Technical Manual
30985020_US, Rev. B
October 2007

Micro Motion® 3098

3098 Gas Specific Gravity Meter

Micro Motion®

EMERSON. Process Management

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IMPORTANT NOTICE

HANDLE THE 3098 WITH GREAT CARE

DO NOT drop the meter.

DO NOT use gases incompatible with **MATERIALS OF CONSTRUCTION.**

DO NOT operate the meter above its **RATED PRESSURE.**

DO NOT expose the meter to excessive vibration **(>0.5g continuous).**

ENSURE all **ELECTRICAL SAFETY** requirements are applied.

ENSURE good **VENTILATION** around the meter/cabinet to prevent gas build up in the unlikely event of a leak.

ENSURE meter is not **TRANSPORTED** when it contains hazardous substances. This includes fluids that may have leaked into, and are still contained, within the case.

A Returns Form (see Appendix C) **MUST** be completed and returned together with the *3098* to the address given on the form.

Contents

Chapter 1
Introduction

This chapter

This chapter contains an outline of how the 3098 works, defines some of the terms commonly used in the manual, and also gives some practical applications for the 3098.

IMPORTANT NOTICE

The 3098 is normally installed in an IP rated enclosure prior to leaving the factory. In some instances however, the 3098 may be supplied *without* the enclosure, in which case the environmental and thermal performance of the meter cannot be guaranteed. Warnings are given throughout this manual when the performance of the meter may be affected by this.

Meters supplied complete have product labels attached to the outside of the enclosure, and none on the main cylindrical body of the 3098. If the 3098 itself is labelled, this indicates that the product was supplied without the enclosure.

For technical details, please refer to the system installer.

IMPORTANT NOTICE

The pressure relief valve has been factory set for the unit to conform to the Pressure Equipment Directive.

UNDER NO CIRCUMSTANCES SHOULD THIS SETTING BE CHANGED.

For further information, contact the factory using the details on the back page.

1.1 Specific Gravity Measurement

Most major gas flow metering systems require the metered quantity to be presented in Heat or standard volume units. To achieve this requirement, it is often necessary to make continuous and accurate measurements of specific gravity. Specific gravity can be evaluated by relating the molecular weight of the gas (or gas mixture) to that of the molecular weight of air, or by evaluating the relative density of the gas (or gas mixture) and compensating the result for the Boyle's Law deviation on both the gas (or gas mixture) and the air.

The 3098 Specific Gravity Meter adopts a combination of these two methods, where, by measuring the density of the gas under controlled conditions, the value of density obtained is directly related to the molecular weight of the gas, and thus to its specific gravity.

Figure 1-1: View of the 3098 Specific Gravity Meter installed in a typical enclosure

1.2 Functional Description

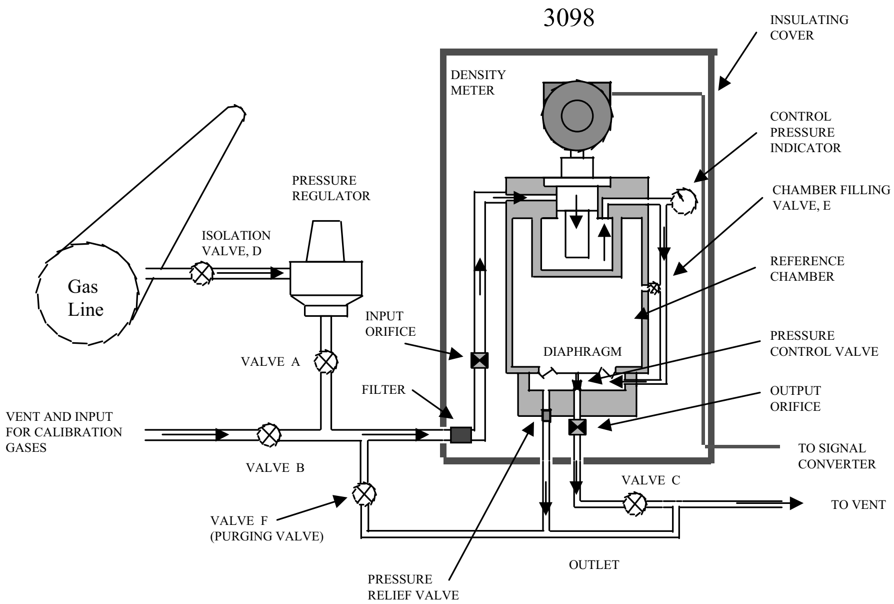


Figure 1-2: Schematic diagram of a typical 3098 Specific Gravity Measuring System

The 3098 Specific Gravity Meter consists of a vibrating cylinder gas density meter surrounded by a gas reference chamber, which helps to achieve good thermal equilibrium. The gas reference chamber has a fixed volume that is initially pressurised with the actual line gas. It is then sealed by closing the reference chamber filling valve, thus retaining a fixed measure and quantity of gas, now known as the reference gas.

Note: Once the chamber has been filled, do not open this valve again.

The sample gas enters the instrument at the enclosure side and passes through a filter, followed by a pressure-reducing orifice. The sample gas is then fed through input pipework so that it enters the gas density meter at the equilibrium temperature of the unit. The gas then flows down to a pressure control valve chamber.

The pressure of the reference gas acts on the separator diaphragm and forces the line gas pressure to rise until the pressures on both sides are equal, thus the gas pressures within the gas density meter and the reference chamber are equal.

As the ambient temperature changes, the pressure of the fixed volume of reference gas will change as defined by the Gas Laws. This change in pressure will affect the sample gas pressure within the gas density meter such that the temperature and pressure changes are self-compensating.

If the sample gas pressure rises above that of the reference chamber pressure, the pressure control valve opens to vent the excess gas via an outlet orifice in the enclosure side, so that the sample gas pressure is reduced to equal the reference gas pressure. For gas to flow it is necessary that the supply pressure is greater than the reference pressure, which in turn must be greater than the vent pressure. (Typically the line pressure must be between 15 and 25% above that of the reference chamber pressure)

[The principles of operation that describe this operation are given in Appendix B]

A pressure gauge is fitted in order to monitor the pressure within the gas density meter. This is desirable when charging the reference chamber and also for general maintenance.

