need to limit overall pressure drop. Therefore, the ‘Z’ pattern arrangement was developed. It was essentially a duty and standby/master meter system – but with an unusually large capacity of $4000m^3/h$.

The oil to be exported would be relatively stable after processing and storage in the FPSO’s tanks, before batch offloading,thus reducing concerns over contaminants, viscosity swings and gassing.

The regulatory body was presented with the supporting design evidence for the propriety of this custody system and approved its use.

Gas Metering

Orifice metering still continues to be the most commonly requested principle for gas flow measurement offshore. Nonetheless, just as with Ultrasonic oil metering, the pace of change to multi-path Ultrasonic custody standard gas flowmeters is increasing.

High acceptability, simplicity, low technology, ease of calibration, and ‘perceived’ robust nature are the primary benefits of orifice meters. A reading of some sort is almost always available from an orifice meter and maintenance is simple, and can always be carried out offshore with limited tools. If the installation is properly designed according to ISO5167/AGA3 (standards) and properly maintained, the accuracy is deemed to be acceptable.

Disadvantages are the inherent overall uncertainty (±0.65% at best), poor turndown (around 3:1) regular calibration of secondary instruments, and relatively large space requirements.

Ultrasonic gas flowmeters offer the benefit of relatively high accuracy (typically ±0.5%), high turndown (minimum 10:1), good reliability and comprehensive diagnostics. Some operators are suspicious of the relatively short time, some

10-13 years, that custody metering has been practiced, and therefore consider the meters to be too complex for the application.

Ultrasonic calibrations can also be a problem. The units need to be taken to onshore test laboratories, where conditions are never identical to the real world installation. It is not yet clear how common mode errors will be identified if the ‘master meter’ type principle is utilized with two meters in series. In this case, the second meter checks, or perhaps even calibrates the first.

Measurement (volume) Accuracy and Meter Accuracy

Measurement accuracy, as applied to volumes, is the absolute accuracy of the volume measured, whereas "meter accuracy" is the accuracy of the meter relative to a reference standard, such as a prover.

Measurement accuracy of volumes is influenced by the following factors:

- Meter repeatability.
- Liquid density corrections due to varying temperature and pressure.
- Meter calibration or proving, including procedures.
- Variations in operating conditions as their effect on a meters performance.
- Calibration of prover, i.e. waterdraw.

Repeatability and Linear

These terms are commonly used to define meter accuracy. Repeatability is the variation in the meter's performance under constant operating conditions, i.e. constant flow-rate, temperature, density, etc. Linearity is the variation in the meter's performance over a range of flow commonly referred to as turndown ratio.

Reliability/Availability

Maintenance offshore is never easy; an operator might continue to run a failing meter rather than to interrupt production. For this reason, it is usually mandatory to duplicate one complete stream of metering equipment on a custody station. This leads to the well known ‘N+1’ meter stream requirement. In addition, modern flowmeters (such as turbines) are relatively compact, and so a calibrated spare can be held offshore to allow failed units to be returned to base for repair.

Sphere detectors are duplicated at each end of offshore prover loops, to give four effective calibrated volumes, which produces considerable redundancy.

Offshore Computer Systems

Most authorities insist upon ‘stand alone’ flow computers for each meter stream. This allows individual units to continue operating, even if a neighbor is damaged. A supervisory computer can ‘manage’ the disparate stream, as well as prover flow computers, and can also perform additional tasks such as flow scheduling and automatic flow sampler control. These are now, most often, ‘dual redundant’ arrangements, rather than the earlier and arguably much more complex ‘hot standby’ systems.

Many now prefer a single station supervisory function, since the primary metering data is retained in the separate flow computers.

Sampling and Analysis

As few offshore installations have comprehensive analytical laboratories, all custody stations are offered with flow proportional automatic samplers. In some cases smaller ‘sub samples’ are extracted and are more easily transferred to the shore base for analysis. High pressure or volatile samples require special handling.

