Gas Measurement Systems and Meter Calibration

(in context to city gas distribution)

A Project Report submitted in partial fulfillment of the requirements for the

Degree of

MASTER OF TECHNOLOGY

in

GAS ENGINEERING

(Academic Session 2003-05)

By

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CERTIFICATE

This is to certify that the Project Report on *"Gas Measurement Systems & Meter Calibration (in context to city gas distribution)"* submitted to University of Petroleum & Energy Studies, Dehradun, by **Ms. Deepshikha Pandey,** in partial fulfillment of the requirement for the award of Degree of Master of Technology in Gas Engineering (Academic Session 2003-05) is a bonafide work carried out by her under my supervision and guidance. This work has not been submitted anywhere else for any other degree or diploma.

Date: 22.5.2005

Dr.Himmat Singh

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This is to acknowledge with thanks the help, guidance and support that I have received during the project.

I have no words to express a deep sense of gratitude to the management of UPES for giving me an opportunity to pursue my project ,and in particular **Dr. Himmat Singh** (Distinguished Professor and programme coordinator M. Tech, UPES) and **Dr .B.P.Pandey** (Dean-College of Engineering UPES) ,for their able guidance and support.

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Executive Summary

The viability of the hydrocarbon business depends on the dispatch of various hydrocarbon fluids to the customers and the realisation of their prices. Since the product quantity is a critical variable, accurate flow measurement becomes a key factor in ensuring good returns for a hydrocarbon business unit.

Accurate measurement is all the more important when the ownership of the product changes hands. Quantities for custody transfer are treated as absolute when they are billed. The responsibility of this measurement is then to reduce all inaccuracies to a minimum so that measured quantities can be agreed upon for exchange custody. Flow meters lose accuracy gradually over time, even if we see no outside damages to the unit, the internal pieces could be giving erroneous readings. For this reason one should calibrate his valuable equipment every year to maintain correct readings and thus calibration is the most critical part of completing the proper custody transfer system.

Objective of the project

Purpose of Study

The purpose of this project is to understand flow metering in the gas industry and the importance of calibration in achieving an accurate flow measurement and thereby reaching a measurement system with minimum LUAG.

Importance of the Study

Today it is important to keep our equipments in top working order, and flow meters are no exception. As time progresses during the life of a flow meter, the performance will degrade slowly over time. If the meter is not accurate, a transport or distribution company could be giving away free gas and not even know of the loss it is suffering. The same way a gas user could be paying for the gas, which is never delivered to him. All these factors reduce the profitability and competitiveness of the company. Any minor inaccuracy in a meter can cause a drop in profit many times greater than the inaccuracy in the meter.

Possible Deliverable from the Thesis Work/Project

The project will help to understand flow measurement system in the gas industry, the various parameters affecting the Lost and unaccounted for gas which is a major factor in determining the success of any company and is an effort towards designing a system with minimum LUAG. Includes the designing of calibration policy for the meters temperature, pressure, flow calibration etc.

This report brings forth, the practical experience gained during the tenure of my summer internship in Mahanagar Gas Ltd. and the knowledge gained by me during my visit to Indraprastha Gas Ltd. installations. It gives an idea of the methodology adopted for the distribution of gas by MGL and the calibration methods, techniques and the schedule practiced by the company. It also brings forward a study on diaphragm meters presently employed by IGL and MGL. The report also has a focus on the "Lost and Unaccounted Gas" policy of the distribution companies, which is the determining factor for the success of any company.

Chapter – 1

INTRODUCTION

Natural gas is fast emerging as the most important energy source for the future. The abundance of natural gas, world-wide as well as domestically, coupled with its environmental soundness and multiple applications across all sectors, implies that natural gas is going to play an increasingly important role in meeting demand for energy world over.

Natural gas is a commodity that is bought and sold in markets throughout the world. In order to attach a value to an amount of gas, that amount must be measured. Typically, this measurement is done when the ownership of the gas passes from one entity to another. This measurement at the point of transfer of custody from one company to another is called CUSTODY TRANSFER METERING. The custody transfer metering is the cash register of the natural gas transmission and distribution industry. Accurate measurement of volume is important for both trade and industry. In the case of the gas trade, for example, metering errors can quickly add up to large sums of money: whether the error is in the customer's favour, so that the supplier is not paid for everything delivered, or in the supplier's favour, so that the customer does not receive the quantity paid for, cost is always an important incentive to meter and particularly to meter correctly. Quality assurance, too, requires good metering accuracy

Maintenance testing may consist of only secondary equipment calibration or complete mechanical inspection of the entire system or an actual throughput test against some agreed upon standards or a combination of these. In any case equipment used to test the meter must be proved and agreed upon. It is critical to ensure that all errors in metering are kept to an absolute minimum since reducing losses due to metering is a sure way to improve profits.

Calibration should be carried out regularly, at intervals to suit maintenance of the required accuracy. This is because meters drift with time, depending on factors such as operating conditions, the medium, the type of meter and how often it is used. It is often a good idea to plan ahead for regular calibrations over a longer period of time. Calibrating his equipment is one of the most important things one can do to minimizing inaccuracies.

Any measuring device for flow, pressure, humidity, etc. is there to tell how much of whatever is being mixed/added/purged. An incorrect reading can cost in time, accuracy, and most importantly, money.

The report card for any business is the balance between what comes in, what is used by the business and what goes out. In pipeline business this is referred to as the "Loss and Unaccounted for" (LUAF) or system balance. The control on the cost of doing business and the profits earned are based on this report. It must be properly and continually monitored so that the control is affected. Management must support the investment of time, money and personnel if they want a meaningful report upon which to base decisions.

Chapter – 2

FLOW

MEASUREMENT

2.1 Flow Metering

Flow measurement is the most important of all process measurements to achieve one or more of the following processes:

1. Fiscal metering
2. Control of chemical and other processes
3. Determination of the efficiency of the process

This typical system illustrates the basic elements of a gas meter installation with the associated equipment normally included.

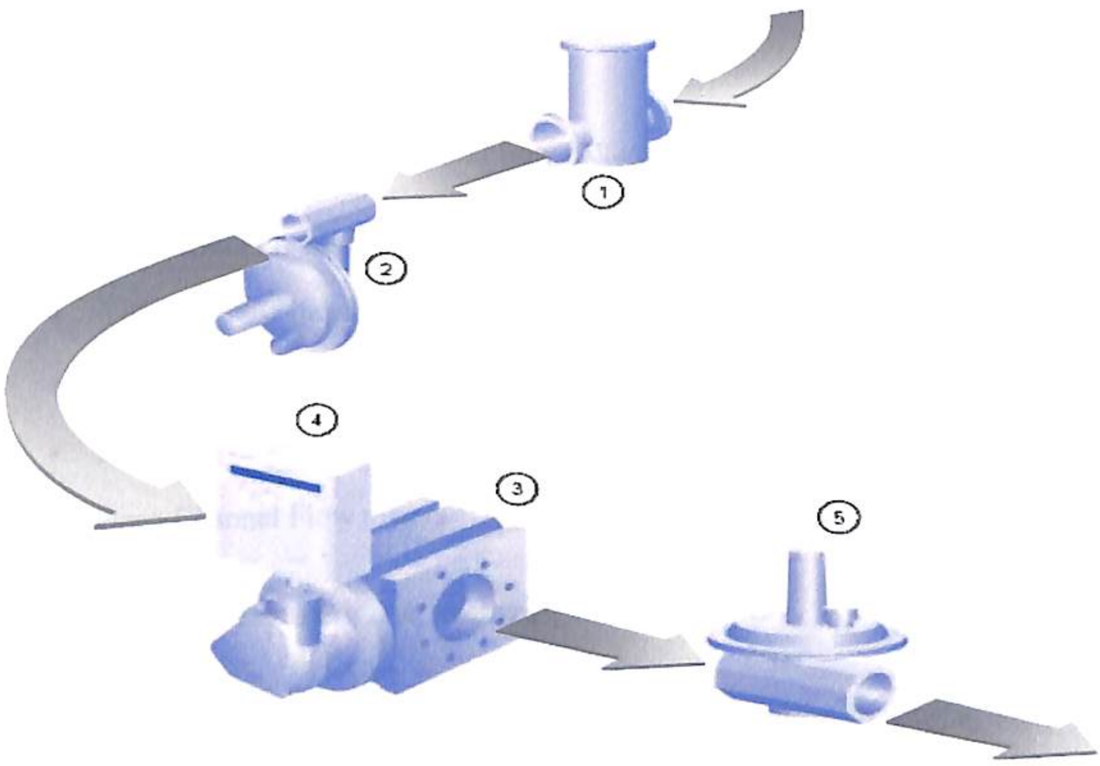

Figure 1: Elements of a gas meter installation

1. Filters remove particulate such as pipe scale, which could impair the operation or accuracy of regulators, meters or gas burning equipment.

2. An upstream pressure regulator reduces line pressure and provides a stable pressure to the meter.

3. The meter itself could be used to monitor the gas usage of an entire plant or a single piece of equipment.

4. An electronic flow computer, or correcting device, can be used to correct for variations in pressure and/or temperature.

5. A downstream regulator further reduces gas pressure as required by a specific piece of equipment.

2.2 Types of Metering

The most common principles for fluid flow metering are:

- Differential Pressure Flow meters
- Velocity Flow meters
- Positive Displacement Flow meters
- Mass Flow meters
- Open Channel Flow meters

Differential Pressure Flow meters

In a differential pressure drop device the flow is calculated by measuring the pressure drop over an obstruction inserted in the flow.

The differential pressure flow meter is based on the Bernoulli Equation, where the pressure drop and the further measured signal is a function of the square flow speed. The principle of differential pressure measurement as an inferred measurement of rate of flow is well established and widely used in many specific forms.Probably the most widely used differential pressure device is the orifice plate , the characteristics of which as a flow measurement device have been researched for over a 100 years , leading to the publication of many national and international standards.

The most common types of differential pressure flow meters are:

- Orifice Plates
- Flow Nozzles
- Venturi Tubes
- Variable Area - Rotameters

Orifice Plate

With an orifice plate, the fluid flow is measured through the difference in pressure from the upstream side to the downstream side of a partially obstructed pipe. The plate obstructing the flow offers a precisely measured obstruction that narrows the pipe and forces the flowing fluid to constrict.

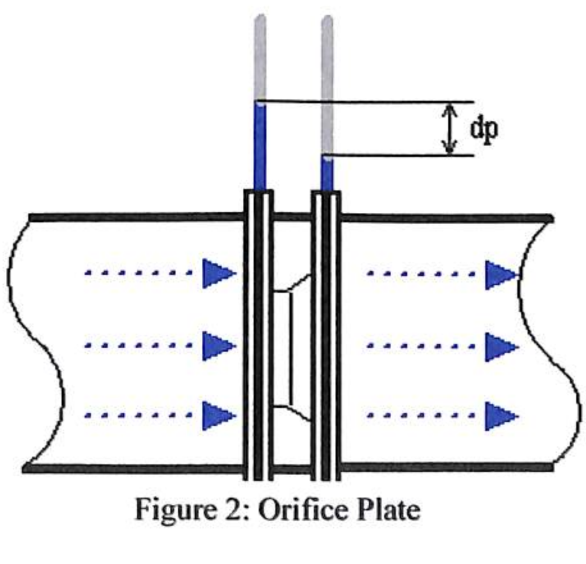

Figure 2: Orifice Plate

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dP, (the pressure drop) measured at the wall on either side of the plate is related to the flow rate using,

$$Q_m = C\frac{\pi d^2}{4}\left[\frac{2\rho 1 \Delta p}{(1-\beta^4)}\right]^{1/2}$$

The measured dP is proportional to the square of the flow rate. When a gas is metered, an adjustment is necessary to allow for a change in density through the contraction. The fluid density changes as a result of both velocity and pressure changes and compressibility effects are therefore important. The only difference between liquids and gases is the inclusion of an expansion factor.

$$\varepsilon = 1 - (0.351 + 0.256\beta^4 + 0.93\beta^8)\left[1-\left(\frac{P_2}{P_1}\right)^{1/k}\right]$$

An orifice plate is a very simple device installed in a straight run of pipe. The orifice plate contains a hole smaller than the pipe diameter. The flow constricts experiences a pressure drop, and then the differential pressure can be related to a flow.

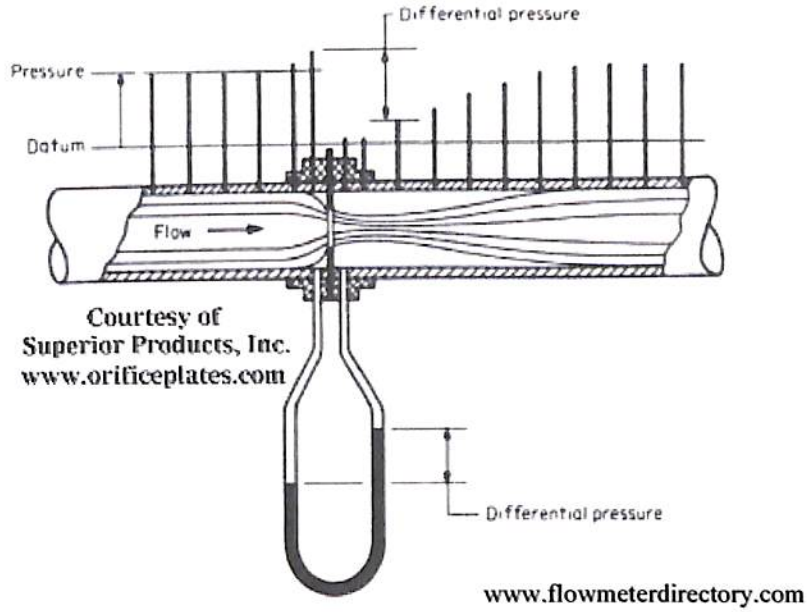
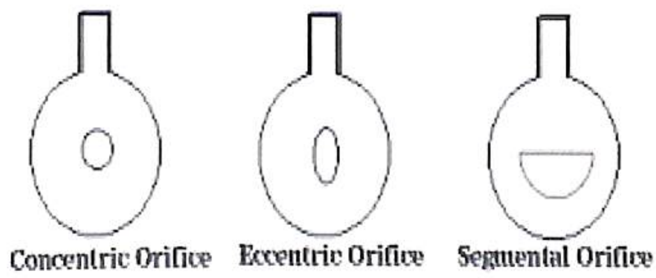


Figure 3: Orifice Plate Arrangement



www.flowmeterdirectory.com

It is also important to note that relating differential pressure to flow across an orifice depends on the location of the pressure taps in relation to the orifice. In Figure below, the pressure taps are designated as P1 and P2. "D" is the diameter of the pipe and "d" is the diameter of the orifice.

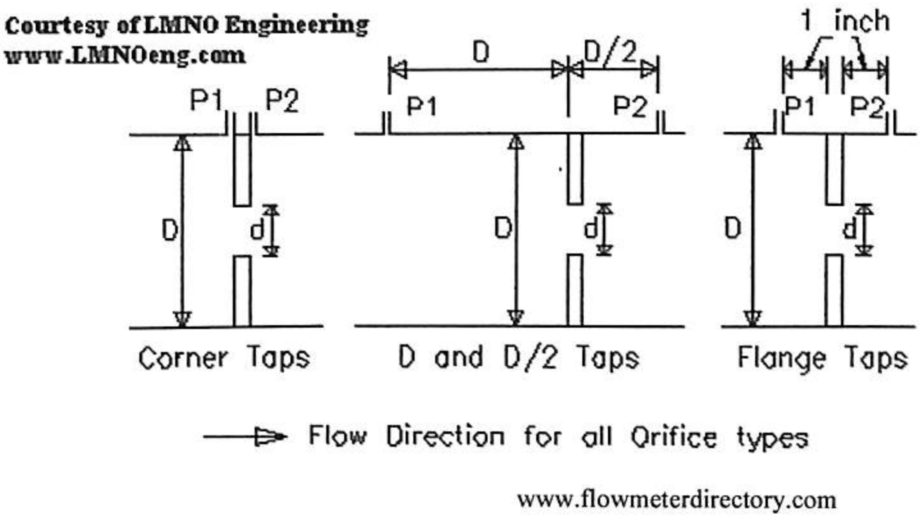


Figure 4: Various Tap Positions for Orifice Plates

Standards

There are two main standards for orifice metering: ISO 5167:1991 and AGA 3:2000

The uncertainty in the basic discharge coefficient depends on the operating Reynolds number and diameter ratio and is around 0.4 – 1%. When uncertainties in the expansibility factor, the measurement of orifice and pipe diameters and the measurement of differential pressures and density are taken into account together with the variations in the ambient and process conditions is unlikely that overall uncertainties much better than about 15 in full scale deflection will be achieved. A figure of about 2% full-scale deflection would be typical even when the installation complies with the requirements of the appropriate standard. However, the orifice plates are robust, simple, cheap and can be delivered for almost any application in any material.

Venturi Tube

Due to simplicity and dependability, the Venturi tube flow meter is often used in applications where it is necessary to work with higher Turndown Rates, or lower pressure drops, than the orifice plate can provide.

In the Venturi Tube the fluid flow rate is measured by reducing the cross sectional flow area in the flow path, generating a pressure difference. After the constricted area, the fluid is passed through a pressure recovery exit section, where up to 80% of the differential pressure generated at the constricted area, is recovered.

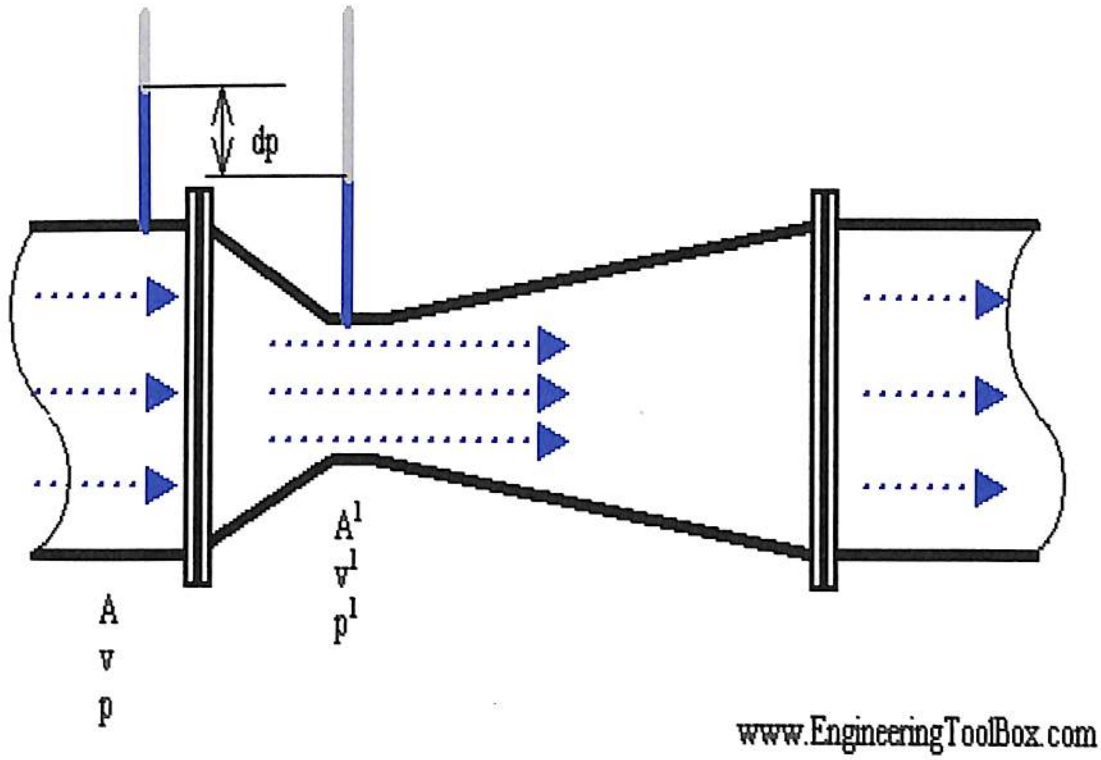


Figure 5: Venturi Tube

With proper instrumentation and flow calibration, the Venturi Tube flow rate can be reduced to about 10% of its full-scale range with proper accuracy. This provides a Turndown Rate 10:1. However, the total measurement uncertainty achievable in gases is around 3% of the full scale.

Flow Nozzle

Flow nozzles are often used as measuring elements for air and gas flow in industrial applications.

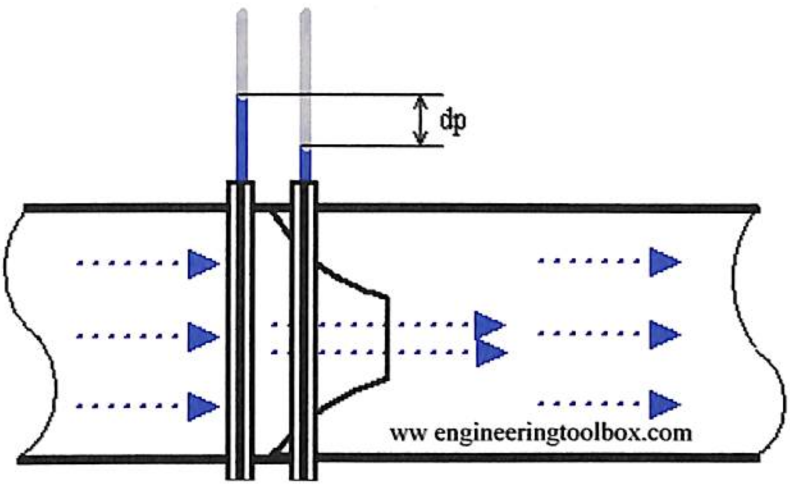


Figure 6: Flow Nozzle

www.EngineeringToolBox.com

The flow nozzle is relative simple and cheap, and available for many applications in many materials. There are two designs of nozzles, which are standardized and are in general use. These are the ISA 1932 nozzle and the long radius or ASME nozzle. Both designs are intended for mounting between pipe flanges with the pressure tappings located in the pipe wall. Corner tapping are used for the ISA 1932 and D and D/2 tappings are specified for the long radius nozzle. The discharge coefficients of all the standard nozzles range between about 0.9 and 0.99 .The uncertainty in the coefficient data varies both with the nozzle design and β ratio.