Electrical connections to the 3098 are taken through the cable gland in the enclosure side and then into the density meter's electronics housing.

When the enclosure is sealed, the complete instrument is insulated so that rapid changes in ambient temperature will not upset the temperature equilibrium of the unit and produce thermal shock errors.

Note that the 3098 may have been supplied without an enclosure - see **Important Notice** on page 1-1.

1.2.1 Meter Sensing Element

The gas density meter consists of a thin metal cylinder which is activated so that it vibrates in a hoop mode at its natural frequency. The gas is passed over the inner and outer surfaces of the cylinder and is thus in contact with the vibrating walls. The mass of gas which vibrates with the cylinder depends upon the gas density and, since increasing the vibrating mass decreases the natural frequency of vibration, the gas density for any particular frequency of vibration can be determined.

A solid state amplifier, magnetically coupled to the sensing element, maintains the conditions of vibration and also provides the output signal.

1.2.2 Installation

The 3098 has been designed to be installed wall mounted, a typical installation set-up being given in figure 1-3 below.

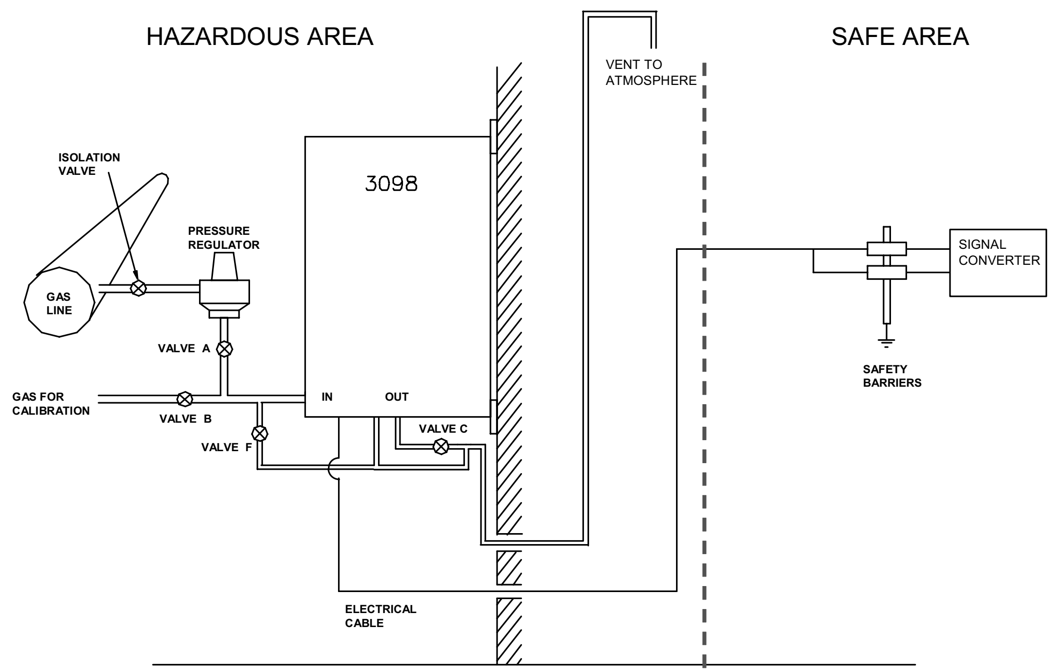


Figure 1-3: Typical 3098 Specific Gravity Measuring System

1.3 Definition of Terms

1.3.1 Specific Gravity (G)

This is the ratio of the molecular weight of a gas (or gas mixture) to that of the molecular weight of dry air; the molecular weight of dry air is normally assumed to be 28.96469 (see Table 1).

i.e $G = \frac{M_G}{M_A}$

where M_G = *Molecular weight of gas (or gas mixture)*

and M_A = *Molecular weight of dry air*

1.3.2 Standard (Base or Normal) Density (ρs)

This is the absolute density of a gas at STANDARD (BASE or NORMAL) conditions of temperature and pressure and is commonly used for STANDARD VOLUME flow determination from MASS flow measurement.

i.e $\rho_s = \frac{PM}{ZRT}$

where P = *Absolute pressure (bars)*

T = *Absolute temperature (degrees Kelvin)*

M = *Molecular weight*

Z = *Supercompressibility factor*

R = *Gas constant (taken as 0.0831434)*

1.3.3 Relative Density (ρr)

This is the ratio of the weight of a volume of gas (or gas mixture) to the weight of an equal volume of dry air (see Table 1), where the weights of both gas (or gas mixture) and air are taken under identical conditions of temperature and pressure.

NOTE: Except for the effects of Boyle's Law deviation upon both the gas (or gas mixture) and the air, G and ρr are synonymous.

i.e $G = \frac{M_G}{M_A}$

$= \frac{\rho_G Z_G}{\rho_A Z_A}$

$= \rho_r \frac{Z_G}{Z_A}$

where ρ_G = *Density of the gas or gas mixture*

ρ_A = *Density of air*

Z_G = *Supercompressibility factor of the gas or gas mixture*

Z_A = *Supercompressibility factor of air*

The relative density of mixed hydrocarbon gases at 1 bar (14.735 lb/in^2) absolute and 15.56°C (60°F) by empirical equation is:

$$\rho_r = 0.995899G + 0.010096G^2$$

1.4 Physical Properties of Gas Compounds

Compound	Formula	Molecular Weight	Specific Gravity
Hydrogen	H_2	2.01594	.069600
Helium	He	4.00260	.138189
Water Vapour	H_2O	18.01534	.621976
Nitrogen	N_2	28.01340	.967157
Carbon Monoxide	CO	28.01055	.967058
Oxygen	O_2	31.99880	1.104752
Argon	Ar	39.94800	1.379197
Carbon Dioxide	CO_2	44.00995	1.519435
Air (3)	-	28.96469	1.000000
Hydrogen Sulphide	H_2S	34.07994	1.176603
Methane	CH4	16.04303	.553882
Ethane	C_2H_6	30.07012	1.038165
Propane	C_3H_8	44.09721	1.522447
i-Butane	C_4H_{10}	58.12430	2.006730
n-Butane	C_4H_{10}	58.12430	2.006730
i-Pentane	C_5H_{12}	72.15139	2.491012
n-Pentane	C_5H_{12}	72.15139	2.491012
Hexane	C_6H_{14}	86.17848	2.975294
Heptane	C_7H_{16}	100.20557	3.459577
Octane	C_8H_{18}	114.23266	3.943859

Table 1

NOTES:

1. Based upon 1961 atomic weights, referred to Carbon-12 Isotope (12 AMU), recommended by the International Commission of Atomic Weights and the International Union of Pure and Applied Chemistry.