For gas, a properly designed orifice metering station and for oil, a turbine meter/bi-directional prover system, is still considered to be an excellent, all round custody metering solution. It is worth noting that few (if any) field partners or government agencies will make a successful challenge to such a system on pure technical grounds.

Offshore production requires many systems and processes. A custody metering is almost universally regarded indispensable.

1.3 Flow Metering and Custody Transfer Measurement

1.3.1 What is Custody Transfer?

Custody Transfer is an agreement between buyers, sellers and transporters, in line with the rules and regulations of customs and government authorities. These agreements outline how the gas entity is to be measured, and how the results will be traceable to recognized standards. The involved parties have an interest in the true net volume and net energy, as in the case of natural gas. Generally, implementation of custody transfer scheme takes into account the past & present practices as well as future developments in the area of metrology and metering technology.

Custody Transfer is applied in natural gas applications:

- Between gas supplier and Gas transporter on the gas feeds, to Gas production/transmission/ distribution pipeline networks.
- Between Consumer and transporter/supplier in Gas transmission and distribution pipeline network.

How Does Custody Transfer Apply in Natural Gas Applications

Generally, on an energy basis. Natural gas Custody transfer is applied to the online energy measurement of gas, at the custody sale point.

Gas energy measurement will involve measurement of the actual volumetric flow-rate and computation of the net volumetric flow-rate at reference conditions, by compensation, with measured operating parameters such as pressure, temperature and super-compressibility. With online BTU (British thermal unit) gas chromatographs, the gas calorific value is determined. The net gas calorific value is then multiplied to the net volumetric flow derived from the energy of the gas.

The gas moisture content needs to be measured, to determine the net heating value of gas sales, specifically where the gas is not dry and contains moisture.

1.3.2 Basic Requirements of Custody

The following are the basic requirements of custody:

- Measurements of Quantity and Quality of gas.
- Type approval certifications of measuring equipments for compliance to metrological controls from accredited agencies authorized by statutory authorities.
- Local legal requirements in line with weights and measures legislations.
- Obligations to implement OIML (International Organization for Legal

Metrology) recommendations in the national legislation (Countries that have signed OIML treaty).

- Verification of the measurements system, including calibration equipment traceable to national/international standards.
- Maintaining valid compliance / certification by the user of the entity at metering site, by regular verifications and validations checks using appropriate methods acceptable by concerned parties/ legal authorities.
- Meter proving requirements like check meters/ master meters, safety, construction codes and standards compliance must be adhered to.
- Gas meters must be type approved by an accredited agency and authorized by the relevant legal authority.
- Initial verification of the gas meters must be carried out at test facilities, in a manner that is traceable and approved by national authorities.
- Subsequent verification of meters must be carried out at regular intervals.
- Initial verifications and subsequent verifications shall be carried out either individually or statistically (The relevant national authority will decide whether the use of statistical method is allowed).

1.3.3 Gas Metering Design Code and Standards

General Design AGA Standards

- AGA–Report No 3: Gas custody metering based on orifice metering.
- AGA–Report No 7: Gas custody metering using turbine meters.
- AGA–Report No 9: Gas custody metering using Ultrasonic flowmeters.
- AGA–Report No11: Gas custody metering using Coriolis mass flowmeters.
- AGA–Report No 8: Compressibility and Super-compressibility for Natural Gas and other Hydrocarbon Gases. Transmission Measurement.
- Report No 10: Speed of Sound in Natural Gas and related hydrocarbon gases.

ISO Standards

- ISO 12765: Measurement of Fluid Flow in Closed Conduits – Methods using Transit Time Ultrasonic Flowmeters.
- ISO 10723: Natural gas – Performance evaluation for On-line Analytical Systems.
- ISO 5168: Measurement of Fluid Flow: Estimation of Uncertainty of Ultrasonic Flowmeters.
- ISO 6569: Natural Gas – Rapid Analysis by Gas Chromatography.

- ISO 6976: Natural Gas – Calculation of Calorific Value, Density and Relative Density.
- OIML DR 3: Draft Recommendations Gas meters (Combined revision of R6, R31 and R32 Draft).