The Sonic Nozzle – Critical Flow Nozzle

When a gas accelerates through a nozzle, the velocity increases and the pressure and the gas density decreases. The maximum velocity is achieved at the throat, the minimum area, where it breaks Mach 1 or sonic. At this point it is not possible to increase the flow by lowering the downstream pressure. This situation is used in many control systems to maintain fixed, accurate, repeatable gas flow rates unaffected by the downstream pressure.

Variable Area Flow meter or Rotameter

The rotameter consists of a vertically oriented glass (or plastic) tube with a larger end at the top, and a metering float, which is free to move within the tube. Fluid flow causes the float to rise in the tube as the upward pressure differential and buoyancy of the fluid overcomes the effect of gravity. Variable area meters are not normally regarded as high performance devices and than the tapered transparent tube variety is usually selected for its cost effectiveness rather than performance .It is also a visual flow indicator .For such meters uncertainties of 2% to 3% of the full scale would be typical. However,versions manufactured on a greater precision can give uncertainties around 0.5% of full scale with individual calibration disadvantage of tapered tube meters with free floats is that they have to be mounted vertically.

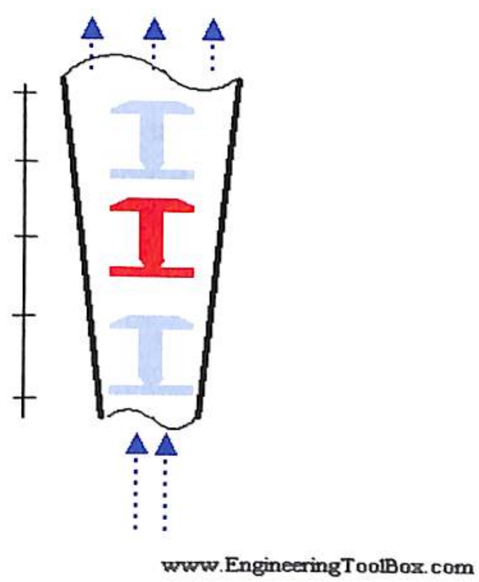


Figure 7: Rotameter

The float rises until the annular area between the float and tube increases sufficiently to allow a state of dynamic equilibrium between the upward differential pressure and buoyancy factors, and downward gravity factors. The height of the float is an indication of the flow rate. The tube can be calibrated and graduated in appropriate flow units. The Rotameter meter typically has a Turndown Ratio up to 12:1. The accuracy may be as good as 1% of full-scale rating.

Velocity Flow meter

In a velocity flow meter the flow is calculated by measuring the speed in one or more points in the flow, and integrating the flow speed over the flow area.

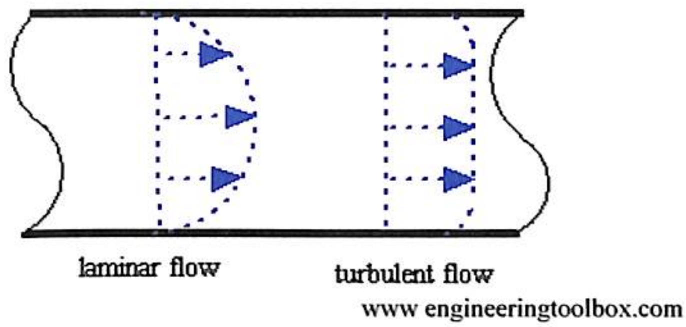


Figure 8: Velocity Flow Meter

Pitot tube

The Pitot tube is the one mostly used (and cheapest) ways to measure fluid flow, especially in air applications as ventilation and HVAC systems, even used in airplanes for the speed measurement.

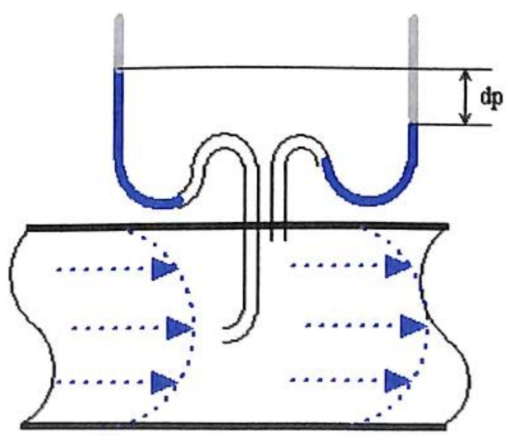


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Figure 9: Pitot tube

The Pitot tube measures the fluid flow velocity by converting the kinetic energy of the flow into potential energy. The use of the Pitot tube is restricted to point measuring. With the "annubar", or multi-orifice Pitot probe, the dynamic pressure can be measured across the velocity profile, and the annubar obtains an averaging effect.

Pitot tubes are seldom used in industrial applications because of vibration, lack of ruggedness and the need for a velocity traverse to obtain an accurate volumetric flow measurement. However, a modified version of pitot tubes called averaging pitot tubes find wide application in industries which overcomes the short comings of a pitot tube.

Calorimetric Flow meter

The calorimetric principle for fluid flow measurement is based on two temperature sensors in close contact with the fluid but thermal insulated from each other.

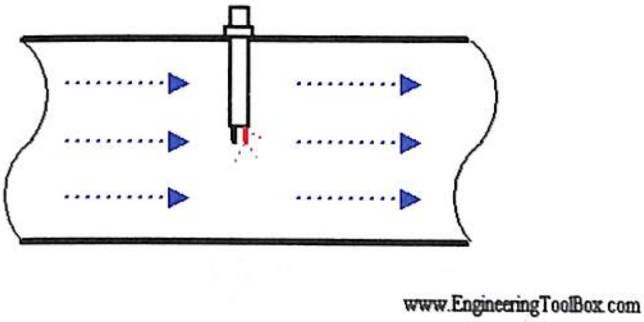


Figure 10: Calorimetric flow meter

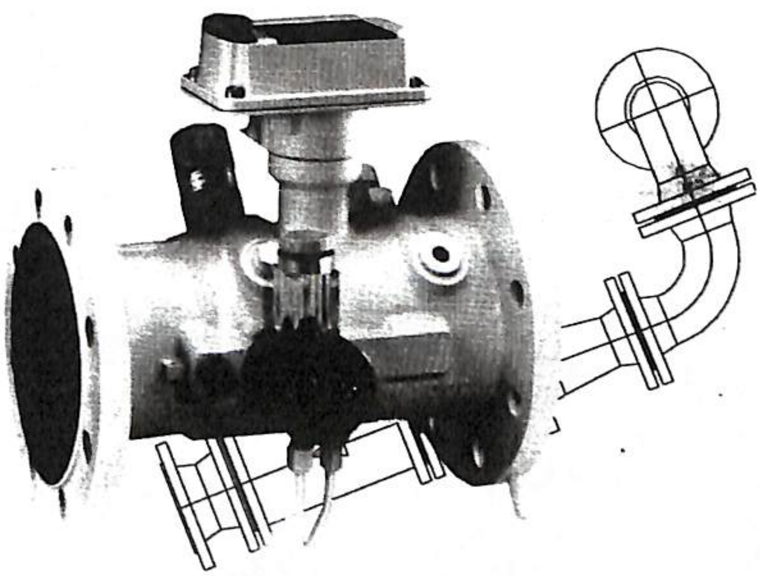
One of the two sensors is constantly heated and the cooling effect of the flowing fluid is used to monitor the flow rate. In a stationary (no flow) fluid condition there is a constant temperature difference between the two temperature sensors. When the fluid flow increases, heat energy is drawn from the heated sensor and the temperature difference between the sensors are reduced. The reduction is proportional to the flow rate of the fluid. Response times will vary due the thermal conductivity of the fluid. In general lower thermal conductivity requires higher velocity for proper measurement. The calorimetric flow meter can achieve relatively high accuracy at low flow rates.

Turbine Flow meter

Turbine type flow metering devices are applied worldwide to the measurement and control of products in the industrial, chemical and petroleum marketplaces. Significant advantages associated with the use of turbine flow meters, in lieu of other metering principles, make increased future use inevitable.

There are many different manufacturing designs of turbine flow meters, but in general they are all based on the same simple principle:

If a fluid moves through a pipe and acts on the vanes of a turbine, the turbine will start to spin and rotate. The rate of spin is measured to calculate the flow.



MGL manual

Figure 11: Turbine meter

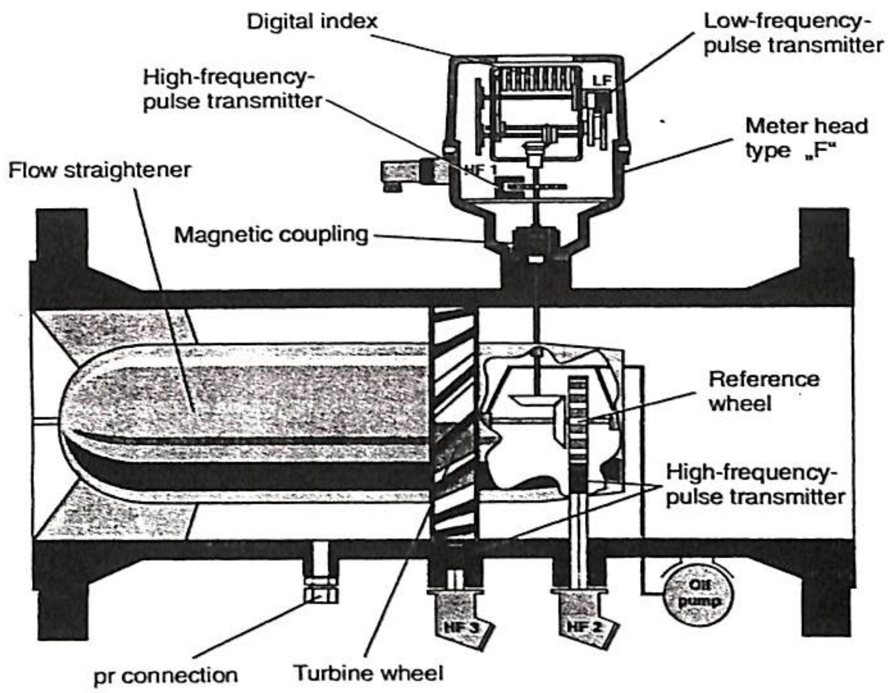


Fig. 1: Sectional drawing of a turbine meter

MGL manual

Figure 12: Sectional drawing of a turbine meter

A gas turbine meter mainly consists of the body, measuring mechanism and the output/readout devices. The body houses the meter internals. The measuring mechanism consists of rotor with a number of angled blades, mounted coaxially on the meter body centerline, supported on ball race type bearings that are either permanently lubricated or lubricated using pumps. The rotor is supported upstream and generally down stream by a spider arrangement, which often incorporates flow straighteners. The movement of gas over the rotor blade imparts force causing the rotor to revolve. The angular velocity of the rotor is directly proportional to the flow velocity. The number of revolutions depends on the passage way shape, size, the rotor design and also on the load imposed due to internal mechanical friction, fluid drag, external loading and gas density. As the driving torque on blades is dependent on the density and the square of the velocity and particularly for gases since low density is involved, the velocity of gas is increased in the annular passage formed by the nose cone and interior o the wall body, providing more torque and increasing low flow rate performance. In order to avoid the over speeding of the bearings, gas turbine meters have blades set at a much smaller angle to the meter axis and maximum velocity limited to a typical value of 50m/sec. For turbine meters with electrical pulse output, either the rotor blades are made up of magnetic material or the blade tips are fitted with a magnetic material. As the blade passes beneath a magnetic pick up coil, a pulse is generated. Total number of pulses provides an indication of volume passed through the meter. The frequency of the output is proportional to the speed of flow. Due to the presence of magnetic field, a small retarding force acts on the blades and the performance is affected variety of alternative methods such as proximity switches, optical sensors etc. have been developed which reduce the drag to almost insignificant level. The readout devices may be of any form suitable for application such as instantaneous flow rate readings from a frequency counter, totalized flow from an integrator and a range of analog indicators compatible with control equipments.

The accuracy of the meter is generally specified as within ±1% of the true volume over flow range (0.2 Qmax – Qmax). For high-pressure meters, as they maintain good performance at low flow rates, in the upper range the meter error can be limited to ±0.5% and ±1% in the lower limits. For better accuracy the gas meters should be calibrated close to the intended operating conditions against an approved secondary standard.

Gas turbine meters are generally designed for maximum flow rate Qmax considering rotor speed and normal pressure loss. The maximum flow rate remains same irrespective of the line pressure within the stated maximum operating pressure. Minimum flow rate is the lowest flow rate at which the meter will operate within the specified accuracy limits, normally set at ±1%. The minimum flow rate is approximated as inversely proportional to the square root of the gas density through the meter.

For each meter, a calibration characteristic (K factor) is required, which is determined by means of a flow calibration. The flow calibration should be carried out over the entire operating range of the meter as it may vary with the flow. Once the K factor has been defined, the flow through the meter can be calculated using

Volume = Pulses / K

The flow rate can be calculated as

$$Q_V = f / K$$

This is a volume flow rate at actual conditions and can be converted into mass flow rate or standard volume flow rate by multiplying by density or performing a PTZ correction.

The turndown ratios may be more than 100:1 if the turbine meter is calibrated for a single fluid and used at constant conditions. Accuracy may be better than +/-0.1%.

Vortex Flow Meter

An obstruction in a fluid flow creates vortices in a downstream flow. Every obstruction has a critical fluid flow speed at which vortex shedding occurs. Vortex shedding is the instance where alternating low-pressure zones are generated in the downstream.

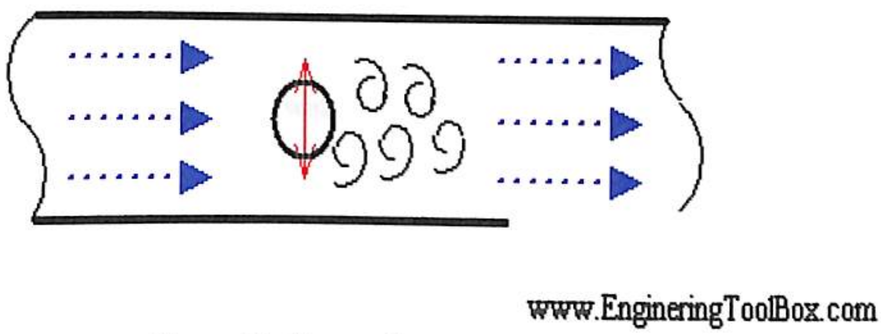


Figure 13: Vortex flow meter

These alternating low-pressure zones cause the obstruction to move towards the low-pressure zone. With sensors gauging the vortices the strength of the flow can be measured. It has been experimentally found that the frequency (f) at which the vortices are shed is proportional to the flow velocity (U) and inversely proportional to the characteristic dimension (width, d) of the bluff body. This permits the measurement of the flow rate by sensing the frequency of the vortex formation on the alternate sides of the bluff body. The proportional ratio called Strouhal number, characterising the bluff body is:

$$S = f.d / U$$

The width of the bluff body for a given meter is fixed hence a constant. The frequency of shedding then is linearly proportional to the average flowing velocity.

Repeatability for the vortex meter is in the order of 0.15% to 0.25% of flow rate. Accuracy (% of rate) is 1.25% calibrated for gas and steam and 1.5% uncalibrated for gas and steam. For gases minimum velocity is between 10 – 20 fps and the maximum flow velocity is limited in between 200 to 250 fps. It is determined by the compressibility of the gas.

Electromagnetic Flow meter

An electromagnetic flow meter operates on Faraday's law of electromagnetic induction that states that a voltage will be induced when a conductor moves through a magnetic field. The liquid serves as the conductor and energized coils outside the flow tube create the magnetic field. The voltage produced is directly proportional to the flow rate. Two electrodes mounted in the pipe wall detect the voltage, which is measured by a secondary element.

Electromagnetic flow meters can measure difficult and corrosive liquids and slurries, and they can measure flow in both directions with equal accuracy. These flow meters have relatively high power consumption and can only be used for electrical conductive fluids as water.

Ultrasonic Flow meter

The effect of motion of a sound source and its effect on the frequency of the sound was observed and described by Christian Johann Doppler.

"The frequency of the reflected signal is modified by the velocity and direction of the fluid flow"

If a fluid is moving towards a transducer, the frequency of the returning signal will increase. As fluid moves away from a transducer, the frequency of the returning signal decreases. The frequency difference is equal to the reflected frequency minus the originating frequency and can be use to calculate the fluid flow speed.

Positive Displacement Flow meter

The positive displacement flow meter measures process fluid flow by precision-fitted rotors as flow measuring elements. Known and fixed volumes are displaced between the rotors. The rotation of the rotors is proportional to the volume of the fluid being displaced.

As the rotor rotates, the gas enters the space between the rotor and the chamber wall. When the rotor reaches the horizontal position a discrete volume of gas is trapped between the rotor and the chamber wall. As the rotor continues to turn, the trapped gas is ported to the meter outlet. The other rotor performs the similar cycle and the process is repeated four times for each complete revolution. Flow is totalized by counting the number of rotations. The rotors drive a counter mechanism via a high torque magnetic coupling. The flow indication of the counter is in "m^3". The number of rotations of the rotor is counted by an integral electronic pulse transmitter and converted to volume and flow rate.

These types of meters are used at pressures upto 80 bar but temperatures do not generally exceed 60 degree C. Rageabilities upto 25:1 can be achieved and flow rates range from 2 x 10^{-3} to 2 m^3/s at line conditions. Uncertainties better than ±0.5% of totalized flow are attainable with clean gases.

Constant volume meters on the other hand are used at temperatures close to ambient and pressure upto 9 bar. They can also be designed to operate at pressure upto 80 bars and are less bulky. The have a rangeability of 25:1 and can measure totalized flow at flow rate upto 3 sm^3 /s to within ±0.5%.

Diaphragm Gas Meters

Diaphragm positive displacement meters are generally employed for the domestic metering of the manufactured gas, natural gas and LPG. The meter consists of housing containing four chambers of which two are enclosed by bellows, which expand and contract as they are charged and exhausted respectively. Flow into and out of the chambers is controlled by the means of slide valves. Each chamber is successively charged and then discharged by the movement of the slide valves. The volume of gas passed through the meter is obtained through a linkage arrangement, which connects the diaphragm to a mechanical counter system, which counts the number of displacements.

Provided these devices are carefully calibrated and maintained, uncertainties in totalized flow of 1% can be attained. Range of metering capacity of the meter is from $5x10^{-4}$ to 10^{-1} m^3/s. Pressure and temperature of the metered gas are usually close to ambient and the meter rangeability is typically 20:1 and meters with rangeability upto 100:1 are also available.

These meters are popular since they are cheaply manufactured and measure directly volume. However they are unsuitable for non-corrosive gases and cannot be used for large flow rates.

Type approval testing of these meters for meteorological requirements against recognized standards is mandatory to break down the barriers in the international trade. Gas meter accuracy should not exceed the maximum established permissible errors and change of accuracy during the course of meter operation should be minimal. These aspects are proved during type approval tests.

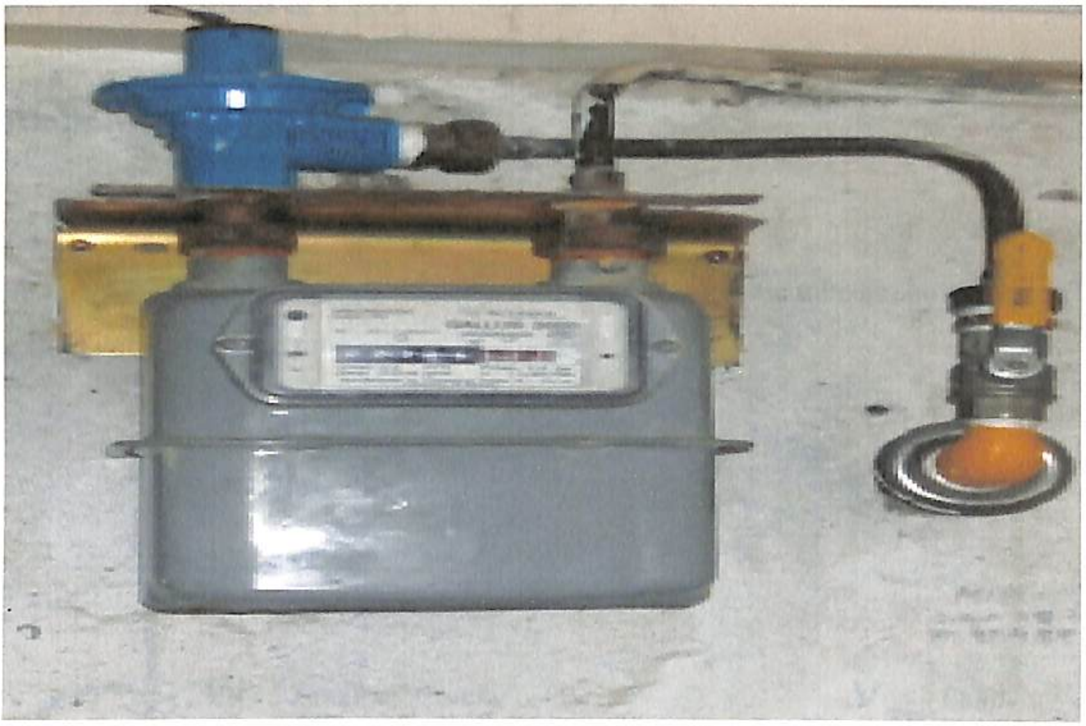


Figure 14: Diaphragm Meter

Figure 15: Safe PNG Supply to Consumers

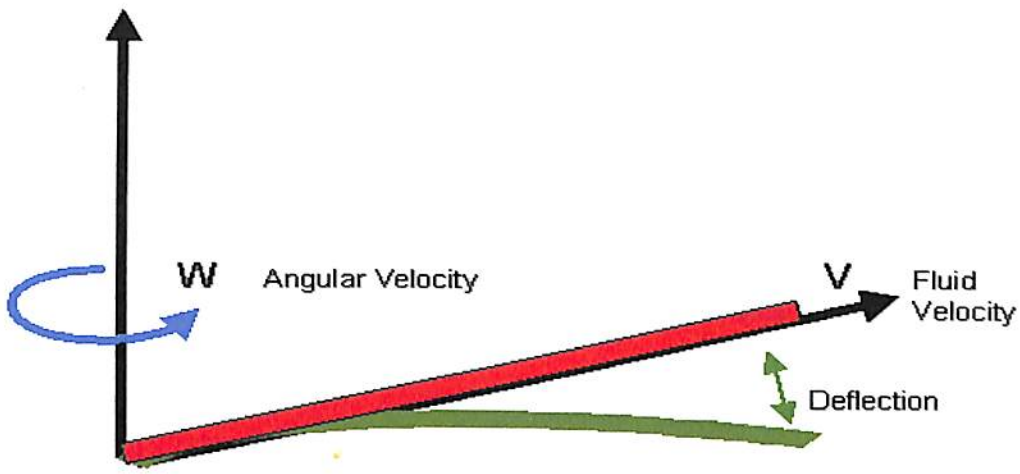
A view inside the kitchen (MGL installations)

Flow Measurement of CNG

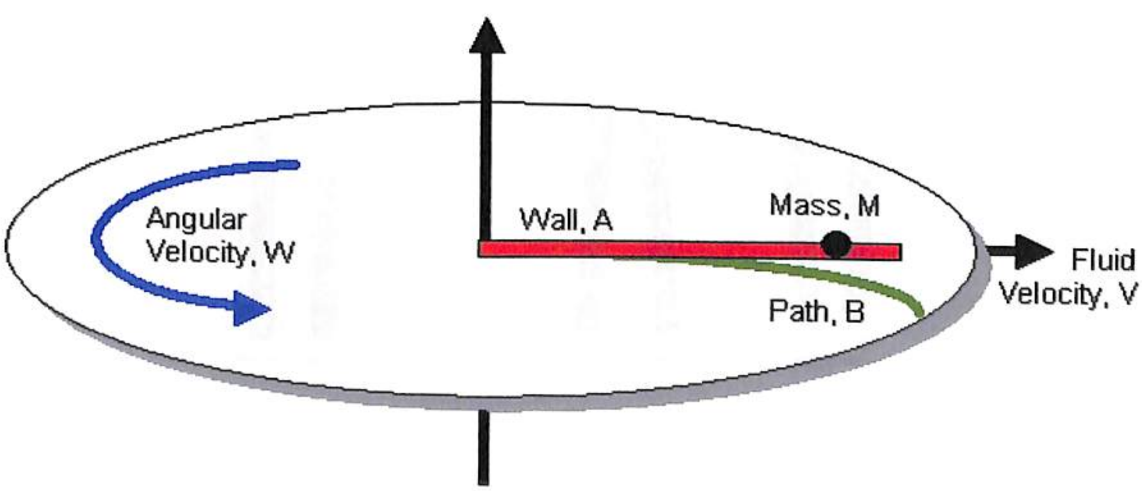
Coriolis Mass Flow Meters

Coriolis Principle

If we imagine a fluid flowing (at velocity V) in a rotating elastic tube as shown below. The fluid will deflect the tube.