2. Perfect gas specific gravity represents the ratio of molecular weight of compounds to the molecular weight of air.

3. Molecular weight of air based upon components of atmospheric air given in Handbook of Chemistry & Physics, 53rd Edition (1972 - 1973). Value of 28.96469 differs from figure 28.966 provided by **NBS** Circular 564 due to minute differences in component content and changes in atomic weights of the elements given in 1961 (**NBS** value based upon 1959 atomic weights).

1.5 Applications

The following are typical applications where specific gravity measurement is an essential parameter.

1.5.1 Supplementary Gas Supply

This system is used to top up normal supplies during peak periods. Specific gravity monitoring of a propane/air mixture for example, enables accurate control to be exercised over the ratio of the mixture, therefore ensuring that the correct burning characteristic/calorific value is maintained.

1.5.2 Wobbe Index Measurement

The burning characteristic of a gas must be well established for efficient combustion and to ensure that no flame lift or flame light-back occurs on a particular burner. Three criteria are used to establish this characteristic; calorific value, specific gravity and flame speed. The calorific value and specific gravity are often combined to form the Wobbe Number i.e:

$$\text{Wobbe Number} = \frac{CV}{\sqrt{G}}$$

where CV = Calorific value

G = Specific gravity

1.5.3 Consumer Gas Costing

This major application has already been described in the introduction, MASS to BASE VOLUME unit conversion, and may be further illustrated by the following equations:

$$\text{Base Unit Volume} = \frac{\textit{Mass Flow}}{\textit{Base Density}}$$

i.e $$V_s = \frac{M}{\rho_s}$$

$$= \frac{M}{G\dfrac{\rho_A Z_A}{Z_G}}$$

Chapter 2
Installation Procedure

2.1 Installation Procedure

The procedure for installing the 3098 involves the following steps:

Check all components are present	(Section 2.2)
Position and fix the 3098 enclosure	(Section 2.3)
Connect the gas supply line	(Section 2.3.2)
Make electrical connections	(Section 2.4 and Chapter 3)
Select a reference pressure	(Section 2.5)
Purge cycle and calibrate the 3098	(Section 2.6)

2.2 Contents

The following items should be enclosed with this 3098 unit:

3098 Specific Gravity Meter.

Labelled enclosure.

Enclosure mounting feet.

Enclosure mounting feet instructions.

This technical manual (30985020).

Safety Instructions (3095008/SI and 30988002/SI).

Accessories kit.

Temperature coefficient Calibration Certificate.

Check that all the above items are present; if not then contact your supplier immediately. (Note that the 3098 may have been supplied without an enclosure.)

2.3 Installing the 3098 enclosure

The following installation instructions apply only to meters supplied with an enclosure (see Important Notice on page 1-1). In all other cases, please refer to the system installer.

2.3.1 Important Precautions

Take care to observe the precautions listed at the front of this manual (page Cont-3).

The 3098 SG meter is contained inside an IP rated enclosure (which provides thermal insulation) and a mounting system (consisting of a bracket and feet) to fix the unit in place. Whilst this structure is designed to minimise damage due to shocks, the box and unit must not be dropped. Dropping of the 3098 either inside or outside its enclosure **will** damage the meter.

Contained inside the enclosure are four box feet which, when attached to a vertical wall will hold the housing. A set of instructions on how to attach these feet is included inside the box. Enclosure dimensions are in Section 2.7.

2.3.2 Connections

There are four connections that need to be made to the 3098: three gas pipeline connections and one electrical connection through an IP rated cable gland. The gas pipeline connections take the form of ¼" Swagelok bulkhead fittings, and are used for the gas input, gas output and pressure relief lines.

Each connection is labelled.

Caution: Connecting the gas input line to the wrong bulkhead fitting might result in damage.

A 7812 gas density meter is used as the measuring instrument in the 3098 and needs to be connected inside the enclosure. All wiring should be connected through the cable gland to maintain the enclosure's overall protection to dust and water ingress.

At all stages during calibration and operation, the 3098 is designed to function with the enclosure sealed. This allows the unit to operate in the condition of thermal equilibrium, which is essential for accurate measurement.

2.4 Electrical Connections and Safety Barriers / Galvanic Isolators

When the 3098 is mounted in a hazardous area, the electrical connections to the meter must conform to stringent conditions. For electrical connections between the meter and its associated flow computer/signal converter, reference must be made to safety instruction booklet 30985018/SI.

Electrical cable connection to the *3098* is made to the terminal block inside the resonator electronics housing (i.e. inside the enclosure). Poor connection to the terminals will prevent correct operation but will not damage the unit - provided that safety barriers or galvanic isolators are included in the circuit for hazardous areas or the maximum power supply does not exceed the 33V maximum limit (as described in chapter 3).

The power supplied to the meter terminals should be in the range of 15.5 to 33Vd.c with the average current drawn by the unit being <20mA. If the current consumption exceeds this value, the polarity of the connections should be checked.

A full description of how to connect the 3098 to a signal converter/flow computer is given in Chapter 3.

2.5 Reference Chamber Pressure Determination

Once the 3098 has been placed in its fixture and all relevant pipework and electrical connections made, the reference chamber pressure needs to be determined.