Gas Meter-Requirements

This draft (OIML DR 3) recommendation standard covers the requirements for gas meters (based on any principal)

- Terminology
- Construction requirement
- Seals and Markings requirements
- Metrological requirements
- Technical requirements
- Requirements of Metrological controls for type approval of gas meter and verification.

1.3.4 Typical Gas Metering Station

Figure 1.2

Gas metering system

Components of a Typical Custody Gas Metering Station

A typical custody gas metering station consists of the following major components:

- Gas filtration – for filtering out solid particles, which may damage the internals of the meter.
- Gas Flowmeter and (or) check meter.
- Temperature Sensor for temperature compensation.
- Pressure sensor for pressure compensation.
- Block Valves on each meter run as well as for the Master meter connections.
- Master Meter.
- Skid and skid instrumentation.

- Gas composition measuring equipment such as BTU Gas chromatograph, Moisture Analyzer.
- Automatic Gas Sampler.
- Flow control valve for controlling/limiting the flow to consumer.
- Gas Flow computer.
- Control room instrumentation consisting of flow computers, a control system for valve control and interlocks, metering system, supervisory system, reporting and logging equipments, quality monitoring instrumentation, communication interfaces.

1.3.5 Types of Meters in Custody Metering

The most commonly used type of Gas flowmeters in hydrocarbon custody transfer applications are:

- Orifice flowmeters in accordance with AGA 3
- Turbine flowmeters in accordance with AGA 7
- Ultrasonic gas flowmeters in accordance with AGA 9.

There are several other gas meters available, but their use depends on the specific application as well as economic considerations.

Table 1.2 summarizes the Accuracy Requirements of Custody transfer meters as per OIML:

Table 1.2

Accuracy requirements as per OIML

Flow-rate(Q)	**On Type approval and initial verification Accuracy Class**			**In Service Accuracy Class**		
	0.5 WME ± 0.2%	1 WME ± 2 %	1.5 WME ± 0.6%	05 -	1 -	1.5 -
Q_{Min}<= Q< Q_t	MPE ±1%	MPE ±2%	MPE ± 3%	MPE ±2%	MPE ±4%	MPE ±6%
Q_t Max	MPE ±0.5%	MPE ± 1%	MPE ± 1.5%	MPE ± 1%	MPE ± 2%	MPE ±3%

Where:

WME: Weighted Mean Error

MPE: Permissible Error

The following are the meter selection guidelines:

- Selection is primarily influenced by

1. Flow-rate, rangeability (turndown)
2. Performance considerations such as accuracy and repeatability
3. Pressure drop
4. Fluid viscosity
5. Wax contents and corrosive properties
6. Maintenance requirements
7. Space considerations

- When selecting a particular meter type, advantages and disadvantages for an application must be carefully considered.
- Economic aspects, such as capital and operational expenditure, and return on investment are carefully considered.

Meter Calibrations

- Before dispatch,mMeters are first calibrated by the manufacturer with low pressure air (less than 100 psig), and then calibrated at gas flow labs (always an approved and traceable facility) for initial verification against a transfer prover master meter.
- Transfer and Sonic Flow Nozzle provers are generally utilized by Flow calibration labs.
- Internationally renowned gas flow calibration labs include CEESI, SWRi, Advantiac, Gasunie Wesrbork (NMI), Ruhrgas Pigsar, Statoil's K-Lab.
- As defined in the OIML recommendation, the calibration / verification method employed should adapt the test conditions for the verification of the meters.
- Accuracy requirements shall be verified while using the condition of the gas, which is as close as possible to the operating conditions (pressure, temperature, gas type), under which the meter will be put into service. Verification may also be performed with a type of gas (e.g. air) other than that which the meter is intended to be used with, if the authorities, responsible for the verification, are convinced (by either the outcome of the test with different gases, or the technical construction of the meter under test) that comparable results will be obtained.

Proving and Validation of Metering Installations

Proving: Adequate tests need to be developed and standardized for the new technological gas meters available in the market, as many gas meters are sensitive to flow disturbances, velocity profiles, pulsations and acoustic disturbances. Online proving of gas meters, at operating conditions, is generally carried out using a master meter in series with the Pay meter.