Further if we consider a Mass M moving from the center to the edge of a rotating plate. This Mass M will take path B as shown below



If the mass M is guided by Wall A (i.e. the tube), a Coriolis force will be exerted on the wall as shown below.

Coriolis force: **Fc = -2 M V W**

Now, consider the interior of the Rota MASS sensor as shown below

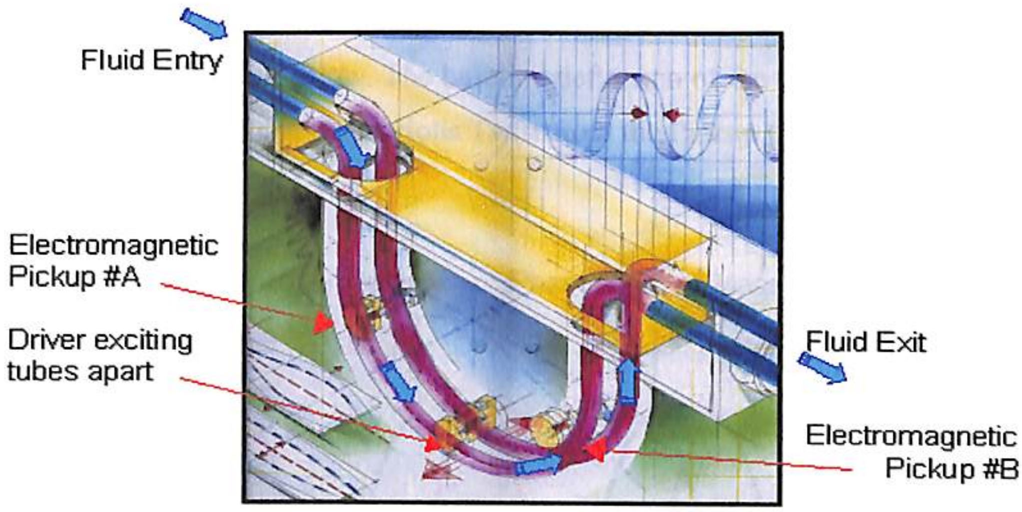


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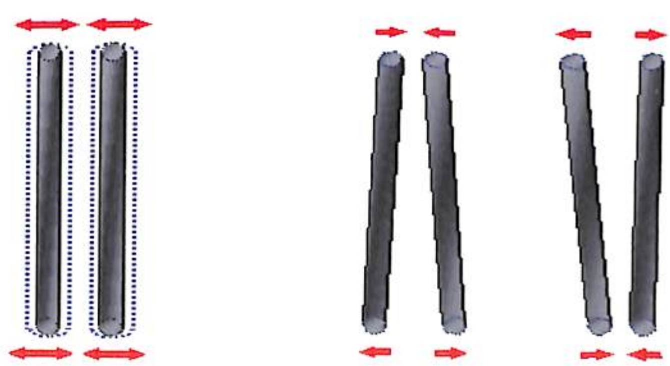
Figure 16: Interior of the Rota MASS sensor

The tube walls guide the process fluid as it flows through the U-Tube pathway. With no fluid inside the tubes the Driver excites the tubes apart at a nominal 150Hz as shown below.

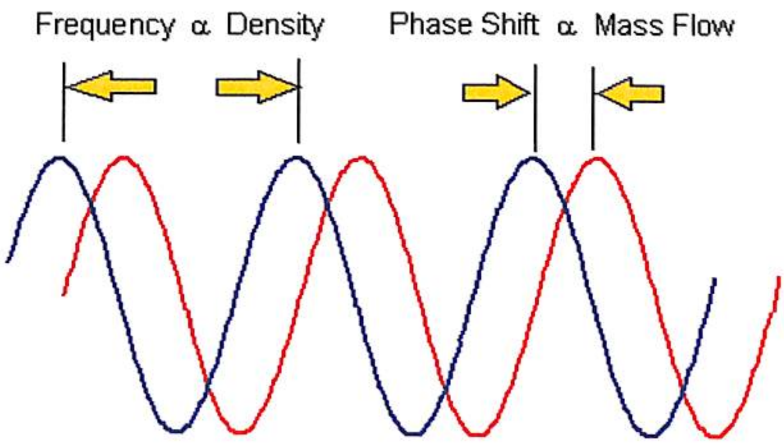


No Flow:
Parallel Deflection

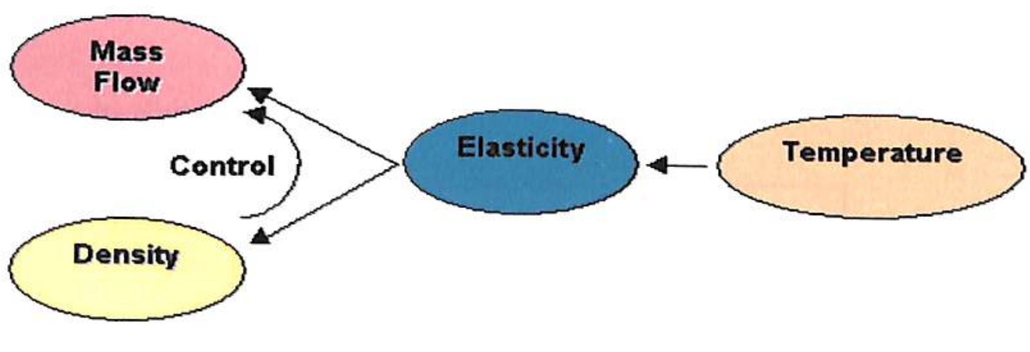
Mass Flow:
Coriolis Twist

Now imagine fluid of Mass M flowing through and out of the RotaMASS tubes. As the fluid flows down the first half of the U-Tubes it will tend to deflect the tubes in towards each other. Conversely, when the fluid flows up the second half of the U-Tubes it will tend to deflect the tubes out away from each other. This Coriolis Twist action is shown above.

Now consider the diagram below. The baseline deflection of the tubes from the Driver is shown by the blue trend and the Coriolis Twist from the Pickup Coil is designated by the red trend.



Now the temperature of these tubes dramatically affects their flexibility. So temperature measurement is very critical as follows;



The Mass flow equation for the RotaMASS can be described as follows;

$$\dot{M} = S_k \frac{A_c}{A_e} \cdot \frac{1}{f_V}$$

Where,

M	= Mass flow rate
Ac	= Amplitude of coriolis oscillation
Ae	= Amplitude of excitation oscillation
Ac/Ae	= Phase Angle
Sk	= Sensor constant (calibration constant)
	= Sk(20°C) (1+Skt x (T-20°C)) temperature
Sk(20°C)correction	
fv	= Sensor constant at 20°C
Skt	= Excitation frequency
	= Temperature correction coefficient (material constant)

The Density equation for the RotaMASS can be described as follows;

$$\rho = KD \cdot \left(\left(\frac{f_I(20^\circ C)}{f_V(20^\circ C)} \right)^2 - 1 \right)$$

p	= Density
fl(20)	= Exciting frequency of the empty tubes at 20°C
fv(20)	= Exciting frequency of the filled tubes at 20°C
KD	= Density calibration constant
fv(20)	= fv / (1+FKT (T - 20 °C)) temperature correction of the actual frequency
FKT	= Temperature correction coefficient, depending on material and size

When a particle moves across the surface of a rotating body, it is caused to accelerate by a force called Coriolis force, which acts normally, to both the direction in which the particle moves and the axis of rotation of the body. The magnitude of the force is directly proportional to the product of the mass of the particle and Coriolis acceleration. These forces are generated whenever a body, which is rotated about a fixed position, undergoes a change of position relative to that fixed position. Instead of rotating the body about a fixed point, these forces may be generated by vibrating the tube. The smallest amount of energy to vibrate the tube is at the natural frequency of the tube.

Coriolis forces occur only when both the axial flow and forced vibration at right angle to the direction of motion occurs simultaneously. Either vibration without flow or flow without vibration causes no twist and hence no output. The motion on any point on the tube represents a sine wave. As mass flow occurs, the inlet side motion of the tube lags the driver phase and the outlet side motion leads the driver phase. The time delay between the two is proportional to the mass flow rate through the sensor and is given by:

$$\mathbf{Q_m = K \,.\Delta\, t\,/\,8\,.\,r^2}$$

The mass flow rate is proportional only to the time interval Δt and some geometric constants, Q_m is independent of the vibrating frequency of the measuring tube.

Because of the steep change in flow at the beginning and end of a filling cycle, the measurement error increases drastically. If the quantity during this very short duration is not appreciable, the same can be ignored to ensure that the customer does not get less quantity of CNG than the indicated amount.

When a fluid of density ρ flows at a constant velocity v along an oscillating tube rotating at any length x of the oscillating tube experiences a transverse Coriolis force of magnitude

$$F = 2.\omega .v. \rho .A. \Delta x$$

Where A is the cross-sectional area of the oscillating tube interior. Since the mass flow rate can be expressed as

$$q_m = v.A.\rho$$

The transverse Coriolis force can therefore be expressed as

$$F_c = 2.\omega . q_m. \Delta x$$

Hence, the measurement of the Coriolis force exerted by the flowing fluid on a rotating tube can provide a measurement of the mass flow rate.
Commercially available Coriolis meters have the following performance specifications:

Size: 1/16" to 6"
Flow rates: gm/h to 10t/min
Range: 25:1(typical) and 100:1 in some applications
Accuracy: 0.15% - 0.25% + zero shift error.

Coriolis meters are increasingly being used in CNG dispensers. Mass flow meter is a reliable convenient way of metering CNG. These meters are fitted with transmitters to transfer the flow data to the micro-controller of CNG dispensers. They are susceptible to temperature and pressure change in the process. For e.g. with the increase of temperature, stiffness of the stainless steel coriolis tube decreases. Output of the meter is typically affected by 4%/100 C on higher pressure stiffness increases and change is about 0.012% per bar. Microprocessor based transmitters are available which not only extend useful range of the meter but also supposed to incorporate compensation on the variation of process parameters. However the impact of this advanced digital technology is not discernible to accommodate rapid fluctuation of flow and pressure.

The maximum permissible errors for custody transfer measurements with natural gas are 1% or 2% depending on the flow rate. For the purpose of initial verification, the coriolis meters may be calibrated with water and used with natural gas. In that case, the meter shall meet reduced error limits of 1.3% (instead of 2%) and 0.3 %(instead of 1%). The fact that a low density the meter will work less accurate makes it necessary to put a harder requirement on the initial verification with water.

Another characteristic of these meters to be reckoned with is the stability of the so-called live zero. Dispenser manipulators normally stipulate a low cut-off of flow at 0.5% of the maximum flow. The rangeability of these meters is typically 30:1.The base line instability may reduce rangeability of the meter and is the source of inaccuracy.

These meters become highly unstable when subjected to two-phase flow. In NGV stations use of oil-lubricated compressors is quite common. Neither SAE's J1616 nor ISO 15403 set specific limits on oil in CNG. Freely suspended oil is normally separated by using coalescer filters. As CNG is a dry gas, presence of certain amount of oil is considered good for engine and SAE is considering to allow up to 80-ppm lube oil in CNG dispensing. However, when here is a two-phase flow, abrupt 'jump' occurs in the meter reading and it is not possible to correlate the amount of jump to any parameter tow work out actual transfer of CNG.

Configuration of the micro-controller used in the dispensers has a profound impact on the accuracy of the dispensed quantity of CNG in a refuelling station. The filling cycle normally starts with resetting the controller through a switch. In many dispensers unless the controller is reset, the controller ignores flow meter signal, even if there is CNG flow. Also, to account for metering characteristics and to incorporate temperature compensation etc, many dispensers do not update the flow display a few seconds after the fill starts. Indeed, occurrence of unmetered gas is possible, for e.g. when the on-off valves.

SOV start passing and if the controller is not reset. SOVs may pass due to the erosion of valve seats or get stuck-up in open position. This is true even in the case of the pneumatic cylinder actuated valves. While problem can be addressed to some degree with effective maintenance programme, the feature is surely a shortcoming of the system design as far as the accuracy of the dispenser system is concerned. This may also become a safety hazard. Mere comparison of the transmitter totaliser and the dispenser totaliser cannot indicate the correction required. One remedy is to allow dispensing through another final control element only during 'permissive' states generated in dispenser logic. Another recourse is to have the totaliser updated after a predetermined time delay once the flow is detected, irrespective of the reset switch status. Thus a standard PLC may be more suited for the purpose especially where the number of dispensers is large and station compressors already using PLC.

Coriolis meters are increasingly being used in CNG dispensers. It has been reported that coriolis mass flow meters, beyond a certain threshold value of flow characteristics of the model of the meter, output of the meter becomes very unstable with high error of increasing magnitude. The meter tested with CNG at 211Kg/cm g with flow rate varying between 7 to 18 Kg/min. The range of the meter was specified at about 0 – 20 Kg/min. From the test curve the error becomes higher than the specified limit of 0.5% at flows beyond a threshold value of 10 Kg/min.

Chapter – 3

Meter Selection

3.1 Selection of a Meter

A very common question asked in any flow measurement is "what type of meter is best for an application?" The answer depends on many factors but should first be preceded by often- ignored consideration about the fundamental nature of the fluid to be measured.

- Is there flashing or condensing?
- Are there well-defined pressure, volume and temperature relationships?
- Does a predictable flow pattern exist based on Reynolds number?
- Is the flow Newtonian?
- Is the fluid free of foreign materials that will affect meter performance?
- Is the fluid a constant composition or a slow changing measurable analysis?
- Is there a fairly constant rate, or do rate variations fall within meter response time and measurement range?
- How about a laminar, irregular, swirling flow pattern?
- Single or multiphase flow at meter inlet?
- Smooth or pulsating flow?
- Will liquid flow fill the line?

Deciding which type of meter is the best choice for a particular application depends upon the following:

- The pressure of the gas being measured
- The maximum flow rate to be measured
- The minimum flow rate to be measured

Gas Pressure

The first consideration in selecting a gas meter is the pressure of the gas being measured. Depending on the specific model, diaphragm meters have pressure ratings up to 100 psig. Rotary meters can operate at pressures up to 285 psig. For applications above 285 psig, a turbine meter is selected.

Maximum Flow Rates

Capacity ratings for the various types of meters overlap as shown in the chart below. However, considering line pressures of 0.25 psig, the following meter choices are typical:

- Diaphragm Meter – max. flow rates of 10,000 scfh or less
- Rotary Meter – max. flow rates of 1,500-15,000 scfh
- Turbine Meter – max. flow rates of 1,000 and above

The overlap in capacity ratings allows for versatility when selecting the correct meter for differing applications. For example, an application's maximum flow rate may fit into the "typical" selection shown above for a diaphragm meter, but the pressure of the gas being measured may be above 100 psig. In this case, a small rotary meter would be considered.

Rangeability

Another consideration to keep in mind when selecting a gas meter is the rangeability of the meter. Rangeability is the ratio of maximum flow rate to minimum flow rate that can be measured within the specified accuracy of the meter.

American Meter diaphragm meters provide an accuracy of ±1% of reading with a rangeability of *greater than* 100:1. Therefore, an AC-250 meter with a maximum rating of 250 scfh will provide ±1% accuracy for flow rates from 2.5 to 250 scfh.

For rotary meters, rangeability at ±1% accuracy ranges from 30:1 up to 120:1, depending on the specific meter size. For applications where ±2% accuracy is sufficient, rotary meters will provide rangeabilities up to 225:1.

A distinct feature of turbine meters is that the rangeability increases as the measuring pressure increases, providing a wider operating range at higher pressures.

For example, a 3" GTS turbine meter operating at a line pressure of 0.25 psig has a rangeability of 12:1. The maximum rated capacity at this pressure is 10,000 scfh, providing an operating range of 833 to 10,000 scfh within the accuracy limitation of ±1% of reading. The same meter in an application with a line pressure of 100 psig has a rangeability of 33:1 and a maximum rated capacity of 78,000 scfh. Given this, the meter has a measuring range of 2,360 to 78,000 scfh within the accuracy limitation of ±1% of reading.

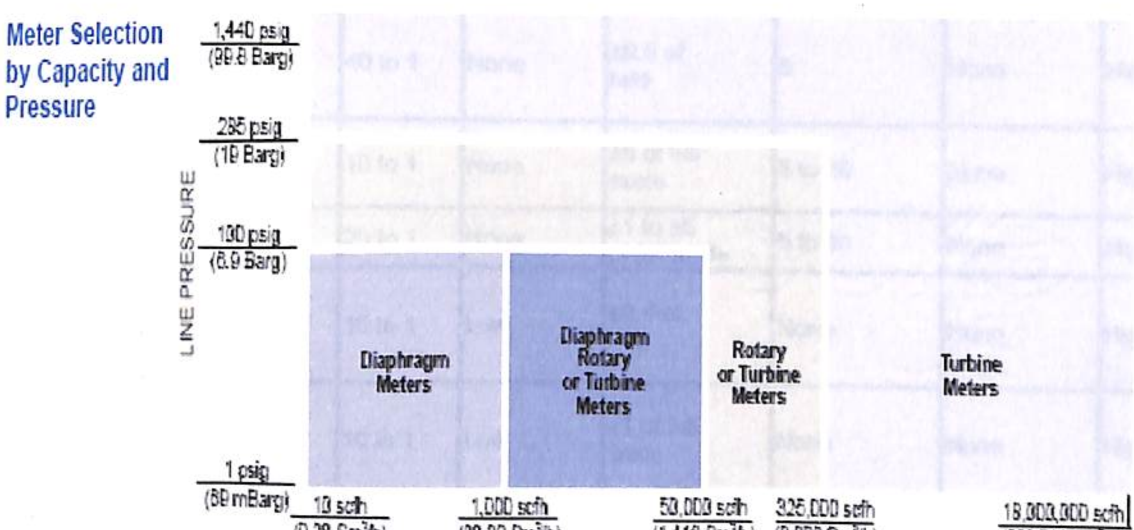


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Table 1 Maximum Gas Flow to Be Measured – Standard Cfh / Cmh

3.2 FLOWMETER SELECTION CRITERIA

Flow meter element	Recommended Service	Range ability	Pressure Loss	Typical Accuracy, percent	Required Upstream pipe, diameters	Viscosity effect	Relative Cost
Orifice	Clean, dirty liquids; some slurries	4 to 1	Medium	±2 to ±4 of full scale.	10 to 30	High	Low
Wedge	Slurries and Viscous liquids	3 to 1	Low to medium	±0.5 to ±2 of full scale	10 to 30	Low	High
Venturi tube	Clean, dirty and viscous liquids; some slurries	4 to 1	Low	±1 of full scale	5 to 20	High	Medium
Flow nozzle	Clean and dirty liquids	4 to 1	Medium	±1 to ±2 of full scale	10 to 30	High	Medium
Pitot tube	Clean liquids	3 to 1	Very low	±3 to ±5 of full scale	20 to 30	Low	Low
Elbow meter	Clean, dirty liquids; some slurries	3 to 1	Very low	±5 to ±10 of full scale	30	Low	Low
Target meter	Clean, dirty viscous liquids; some slurries	10 to 1	Medium	±1 to ±5 of full scale	10 to 30	Medium	Medium
Variable area	Clean, dirty viscous liquids	10 to 1	Medium	±1 to ±10 of full scale	None	Medium	Low
Positive Displacement	Clean, viscous liquids	10 to 1	High	±0.5 of rate[3]	None	High	Medium
Turbine	Clean, viscous liquids	20 to 1	High	±0.25 of rate	5 to 10	High	High
Vortex	Clean, dirty liquids	10 to 1	Medium	±1 of rate	10 to 20	Medium	High
Electromagnetic	Clean, dirty viscous con-ductive liquids and slurries	40 to 1	None	±0.5 of rate	5	None	High
Ultrasonic (Doppler)	Dirty, viscous liquids and slurries	10 to 1	None	±5 of full scale	5 to 30	None	High
Ultrasonic (Time-of-travel)	Clean, viscous liquids	20 to 1	None	±1 to ±5 of full scale	5 to 30	None	High
Mass (Coriolis)	Clean, dirty viscous liquids; some slurries	10 to 1	Low	±0.4 of rate	None	None	High
Mass (Thermal)	Clean, dirty viscous liquids; some slurries	10 to 1	Low	±1 of full scale	None	None	High
Weir (V-notch)	Clean, dirty liquids	100 to 1	Very low	±2 to ±5 of full scale	None	Very Low	Medium
Flume (Parshall)	Clean, dirty liquids	50 to 1	Very low	±2 to ±5 of full scale	None	Very low	Medium

Table 2

Chapter – 4

Meter Parameters

The most important parameters in a meter's operation are its proving results. For both PD and turbine meters, changes in the meter factor curve outside the acceptable tolerances are an indication that an effective change is taking place and may a signal need for disassembly of the meter to repair any damage. The meter proving should be summarised in a meter factor control chart that can be monitored to identify changes in the meter performance.

