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On-line gas densitometers

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ON-LINE GAS DENSITOMETERS

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Introduction

A brief examination of the methods of gas metering soon highlight the importance of determining the on-line gas density. If using volumetric meters such as Positive Displacement, Turbine or Vortex Shedding meters, these measure the line volume flow, which to be meaningful, must be corrected to indicate volume flow at a reference condition, or gas flow in mass or equivalent heat units. The correction method which is normally applied uses measurements of pressure and temperature; however there are significant accuracy limitations in this method at high line pressures due to the non ideal behaviour of gases. In consequence many of the more critical measurement applications now also use on line densitometers to obtain a definitive measurement in mass units. This can then be modified to obtain measurements in standard volume or equivalent heat units.

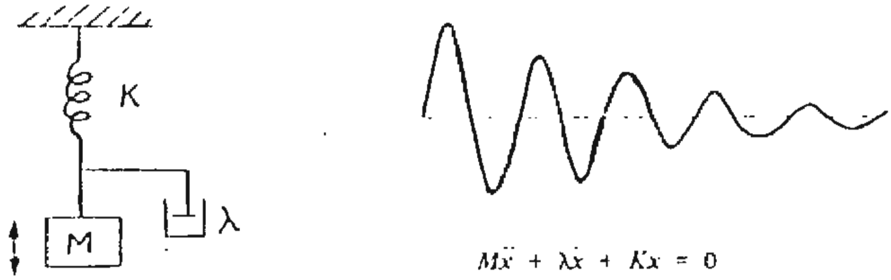
When using orifice metering systems, the importance of gas density is even more basic since it is line density, differential pressure and the physical dimensions of the system which define the flow rate. Until recent years, it has been the practice to calculate line density from measurements of pressure, temperature and gas composition. This method has severe limitations for many applications and the use of on-line densitometers is now the recommended practice in many countries.

This paper describes some of the techniques which are used for on-line gas density measurement and some of the recommendations which help ensure that the best performance is achieved.

On-line Gas densitometers

A number of techniques have been employed for on-line gas density measurement. Some of the early instruments use the buoyancy technique which measures the upthrust force on a displacer within the gas. This force is directly related to the gas density, but, because of the required sensitivity, these instruments are difficult to apply to on-line conditions. Other early instruments use the centrifugal technique whereby a differential pressure is generated by a constant speed centrifugal blower. This pressure is directly proportional to gas density, but, due to operational difficulties and the problem of measuring small differential pressures at high line pressure, these instruments are now rarely used.

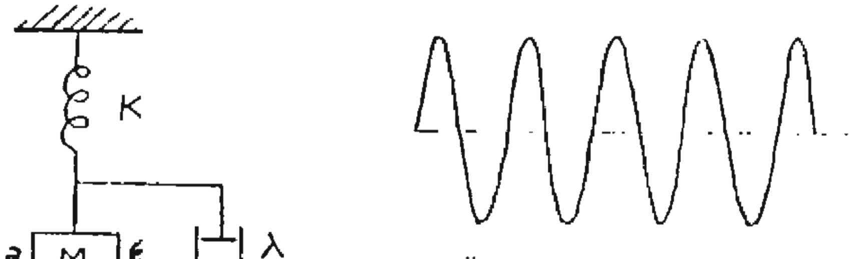
In recent years instruments which use a vibrating element have become the most favoured. The vibrating element is usually in the form of a flat plate, a cylinder or a fork and is maintained in resonance by some electronic feedback system. The operating principle for all these instruments is the same and is that of a mass spring system. As the product density changes, it in turn changes the vibrating mass which can then be registered by a change in the resonating frequency.



$$M\ddot{x} + \lambda\dot{x} + Kx = 0$$

Fig. 1

Fig. 1 shows a simple mass spring system. When the mass is displaced and released, it will oscillate at a natural frequency until it comes to rest due to viscous damping. An oscillation at the natural frequency may be maintained by supplying a driving force to overcome the effects of damping. This is illustrated in Fig.2.



$$M\ddot{x} + Kx = 0$$

$$\text{Resonent Frequency} = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

Fig. 2

The vibrating cylinder is widely used for gas density measurement since it offers very high sensitivity whilst still being adequately rugged for on-line use. An example of such an instrument is shown in Fig 3.