Validations: Online verification of gas meters, at operating conditions, is generally carried out using a master meter in series with the Pay meter. A common master meter is installed in the metering station, which is then lined-up when the pay meter is required to be proved. Only the master meter is sent for recalibration, to recognized gas flow test labs.

Important points to be considered in the validation of metering installations:

- A common master meter can also be kept for multiple metering stations.
- A pay and check meter, in a series configuration, is also used in metering stations of very large capacity, for continuous verification of the pay meter against the check meter.
- A quality measuring equipment calibration is done using certified calibration gases.
- An automatic gas sampler, and the lab analysis results of sampled gas, is also used for verifying the BTU Gas chromatograph performance.

1.3.6 Dry Calibration and Verification of Ultrasonic Gas Meter

Dry Calibration

For Ultrasonic gas flowmeters, the meters are first dry calibrated at the factory, where the zero point precision is checked. In Zero calibration, the meter is sealed at both ends, using blind flanges. The meter is then filled with a gas of known composition, for which the theoretical sound velocity can be calculated using gas composition and condition. This means that theoretical ultrasonic signal transmit times are defined, with respect to measuring path length. As soon as thermal equilibrium is reached after the gas is filled, the transit time difference of ultrasonic path and, therefore, the zero point precision is checked (using measured and theoretical sound velocity). The zero calibrated meters are then flow calibrated with gas at gas flow labs.

Meter Performance Verification with SOS at Metering Installation

At actual operating conditions, the Ultrasonic meters give measurements of speed of sound for all the ultrasonic paths. Also, using AGA-8 and AGA-10 calculations, the speed of sound can be calculated using measured gas composition, and operating conditions with on-line Gas chromatographs (GC). Comparison of SOS (standard offer service) as measured, and as calculated from measured composition, gives a good verification tool for gas meter performance as well as the individual ultrasonic path functioning. GC measurements are also verified by means of the analysis of samples collected by an Auto gas sampler.

1.4 Fundamentals of Gas and Liquid Measurement

1.4.1 Gas Measurement Principle

Gas measurement fundamentals include the units of measurement; the behavior of the gas molecules; the property of gases; the gas laws and the methods, and means of measuring gas. It is important to have an understanding of natural gas chemistry, as the quality of gas is often the responsibility of the gas measurement technician. To understand what a gas molecule is, one needs to know what matter is.

Matter: This can be defined as anything that possesses mass and occupies space. It is made up of elements and compounds of elements. An element is matter that cannot be further decomposed by ordinary means, and thus is the simplest form in which matter can exist. The universe is made of elements or combinations of elements.

Atom: Elements are differentiated by their atomic structure. Atoms are the smallest parts of an element, which can be divided and still, retain all the properties of that element. The atom is the smallest unit of matter, which can enter into combination with itself, or atoms of other elements.

1.4.2 The Kinetic Theory of Gas

Behavior of the Gas Molecules

In order to better understand the gas laws and the fundamentals of gas measurement, the behavior of the gas molecules has to be known. Air is made up of a mixture of gas molecules, essentially consisting of nitrogen and oxygen, which occurs everywhere in the earth's atmosphere. A cubic centimeter of air (or any gas at standard temperature and pressure conditions) contains about 26 billion molecules; there is a large amount of frictionless empty space around each molecule. At low pressures the relative size of the space surrounding the molecule is so great that the actual volume occupied by the molecule itself is minimal. The gas molecule, itself, is incompressible. The gas can be compressed by bringing the gas molecules closer together, in a relatively large empty space occupied by the gas. This is done by adding more molecules or reducing the space occupied by the gas.

Gas molecules are in a chaotic state and continually move in violent motion. They travel in a straight line until they collide with other molecules or a confining wall. As the collisions are perfectly elastic, there is no energy loss.