In general, turbine meter's factor begins to become non-linear at flow rates equal to or below 5% of the meter's maximum capacity. With higher viscosities, the point of deviation may be as high as 35% of maximum capacity. Turbine meters are normally monitored electronically. Therefore, any losses due to readout should be insignificant. Once a base meter factor curve is established for a meter, changes outside established bounds will indicate cleaning or replacement is needed.

Meter accuracy is a much-abused term. Manufacturers often default to it "selling shorthand", but those specifying and buying meters to measure flow should be aware of several caveats.

Simply relying on a manufacturer's statement of accuracy is indeed an incomplete and inadequate way to evaluate meters. Proper determination of accuracy, rangeability, linearity, repeatability and hysterisis data are basic but still only a part of the job in achieving the best flow measurement; operation and maintenance must also be considered.

4.1 Meter Factor

Meter factor is a dimensionless correction that mathematically modifies a meter's indication to a corrected true reading based on knowledge of the flow and flowing conditions. Corrected readings may be manually calculated periodically or the meter factor automatically applied continuously.

In the first place no meter is absolutely accurate! There are no absolute standards of gas or liquid against which to compare a meter reading to see how closely that reading compares with what is actually flowing through the meter .Any statement of accuracy must include not only the best possible estimate of how accurate the measurement is but also over what flow range the estimate applies. The more diligent manufacturers usually supply such detailed information.

4.2 Rangeability

Rangeability expresses the flow range over which the meter operates while meeting a stated accuracy tolerance. It is often stated as "turndown," maximum flow divided by minimum flow over the range. For example meter with maximum flow (100%) of 100 gallons per minute and minimum flow (within a stated tolerance such as ±0.5%) of 10 gpm has a 10 to 1 rangeability or turndown of 10.It will be accurate 0.55 from 10 to 100 gpm.

The meter may provide a higher tolerance over a limited range-say 10 to 1 within ± 0.5% of actual flow as above, but 3 to 1 within the ±0.25% accuracy range. This means the user can select the tighter tolerance of ±0.25% for a range 33 to 100% flow (33 to 100 gpm).

PD meters have a usable flow range of between 50:1 and 100:1.The turbine meter has about a 10:1 range with low viscosity liquids or with viscosity characterisation .A turbine meter's usable range decreases at higher viscosities without indexing and with decreasing relative density (relative density of 0.55 or less).

4.3 Linearity

Linearity defines how close to a specific accuracy the meter registers over a stated flow range. Its proof curve will approximate a straight line. It may be significantly inaccurate but quite linear.

4.4 Repeatability

Repeatability means how nearly the same reading the meter will provide for a series of measurements of the same quantity and procedure carried out by the same operator and the same equipment and the same location over a short period of time given flow condition. As with linearity, it may be more important to always get the same reading for specific flow rates than that those readings be extremely accurate. The repeatability of a properly applied PD meter should be in the range of ±0.05% or better with the same flowing parameters. Turbine repeatability should be 0.2% or better when the meter is operating properly. Unless a turbine meter is mechanically impaired, it will maintain its repeatability even when the meter becomes non-linear.

4.5 Hysterisis

Hysterisis is closely related to repeatability .It describes what happens to meter output as a given flow rate is approached from larger and smaller rates. Suppose a flow rate of 80 gpm is increased to 100 gpm, and a meter then registers 99 gpm. Now that the flow rate increases to 120 gpm and returns again to 100 gpm; the meter registers 101 gpm .Its hysterisis is 1 gpm, and the dead band is ±2 gpm at a 100 gpm flow rate.

Pressure Drop

Pressure drop is affected by many factors:

- Flow rate
- Viscosity
- Density or relative density
- Temperature and
- Flowing conditions

Any significant change in pressure drop will signal that inspection and/or repairs should be scheduled as soon as possible. Typically the pressure drop on a turbine meter is about 4 psi at maximum flow (6 psi at 130% flow) on water and is a function of each meter's internal design. At higher viscosities, the pressure drop will be larger. However the pressure drop does not pose the potential problem for a turbine meter that it does for a PD meter.

Characteristics to be considered while evaluating a meter include:

I. Achievable uncertainty
II. Comparative cost
III. Use acceptance and specific use
IV. Repeatability
V. Maintenance costs
VI. Operating costs
VII. Few or no moving parts
VIII. Ruggedness
IX. Service life
X. Rangeability
XI. Style to meet fluid property problems
XII. Pressure and temperature ratings required
XIII. Ease of installation and removal
XIV. Power required
XV. Pressure loss caused by meter (running and stopped) and
XVI. How well calibration can be proved

Specific meters prove useful with specific applications. A meter must provide acceptable performance/cost ratios, considering initial cost plus other required investments in proper installation, operation and maintenance, or it won't complete the trip down the acceptance road.

4.6 Common causes of error in meter performance

1. **Foreign matter**: Dirt or trash will change the performance of a meter by either speeding up or slowing the rotor.

2. **Turbulence**: Turbulence simply causes erroneous readings.

3. **Flashing**: When the product flashes, it increases the rotational speed of the rotor. This not only produces unreliable data output from the meter but also increases the probability of meter failure due to lack of bearing lubrication.

Steps while Testing a Meter

1. Visual inspection for any signs of improper operation such as leakage and unstable flow – includes a review of the entire attendant equipment and their indications and recordings.

2. If station appears to be operating properly, the individual elements of the station such as meter and the correction for pressure, temperature, density and composition should be individually verified or calibrated with the assumption that if all parts are in calibration, the system will be in calibration to the limits calculated by the uncertainty equation- commonly used for flow metering in industries.

Cost control and quality assurance

Accurate measurement of volume is important for both trade and industry. In the case of the gas trade, for example, metering errors can quickly add up to large sums of money: whether the error is in the customer's favour, so that the supplier is not paid for everything delivered, or in the supplier's favour, so that the customer does not receive the quantity paid for. Cost is always an important incentive to meter, and particularly to meter correctly. Quality assurance, too, requires good metering accuracy.

Calibrated meters are often an important element in a company's quality system. Stock control and cost monitoring - e.g. of consumption of some substance - are other areas where volume measurement is important but just how accurate is the meter? It is not until a meter has been calibrated that its accuracy is known.

4.7 Metering Standards

In order to maintain accuracy, it is advisable to utilise certain accepted standards of metering. The most widely accepted methods for the custody transfer metering of natural gas are those developed by the American Gas Association (AGA).

AGA 5

This standard defines the steps to calculate the heating value per unit volume of a gas from its molecular composition. From the heating value one can calculate the total metered energy value, for billing purposes, by multiplying the heating value by the total metered volume. Any error in the AGA 5 calculation will produce an error in the heating value which will cause an error in the final metered energy calculation. The AGA 5 calculation for the heating value in BTU/foot is:

$$HHV = 144 + 1571.5 \times \text{Specific gravity} - 25.318 \times \text{Vol\%}\ CO_2 - 16.639 \times \text{Vol \%}\ N_2 - 18.801 \times \text{Vol \%}\ O_2 - 3.612 \times \text{Vol \% He} - 13.424 \times \text{Vol \% CO} - 13.462 \times \text{Vol \%}\ H_2S - 11.214 \times \text{Vol \%}\ H_2O + 0.713 \times \text{Vol \%}H_2$$

AGA 7

This standard was specially designed for the turbine meters. The AGA 7 standard is used to convert the actual flow rate to a standard flow rate.

$$Vb = Vm \times (P/Pb) \times (Tb/T) \times (Zb/Z)$$

Where:

Vb = Converted volume to Standard conditions.

Vm = Volume measured at metering conditions.

Tb = Standard Temperature (288.15K)

T = Gas temperature at the metering conditions.

Pb = Standard pressure in Bar.

P = Pressure at metering end (as absolute)

Zb = Gas compressibility factor at standard conditions

Z = Gas compressibility factor at metering conditions

AGA 9

This standard covers the design, installation and use of ultrasonic flow meters. The report refers to AGA 7 for all metering calculations.

AGA 3

This standard is used for orifice plate metering where the flow computer is provided with an upstream pressure, a flowing temperature and a differential pressure. The difference between the AGA 3 and AGA 7 equations lies in the calculation of the actual volume flow rate at flowing conditions. The orifice plate metering is also highly dependent on the accurate measurement of the differential pressure drop, the internal pipeline diameter and the orifice bore diameter.

Any error in pressure, temperature or the compressibility calculation will result in a direct error of the metered flow rate. As an example, an error of only 3 C will result in a 1% error in the metered flow rate

Chapter – 5

Design and Technical Limitations in a Flow Meter

All flow meters use fluid mechanics principles in arriving at flow from the fluid's transport properties. Each of these principles has technical as well as practical limitations. For e.g. Orifice meter is one category of meters that require a pressure drop larger than the pressure drop in normal piping for proper measurement .If sufficient pressure drop is available for measurement, then a head meter cannot be used accurately. This statement seems self-evident; however users sometimes apply an orifice meter with only a few inches of water differential and still want accurate flow measurement. Similarly an ultrasonic meter that senses velocity must sense an accurate average velocity in relation to a known hydraulic area of the meter opening, or else there is no way to calculate accurate volumes. This means a proper profile must be presented to the meter, and the meter must be kept clean.

5.1 Density

Accurate calculation of standard volume through a meter requires knowing the fluid density at the meter and proper interpretation of the measurement through use of appropriate equations to reduce the flow to base conditions. The density measurement is needed at the flow sensitive points such as the plane of the orifice plate bore or at the rotor in a turbine meter. A densitometer may be installed in a less sensitive location providing correction or control of the variables is made to arrive at the correct density from the remote location. When a gas chromatograph is used, it can provide density data. It is important always to keep in mind that the end product sought is the actual density at the measuring point.

5.2 Differential Pressure

Two of the major sources of error in application of a head meter come from taking the square root of the differential pressure measurement and from the effects of small errors in low differentials, which can cause large errors in flow data. for e.g. an error of 0.5 inches at 100 inches represents a 0.23% error of flow, at 75 inches it's a 0.33% flow error, but at 10 inches it creates a 2.5% flow error.

A good practice to achieve high accuracy dictates that the differential pressure be kept as high as possible within strength limitations of the primary device, and the range of flow fluctuation should be limited to the differential measuring device range.

5.3 Temperature

Errors in temperature measurement have a small effect on head-meter flow accuracies for most gases, since the absolute ambient temperature range of measurement causes about 0.1% error in flow rate per degree Fahrenheit error. For non-head meters, the temperature error causes measurement errors twice as large.

5.4 Specific Gravity

For each 0.001% error in reading, specific gravity of natural gas make about 0.1% error of flow measurement with a head meter: this can introduce fairly large errors on gases with changing composition unless the measurement is integrated into the volume calculation rather than averaged over time period. This factor also enters the "accuracy" statement of an orifice meter as a secondary factor in determining the compressibility factor. Specific gravity only affects the compressibility determination for non-head meters and does not enter as a direct correction.

5.5 Gas Compressibility

The compressibility factor of natural gas is roughly a 0.5% correction in volume per 100psi of pressure for an orifice meter at normal pressure and temperature conditions. Hence, an error of several percent in factor is only a small error in volume. However, if the gas is reduced near its critical point, correction factors as much as much as 225% are required and small errors in measured variables are reflected as large errors of volume.

Likewise, gases with large concentrations of non-hydrocarbon gases in their mixtures are not as difficult to calculate as accurately, since new data are available from AGA on these mixtures. Some of the theoretical values obtained by pseudo critical method have shown errors of several percent when compared with empirically determined test data on the same gas. This problem becomes more pronounced as the percentage of methane is reduced. If the value of the product handled is sufficient, then actual compressibility tests are recommended for confirmation of the calculated data to the tolerances required.

It is also important to consider the fluids critical temperature and pressure .A meter's specified accuracy is invalid if the fluid to be measured exhibits large volume changes with minor temperature and pressure changes, which is the case near critical conditions.

At a meter station measuring a product worth $1million a day, an inaccuracy of ±0.2% represents $2,000 a day, or $ 73,000 a year—an amount that justifies considerable investment to improve flow measurement. The same error for a station measuring $1,000 worth of product a day represents only $2 a day, and the law of diminishing returns limits investment justifiable to improve a measurement accuracy.

Control measurement may be accepted at ±2%; operational measurement may require no more than ±5%, as contrasted with the ±0% target for custody transfer metering.

5.6 Accuracy and Uncertainty

A term used frequently in flow measurement is **accuracy**. In custody transfer measurement accuracy is usually defined as the difference between the measured value and the true value expressed as a percentage. The problem however with the definition is that the indicated value is read from the meter, but the method of obtaining the true value cannot be specified: therefore, true value is not precisely known.

Performance of the measurement under flowing conditions can be evaluated by making an **uncertainty** calculation; many calculation procedures are available in the standards and flow-measurement literature. Calculation of the equation's variables is not the total concern for complete uncertainty determination; allowance must be made for errors from human interpretation, recorders or computers, installation and fluid characteristics.

The uncertainty equation assumes that the meter is properly installed, operated and maintained .If maintenance is neglected and the meter has deposits on it that change its flow characteristics, then the calculation is meaningless until the meter is cleaned.
Without tests to reconfirm the original accuracies of the metering system, any statement of accuracy is not complete. If there is a desire to reduce measurement tolerances, then an actual throughput test can be run against a "master meter" or a prover system. The master meter should be calibrated and certified to some accuracy limit by a testing facility, a government agency, a private laboratory, a manufacturer or the user using agreed upon flow standards. Periodically the master meter has to be sent back to the testing facility for recertification. Retesting frequency depends upon the fluids being tested and treatment of the master prover between the tests.

Recognition of a meter's operating limits must be considered for a meter to meet its stated accuracy. Most meters operate within stated limits and should not be used in the extremes of ranges for custody transfer metering .If there is no one meter with the range required to operate in the accurate part of its range, then use of multiple meters with some type of flow switching control to turn meters in and out of services is required. In addition to basic meter problems, the secondary equipment that measures pressure, temperature, differential pressure, density or specific gravity, and composition of flow can also have problems. Normal specifications on these devices are stated as percent of full scale. Selecting an instrument with the wrong range for the parameters to be measured introduces errors. A system properly chosen, designed, and installed may still fail to meet expectations if the meter is not used to operate in its most accurate range.

An ideal meter station will be one in which pressure, temperature and flow are stable-both long and short term- changing less than several percent. The fluid should be clean of non-changing composition, and with no pulsation. Ample installation space should be available for the required straight meter tube lengths up stream and downstream. Duplicate instrumentation with automatic switch over to standby units in case of primary equipment failure should be included. Instrument should include automatic transducer testing, and sufficient periodic maintenance should be planned to reconfirm the meter's uncertainty. Meter data should be transferred automatically to the billing o other department with all volumes involved reviewed and accepted by everyone concerned. Seldom does such an ideal station ever exist in real flow measurement. Therefore allowances must be made for the non-ideal characteristics and measurements evaluated accordingly.

To verify meter selection and system operation, the following data should be collected and analysed:

- Meter (number and location)
- Volumes measured at each (range and total)
- Measurement variable
- Types
- Readout system
- Accuracies expected
- Range
- Station design and installation
- Operating procedure
- Maintenance procedure
- Fluid condition
- Calibration test reports and
- Maintenance reports

  Information flow
- Field (electronic or charts)
- Communication (procedure and controls)
- Office (procedure and controls) and
- Accuracy check at each point

Once a problem is identified, complete examination of the section should be made including:

- Meter and meter installation for compliance to industry and/or company standards
- Gas quality meets contractual requirements with no carry over of solids or liquids
- Inspection of meter tube, secondary (transducers) and tertiary equipment (computers) to confirm they meet standards followed by a thorough test report review
- Maintenance procedures checked for recurring calibration problem that may require upgrading or change of the present equipment.

5.7 Meter Data

Depending on the type of system employed, flow information must be moved to a central office to complete the billing process. This handling and rehandling of data must be controlled at all points: In the field, the transmittal system, the office data system and the billing systems. Checks and auditing, including integrity check throughout the process can confirm that information in moved without degradation.

Fluid characteristics and their effects on meters must be reviewed. With production gases there are often problems in maintaining a single phase and getting a legitimate sample for determining the heat value and other properties. Pipeline quality gases that have been separated and dried do not have as many problems.

Chapter – 6

Calibration

Calibration can be defined as the process of checking the zero, span and range of a device and its linearity or fit to a known calibration curve. Simply, this means how well the device duplicates the output it is being asked to follow. The device used as a reference for the calibration should be traceable to the National Institute of Standards and Technology (NIST).

A creditable calibration should include five points of reference. Points at 0%, 25%, 50%, 75% and 100% are usually sufficient. Zero percent is important, because in most cases, for a quick check, the transmitter can be valved off from the process and vented to atmosphere. If only zero seems to be off, many times a complete calibration is not needed.

A complete calibration should include both an up and a down calibration in order to pickup any hysterisis or any lack of repeatability. Most modern transmitters have non-interacting zero and span adjustments, thereby reducing the number of calibration adjustments. Field calibrators available today are rugged have the accuracy to provide laboratory grade calibration, are battery powered and are very portable.

Instruments may be checked in the shop, but the final check of calibration may be more meaningful if done in the field to include ambient effects, transmission cable and rack or control room readouts, and devices. Stray pick up, improper grounding, too much resistance in the loop, etc., can become a significant input to the loop calibration.

6.1 Basic Calibration Concepts

The discussion of the basic concepts begins with a definition of calibration

A comparison is made between an instrument and a reference standard for the purpose of adjusting the instrument characteristics to provide agreement with the reference standard.

A pressure transducer is used as an example. When a pressure transducer is calibrated the standard is a deadweight tester. In some cases a hand held transfer standard may be used, but it is always calibrated against a deadweight tester. The calibration process involves establishing a steady pressure to both UUT (unit under test) and standard. The outputs of both devices are recorded; this becomes a "data point". The process is repeated at several pressure values over the pressure range of interest. The transducer is then adjusted based on analysis of the data points. Sometimes a few additional data points are taken to confirm that the adjustment was correct.

A turbine meter is used as the second example. When calibrating a turbine meter the standard is usually another flowmeter. That flowmeter has been calibrated against a primary standard. The calibration process involves establishing a steady flowrate through out both UUT and standard. A data point is obtained that consists of the average value of a series of samples. Several additional data points are then obtained at the same flowrate. The flowrate is changed and data are obtained at several flowrates with several samples at each flowrate.

6.2 Uncertainty Issues

The basic concepts important to understand the role of calibration are closely related to concepts of uncertainty. When an instrument is used to make a measurement there is an uncertainty associated with that measurement. The uncertainty is an estimate of the interval width that contains the true value being measured. For example: the statement "100 ±1 psi" means the true value is estimated to be between 99 and 101 psi. Uncertainty is usually made up of several components the components can be classified based on how they affect a measurement process. If the process is repeated and the result changes with repetition, the changes are due to random effects. Effects that do not contribute to change are systematic effects. The process of calibration usually involves replacing a systematic effect with a smaller systematic effect plus a random effect.

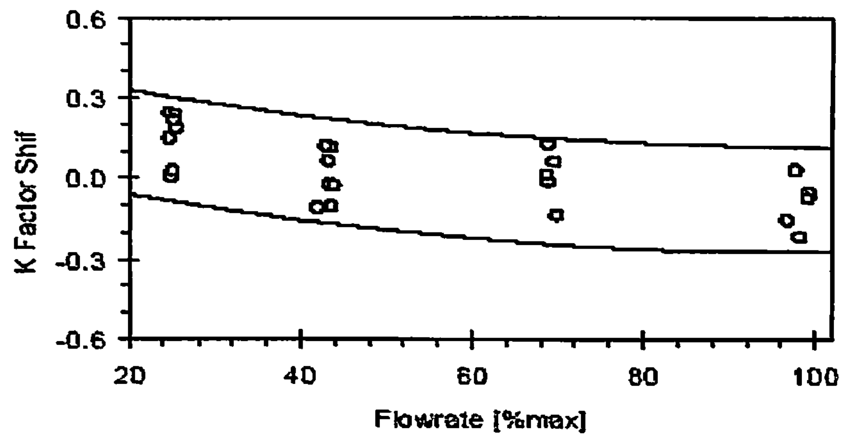
Pressure Transducer Example

This first example is based on a hypothetical pressure transducer. The transducer is used in conjunction with a flowmeter to correct the measured flowing volume. In the current example the transducer measures pressure with a span 1000 psi. The manufacturer claims the uncertainty to be ±0.5% of span, which corresponds to ±5 psi. If the transducer indicates a pressure of 500 psi, the actual value will be between 495 psi and 505 psi.

The pressure transducer is sent to a lab for calibration. The lab claims that the uncertainty is ±0.2% of reading. For a measurement of 500 psi this corresponds to a value of ±1 psi. With the calibration the larger uncertainty value of ±5 psi can be replaced with the smaller value of ±1 psi. Now when the transducer indicates a pressure of 500 psi, the actual value will be between 499 psi and 501 psi. The improved performance due to the calibration is quite clear.