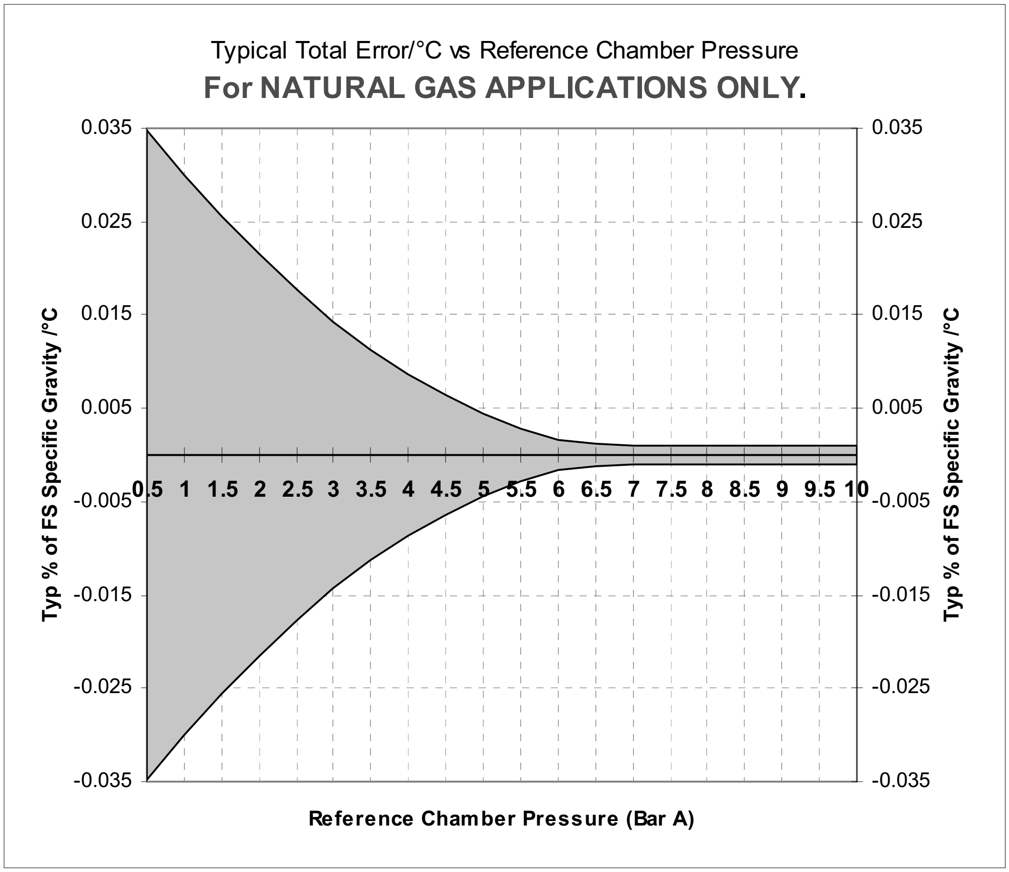
The gas type and reference chamber pressure define the 'controlled condition' at which the unit allows gas to flow and establishes a direct relationship between density and the specific gravity of the sample gas.

The choice of reference chamber gas pressure is dependent upon 3 factors:

1. The span of specific gravity to be measured.
2. The expected change in sample gas supercompressibility, Z.
3. The accuracy required.

The graph below gives an indication of the **typical** errors associated with using different reference chamber pressures for natural gas with a reasonably constant specific gravity (in the range of 0.55-0.8). This is typical for natural gas metering market, where the gas is available at a line pressure of 7 Bar abs.

As can be seen, below 7 Bar abs, the total error begins to increase; using a higher reference pressure will not improve accuracy, but may encourage gas leakage. Therefore, for the conditions specified, 7 Bar is the recommended pressure.



This graph should **only** be used for natural gas applications, and.gives **typical errors** seen on the 3098 if it is not used at the recommended reference chamber pressure.

If the span of specific gravity or change in supercompressibility, Z, is large, and the gas is not a methane/nitrogen mix, then the best reference chamber pressure can still be determined. The calculation for doing this is explained in Chapter 4, 'Accuracy Considerations'.

Once the desired reference pressure has been found, the 3098 can now be purge cycled and then calibrated.

2.6 Set-up procedure - Purge Cycling and Calibration

IMPORTANT NOTICE

The pressure relief valve has been factory set for the unit to conform to the Pressure Equipment Directive.

UNDER NO CIRCUMSTANCES SHOULD THIS SETTING BE CHANGED.

For further information, contact the factory using the details on the back page.

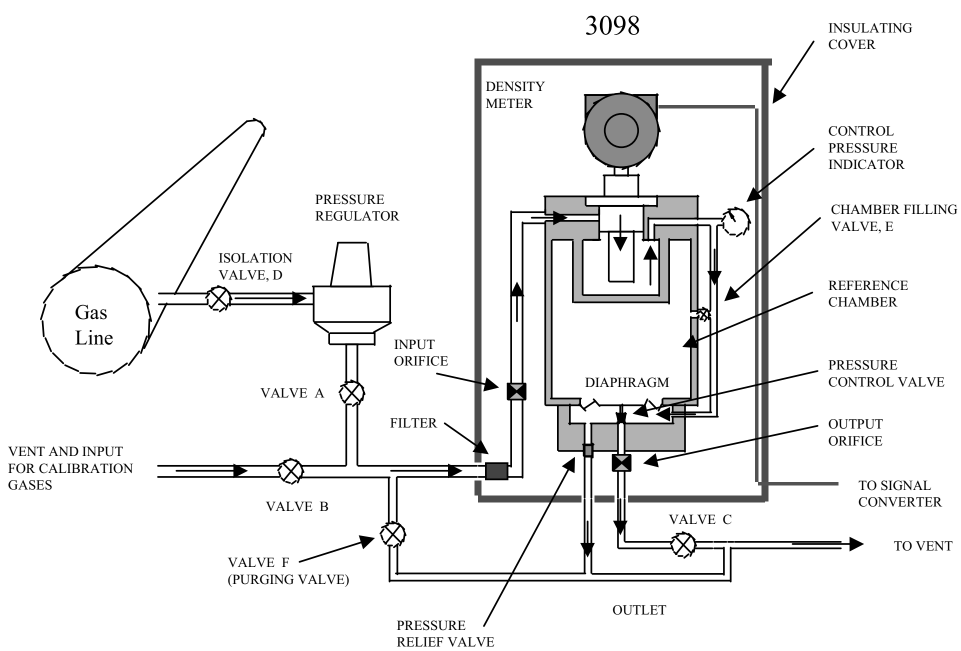


Figure 2-1: Schematic diagram of a typical 3098 Specific Gravity Measuring System

The procedure for purging and calibrating the 3098 is given below:

1. Ensure isolation valve (D) is closed.
2. Ensure valve (A) is closed.
3. Ensure valve (B) is closed.
4. Ensure valve (F) is closed.
5. Open valve (C).
6. Open chamber filling valve (E).
7. Set the pressure regulator to the required value - i.e. the actual working pressure of the system.
8. Open isolation valve (D).
9. Open valve (A) and allow gas to flow for 3 minutes.