Exerted Pressure

Under ideal conditions, the number of collisions by a given amount of gas molecules with the confining wall is directly related to the pressure exerted. The pressure exerted by gas depends upon the collision of the molecules with these confining walls. Each time a gas molecule collides with a confining wall, it exerts a force. The sum of these forces at any moment, give the pressure exerted. Also, the molecular collisions depend upon the number of gas molecules, and hence the pressure exerted. The fewer the gas molecules in a confined chamber, the less will be the molecular collisions, and therefore the lower the exerted pressure. To reduce pressure in a confined chamber, gas molecules must be removed from the chamber or the confined volume must be increased for a given number of molecules. This reduces the number of molecular collisions with the confining wall. A regulator valve reduces the number of gas molecules per unit of space in a downstream segment of pipe, thus reducing the gas pressure.

The opposite (vice versa) also applies, pertaining to an increase in pressure. In order The number of gas molecules must be increased in a confined volume, such as packing a section of pipe. Alternatively, the number of molecules can be held constant while the confined space is reduced (such as with a piston compressing the gas in a reciprocating engine).

Actual, Kinetic and Dynamic Pressures

Under ideal conditions, the pressure exerted is referred to as kinetic pressure. Actual pressure exerted by gas molecules is seldom the same as the ideal for kinetic pressure. The actual pressure consists of the algebraic sum of the kinetic pressure, and a much smaller component called the dynamic pressure. The dynamic pressure is the sum of two deviation forces. One is caused by an attractive force between molecules and the other by a repulsive force between the same molecules.

The relation between the actual, kinetic and dynamic pressures is illustrated by the following equations:

$P = P_k + P_d$

Where:

$P_d = P_a + P_r$ or $P = P_k + P_a + Pr$

P = Actual pressure exerted by molecules

P_k = Ideal or kinetic pressure

P_d = Dynamic or deviation pressure

P_a = Attractive force between molecules

Pr = Repulsive force between molecules.

The attractive force (Pa) between molecules opposes the kinetic pressure translated by the collision of the molecules with the confining walls. This force tends to reduce slightly the momentum of the molecules. This reduces the force of impact between the molecules and confining walls, and as a result, slightly reduces the pressure that would be exerted under ideal conditions.

If more molecules are confined in a volume, then the molecules become closer and hence produce a large attractive force. Since this force has a negative effect on the kinetic pressure, with higher pressures, the larger of the two will be the deviation force.Therefore, the actual pressure exerted will be less than that of the ideal.

In a confined chamber, and at a known absolute pressure and temperature, the volume of gas normally calculated will be less than the actual volume. Therefore, a deviation factor must be applied, to determine the actual volume of gas in the chamber. It stands to reason that a deviation factor must also be applied, in gas measurement, to determine the actual volumeof the gas being measured.

The attractive force between molecules can best be demonstrated by observing a liquid such as mercury on a flat surface. The mercury tends to form droplets.

When these droplets get close enough together, they attract each other and combine to form a larger mass of liquid. Although this attractive force is relatively slight in gas (compared to the mercury), it does become significant at very high gas pressures.

The repulsive force (Pr) between molecules acts opposite to the attractive force. As gas pressure increases, there is a larger number of gas molecules in a confined volume.   These molecules are brought closer together.

At very high pressure, the molecules get even closer together. However, since each molecule is compelled to remain outside the space occupied by the others, they exert a repulsive force on other molecules. As a result of this, the space available for the molecules to move, is greatly reduced. The repulsive force thus adds a positive increment to the dynamic or deviation pressure. As pressure increases, by the introduction of more gas molecules into a confined space, the repulsive forces reduce the effect of the attractive forces, thus reducing the deviation effect. At a high enough pressure, a point is reachedwhere the repulsive force between the molecules equals the attractive force, thus producing ideal conditions, where the actual pressure exerted by the molecules is the same as the kinetic pressure.

Effects of Temperature

Motion of the gas molecules depends upon the variations in temperature. The higher the temperature, the faster the gas molecules will move. This, in turn, will cause more collisions between a given number of molecules. The net result of this, is more collisions with the confining wall.