The inherently digital nature of the output signal from these vibrating element sensors make them ideally suitable for applications with modern microprocessor-based flow computers. There need be no loss of accuracy due to signal transmission and measurement or to calculation procedures.

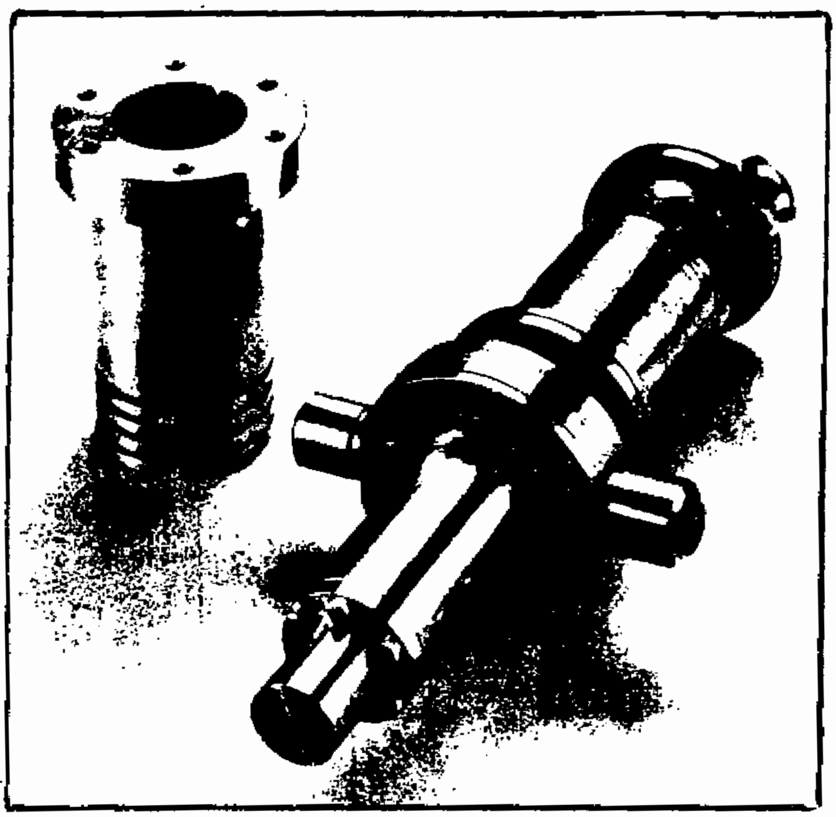


Fig. 3. The Gas Density Transducer with pocket for on-line measurement.

Application

Most on-line gas densitometers are used in conjunction with either a volumetric flow meter or an orifice metering system. In both cases it is necessary to ensure that the conditions of density measurement within the density meter are identical to that which is necessary for mass flow measurement. The importance of this installation requirement is best illustrated by the basic gas equation.

$$\text{Gas Density} = \frac{KMP}{TZ}$$

where M = Molecular Weight
P = Absolute Pressure
T = Absolute Temperature
Z = Compressibility Factor
K = Constant

Good representivity of gas is achieved by an adequate sample flow rate.

Good temperature equilibrium is best achieved by mounting the density sensor in the pipeline, either directly or within a thermowell, and by the use of adequate thermal insulation.

Good pressure equilibrium is achieved by ensuring only small pressure drops in the sample pipework.