Purge Cycling

10. Close valve (C).
11. When Control Pressure Indicator is at the desired value, shut valve (A) and open valve (F). Allow the gas to vent to atmospheric pressure.
12. Close valve (F) and open valve (A).
13. When Control Pressure Indicator is at the desired value, shut valve (A) and open valve (F). Allow the gas to vent to atmospheric pressure.

Actions 12 and 13 define the purging cycle required for setting up the reference chamber gas in the 3098.
The number of times that this procedure should be repeated depends upon the gas regulator pressure used and is defined by:

$$\text{Number of purge cycles} = \left[\frac{3 \times 7}{\text{max regulator pressure}} \right]$$

14. Once the required number of cycles has been performed, close valve (F) and open valve (A).
15. When the desired gas pressure inside the chamber has been reached (as shown by the Control Pressure Indicator) shut the chamber valve.

DO NOT open the chamber valve again.
The gas now inside the 3098 chamber is the line reference gas.

3098 Calibration using two known gases

16. Close valve (A).
17. Connect the first calibration gas bottle to the pipework and set the pressure to be typically 25% above that inside the reference chamber.
18. Open valve (B).
19. Ensure valve (C) is open and allow gas to flow until the time period as measured by the signal converter/flow computer is stable to ±1ns or better (the typical stability will be better than this). [For the required electrical connections see Chapter 3]
20. Note this time period (τ_1) together with the certified SG from the bottle of gas (SG_1).
21. Shut valve (B).
22. Replace the first calibration gas bottle with the second calibration gas bottle.
23. Set pressure to typically 25% above that inside the reference chamber and open valve B.
24. Allow gas to flow until the time period shown by the meter is stable to ±1ns or better.
25. Note this time period (τ_2) and the certified SG from the bottle of gas (SG_2).
26. Apply these noted numbers into equations (1) and (2) below:

$$K_2 = \left[\frac{SG_1 - SG_2}{(\tau_1)^2 - (\tau_2)^2} \right] \qquad (1)$$

$$K_0 = SG_1 - K_2(\tau_1)^2 \qquad (2)$$

Alternatives to this are to use the calibration certificate shown in table 4 (found in Chapter 4), or to use the Excel program ‘Calcert.xls’ that is supplied on the attached floppy disk.

28. Shut valve (B) and disconnect the second calibration gas bottle from pipework.
29. Open the isolation valve (D).
30. Open valve (A).

IMPORTANT NOTE

If the application is running with a reference pressure less than 45.5 psi (3 BarA), the maximum flow rate that can be used for correct operation is 50cm^3/s. A full explanation of this effect is given in Accuracy Considerations, Chapter 4.

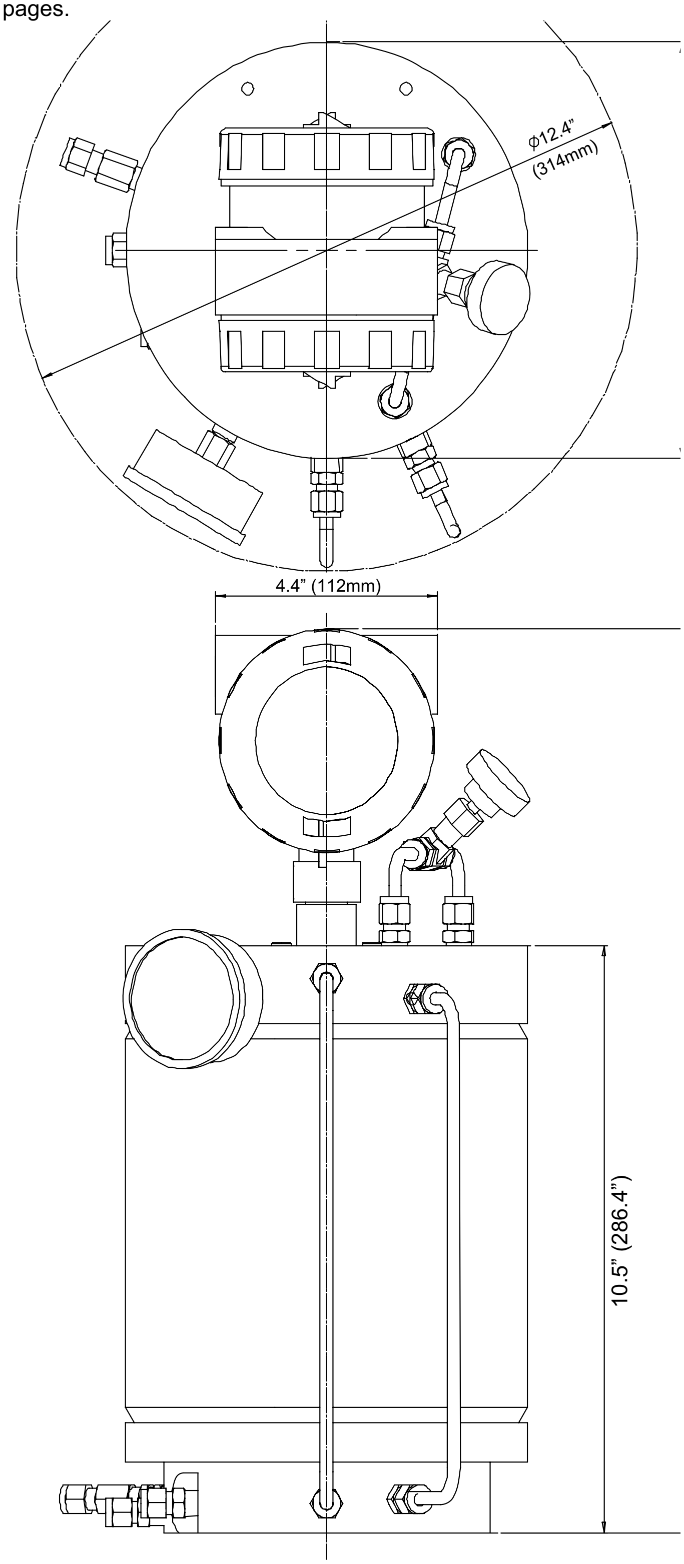
The unit should now give a live reading of the measured gas SG. If the unit does not output a sensible reading, certain checks can be made. These checks are summarised in Chapter 5, ‘Maintenance & Fault finding’.