Under constant volume conditions, the pressure may either be more or less. If the pressure is greater, but at a lower temperature, the gas molecules will move slower, thus causing fewer collisions between the molecules and the confining walls. On the contrary, if the pressure is less and the temperature increases, the collisions between the molecules and the confining walls will increase.

As the temperature increases, the gas molecules must be released in order to maintain a constant pressure within a confined space. As the temperature decreases, more gas molecules must be introduced, to maintain a constant pressure. It is interesting to note that at lower temperatures, the deviation forces are more pronounced than at higher temperatures, where they tend to flatten out. At high pressures, a point is reached where the repulsive forces between molecules equals the attractive force, thus producing ideal conditions. For example, at a point between 4,000 and 4,500 psig, at 240°F, no deviation exists and the gas behaves ideally.

Thermal Energy of Gas Molecules

Energy is the capacity for doing work. Energy may be stored in the form of thermal, mechanical, electrical, chemical, or nuclear energy. Energy can be transferred from one form to another but can neither created nor destroyed. For example, if a pan of water is heated with a natural gas flame, the chemical energy is converted to heat or thermal energy, as shown in the chemical equation for the combustion of methane gas:

CH_4 + $2O_2$ à $2H_2O$ + CO_2 + heat

If the same pan of water was heated on an electric stove, electrical energy is transferred to thermal energy. If the electricity used was generated by nuclear means, then the transfer of energy follows the sequence:

Nuclear à Thermal; Thermal à Electrical and Electrical à Thermal

The state of matter can be changed by thermal energy. To better understand this phenomenon, the behavior of the molecules in each of the three states is examined.

Gas: Molecules in the gaseous state are free to move, unrestricted, within a confined space. They move rapidly and in all directions, colliding with each other and the confining wall.

Liquid: Molecules in the liquid state are free to move within the liquid body. They do not have unrestricted motion, in this confined space, because of a strong attraction between the molecules. The attractive force of molecules in a liquid is much stronger than the attractive force of molecules in a gas.

Solid: Molecules in a solid state are in motion, but they are very restricted. The motion may be considered more of a molecular vibration. The attractive force, between molecules, is very strong.

When heat is introduced in the solid material, the molecules start vibrating more rapidly. As the thermal energy increases, the molecular motion increases until a temperature is reached, where the boundary walls or cohesion between molecules are broken down. To change from a liquid to a gas, more heat is applied until the single barrier to the molecules, which happens to be the surface of the liquid, is destroyed and the molecules escape the attractive force of surface tension. Thus, they are free to move unrestricted in the confined space. It is a known fact that thermal energy is released, whenever there is a change from a gaseous state to a liquid state.

Avogadro's Gas Laws

Avogadro's Law states that equal volume of gases, measured at the same temperature and pressure conditions, contain the same number of molecules.

Under standard conditions, one gram molecular weight of gas will occupy a volume of 22.4 liters. One mol-volume or molecular weight, at 60°F and 14.73psia (pounds per square inch absolute), occupies a volume of 378.9 cubic feet. Under standard conditions 22.4 liters of any gas contains 6.023×10^{23} molecules, which is Avogadro's number. The measurement of gas quantity or volume could be related to the number of gas molecules in a given space, or the rate of flow of the gas expressed in the number of molecules per unit of time.

Kinetic Energy of Translation

The behavior of the gas molecules, in a confined space, is explained by the Kinetic theory of gas molecules. It is already known that the gas molecules are in rapid motion, and that they collide with each other and with the confining walls. The relationship between the size of the gas molecule, its velocity and the kinetic energy of translation is expressed as:

$$K.E. = mv^2$$

Where:

K.E. = kinetic energy of translation

m = mass of the molecule

v = velocity of the molecule.