Turbine Meter Example

The second example is based on a hypothetical turbine meter. Initially this turbine meter is used in accordance with AGA Report 7, which states that the uncertainty is ±1% of reading. If the meter records a corrected volume of 100 MMCF, the uncertainty will be ±1 MMCF. The actual volume will be between 99 MMCF and 101 MMCF. The turbine meter is now sent to a lab for calibration. The lab claims that the uncertainty is ±0.25% of reading. For the corrected volume of 100 MMCF the uncertainty is now ±250 MCF. The actual volume will be between 99.75 MMCF and 100.25 MMCF. Once again the improved performance due to the calibration is quite clear.



Colorado Engineering Experiment Station, Inc. (CEESI)

Figure 17: Performance curve on calibrating a turbine meter

Interpreting flowmeter calibration results is more complex than pressure transducer calibration results. This example continues based on the calibration results shown in Figure. The y-axis shows percent shift from the nominal K Factor provided by the manufacturer. The x-axis is flowrate expressed as a percent of the maximum meter capacity. The data were obtained as described in the first section above. The maximum value of K Factor shift is +0.24%, the minimum value is –0.22%. The first conclusion is that this meter meets the requirements of AGA 7. The second conclusion is that the data all fit within ±0.25%, which is consistent with the numerical value from earlier in the example. This conclusion is not entirely correct for reasons discussed below. The solid lines in Figure 1 represent the narrowest possible interval that contains all the data, the interval width is ±0.19%. This interpretation requires that the K Factor varies with flowrate. The benefit of this method is a slightly lower uncertainty, it comes at the price of increased complexity in volume calculation. The additional calculations arise from the need to recalculate K Factor. t [%].

The data of Figure represent only the random effects present during the calibration process. There is additional uncertainty associated with systematic effects, each data point has uncertainty due to the laboratory instruments and standards. This uncertainty value needs to combined with the uncertainty associated with the random effects.

A statement from above is repeated in the context of the present example. The process of calibration involves replacing a systematic effect with a smaller systematic effect plus a random effect. The AGA 7 value of ±1% is the systematic effect that is being replaced. The smaller systematic effect is associated with the laboratory instruments and standards. The random effect is the ±0.24% or ±0.19% value from Figure .

A final comment on this example: The newest flow measurement technology in current use is the ultrasonic meter. The turbine meter discussion in this example is equally applicable to the ultrasonic meter. The only significant difference is that AGA Report 9 is based on an uncertainty value of ±0.7% instead of ±1%.

6.3 Cost Issues

Cost issues are important in factoring calibration into business decisions. In the turbine meter example the uncertainty is reduced from ±1 MMCF to ±250 MCF. At $3.00 per MCF the cost of uncertainty is reduced from ±$3000 to ±$750, a savings of $2250. This savings is then compared to the cost of calibration to determine the payback period. A similar analysis can be performed for the pressure transducer. Suppose it is used with the turbine meter above. The reduction in uncertainty from ±5 psi to ±1 psi corresponds to a reduction from ±1% to ±0.2% based on a 500 psi measurement. This in turn corresponds to a reduction from ±1 MMCF to ±200 MCF; or from ±$3000 to ±$600, a savings of $2400.

6.4 Time Issues

As soon as an instrument is returned to service after calibration, the uncertainty begins to increase. While the increase is usually very slow, the uncertainty can increase quite a bit given enough time. This performance feature, called "uncertainty growth", requires an instrument be recalibrated on a periodic basis. For a pressure transducer the manufacturer will usually provide a "stability" specification that is expressed in terms of additional uncertainty during a time period. The time period may range from a few months to a few years. With a stability specification the calibration interval required to maintain an acceptable value can be calculated. The recalibration interval for a turbine or ultrasonic meter is a bit more difficult to determine. Neither the manufacturers nor the AGA standards provide guidance. The best recommendation is to implement a regular check on the meter that would indicate the need to recalibrate. For a turbine meter the spin test checks the bearing operation, the most likely component that would warrant a recalibration. While ultrasonic meters are still new to the industry, the speed of sound has been proposed to serve as a performance check.

6.5 Field Calibration

Field calibration saves time since it does not usually require the removal of the instrument from the process or from its mounting bracket. In many cases it also allows the field device to be tested or calibrated at the true process and ambient conditions, which may be considerably different from instrument shop conditions.

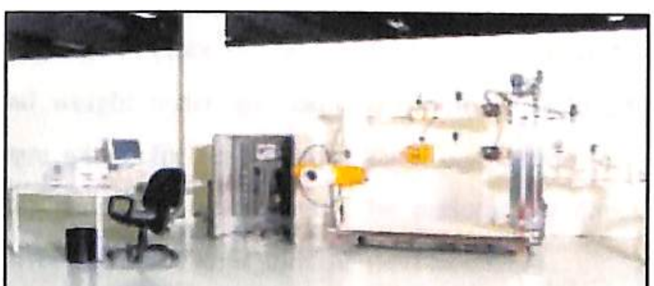
Today's field calibration devices can be purchased with calibration accuracies that are equal to those of shop type calibrators. They are made to withstand field abuse and have digital displays that maintain their accuracy and are easy to read.

6.6 Pressure Calibration

Pressure calibration equipment must include a device to produce the calibration pressure, a device to accurately indicate the pressure being produced, and readout of the transmitter output, either pneumatic or electronic.

6.7 Low pressure calibration system

These systems are designed for the calibration of small turbine and rotary meters at pressures up to 8 bars. The reference is the Instromet IRM Duo rotary meter which offers a perfect solution for calibrating meters up to 1000 m3/h capacity.



Low pressure calibration system

Figure 18

www.instromet.com

6.8 High pressure calibration system

Instromet is actively involved in working to increase the accuracy of national reference standards and calibration facilities. Most of them use Instromet reference meters and Instromet itself has several calibration stations, including an 8 bars facility using natural gas. Instromet is also deeply involved in the creation of the largest calibration facility in the world in Winnipeg, Canada. In this sophisticated facility, meters can be calibrated at flows up to 3,300,000 m3/h at 65 bar.

High pressure calibration facility Winnipeg www.instromet.com

Figure 19

6.9 Hand Operated Portable Pumps and Comparator Testers

These devices use the same pump arrangements as do the shops type dead weight testers, but they substitute a test gauge in place of the standard weights. This device is somewhat more portable than a dead weight tester and can tolerate more field abuse. The tester uses a standard type pressure gauge for readout and has a connection to attach the device being calibrated .The tester gauge, however should be periodically checked against a certified standard gauge; a correction curve kept with the field tester.

6.10 Hand-held, Comparator testers

These testers are relatively small, light in weight, and portable. They must be used in conjunction with an accurate test gauge. Air operated pumps can be hand pressured to about 200 psig, but hydraulic hand pumps can calibrate to as high as 5000 psig.

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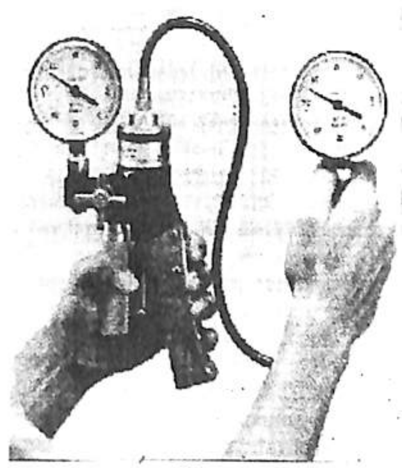


MGL

Figure 20: Hand-held, Comparator testers

Small hand held pneumatic calibrators are available that are calibrated in inches of water ranges for differential transmitters of draft gauge calibration. They are also made to cover a range of 0-18 psig for troubleshooting as well as field calibration of valve positions and I/P transducers.Any portable pressure tester receives hard use and must have its readout periodically checked against a dead-weight tester or other traceable calibration device in order to guarantee its accuracy.When dealing with high pressures care must be taken when bleeding the transmitter or tester to atmospheric pressure. Always bleed the tester before disconnecting the tubing and vent away from face or body. High-pressure applications usually have a block-and-bleed manifold to allow controlled relief before disconnecting the process connection.

A major problem with pressure calibration is maintaining a constant calibrator pressure while making adjustments. To prevent leaks from the calibration source or any other tubing, be sure fittings and any O-rings are clean and in good shape. Teflon tape is recommended on any screwed fittings. Tighten or adjust fittings until a fixed calibration pressure can be maintained long enough to make the adjustments.

6.11 Differential Pressure Calibration

Calibration pressure is generated in the same manner as for pressure, but on most cases the differential pressure is quite small. The low side of the dP device is usually vented, and the test pressure applied to the high side of the device .The low side of the body of the dP device should be vented or drained to remove any source of potential pressure.

Although the differential pressure may be small (in inches of water), the line pressure may be at hundreds and even thousands of pounds pressure, or the liquid seal, if vented may quickly become high temperature steam.

When differential pressure transmitters are used for flow measurement transmitters, their calibration is in the inches of water range. Most orifice plate measurements are 0 to 100 inches of water but can range from as low as 50 inches to a high of 250 inches of water or higher. Pitot tube flow measurement ranges are usually just a few inches of water and require careful calibration and special low range calibrators.

When calibrating differential pressure transmitters for orifice late or other square root signal sensing devices, finalise the calibration by checking zero. This is most sensitive portion of the scale and, if off by even a small amount, can contribute to flow indications or totalizers counting when there is no flow. If the transmitter has allow signal cut off or the system has a software scheme to allow for a stable zero display and use the absolute zero is not as important as when there is no method to take care of this sensitivity.

6.12 Level Calibration

When a standard differential pressure transmitter is used to measure level by sensing liquid backpressure, calibration is the same as for pressure or differential pressure, with one exception. When a pressurised tank is measured and a wet leg is used, the differential pressure transmitter is reverse calibrated so that, with no pressure on the level measuring side (high side), the back pressure from the filled reference leg (low side) will cause the transmitter output to be 3psi or 4mA (zero level), and the output will be 15psig or 20 mA (100% level) when the high side pressure equals the low side pressure, i.e., the differential is zero.

Bubble tube level measurements use differential pressure or low-pressure transmitters to sense bubble tube backpressure and are calibrated the same as any pressure transmitter application.

When a diaphragm-type level transmitter is to be calibrated, a special fitting must be used that will allow the level transmitter sensing head to sense the pressure-calibrating medium. Various special fittings can be shop-built or purchased to handle any type of pressure-sensing head transmitter that needs calibration.For level applications, most of the pressures do not exceed 30 to 40 psig, and instrument air is used as the pressure medium.

6.13 Temperature Calibration

Temperature calibration includes liquid or gas filled thermal systems, electrical measurement using thermocouples, resistance bulbs and thermistors.The thermocouple and the RTD are used extensively for industrial temperature measurement.

An explanation of the possible errors include in direct wiring from the field sensor to the readout is necessary to explain why simply checking the TC or RTD sensor calibration will not always produce an accurate temperature reading. An unbalance in thermocouple lead wire occurs because the two lead wires have the same thermoelectric properties as the thermocouple itself; in effect, there are two different materials on the two equal length wires, and their resistance is not the same.

In the case of RTDs, a similar effect will be seen because, although the three wires are all copper, there are two wires on one or the other. There will be a difference in voltage drop and so the transmission accuracy may be affected.

If transmission accuracy is a problem, the answer may be to change to field-mounted transmitters mounted directly near or adjacent to the sensors. The signal from the temperature location of the sensor is now transmitted on two copper wires with a high level, 4-20 milliamp current signal. If twisted, shielded pair cable is used and installed properly, the stray current induced by motors starting and other electrical noises will cancel out. It is usually preferable to use TC and RTD transmitters when the signal is used in a control loop or a high degree of accuracy is required, with minimum field interference.

6.14 Block Calibrator

The modern way to calibrate a temperature probe is to use a "dry block calibrator". These devices are portable, have accuracies to within 0.3% with resolution to 0.1 degree and stability to within 0.1°C. They are safe since they do not use liquids as heat transfer medium and, therefore, do not have flash points to consider or noxious fumes and do not require an air supply. Ranges are from 25 °C to 650 ° C. Readouts are selectable between °C and °F. Dry block calibrators are very simple to use. Just place the sensor at the appropriate insertion tube, switch the unit on, select the readout in degrees, dial in the temperature to stabilise, and then calibration points that provide a good sampling of the span of the sensor being calibrated.

6.15 Thermocouple or RTD Simulators

Calibration of the probe is sometimes not required when well or protecting tube protects the sensing elements and the element is new. The easiest check is to calibrate the transmitter using a hand held TC or RTD simulator-type tester. The simulator produces an electromagnetic force or resistance that duplicates the output of these two types of sensors, if this check varies a zero or span correction is needed, recalibrate the transmitter, using the simulator. Reconnect the sensor to the sensing head and check the output reading against any local temperature reading that is available and is accurate.

6.16 Utility of Calibration

Meter Calibration: ***key to accurate gas measurement***

It is imperative that the cash register of any business be accurate and it is a cliché – but nevertheless a fact – that gas custody-transfer meters are the "cash registers" of production, transmission and distribution companies.

Companies and their customers rely on accurate gas measurement for many reasons. Perhaps the most important is fair and equitable payment for gas delivered. In addition to the financial consequences of measurement errors, there can be other adverse effects related to operational, safety, legal and environmental issues. Furthermore, once an error is discovered, the parties' business relationship can be strained or there can be costly litigation.

Cost-effective means are available to reduce or eliminate most measurement errors. API, AGA, GPA and ISO standards provide guidance on the proper selection, installation, operation and maintenance of flow metering equipment to minimize errors. Measurement errors can also be identified and eliminated through meter calibration.

Calibration's value: One common misconception is that gas measurement errors are random and that precision errors will "average out" to zero over the long term. To the contrary, most measurement errors are bias or systematic errors. Bias errors are repeatable in both magnitude and direction. For example, a biased gas meter that under-registers today will under-register tomorrow and the days that follow.

A principal cause of gas pipeline system imbalance is meter bias. System imbalance is the difference between the quantity of gas metered into and out of a pipeline network. From an operational standpoint, companies need to know if system imbalances or unaccounted-for gas volumes result from metering errors or system leakage. Safety and environmental concerns dictate that these issues be dealt with separately.

A well-run gas transmission pipeline network will have an overall system imbalance of less than ±0.5%. Large pipeline operators potentially can save millions of dollars annually by reducing system imbalance by just one percentage point.

To illustrate the potential for cost savings, consider the financial impact of bias error in one 12-in. diameter, ultrasonic flowmeter installed in a typical interstate transmission pipeline. The industry's recommended practice – American Gas Association Report No. 9 – specifies that meters of this type and size may have a maximum error of up to ±0.7% over the upper 90% of the rated flow range. The report further states that measurement bias errors attributed to pipe configuration at the meter station must not exceed +0.3%.

We assume that gas continuously flows through the meter at a rate comparable to the meter's mid range and that the meter has a bias of –0.5%, meaning it consistently under-registers the volumetric flowrate by 0.5%. This meter's bias error is well within the allowable limits of Report No. 9, but would still result in a measurement error valued at more than $2,500 per day, or almost $1 million per year. Such bias errors can usually be eliminated by flow calibrating the meter at a cost of $5,000 to $50,000, depending on the calibration method.

6.17 Calibration procedure

A flowmeter calibration should take into account operational effects and, when practical, installation effects that may adversely affect meter performance. Flow calibrations can be performed either in situ, using a reference test flowmeter plumbed in series at the meter station, or offsite at a test facility.

For in situ calibrations, the station should have been designed for a reference test flowmeter to be installed onsite. There are no gas industry standards or guidelines for in situ or field-meter proving. Offsite calibrations are preferred in most cases because test conditions can be more precisely controlled than in the field.

There are important factors to consider when selecting a qualified laboratory for offsite meter calibrations. Here's a short list:

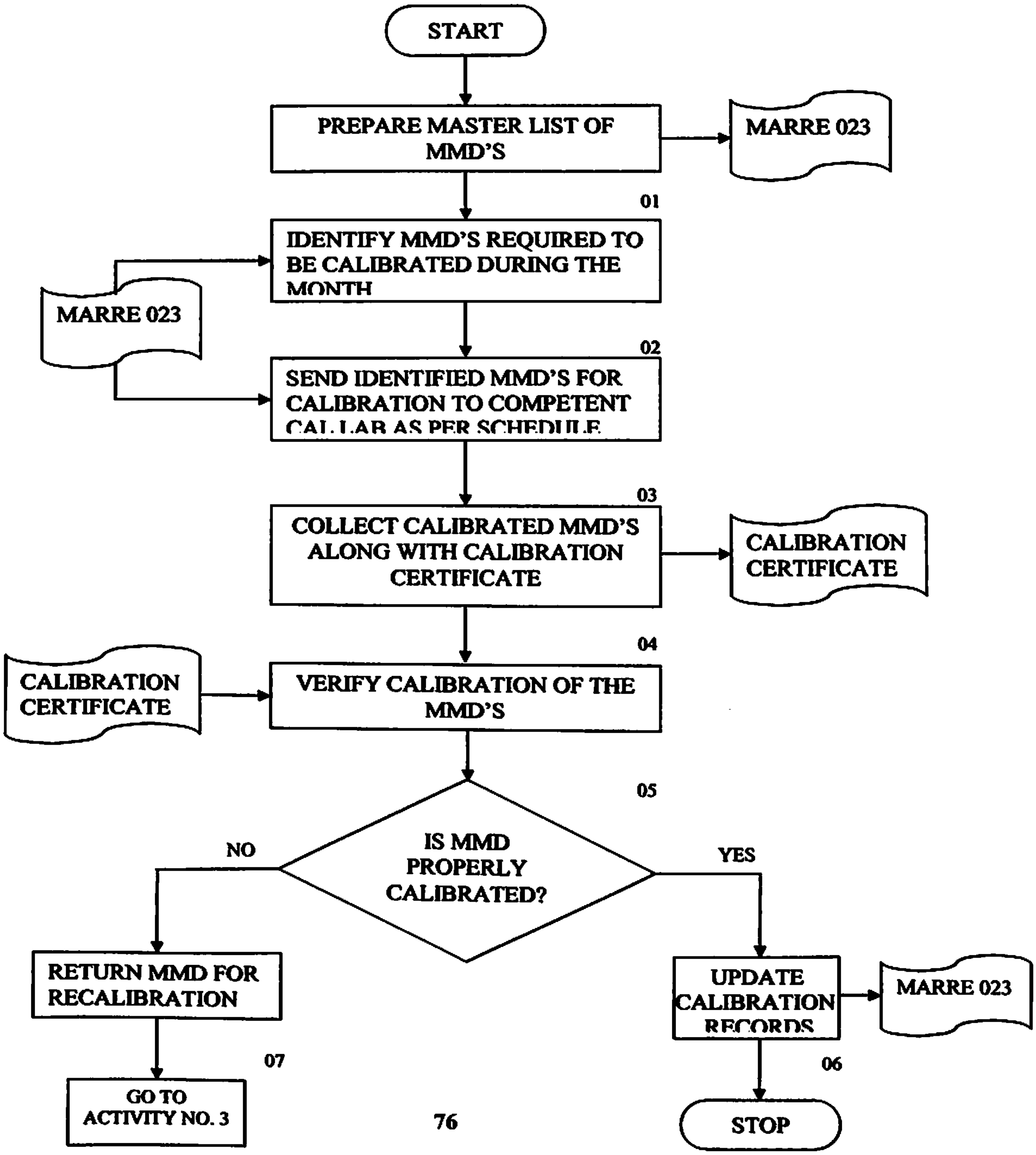
- Responsiveness to client's needs
- Independent, unbiased business perspective
- Ability to maintain confidentiality
- Ability to approximate field operating conditions in the test lab

- Traceability of the laboratory's reference measurement standard(s) to national and/or international standard(s)
- Documented history of good laboratory measurement accuracy, repeatability, and reproducibility
- Cost and range of services
- Experienced staff having the ability to quickly troubleshoot and correct problems
- Flexibility in scheduling tests
- Effective and timely reporting and record keeping
- Good working relationship with gas measurement equipment manufacturers
- Familiarity with all industry standards for natural gas measurement
- Active involvement in developing measurement technology.

Today it's important to keep your equipment in top working order, and flow meters are no exception. Flowmeters will lose accuracy gradually over time. Even if we see no outside damages to the unit in question the internal pieces could be giving erroneous readings. As time progresses during the life of a flowmeter, the performance will degrade slowly, over time, until the flowmeter in question is no longer reading correctly. For this reason one should recalibrate his equipment every year to maintain correct readings.

A sample of a calibration procedure flowchart followed by MGL

Flowchart For Control of Monitoring and Measuring Devices



The reasons for a flowmeter falling out of calibration are many and varied. Some of the reasons are,

- **Deposits in the flowmeter**: Minerals, oils, solvents and other foreign matter can have a dramatic impact on the meter's performance.
- **Aging**: Internal parts of any mechanical object will eventually fail or break, many times the bearings are the cause.
- **Damage**: A flow meter that has received a substantial impact or has been dropped can change the performance output of a flowmeter.
- **Improper Installation**: Many times, a flowmeter is put out of calibration simply because it was installed improperly. By not following the manufacturer's specifications, one can break the meter instantly.

Calibrating one's equipments is one of the most important things one can do as a manufacturer. Any measuring device for flow, pressure, humidity, etc. is there to tell us how much of whatever is being mixed/added/purged. An incorrect reading can cost us in time, accuracy, and most importantly, money.

The best results are normally obtained if calibration can be performed **on-site**, with the meter installed in its normal system. Calibration can then allow for sources of error resulting from such causes as the system itself, signal processing and ancillary equipment. Calibration on-site also means that it can be performed using the correct liquid and often those expensive shutdowns can be avoided.

6.18 Calibration Schedule

If one is setting up a schedule for calibration, a simple rule of thumb is to have one's flow meters calibrated once a year. If one is using a new meter or one that is in an unfamiliar environment, it is recommend that initially calibration should be done every 6 months until an accurate "footprint" of the meter is represented (usually in the first year) , then one should switch back to an yearly calibration.