The calibration of volumetric flow meters is with reference to the volume flow at a specified "Pressure Tapping Point". In consequence it is important that the density measurement is with reference to the same point. The normal practice is to mount the density sensor in a thermowell down stream of the volumetric meter to ensure good temperature equality, and to connect the sample flow to the Pressure Tapping Point to ensure pressure equality with this point. Fig 4 illustrates such an arrangement where the sample is taken from an upstream high pressure point with a flow restrictor and then returned to the Pressure Tapping Point.

The flow rates are calculated as follows:

Line Volume Flow Rate $= kf$

Mass Flow Rate $= kf\rho$

Standard Volume Flow Rate $= \dfrac{kf\rho}{\rho s}$

Where K = Pulse volume factor
f = Turbine frequency
ρ = On-line density
ρs = Standard density

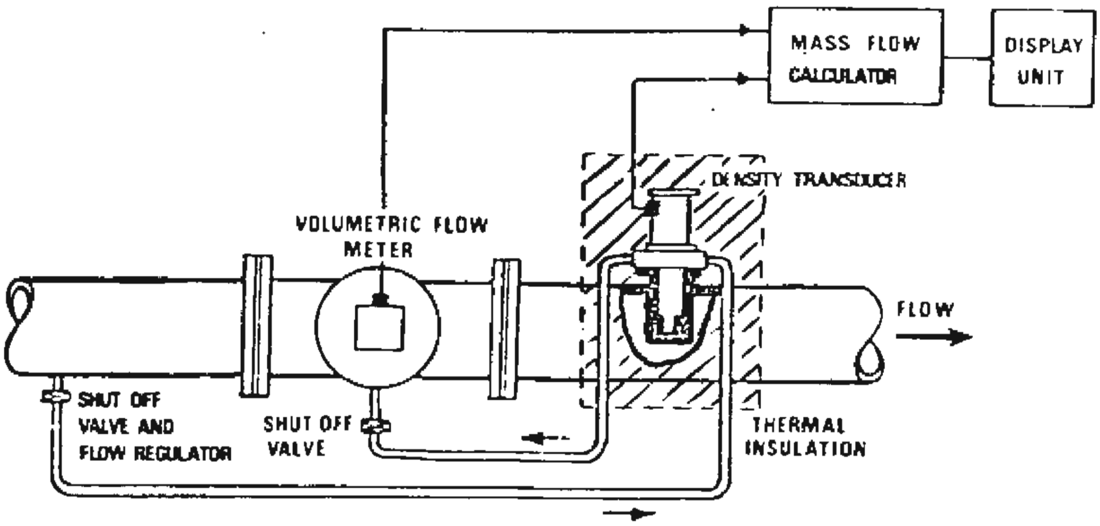


Fig 4 Typical Volumetric Metering System

For orifice metering systems the flow rates are calculated as follows:

Mass Flow Rate $= K\sqrt{h\rho}$

Line Volume Flow Rate $= K\sqrt{\dfrac{h}{\rho}}$

Standard Volume Flow Rate $= \dfrac{k\sqrt{h\rho}}{\rho s}$

Where k = The orifice factor
h = Differential Pressure
ρ = on-line density
ρs = Standard density

It is not possible for an orifice metering system to directly measure the gas density at the point where it is required for the flow rate calculations. Gas density will change from upstream of the orifice to downstream due to the pressure drop across the orifice. This is as illustrated in Fig 5.

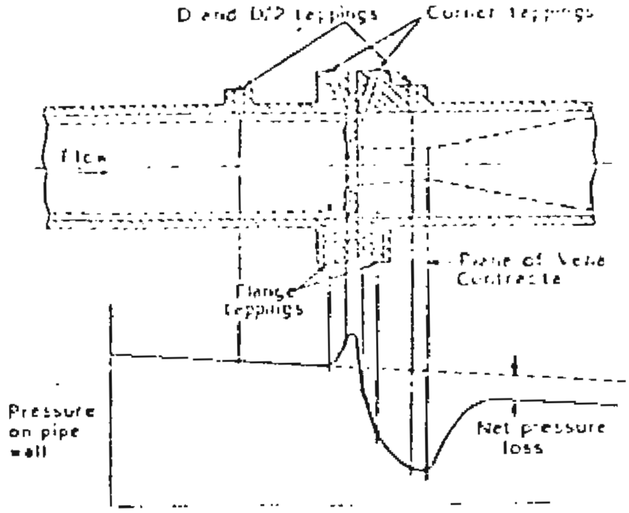


Fig. 5. Section of square-edged orifice plate showing variation of pressure along the pipe wall