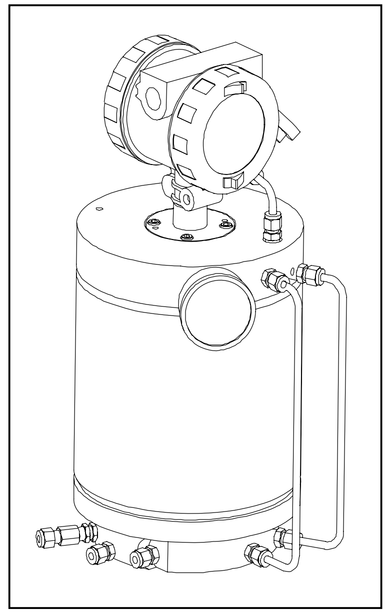
If optimum SG accuracy is required, the optimisation method described in Appendix A - which compensates for errors due to gas velocity of sound, compressibility and temperature coefficient - should be used.

For optimum accuracy, the time period (τ) must be resolved to ±0.1ns. This can be achieved using 7950/7951/7955 signal converters and flow computers set to a cycle time of 10s.

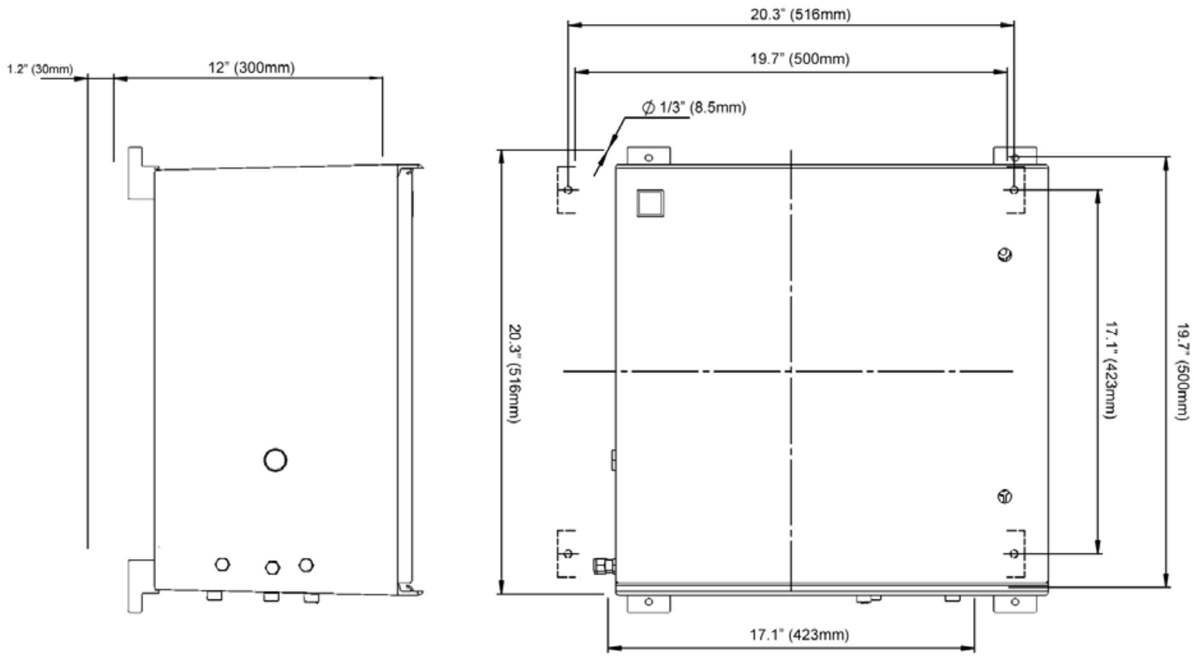
2.7 Outline dimensional drawings

The drawings below show a 3098 *without* an enclosure. For dimensions of small and large enclosures, see the following two pages.