Calibration should be carried out regularly, at intervals to suit maintenance of the required accuracy. This is because meters drift with time, depending on factors such as operating conditions, the medium, the type of meter and how often it is used. It is often a good idea to plan ahead for regular calibrations over a longer period of time. Calibration means that the error of indication of the meter is measured, i.e. figures are given on how much the output value from the meter has to be adjusted in order to be correct.

When manufactured, a meter with a pulse output signal is often marked with a K-factor (pulses/litre). The correctness of this K-factor is found out only after calibration. As the K-factor normally varies with the flow, the meter needs to be calibrated at different flows for better accuracy.

At the calibration, it is important that it is the output signal, which is used, that is calibrated. The output in use can for example be pulse- or current signals, or a display. The output signal can be handled by separate amplifiers and have different time constants or zero-point suppressions. It is therefore important to calibrate the complete chain of signals.

A typical calibration schedule- a case of MGL

MASTER LIST CUM CALIBRATION SCHEDULE OF MMD's

FORMAT NO MARRE 024

Sr No	Location	Instrument	Code	[illegible]	[illegible] Required	Plan	Actual Date	Calibration Certf No	Plan	Actual Date	Calibration Certf No
1	Nicholas Piramal	Turbine Meter	NICPIR/TM	[illegible]	[illegible]	2007			2012		
2	S H Kelkar	RPD	SH KEL/TM	[illegible]	[illegible]	2007			2012		
3	V V F Sen	Turbine Meter	VVF/TM	[illegible]	[illegible]	2007			2012		
4	Vishnu Dyeing	RPD	VIS DY/TM	[illegible]	[illegible]	2007			2012		
5	Asian Paints	Turbine Meter	AS/TM	[illegible]	[illegible]	2007			2012		
6	The Club	RPD	THECLUB/TM	[illegible]	[illegible]	2007			2012		
7	Johonson & Johonson	Turbine Meter	J&J/TM	[illegible]	[illegible]	2008			2013		
8	[illegible]	Turbine Meter	PARA SL/TM	[illegible]	[illegible]	2007			2012		
9	[illegible]	RPD	[illegible]/TM	[illegible]	[illegible]	2007			2012		
10	P D Hinduja	Turbine Meter	PD Hin/TM	[illegible]	[illegible]	2007			2012		
11	Parekh [illegible]	Turbine Meter	Parekh/TM	[illegible]	[illegible]	[illegible]			2013		

[illegible] PG Pressure Gauge DPG Diff Pressure Gauge [illegible]
[illegible] PT Pressure Transmitter TM Turbine Meter

Table 3

The different types of meters require different calibration methods and calibration equipment for best results. Useful questions to ask are:

I. Type of meter? (Principle, resolution, type of output signal, time of integration etc)
II. Type of liquid? (Density, viscosity, aggressiveness, temperature, pressure etc)
III. Manner of use? (Flying or standing start and stop, normal volume to be measured, installation etc)
IV. Acceptable measurement uncertainty? (Often 3 to 10 times better than the acceptable tolerance when in use) To meet the different requirements of calibration, our volume laboratory at SP is equipped with some ten different types of calibration rigs. Several of these have been developed in house.

Maintenance testing may consist of only secondary equipment calibration or complete mechanical inspection of the entire system or an actual throughput test against some agreed upon standards or a combination of these. In any case equipment used to test the meter must be proved and agreed upon. Such devices include certified thermometers for temperature, certified differential testers for differential meters, certified chromatographs for component analysis and certified provers for throughput tests. Certification is important to both parties to minimize concern about the test equipment acceptability. The test equipment however should be recertified on a timely basis by the agency or the manufacturer that originally certified the equipment.

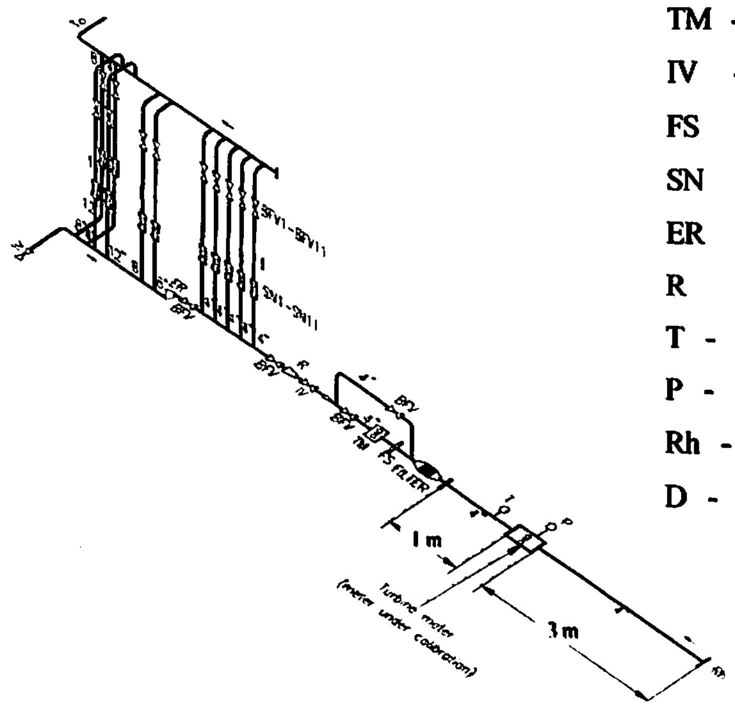
A master meter used in transfer proving is calibrated and certified to some uncertainty limit by a testing facility of a government agency, private laboratory, a manufacturer or a user using agreed upon flow standards. Periodically the master meter has to be sent back to the laboratory for rectification. However the frequency of testing depends on the fluid being tested and the treatment of the master meter between the tests.

Calibration set up and instrumentation

Set up for calibration

The turbine meter is mounted at the upstream of the venturi nozzles. Sufficient straight lengths are provided both at upstream/downstream of the meter under calibration.

Provision is made for the measurement of pressure, temperature at upstream of nozzles and pressure, temperature of air passing through the flow meter. The pressures are measured using a multifunction pressure indicator. The pulse output and time are measured using universal counters. The time required for a particular volume transfer is noted using a digital stopwatch .The temperatures are measured using Resistance Temperature detectors with indicator and the relative humidity is measured using hygromeasuring system.



BFV- Butterfly valve
TM - Turbine meter
IV - Iris valve
FS - Flow straightener
SN - Critical flow venturi nozzle
ER - Eccentric reducer
R Reducer
T - Temperature
P - Pressure
Rh - Relative humidity
D - Diameter

FCRI, Kerala

Figure 21 Calibration set up for a turbine meter

Procedure and Data Reduction

Before starting the calibration, sufficient leak tightness is ensured in the whole set up. The blower is started and sufficient time is allowed for the flow to reach the standard conditions. Conditioned air sucked through the turbine meter after passing through selected reference nozzles is exhausted to the atmosphere by means of the blower located at the end of the loop. The critical condition is ensured for each flow rate by adjusting the downstream pressure so that the upstream pressure remains constant. The flow rate through the turbine meter is varied either by closing/opening the required nozzles using pneumatically operated butterfly valves. For each flow rate the following data is recorded manually.

Turbine meter

Pressure
Temperature
Initial volume
Final volume
Time for the volume transfer

Nozzles

Pressure
Temperature

Ambience

Pressure
Temperature
Relative humidity

The above procedure is repeated for different flow rates of approximately 5%, 10%, 25%, 40%,50%,60%,75%,90% and 100% of the maximum capacity of the meter as per standard covering the range of the meter.

Chapter – 7

Present day flow metering and calibration procedure

A study of MGL

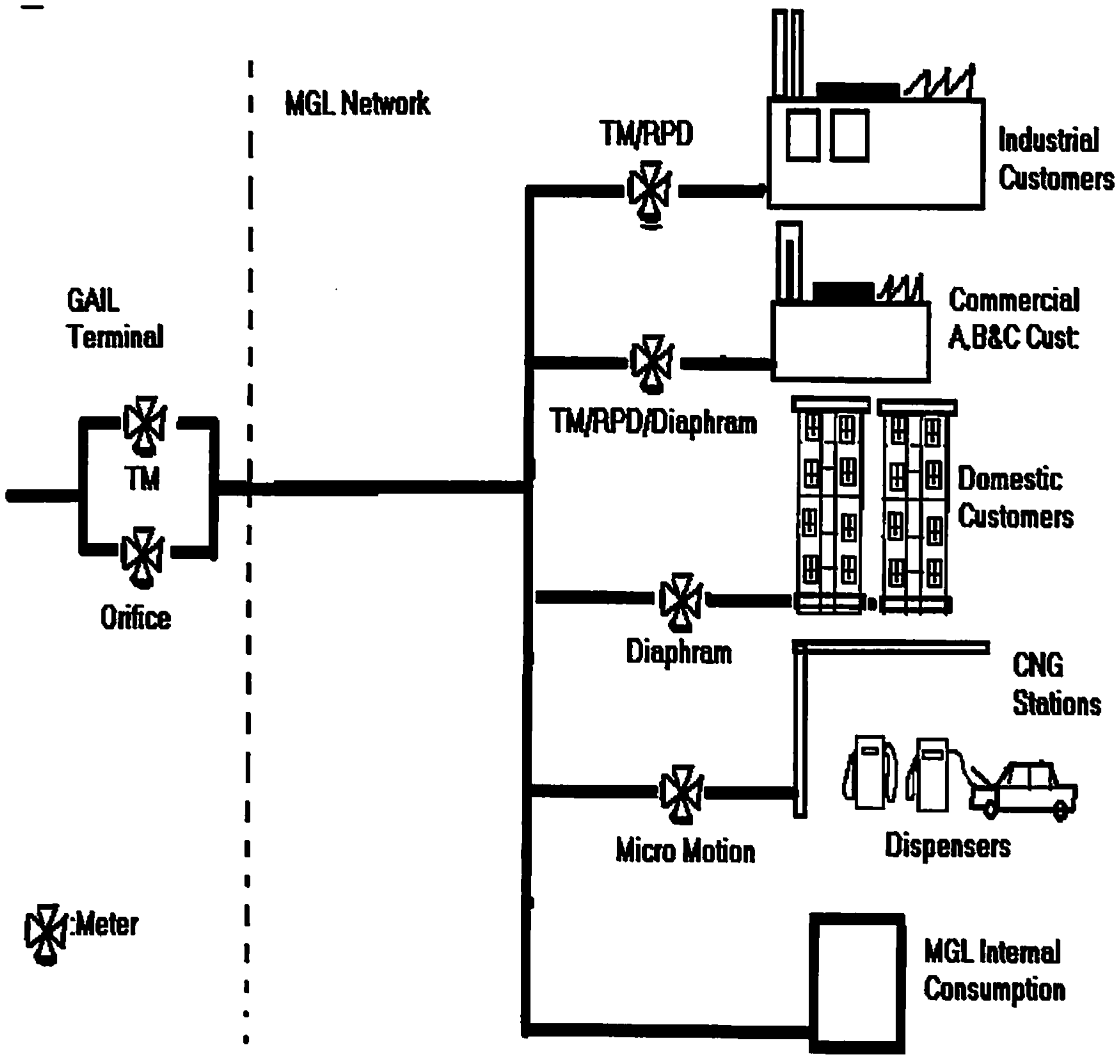


Figure 22: Metering Network of MGL

- **GAIL custody transfer meters**

GAIL has installed two orifice meters in parallel at the main intake of MGL with an accuracy of ±1 %. Barton make flow computer is used for pressure and temperature corrections. The parameters required for the flow calculations are loaded and updated periodically to the computer (as per AGA requirements). Pressure and temperature transmitters installed in the line give actual pressure and temperature readings to the computer.

- **Calibration**

Flow meters are calibrated yearly and pressure & temperature transmitters are calibrated once every three months.

- **Industrial and Commercial C Meters**

MGL has a number of small Industrial customers. All Industrial customers have metering & regulating stations (MRS). Gas volumes are measured by turbine meters or Rotary positive displacement meters. Meter sizes vary from G65 to G1000. Supply pressure to the industries depends upon the requirement ranging from 500 mbar to 16.5 bars. All industrial and commercial meters have an accuracy of not less than ± 1.0%.

- **Calibration**

MGL calibrates these meters once in five years. The calibration of pressure temperature transmitters is done once a year. MGL takes daily meter readings and calculates gas balancing every day. If the flow meter is erratic it will be known and will be re-calibrated.

- **Commercial A & B Meters**

The types of meters used by these customers are diaphragm meters (G25 to G100) and RPD meters. The diaphragm meter has an accuracy of not less than ± 0.5% and RPD has an accuracy of not less than ± 1.0%.

- **Domestic Meters**

The majority of MGL customers are domestic. Presently MGL has 110,000 domestic customers. Diaphragm meters of different makes are used for domestic customers. The supply pressure to domestic meters is 21 mbar. These meters have an accuracy of not less than $\pm$ 0.5%.

- **Calibration**

Domestic diaphragm flow meters are factory calibrated. It is planned that MGL will randomly select a meter population and calibrate it to give a picture of the batch accuracy. Errors will be plotted and the probability distribution fitted to it. This error is to be multiplied by the average consumption, and scaled in to represent the entire population to estimate the unaccounted gas for domestic users.

- **CNG**

MGL sells approximately 50% of its natural gas volume to CNG vehicles. CNG stations receive gas at 19 Bar or less and compress the gas to 220bar. The compressed gas is supplied to vehicles through CNG outlet dispensers. Metering of CNG is done at the dispenser point using coriolis based mass flow meter. Gas is sold in Kgs and the cumulative quantity sold is read on a separately mounted non-resetable totalizers (electro-mechanical/electronic totalizes). Billing to Oil Marketing Companies as well for MGL outlets are based on these totalizes. In addition to the above totalisers, the mass flow meters also have inbuilt electronic non-resetable totalisers which can be read using a communicator. Presently MGL is carrying out reconciliation of dispenser sales by verifying the readings of the above two totalisers on a monthly basis.Most of the online compressors (except the ones which are at CGS-mother station and 9 online stations) have got mass flow meters installed on the discharge side. Reconciliation of sales is also done between dispenser mass flow meters and compressor meters wherever installed. Micro motion meters have an accuracy of not less than $\pm$ 1.0%. In order to reduce the effect of errors due to this meter calibration is undertaken annually.

- **Calibration**

Calibration for these meters is scheduled every year.

METER DETAILS IN MGL

Sr. No.	Industry	MRS	Stream	Meter Make	DN	Type	G Size
1	Contemporary Healthcare (03)	Schlumberger	Twin	Schlumberger	2	RPD	65
2	Pooja Textiles	Schlumberger	Single	Schlumberger	2	RPD	65
3	Hotel BD & P	Schlumberger	Single	Schlumberger	3	RPD	100
4	Roshan Tin Printers	Schlumberger	Single	Schlumberger	3	RPD	100
5	Ujagar Textiles	Schlumberger	Single	Schlumberger	3	RPD	100
6	Burrough Wellcome	Schlumberger		Schlumberger	3	RPD	160
7	Chembur Hospital	Schlumberger	Single	Schlumberger	3	RPD	160
8	Juhu Beach Rsorts	Schlumberger		Schlumberger	3	RPD	160
9	Star Metal	Schlumberger	Single	Schlumberger	3	RPD	160
10	Radha dying &Printing	Schlumberger	Single	Schlumberger	6	RPD	400
11	Contemporary Healthcare (01)	Schlumberger	Twin	Schlumberger	3	Turbine	160
12	The Club	Schlumberger	Single	Schlumberger	3	Turbine	160
13	Asian Paints Ltd.	Schlumberger	Twin	Schlumberger	3	Turbine	250
14	Echjay Forging	Schlumberger	Single	Schlumberger	3	Turbine	250
15	Godrej & Boyce 17	Schlumberger	Twin	Schlumberger	3	Turbine	250
16	Godrej & Boyce13	Schlumberger	Twin	Schlumberger	3	Turbine	250
17	Hotel Ambassador	Schlumberger	Twin	Schlumberger	3	Turbine	250
18	Italiya Dyeing	Schlumberger	Single	Schlumberger	3	Turbine	250
19	Johnson & Johnson	Schlumberger	Single	Schlumberger	3	Turbine	250
20	Kamani Oil	Schlumberger	Single	Schlumberger	3	Turbine	250
21	Mahindra & Mahindra (Auto)	Schlumberger	Twin	Schlumberger	3	Turbine	250
22	Newkem Products	Schlumberger	Single	Schlumberger	3	Turbine	250
23	Paramount Fabrics	Schlumberger	Single	Schlumberger	3	Turbine	250
24	Paramount Silk Mills	Schlumberger	Twin	Schlumberger	3	Turbine	250
25	Parekh Dyeing & Printing	Schlumberger	Single	Schlumberger	3	Turbine	250
26	Seajuly Property	Schlumberger	Twin	Schlumberger	3	Turbine	250
27	Taj Air Caterers	Schlumberger	Twin	Schlumberger	3	Turbine	250
28	Vitrum Glass	Schlumberger	Twin	Schlumberger	3	Turbine	250
29	Asian Hotels (Hyatt Regency)	Schlumberger	Twin	Schlumberger	4	Turbine	160
30	P.D. Hinduja Hospital	Schlumberger	Twin	Schlumberger	4	Turbine	160
31	Godrej Soaps	Schlumberger	Twin	Schlumberger	4	Turbine	250
32	Hotel Leela	Schlumberger	Single	Schlumberger	4	Turbine	400
33	L & T, Group II	Schlumberger	Single	Schlumberger	4	Turbine	400
34	Lilavati Hospital & Research Center	Schlumberger	Twin	Schlumberger	4	Turbine	400
35	Merind	Schlumberger	Twin	Schlumberger	4	Turbine	400
36	Parle Products	Schlumberger	Single	Schlumberger	4	Turbine	400
37	Pepsico India Holdings Lt	Schlumberger	Single	Schlumberger	4	Turbine	400
38	Seajuly Property	Schlumberger	Twin	Schlumberger	4	Turbine	400
39	Tata SSL	Schlumberger	Twin	Schlumberger	4	Turbine	400
40	Ujagar Print	Schlumberger	Single	Schlumberger	4	Turbine	400
41	Victory Flask	Schlumberger	Twin	Schlumberger	4	Turbine	400
42	Borosil Glaas Works	Schlumberger	Twin	Schlumberger	6	Turbine	650
43	Jollyboard	Schlumberger	Single	Schlumberger	6	Turbine	650
44	VVF Ltd.	Schlumberger	Twin	Schlumberger	6	Turbine	1000

Table 4

Chapter - 8

Lost & Unaccounted Gas

The report card for any business is the balance between what comes in, what is used by the business and what goes out. In pipeline business this is referred to as the "loss and unaccounted for" (LUAF) or system balance. The control on the cost of doing business and the profits earned are based on this report. It must be properly and continually monitored so that the control is affected. Management must support the investment of time, money and personnel if they want a meaningful report upon which to base decisions.

Controlling system balance is a matter of identifying influences that create differences between inlet measurement and outlet measurement and either eliminating them or reducing them to acceptable levels. Pursuing sources of "loss and unaccounted for" should be regular and ongoing process within a company dedicated to managing its system balance.

At one time significant amount of gas was actually lost through leaks in pipelines. However, with the conversion to natural gas, higher pressure, higher volume production and long distance pipelines, leaks were found by the presence of discoloured vegetation or by spotting gas leaks-primarily made noticeable because of high velocity noise-when walking the lines.

Other than very small leaks such as valves and flanges most unaccounted for gas today is caused by the limitations of flow measurement resulting from poor meter application, operation and maintenance. Under best circumstances, all flow measurements have uncertainties that prevent achieving 100% accuracy. Thus always there is some degree challenge of controlling the loss and unaccounted for gas.

The principal concern is to determine whether there is a problem of significance or whether the results fall within realistic expectation. The sources that help define realistic expectations are:

1. The operating company's past history of specific measurement balances.
2. The experiences of similar operating companies' balances.

Depending on the system and flow measurement complexities, a realistic expectation can vary from ±0.25% to ±0.5% for large pipeline companies, and from 3% to 10% for production field balances. Distribution companies usually fall somewhere in the 3.0 to 20.0% limits. All unaccounted for gas is lost revenue, so there are economic reasons for finding the loss sources.

A system balance review should include the type of meters installed, their location, their installation, and sizes and types including primary elements and associated readout equipment. Equally important are the fluid properties and how they are being determined. From this information, an estimate of expected system uncertainty can be determined. The review should include operating ranges and maintenance history of each station with emphasis on the larger volume stations as potential sources of significant loss.The meters should be compared to the latest industry standards and procedures. Operational procedures and standards are updated continually as new knowledge is obtained on the various meters' performance and the means of reducing uncertainties.

LUAG Policy of MGL

Mahanagar Gas Limited supplies natural gas to domestic, commercial & industrial customers and compressed natural gas to vehicles. There is a single source of gas supply, which is GAIL. GAIL has a metering and pressure reducing station and metered gas at maximum pressure of 19 bar is supplied to the MGL network. In addition to this MGL has an unregulated gas supply which supplies four gases driven engines for operating CNG compressors and three gases based air conditioners. MGL distributes gas in Greater Mumbai through steel and PE networks to domestic, commercial & industrial customers and CNG vehicles. The gas supplied to all customers is metered. However unaccounted losses can arise from measurement errors, volume calculation errors, accounting errors and system losses.

Constituents of the Design of an LUAG Report

Measurement Error

Meter Inaccuracies

Accurate measurement of gas volume is a function of the meter performance and the factors used to adjust the meter reading. MGL uses different types of meters depending on gas consumption (Turbine flow meter, rotary positive displacement meter, diaphragm flow meter, mass flow meter) of different makes for volume accounting, each having a different range and accuracy. The volume of gas registered by the meter requires adjustment for temperature, pressure, elevation, specific gravity and diluents. Difference between volumes of gas actually registered by the meter, and that, which would have been registered under standard reference condition results in an error. Errors in volume measurement can occur due to:

Volume Calculation Methods

Standard Volume calculation

MGL accounts for gas volume in standard conditions but meters measure the actual volume passed. The actual volume reading is converted to standard reference conditions. In order to convert to the standard condition MGL uses the following method:

$$V_b = V_m \times (P/P_b) \times (T_b/T) \times (Z_b/Z)$$

Where:

Vb = Converted volume to Standard conditions.

Vm = Volume measured at metering conditions.

Tb = Standard Temperature (288.15 K)

T = Gas temperature at the metering conditions.