Under constant temperature and pressure conditions, all gas molecules will translate the same amount of kinetic energy. The velocity of the gas molecule is directly proportional to the weight of the gas molecule. With a given number of gas molecules, both the heavy and light molecules will exert the same pressure. The lighter molecules have greater numbers of collisions due to their higher velocity, but each impact creates less force. The heavier molecules have fewer collisions due to their heavy weight, but create more force. If the velocity of gas molecules is held constant, then the kinetic energy translated, will be directly proportional to the mass of the gas. This relationship is used for determining the specific gravity of a gas, and is the basis for mass and turbine meter measurement.

1.4.3 Liquid Measurement Principle

Liquids expand with increased temperature and shrink with lower temperature. So, when consumer buy a barrel of cold oil, he actually get more oil for the price of one barrel. Likewise, when a retailer sell a barrel of hot oil, he actually sell less oil for the price of one barrel. To avoid this dilemma, the Petroleum Industry has adopted standards of volume. In the United States, the standard volume is a barrel containing 42 US gallons measured at the standard temperature of 60°F. In Europe and many other parts of the World, the standard volume is the liter, measured at a standard temperature of 15°C. Tables of Volume Correction Factors (VCF), for correcting volumes measured at any temperature, to the equivalent volume at standard temperature are available from the American Petroleum Institute (API) and the International Standards Organization (ISO). So, it is not enough to just measure volumes of oil with meters or in tanks. It is also necessary to measure the temperature of the oil at the time of volume measurement.

The physical properties, which are important to measure, include:

- Density (or relative density)
- Sediment and Water (S&W)
- Vapor Pressure (RVP or TVP)
- Viscosity.

These physical properties may affect the volume measurement, the quality (hence, price) of oil, and the method of measuring volume.

Density or Gravity

Density: This is defined as the mass of fluid per unit volume at a given temperature. Examples are grams per cubic centimeter (gm/cc), pounds per cubic foot (?b. /cu. ft.) and kilograms per cubic meter (kg/cu.m.). Table 1.3 shows some typical density ranges, for various types of petroleum liquids.

Relative Density: This is defined as the ratio of the density of a liquid, at a given temperature, to the density of pure water at a standard temperature, which is either 60°F or 15°C. The temperature of the liquid and the temperature of water are shown as 70°F/60°F, for example, and must be included with the density statement.

Density and relative density are most commonly used for light liquid hydrocarbons (e.g. LPG, NGL, etc.), petrochemicals and, sometimes, refined products. Relative density is also used for determining VCF for crude oils.

Table 1.3

Density ranges of various petroleum liquids

Petroleum Liquid	**Relative Density**	**API Gravity range**
Crude oils	1.000-0.780	10 - 50°
Fuel oils, jet fuels	0.875- 0.780	30 - 50°
Gasoline	0.780 – 0.685	50 – 75°
Butanes, Propane	0.685 – 0.505	75 – 115°

API Gravity: This is a special gravity scale, commonly used in the petroleum industry. API gravity is most often measured with hydrometers, which were developed from the hydrometers that were first used for measuring sugar content of grape juice in the wine industry. API gravity is related to relative density and the density of water (which is defined as10°API) by the following formula:

API gravity is inversely related to relative density. So, liquids which are commonly called "heavier”, have low API gravities and high densities or relative densities, and liquids which are commonly called “lighter", have high API gravities and low densities or relative densities.

Compressibility

Liquids expand when pressure is reduced, and shrink in volume when the pressure is increased. The effects of compressibility are less than those due to temperature, but are not negligible. Correction factors can be calculated from the following formula:

$$CPL = 1/ [1-(P-P_e)*F].$$

Where, P is the operating pressure in psig (Pounds per square inch gauge).

Table 1.4 shows the compressibility factors per pounds sq.In (square Inch) (Divide all numbers by 100,000).

P_e is the equilibrium vapor pressure at operating pressure (which becomes zero for liquids with vapor pressures less than atmospheric pressure), and F is the compressibility factor.

Table 1.4

Compressibility factors per pounds sq.In. (Divide all numbers by 100,000)

Temp	**API Gravity At 60 Deg. F**				
Deg F	18.0	18.5	19.0	19.5	20.0
-99.0	0.434	0.437	0.440	0.444	0.447
99.5	0.434	0.437	0.441	0.444	