In order to compensate for these density changes, it is necessary to apply a correction factor within the flow equation. This is commonly known as the EXPANSION FACTOR ( ) and it is most important that, having selected the most suitable tapping point for density measurement, the correct expansion factor is applied.

In AGA Report No. 3, the expansion factor for an upstream 2½ D pipe tap, an upstream flange tap, a downstream flange tap and a downstream 8D pipe tap are specified. From these factors it is possible to calculate the change in density across the orifice plate and, as shown in Fig 6, this highlights the importance of selecting the correct expansion factor with respect to the point of density measurement.

Fig 6. EXPANSION FACTORS FROM A.G.A. REPORT 3.

Type of Pressure Tap	h/p	Expansion Factor				Density Offset %			
		ß Ratio				ß Ratio			
		.45	.54	.62	.70	.45	.54	.62	.70
Upstream Pipe [2½D]	0	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000
	1	.9839	.9803	.9764	.9677	+3.19	+3.90	+4.66	+6.36
	2	.9678	.9607	.9529	.9355	+6.34	+7.71	+9.20	+12.48
	3	.9517	.9410	.9293	.9032	+9.43	+11.45	+13.64	+18.42
Upstream Flange	0	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000
	1	.9882	.9878	.9872	.9863	+2.3	+2.43	+2.54	+2.72
	2	.9764	.9756	.9744	.9726	+4.66	+4.82	+5.05	+5.40
	3	.9647	.9634	.9615	.9588	+6.94	+7.19	-7.55	-8.07
Downstream Flange	0	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000
	1	1.9963	1.0059	1.0053	1.0044	-1.26	-1.18	-1.06	.88
	2	1.0127	1.0119	1.0107	1.0090	-2.56	-2.39	2.15	-1.80
	3	1.0192	1.0180	1.0162	1.0137	-3.88	-3.63	-3.27	2.76
Downstream Pipe [8D]	0	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000
	1	1.0021	.9986	.9940	.9862	- .42	+ .28	+1.20	+2.74
	2	1.0044	.9975	.9886	.9732	- .88	+ .50	+2.27	+5.29
	3	1.0068	.9967	.9836	.9648	-1.36	+ .66	+3.25	+7.69

[h/p = INS H_2O/PSI]

To minimise flow measurement errors, it is best to select a density measurement tapping point for which the expansion factor is closest to 1.0000. This is equally applicable when applying metering standards such as ISO 5167 which require the density at the Upstream flange tap and which only specify the expansion factor for this point since if required this density is easily obtainable from measurements at alternative points and by the application of the relevant expansion factors. eg.

$$\rho_1 = \rho_2 \left(\frac{\varepsilon_2}{\varepsilon_1}\right)^2$$

where ρ_1 = Upstream Density
ρ_2 = Downstream Density
ε_1 = Upstream Expansion Factor
ε_2 = Downstream Expansion Factor.

For an orifice metering system, the recommended arrangements is as illustrated in Fig 7. The gas flow through the density sensor is caused by the differential pressure due to the downstream pressure recovery. This arrangement offers the following benefits.

1. The location of the density sensor is 8D downstream of the orifice plate and in consequence, is in compliance with the orifice metering pipe standards.

2. The sample gas take off is at the 8D downstream pipe tap which is close to the density sensor to provide simple sample pipework and good response to gas quantity changes.

3. The sample gas return is to a flange tap which is selected as the density measuring point by the use of a flow restricting valve at the take off point.