Pb = Standard pressure in Bar.

P = Pressure at metering end (as absolute)

Zb = Gas compressibility factor at standard conditions

Z = Gas compressibility factor at metering conditions

Electronic Flow Volume corrector

This device is used for the conversion of normal volume to standard conditions. It will measure the temperature and pressure dynamically and apply correction accordingly to the meter pulse. At present MGL has 14 Industrial customers with Electronic volume converting devices. In this device the accuracy depends on meter and pressure temperature measuring elements. MGL plans to install EVC to all customers whose consumption is 1000 SCMD and above. For all new customers in this sector EVC will be installed as a part of their MRS. An EVC is installed to improve the accuracy of gas measurement.

Fixed Factor Correction

MGL supplies gas to 32 Industries without any Electronic Volume correcting devices. The calculation of correction factor to standard condition is done as per the formula mentioned above assuming the average metering temperature is 25 deg C, and pressure as the gauge pressure at the regulator outlet. The seasonal temperature variation (15 to 35 deg C) and pressure gauge inaccuracies will result in an error. A detailed study of temperature and pressure variation is shown below. It is observed that a Percentage variation of 0.7% can occur due to the fixed factor correction.

Volume = Mass of Gas / Density of Gas.

The density factor is calculated as per the Gas Analysis Report from GAIL, which is received weekly. The changed density factors will be applied once in a week and are applicable for the whole week. The density of gas during this period will vary depending upon the composition of the gas.

Calculation Of The Correction Factor for Standard Volume

Sr. No.	Industry	Volume At Operating Conditions = Vm	Volume At Standard Conditions = Vb	Operating Pressure	For 3% Inaccuracy at 20 Degree C.	Correction Factor = CF	Volume For 20 Degrees. = V20	Differecne
1	Radha dying &Printing	2950	4257.8825	500	515	1.457652547	4300.075013	42.19251279
2	Hindustan Composites	4392.7	6340.203545	500	515	1.457652547	6403.030342	62.82678893
3	Echjay Forging Pvt. Ltd.	2514	3628.5819	500	515	1.457652547	3664.538502	35.95660243
4	L & T Heavy	3504	5057.4984	2000	2060	2.931281328	10271.20977	5213.711373
5	Premier Textiles	1750	2525.8625	500	515	1.457652547	2550.891957	25.02945674
6	Universal Knitting	1400	2020.69	500	515	1.457652547	2040.713565	20.02356539
7	Vishnu Dyeing	1200	1732.02	500	515	1.457652547	1749.183056	17.16305605
8	indian Smelting	3400	4907.39	500	515	1.457652547	4956.018659	48.62865881
9	Victory Flask	2400	3464.04	800	824	1.752378303	4205.707927	741.667927
10	Juhu Beach Resorts	2030	2930.0005	500	515	1.457652547	2959.03467	29.03416982
11	Pepsico India Holdings Lt	1100	1587.665	500	515	1.457652547	1603.417801	15.73280138
12	Shakti Textiles	1809	2611.175402	500	515	1.457652547	2637.050247	25.87484543
13	Hotel Leela	1709	2467.165728	500	515	1.457652547	2491.613543	24.4478145
14	Hotel Raheja (Chalet)	1605	2316.155584	500	515	1.457652547	2339.106998	22.95141402
15	Contemprory Health Care	1507	2175.12845	500	515	1.457652547	2196.682368	21.55393789
16	S H Kelkar	1350	1948.5225	500	515	1.457652547	1967.830938	19.30843806
17	Godrej Plant 4	1160	1674.286	500	515	1.457652547	1690.876954	16.59095418
18	Ujagar Print	1500	2165.025	500	515	1.457652547	2186.47882	21.45382006
19	L & T Switchgear	500	721.675	500	515	1.457652547	728.8262734	7.151273355
20	Hotel ITC	999	1442.096871	500	515	1.457652547	1456.387	14.29012911
21	Johnson & Johnson	700	1010.345	500	515	1.457652547	1020.356783	10.0117827
22	Metal Tubes	1450	2092.8575	500	515	1.457652547	2113.596193	20.73869273
23	Valson Dyeing	2150	3103.2025	500	515	1.457652547	3133.952975	30.75047542
24	Newkem Products	876	1264.3746	500	515	1.457652547	1276.903631	12.52903092
25	Parekh Dyeing	1300	1876.355	500	515	1.457652547	1894.948311	18.59331072
26	P D Hinduja	742	1070.9657	500	515	1.457652547	1081.57819	10.61248966
27	Crompton Greaves	690	995.9115	500	515	1.457652547	1005.780257	9.868757229
28	Hotel Sea Princess	647	933.84745	500	515	1.457652547	943.1011977	9.253747721
29	Oberoi Flight Services	623	899.20705	500	515	1.457652547	908.1175366	8.9104866
30	Kanjur Bleaching	567	818.37945	500	515	1.457652547	826.486994	8.109543984
31	Hotel BD & P	543	784.0526675	500	515	1.457652547	791.8220581	7.769390584
32	Italia Dyeing	541	780.85235	500	515	1.457652547	788.5900278	7.73767777
33	Roshan Tin Printers	521	752.4795531	500	515	1.457652547	759.9360772	7.456524028
34	Star Metal	514	741.5661164	500	515	1.457652547	748.9144962	7.348379823
35	Mahalaxmi Glass Works	500	721.675	500	515	1.457652547	728.8262734	7.151273355
36	Godrej Plant 19	500	721.675	500	515	1.457652547	728.8262734	7.151273355
37	The Club (Khanna Hotel)	312	450.3252	500	515	1.457652547	454.7875946	4.462394573
38	Holiday Inn	146	210.7291	500	515	1.457652547	212.8172718	2.08817182
39	Ruby Mills	11000	15876.85	500	515	1.457652547	16034.17801	157.3280138
40	Pooja Textiles	135	194.85225	500	515	1.457652547	196.7830936	1.930843806
41	Chembur Hospital	17	24.53695	500	515	1.457652547	24.78009329	0.243143294
42	Lilavati Hospital	700	1010.345	500	515	1.457652547	1020.356783	10.0117827
43	Harinagar Sugar Mill (Shangrilla)	1000	1443.35	500	515	1.457652547	1457.652547	14.30254671
44	Ruby Mills	11000	15876.85	500	515	1.457652547	16034.17801	157.3280138
								6957.277294

Table 5

Accounting Errors for LUAG

Through billing/ Reading cycle

- **Gas Purchase reading**

The total gas purchased figure is the reading MGL gets from GAIL custody meter. This is the gas supplied for twenty-four hours i.e. between 6.00 hrs to 6.00hrs.

- **Industrial and Commercial C customers**

For industrial and commercial customers MGL takes daily readings. The reading is taken between 06.00hrs and 14.00hrs and a correction for the 24 hour period is applied, this is based on the assumption that all our customers are using gas on a uniform rate at all times.

- **Commercial A&B customers**

For commercial A and B customers readings are taken monthly and this reading is divided by the number of days to get the average consumption of a customer. These average consumptions are used for calculation of daily gas balancing.

- **Domestic**

Because of practical difficulties in covering the large number of domestic customers, MGL takes reading once in four months. And the consumption for the other period is projected. The difference is adjusted in the next cycle. For the Gas Balancing purpose the average consumption of a customer is derived from the billed customers and the same average is multiplied with the total number of customers to find out the daily domestic consumption.

All these readings are compared with the Gas Purchased reading for the Gas Balancing.

- **Meter Manipulation and Theft**

All industrial metering and regulating stations of MGL have a bypass line used to supply gas if the flow meter is to be taken out for calibration, maintenance or repair. Customers may open this bypass line and use the unmetered gas. Since meter readings are taken daily the possibility of a customer using the unmetered bypass line is low. Customers can also tamper meters, but it is planned to install tamper seals to bypass lines which may be checked during meter reading and breakages investigated. Non-routine visits and daily meter reading will help mitigate risk of theft. All metering and regulating stations are locked and the key is kept with MGL.

System Losses

Leakage in distribution network

- **Pipeline External Damage and Loses at regulating and metering stations**

To avoid and minimize the above, MGL does daily patrolling of the entire steel and 4 bar networks. Patrolling helps reduce the potential threat of external agency damages on MGL line. It also helps to find and rectify leakages. To reduce losses at the metering and regulating station regular visits and maintenance is done.

- **Pipeline Corrosion**

Leakage can occur from deterioration of steel pipes due to corrosion. A combination of corrosion protection coating and cathodic protection is applied on underground steel pipelines to avoid corrosion.

- **Commissioning/Decommissioning / Purging**

During commissioning and decommission of mains and services, gas is released, the quantity is dependent on the section of purge being under taken. The volumes are derived by calculating the volume of gas in the pipe section and multiplying by the pressure.

- **Compressor stations**

Gas escape from natural gas compressing/ filling stations occurs due to:

- Compressor shaft seals leakage.
- Compressor pipe joint leakage.
- Blowing off safety relief valves.
- Venting at the time of vehicle filling.

To mitigate this regular scheduled maintenance is carried out and gas detecting and alarm systems are installed on all the compressor units.

Maintenance activities (depressurizing & venting)

Appropriate planning of maintenance activities is carried out to reduce the frequency of venting by ensuring that the maintenance activities are coinciding with inspections.

Company's Own Use

MGL uses gas for running four gas engines for CNG compressors at City Gate station and AC units in the offices. Also the office pantries use gas for making tea etc. The gas used in CNG compressor is calculated by taking into account the unit efficiency and time of operation. The gas used in AC units and pantries is metered.

Monitoring LUAG

MGL uses the following methods to monitor significant changes in the loss and unaccounted gas.

- **Daily Gas Balancing Report**

MGL generates daily gas balancing report to give the dynamic picture of the LAUG. The procedure for gas balancing is as follows. The gas purchase volumes are compared with all MGL sales and internal use. Sales in the various sectors like Industry Commercial A, B, C, CNG, Domestic and Internal Consumption are calculated separately. For Industrial and Commercial C customers actual meter readings are taken. For commercial A, B and Domestic consumers average consumption based on the previous month is taken. For CNG sales, the total CNG sales in Kg are converted to standard volume by applying a conversion factor. Gas balancing is done in SM^3 of gas and the difference is calculated in SM^3. The variation in % is calculated by dividing gas purchased with the difference between the gas sale and purchase.

- **Monthly/ Yearly Gas Balancing Reports**

Every month a report is generated which gives a total picture of MGL gas balancing for the month. This report also shows year to date % variation for the current financial year and the 12 month rolling average % variation. Actual billing records are used monthly to calculate actual LUAG and compared with accumulated gas balancing reports.

A DAILY GAS SALES REPORT IN MGL

(DATE : 17/07/2004)

Sr.No	Particulars	Unit	Nominated Qty	Quantity	Total in this month	Total in this year
I.	**GAS PURCHASED FROM GAIL**	SCMD		**1178866**	**20032501**	**116210779**
II	**GAS SALES**					
A	***Industrial***	SCMD				
1	Pepsico		1800	1705	29411	314882
2	Ujagar Prints		1200	1601	17061	131613
3	Victory Flask		3400	3500	61547	486922
4	Empire (Vitrum)		20000	22032	367530	2871690
5	Borosil Glass		6000	8403	142978	1174700
6	L & T Industries		5000	1606	68165	487595
7	Parle Products		12000	10124	162000	1158279
8	Jollyboard		12000	224	180090	1666681
9	Star Metals		1000	25	13798	143832
10	Just Textiles		4000	5277	75622	556338
11	Metal Tubes	.	1000	2905	42430	275798
12	Premier Textiles		3400	2723	38356	351913
13	Haldyn Glass		20000	22868	414322	3312227
14	Shakti Textiles		2000	1904	23244	260374
15	Radha Dyeing		2000	3684	59391	481443
16	Johnson & Johnson		1000	904	16390	131018
17	Godrej Soaps (Including MRS I & II)		37300	46853	725881	4831211
18	Indian Smelting		3900	4575	74179	614223
19	Univesal Knitting		3000	2678	36776	331324
20	Mahindra& Mahindra (Incl.Automotive Div.)		12000	11395	203887	1665593
21	Valson Dying		2800	2639	54249	422063
22	Tata SSL		15000	10911	181369	1376196
23	Merind		12400	16683	276113	2248310
24	Godreg & Boyce		8000	9510	153813	1274673
25	Amforge		5500	3289	83961	595363
26	Asian Paints		2000	546	14173	138899
27	Nicolas Piramal		1200	2801	53537	320932
28	V.V.F		30000	32323	581684	4197034
29	Vishnu Dyeing		1800	2030	18368	247960
30	S. H. Kelkar & Co.		1700	2103	40520	245718
31	Para Mount Silk Mills Pvt. Ltd.		5000	4197	55233	584130
32	Century		27000	23200	414726	3419224
33	Parekh Dyeing & Printing		2500	2873	32196	252102
34	Echjay Forging		3300	3684	60297	488780
35	Mahalaxmi Glass Works		1000	0	4414	54974
36	Hari Nagar Sugar Mills (Shangrilla)		1250	1271	25288	195734
37	Paramount Fabrics		2000	3101	40710	308168
38	Hindustan Composites		5750	7003	69522	629029
39	Prakash Cotton Mills		2800	3102	47914	186513
40	Ruby House		11500	10809	153247	337672
41	Jayant Oil Mills		1900	2087	43309	65871
42	Laminator		1000	93	1822	1857
43	M.S.E.B.			0	0	0
44	Nicolas Piramal (AC)			73	73	73
45	Kamani Oil Mills		9000	10489	163497	1209910
	Sub total		**306400**	**309803**	**5323093**	**40048841**
B	***Commercial 'C'***	SCMD				
1	Hotel Leela		3000	2754	44116	274572
2	Hotel Raheja		5000	3853	74121	442183
3	BD&P Hotels		1000	881	14065	88117
4	ITC		1800	1739	29699	170366
5	Asian Hotels (Hyatt Regency)		1500	1630	24207	150989
6	Taj Air Caterers		2750	2863	47461	291312
7	Hotel Ambassador		1100	1119	17869	110416
8	Hinduja		1000	1188	20795	117326
9	Khanna Hotels (The Club)		800	786	13761	91561
10	Bharat Hotel (Inter Continental)		1500	1568	23113	149395
11	Grand Hyatt (Meter No. 500201 + 500301)		13750	7013	97162	602832
12	Leelavati Hospital		1000	970	18287	109996
13	Hotel Sea Princess (Mtr. No. 15094359)		800	976	5211	50697
14	Hotel Sun & Sand (Mtr. No. 710131+41+38)		800	1336	19373	131352
15	Hotel Taj Land End (Meter No.2002 + 2003)		2100	3787	66760	199096
16	Shoppers Stop		400	361	4693	36920
17	Hotel Raffle (Meter No.-710186+710201)		300	763	10615	61084
18	Contemp. Health Care(Meter No.-601+603)		1300	1446	28725	173249
	Sub total		**39900**	**35033**	**560033**	**3251463**
C.	***Commercial 'A'***	SCMD		14945	245844	1435931
a.	Consu 474					
b.	Average consumption based on previous mc 31.53 SCMD					
D	***Commercial 'B'***	SCMD		35770	590291	3540462
	Consu 107 Nos.					
	Average consumption based on previous mc 334.3 SCMD					
E	***Domestic***	SCMD		83657	1402145	5580466
	Consumers 2E+05 Nos					
	Average consumption based on previous mc 0.52 SCMD					
F	***CNG #### kg***			683994	11650428	67654066
	Conversion Factor 0.6832	SCMD				
H	Internal Consumption	SCMD		1,873	30501	191409
	Total	SCMD		**1165075**	**19802336**	**115800463**
	Difference	SCMD		**-13791**	**-230165**	**-410316**
	% Variation	%		**-1.17**	**-1.15**	**-0.35**

Table 6

MIS Month : April 2004(Revised)

GAS BALANCING REPORT

	PARTICULAR	QUANTITY (in SCM)	Total For The Year Till This Month	Quantity Of The Month Last Year	Quantity For The Last 12 Months
A	**Gas Purchase** (As per Custody Transfer Meter)	31,569,097	31,569,097	21,666,428	31,569,097
B	**Gas Sales**				
i)	Domestic (Average consumption is 0.52 SCMD/ Customer)	2,360,272	2,360,272	1,794,248	2,360,272
ii)	Commercial A (Actual)	397,584	397,584	269,866	397,584
iii)	Commercial B (Actual)	992,335	992,335	630,772	992,335
iv)	Industrial (Actual)	8,199,330	8,199,330	6,778,478	8,199,330
v)	Commercial Contract (Actual)	916,425	916,425	581,396	916,425
vi)	CNG (Actual)	18,383,251	18,383,251	11,526,422	18,383,251
vii)	Internal use	52,817	52,817	49,932	52,817
viii)	Gas accounted for additional steel line & PE line commissioning	102	102	0	102
ix)	Gas escaped by safety valve popoff at GAIL terminal	0	0	-	0
x)	Gas Adjustment (Jaya Auto)	0	0		0
	Total Sale	31,302,116	31,302,116	21,631,114	31,302,116
	Variation (B - A)	-266981	-266981	-35314	-266981
	Loss / Gain	-266981	-266981	-35314	-266981
	Percentage of Loss / Gain %	-0.85	-0.85	-0.16	-0.85

Table 7

Control Measures

- **Electronic Flow Volume Corrector and Telemetering**

It is proposed to install this system for all industrial and commercial customers who consume more than 1000 SCMD of gas. All new installations in commercial and industrial sector will have EVC and telemetering installed as a part of the metering and regulating station. This is being done to improve the accuracy of measurement.

- **Gas density**

Gas density is obtained from GAIL once a week and for the whole week the same value is used to calculate the SM^3 gas sold as CNG. During the week the actual gas density may vary because of the gas composition, which will result in variation in volume calculation. MGL has conducted a study by taking the gas density figures for one year (Jan 02 to Dec 02) to find out the extent of variation. The percentage variation due to density factor is 1.79% for CNG sales. An online density meter will reduce errors due to density fluctuation.

- **Calibration of Custody meters**

In case of significant variations in LUAG, joint recalibration will be done in GAIL custody transfer meters.

Target

MGL has a target to achieve LUAG of $\pm$ 1.5 %. (Stretch target $\pm$ 1.2 %).

Chapter – 9

Conclusion & Scope for future work

When money is to be exchanged, the best flow measurement becomes important. The performance of any measurement system is judged by the evaluation of the uncertainty in the measurement and if there is a desire to reduce the inaccuracies proper maintenance and calibration of the meters becomes essential. Properly trained personnel, who understand the importance of the maintenance of equipment they are working with, are the keys to accurate measurement.

With proper procedures, accurate test equipments and a timely test frequency any company can have an acceptable "loss & unaccounted for" record. Many different capabilities are required to measure flow. Each job should be well defined so that the expectations of accuracy can be balanced against cost to device the most cost effective installation that will do the required job.

Revenue Loss For A Given Inaccuracy In The Flow Meter

Sr. No.	Consumption of Gas in Meter Cube/Day	Considering 1% Inaccuracy in Meter	Cost Implication Per Day Considering Rs 2.5/ Meter Cube	Cost Implication For One Year	Cost Implication For Five Year	Considering 2% Inaccuracy in Meter	Cost Implication/Day Considering Rs. 2.5/Meter Cube	Cost Implication For One Year	Cost Implication For Five Year
1	500	5	12.50	4562.50	22812.50	10	25.00	9125.00	45625.00
2	1000	10	25.00	9125.00	45625.00	20	50.00	18250.00	91250.00
3	1500	15	37.50	13687.50	68437.50	30	75.00	27375.00	136875.00
4	2000	20	50.00	18250.00	91250.00	40	100.00	36500.00	182500.00
5	2500	25	62.50	22812.50	114062.50	50	125.00	45625.00	228125.00
6	3000	30	75.00	27375.00	136875.00	60	150.00	54750.00	273750.00
7	3500	35	87.50	31937.50	159687.50	70	175.00	63875.00	319375.00
8	4000	40	100.00	36500.00	182500.00	80	200.00	73000.00	365000.00
9	4500	45	112.50	41062.50	205312.50	90	225.00	82125.00	410625.00
10	5000	50	125.00	45625.00	228125.00	100	250.00	91250.00	456250.00
11	5500	55	137.50	50187.50	250937.50	110	275.00	100375.00	501875.00
12	6000	60	150.00	54750.00	273750.00	120	300.00	109500.00	547500.00
13	6500	65	162.50	59312.50	296562.50	130	325.00	118625.00	593125.00
14	7000	70	175.00	63875.00	319375.00	140	350.00	127750.00	638750.00
15	7500	75	187.50	68437.50	342187.50	150	375.00	136875.00	684375.00
16	8000	80	200.00	73000.00	365000.00	160	400.00	146000.00	730000.00
17	8500	85	212.50	77562.50	387812.50	170	425.00	155125.00	775625.00
18	9000	90	225.00	82125.00	410625.00	180	450.00	164250.00	821250.00
19	9500	95	237.50	86687.50	433437.50	190	475.00	173375.00	866875.00
20	10000	100	250.00	91250.00	456250.00	200	500.00	182500.00	912500.00
21	10500	105	262.50	95812.50	479062.50	210	525.00	191625.00	958125.00
22	11000	110	275.00	100375.00	501875.00	220	550.00	200750.00	1003750.00
23	11500	115	287.50	104937.50	524687.50	230	575.00	209875.00	1049375.00
24	12000	120	300.00	109500.00	547500.00	240	600.00	219000.00	1095000.00
25	12500	125	312.50	114062.50	570312.50	250	625.00	228125.00	1140625.00
26	13000	130	325.00	118625.00	593125.00	260	650.00	237250.00	1186250.00
27	13500	135	337.50	123187.50	615937.50	270	675.00	246375.00	1231875.00
28	14000	140	350.00	127750.00	638750.00	280	700.00	255500.00	1277500.00
29	14500	145	362.50	132312.50	661562.50	290	725.00	264625.00	1323125.00
30	15000	150	375.00	136875.00	684375.00	300	750.00	273750.00	1368750.00

Table 8

Revenue loss due to present day calibration policy over a period of one year

Analysis of data

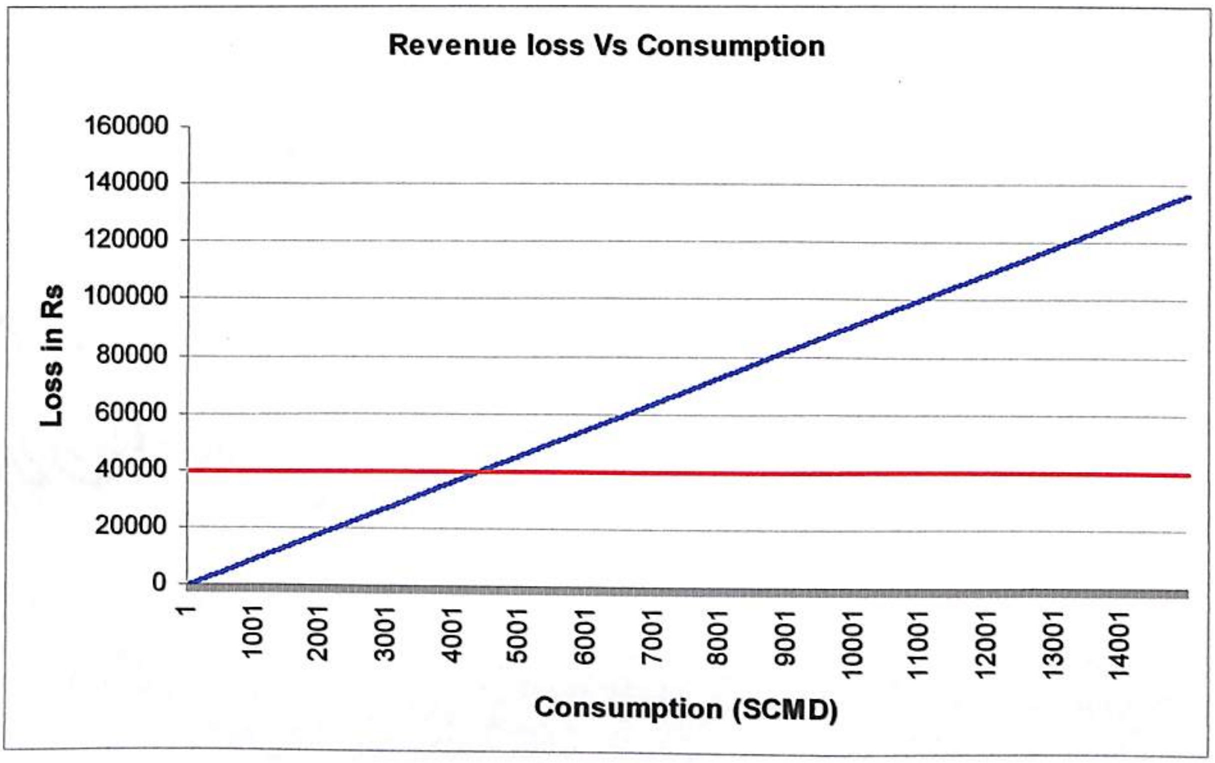


Figure 23: Revenue loss Vs consumption plot for one year

Interpretation from data

Considering an inaccuracy of 1% in the meter and the cost of calibration for a single meter as Rs 40, 000, on plotting a curve "Revenue loss Vs consumption" it can be interpreted that it is not economical to calibrate a meter every year for a consumption upto 5000 SCMD. While above a consumption of 5000 SCMD it is necessary to calibrate the meters every year else the revenue loss becomes much higher than the cost of calibration.