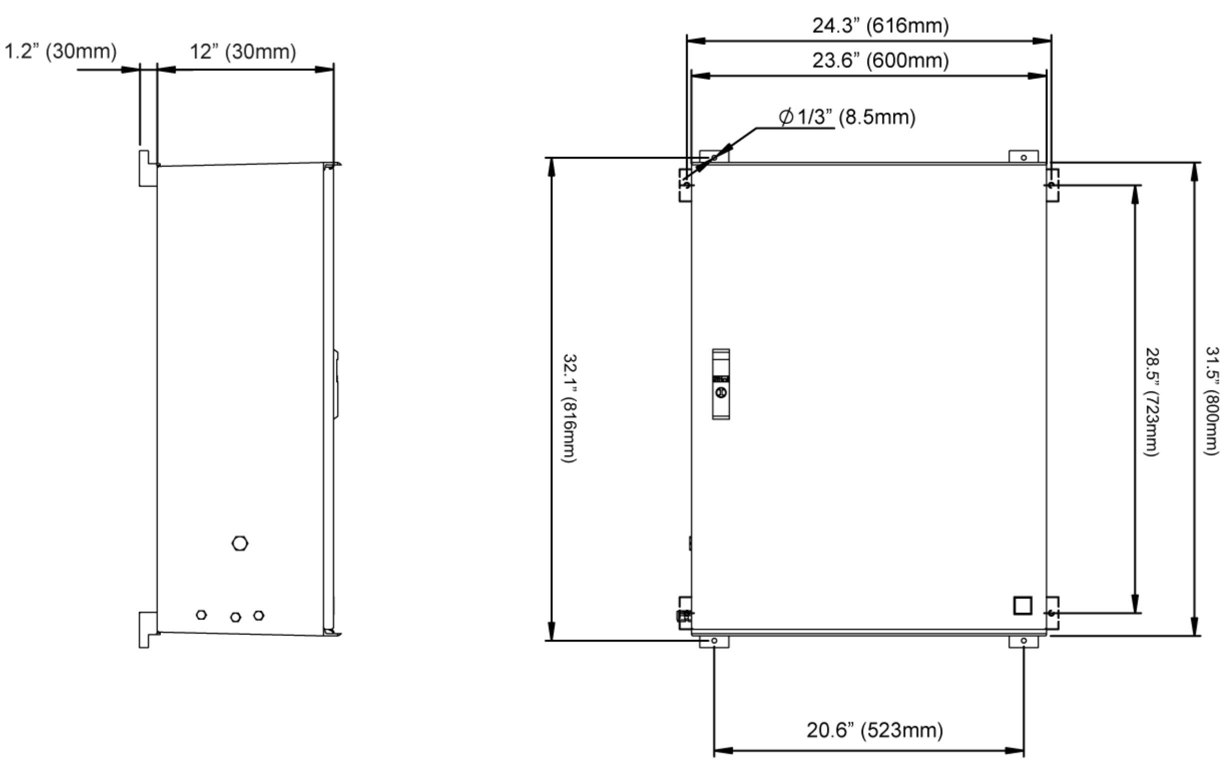




Small Enclosure Dimensions



Large Enclosure Dimensions



Chapter 3
Electrical Connections

This chapter

This chapter contains details and wiring diagrams for connecting the 3098 to 7950/51/55 Signal Converters and Flow Computers, and more generally to other equipment in both hazardous and non-hazardous situations.

3.1 Introduction

The electrical connections to the 3098 are made to the *7812 gas density meter* held inside the enclosure. When installed in hazardous areas, connections between the meter and the power supply/readout equipment must be completed through ZENER SAFETY BARRIERS [or galvanic isolators]. The electrical cable enters the enclosure (if supplied - see Important Notice on page 1-1) through a cable gland assembly and then passes into the amplifier housing.

The meter terminal layout is shown in Figure 3-1.

The amplifier housing has two chambers. The one nearest the cable gland axis contains the terminals for connection to the meter/signal processing instrument. The other chamber contains the maintaining amplifier unit. The amplifier board is encapsulated in a circular plastic container, with the complete module secured by a keyway and a centrally positioned clamping screw. Behind the amplifier there is an interconnect terminal board which links the sensor to the maintaining amplifier, and the amplifier to the user connect board (see Figure 3-2).

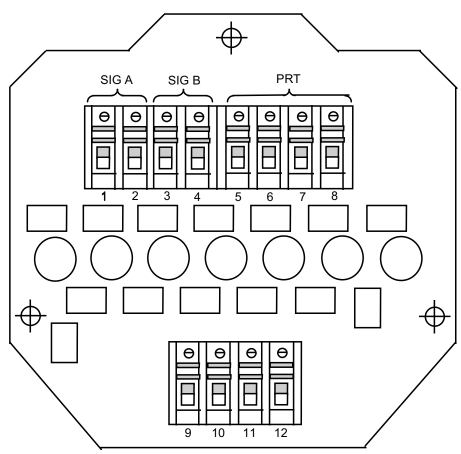


Figure 3-1: Main Terminal Board Connections

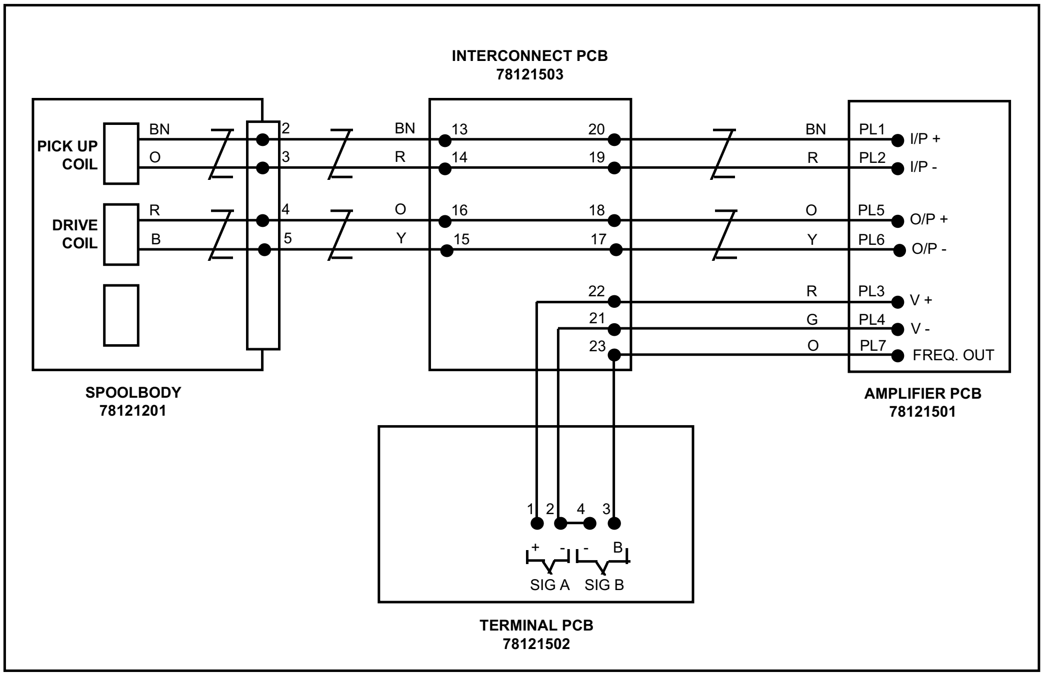


Figure 3-2: Interconnection diagram

3.2 EMC Cabling and Earthing

To meet the EC Directive for **EMC** (Electromagnetic Compatibility), it is recommended that the meter be connected using a suitable instrumentation cable and earthed through the meter body and pipework. The instrumentation cable should have an individual screen, foil or braid over each twisted pair and an overall screen to cover all cores. Where permissible, the screen should be connected to earth at both ends. Note that for intrinsic safety, termination of the screen to earth in the hazardous area is **NOT** generally permitted.