4. Shut-off valves enable the density sensor to be isolated from the pipeline gas for calibration checks and maintenance.

Whilst the density meter, as illustrated, does contain gas filters the use of an additional filter upstream of the density meter would be recommended for dirty pipeline conditions or to remove condensates.

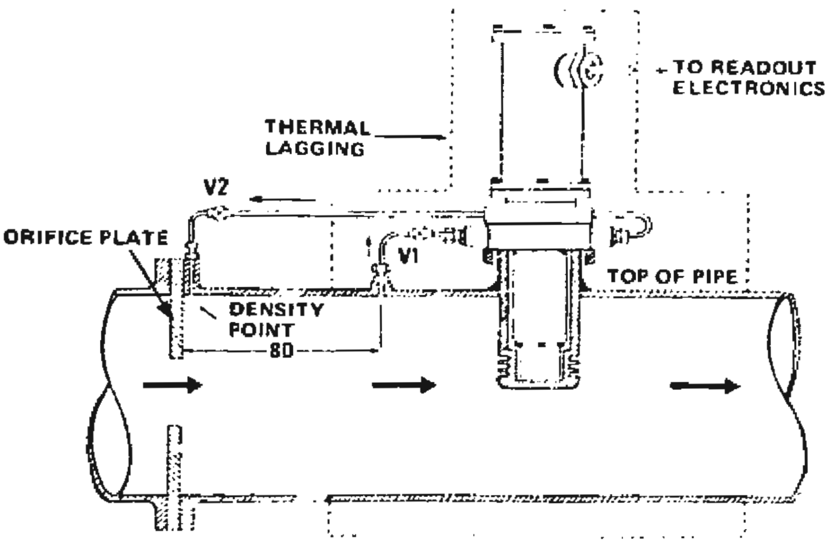


Fig 7. *Typical Orifice Plate Metering System*

Calibration and Performance Verification

The calibration of a gas densitometer is normally carried out by the manufacturer or by a certified laboratory using samples of known gases at defined conditions of temperature and pressure. The accuracy of this procedure is mainly limited by the reference data on the pressure-temperature-density relationship. Prime calibrations by mass balance are also carried out in some laboratories.

On-line calibration of gas densitometers is not recommended due to the practical difficulties associated with this task.

The frequency of recalibration will depend on the characteristics of each type of instrument. In general the vibrating element density sensors have excellent long term stability and should only require periodic calibration checks.

Most gas densitometers have small systematic errors associated with temperature, pressure and gas composition changes. The user should fully understand the magnitude of these effects and if necessary apply corrections. For example it is important to establish that a laboratory calibration using a particular gas is valid for an on-line measurement with a different gas.

For performance verification, it is necessary to ensure that the installation is not causing measurement errors and that the density meter continues to operate to specification. Installation checks are normally carried out as part of a system type approval test and during commissioning. There are several possibilities for calibration checks on the densitometer. Often the tests are comprehensive and frequent on new important installations and become less frequent and comprehensive with time and as good historical records are established.

When using vibrating element gas densitometers the most widely used checks are.

1. To isolate and vent the densitometer to atmospheric pressure and then to check the density reading at this condition. This check will highlight any contamination, damage or calibration drift. A vacuum check (zero density) is also used for this purpose. These are simple checks and give the user good confidence that there has been no change in calibration.

2. To compare the measured density with a calculated value from gas analysis and from pressure and temperature measurements.

3. To compare measurements from two densitometers. This can be arranged to highlight a discrepancy automatically but may not highlight some common systematic error and hence would put more emphasis on the type approval of the installation.

Summary

There are now several thousand metering stations which use on line gas density meters. Most of these are of the vibrating element type and they are used in conjunction with turbine and orifice systems for the more critical application such as high pressure natural gas and special gases like ethylene.

References

I.P. Petroleum Measurement Manual Part VII Density, Section 2 Continuous Density Measurement.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.