Revenue Loss Due To Present Day Calibration Policy over a Period of Five Years

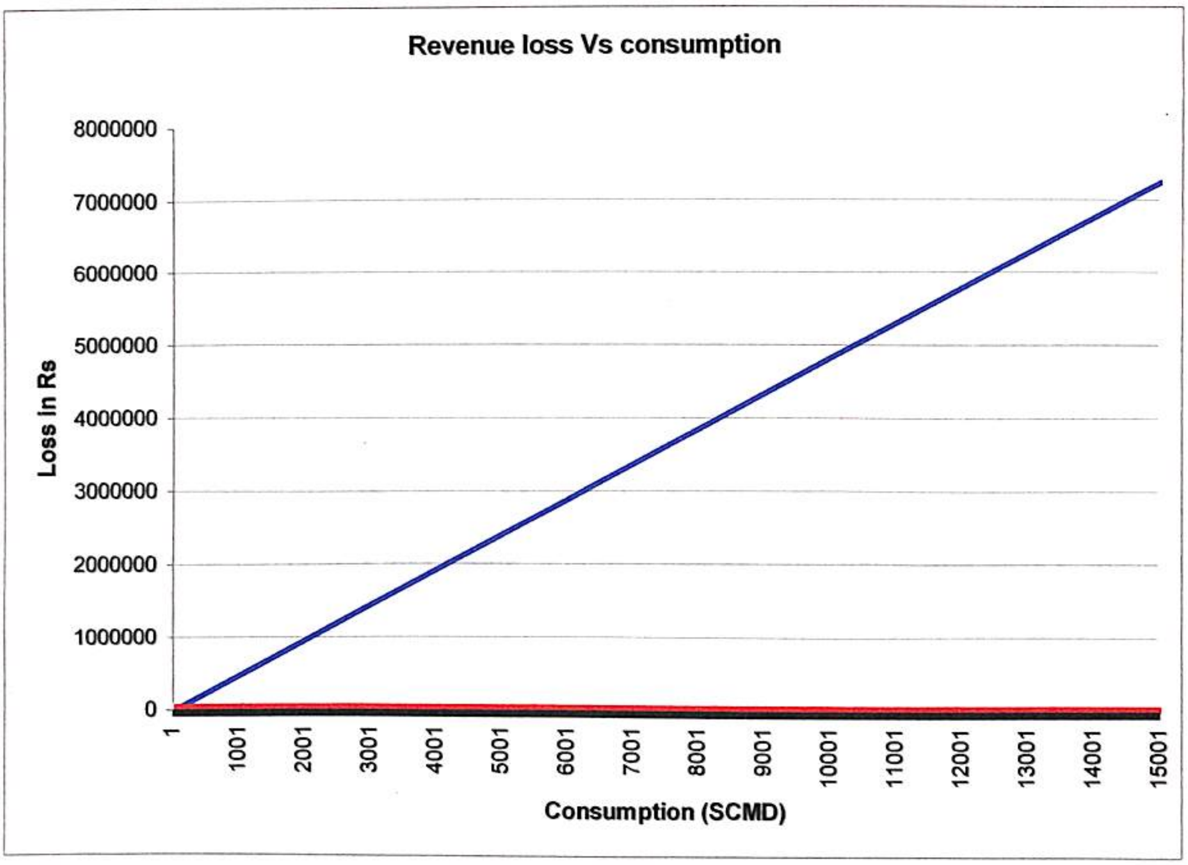


Figure 24: Revenue loss Vs consumption plot for a period of 5 years

Interpretation from data

If a curve is plotted for a period of 5 years we find that the revenue loss is manifolds higher than the calibration cost. However, if the inaccuracy in meter becomes 2% it will further add up to the losses. Thus it is beneficial to the company if the present policy of calibrating meters every five years is revised accordingly.

Issues associated with Domestic diaphragm meters

A study of residential diaphragm meters presently installed

Case of Mumbai city

As per the observations of the company the maximum consumption of gas by the domestic users is between 5a.m–9 a.m and 5 p.m –11 p.m. Thus the consumption of gas is about 10 hours daily.

At present we are using a meter of capacity 2.5 m^3/hr while the average daily consumption of gas is 0.5 m^3/day. i.e. 0.05 m^3/hr.

From the accuracy curve for the residential diaphragm meter it is seen that all meters are tested at Q min, 0.2 Q max and Qmax. It is seen that the error in measurement is maximum when the meter is operated below 2Qmin

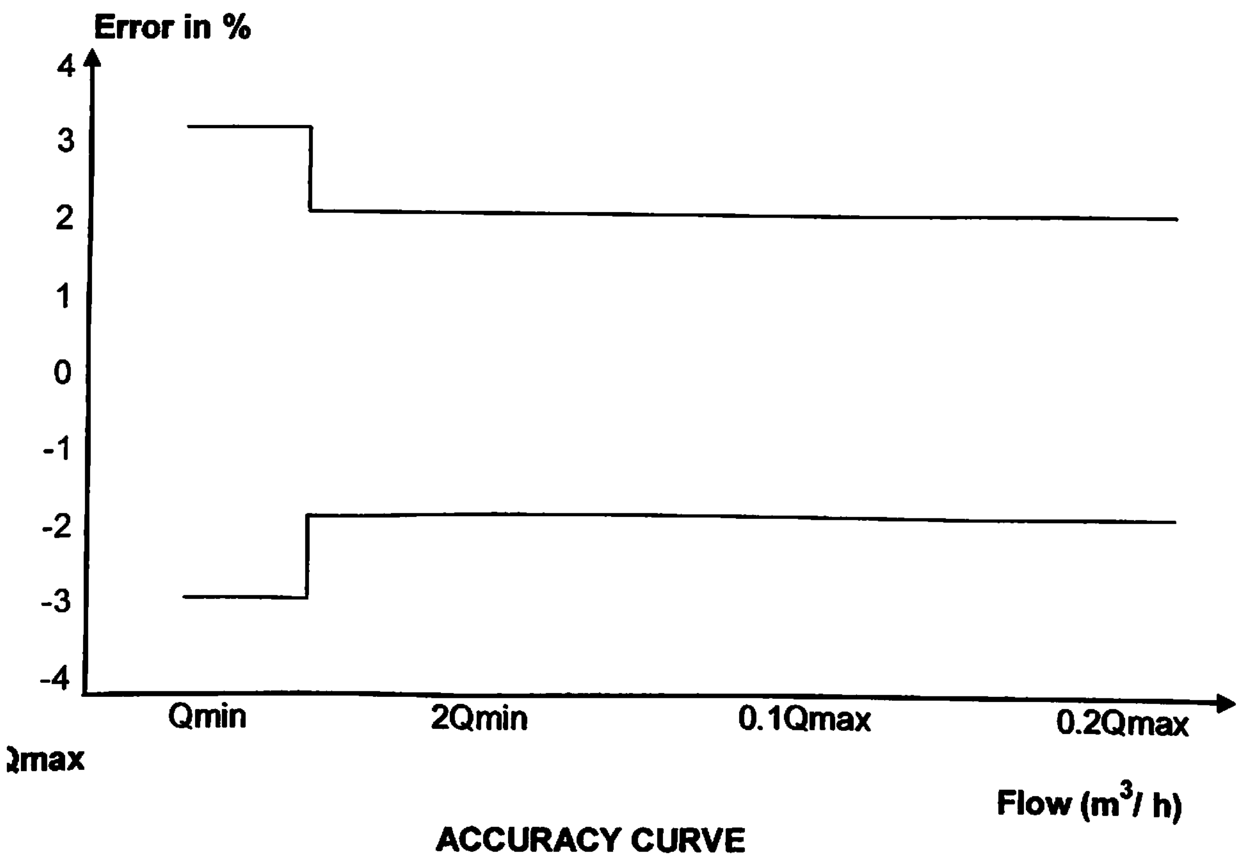


Figure 25: Accuracy Curve

For RF1 G6 make of the residential diaphragm meter as per the technical characteristics

$Qmin = 0.06\ m^3/hr$

$2Qmin = 0.12\ m^3/hr$

While we are operating at 0.05 m/hr which is less than 2Qmin and hence the meter is operating at maximum inaccuracy regime. Thus meter selection should be done as per our residential requirements and hence we should choose a meter with a lower Qmin.

At present there is no fixed policy in MGL for the calibration of diaphragm meters.

A proposal for calibration

We can take any number of meters from a lot of meters purchased in a given year. Say MGL purchased 10,000 meters for the year 1995.We can take 100 meters out of this lot and calibrate. The company must fix a tolerance limit for the inaccuracy in the meter. After interpreting the calibration characteristics one can decide whether the inaccuracy falls within the fixed tolerance limit or not. If it falls below the limit than the meters can be continued with else the entire lot for a given year can be calibrated or replaced.

Case of Delhi city

- Maximum consumption of gas by the domestic users is between 5a.m–9 a.m and 6 p.m –11 p.m. Thus the consumption of gas is about 9 hours daily.
- A meter of capacity 2.5 m3/hr is used while the average daily consumption of gas is 0.7 m3/day i.e. 0.077 m3/hr.
- 2Qmin = 0.12 m3/hr

While we are operating at 0.077 m3/hr which is less than 2Qmin and hence the meter is operating at maximum inaccuracy regime.

Thus we can observe from the interpretation of data that an inaccuracy of just 1% in a flow meter leads to a revenue loss manifolds when compared with the cost of calibration. The present day existing policy should thus be revised by the company accordingly which can lead to vital amount of savings by any company. A well defined calibration policy and the usage of the required capacity diaphragm meter will lead to minimization of the inaccuracies involved. Thus a better report card can be generated for any company in terms of the LUAG which is the determining factor for the success of any company.

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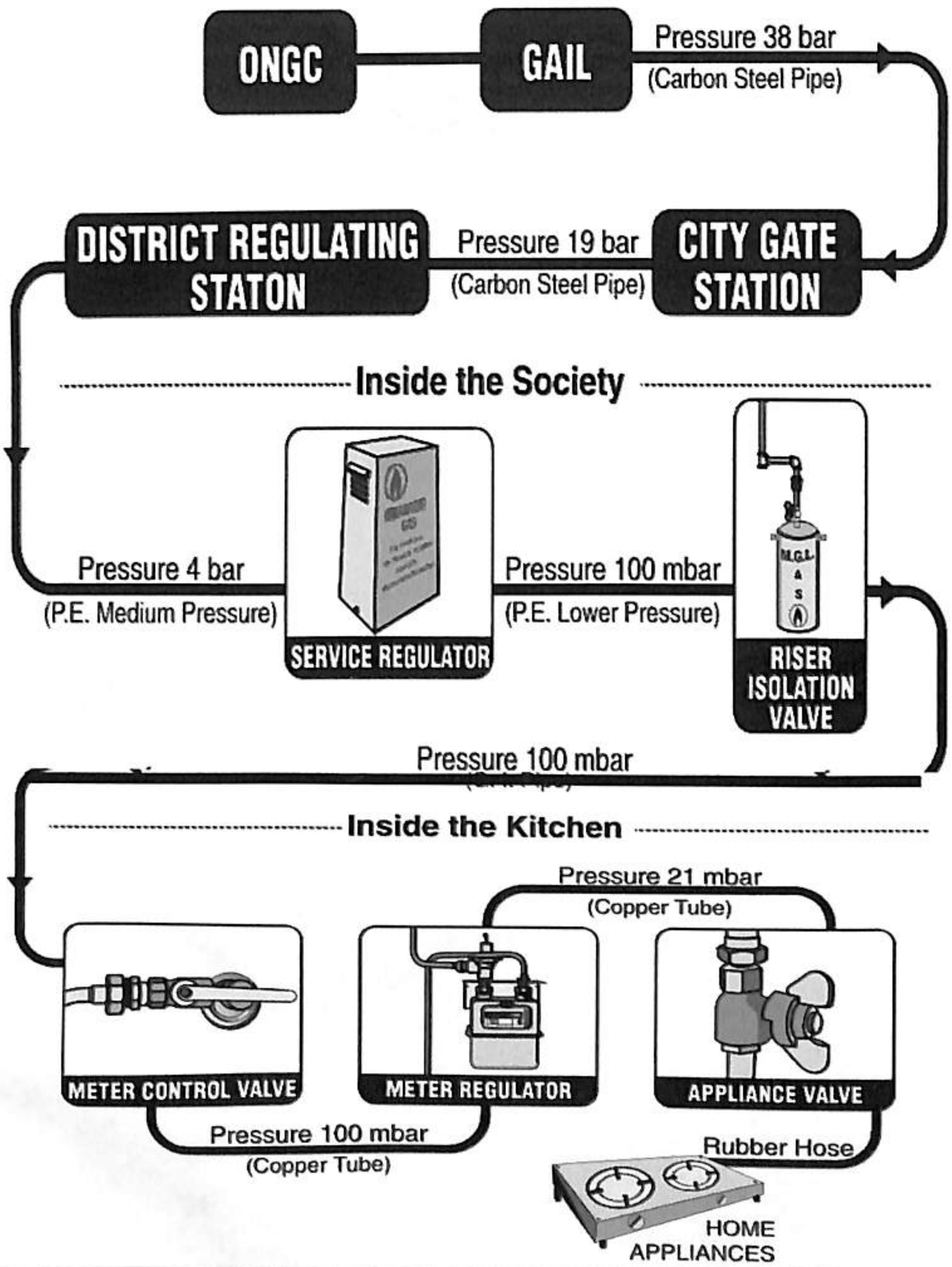
City gas distribution
in
MGL

Some Images

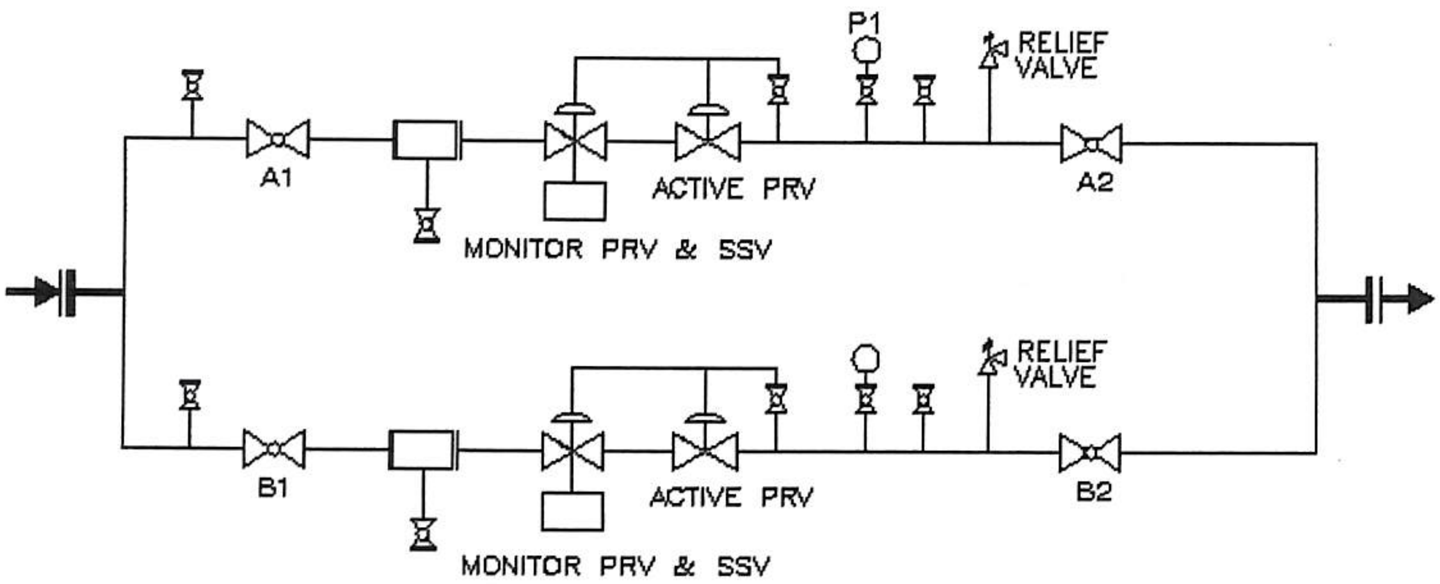
A view of the Gas Terminal at City Gate Station (Mumbai)



Gas Distribution System by MGL

View of a District Regulating Station (DRS)

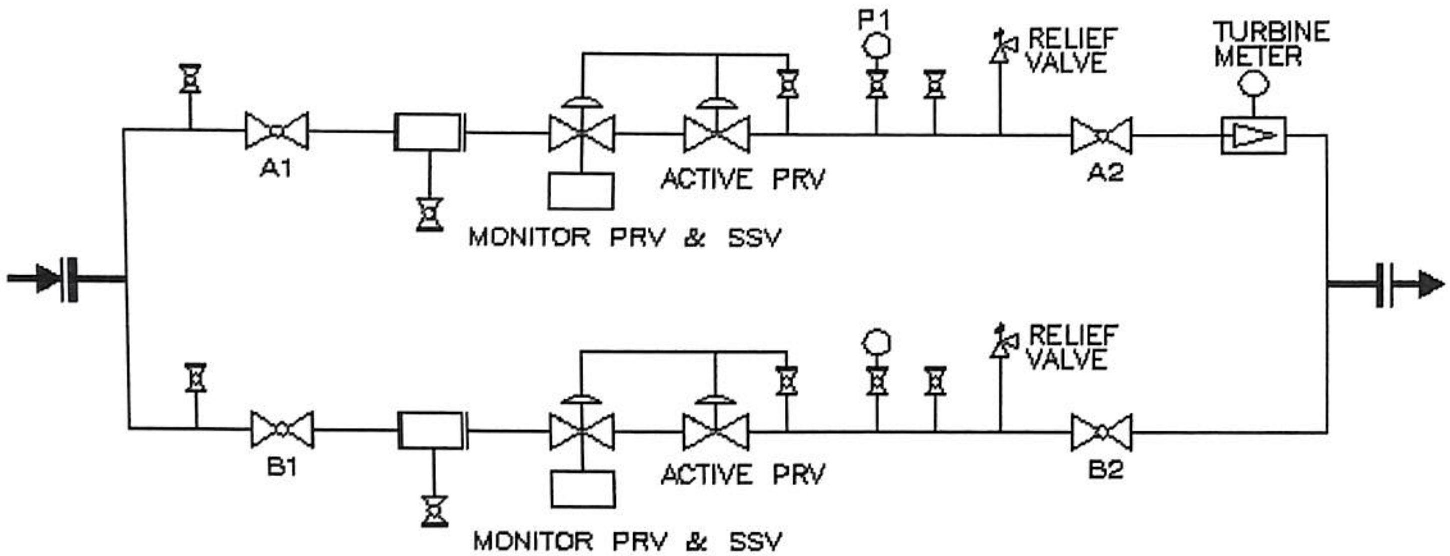
MAHANAGAR GAS LTD.



P & I DIAGRAM FOR DRS (ACTIVE MONITOR TYPE)

A Metering and Regulating Station (MRS)

MAHANAGAR GAS LTD.



P & I DIAGRAM FOR MRS