Typical cables that are suitable are those that meet BS5308 Multi-pair Instrumentation Types 1 and 2, such as Belden types 9500, 9873, 9874, 9773, 9774 etc.

3.3 Certificate conditions for hazardous areas

For details of hazardous area installations, please refer to safety instructions (30985018/SI).

The 3098 can be electrically connected in either a **2-wire** or **3-wire** configuration. A schematic block diagram of these two types is given in figures 3-3 and 3-4 below:

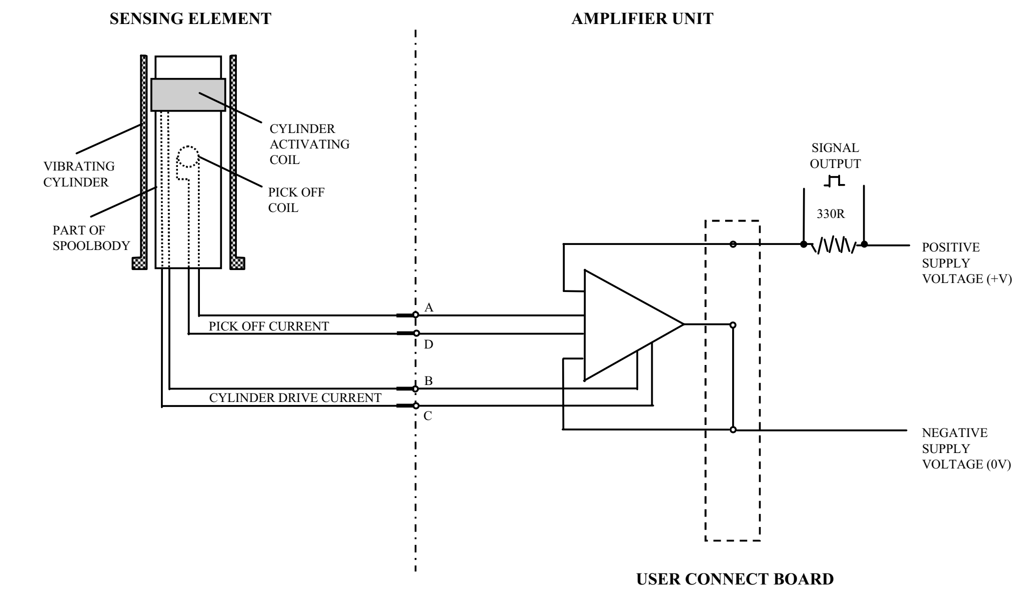


Figure 3-3: Schematic Block Diagram of Meter Circuit (2-wire System)

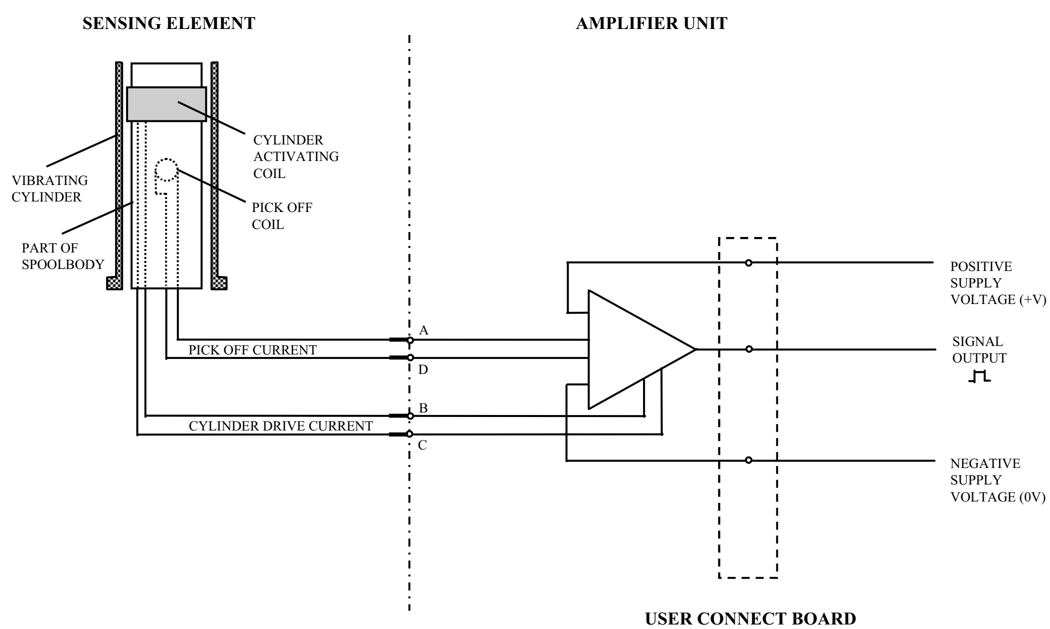


Figure 3-4: Schematic Block Diagram of Meter Circuit (3-wire System)

3.4 Use with Signal Converters and Flow Computers

The meter can be operated in two general environments, either in SAFE AREAS or in HAZARDOUS AREAS. **When used in hazardous areas, safety barriers or galvanic isolators MUST be placed between the meter and the signal converter/flow computer**.

When operating in a safe area with a 3-wire system, the line resistance between meter and signal converter must be greater than 40 ohms. This can be achieved by placing a suitable resistor in the line or by using the inherent resistance of the cable used (if the resistance per km and length of cable used is sufficient).

Given these conditions, we recommend that the maximum cable length between the *3098* and signal converter - assuming a BS5308 standard cable - is 2km.

For details of hazardous area installations, please refer to safety instructions (30985018/SI).

For the purposes of clarity, all wiring diagrams describing a 'Safe Area' setup using the 3-wire system have had a 40 ohm resistor placed into the +24V power supply line.

3.5 System Connections (7951/7950/7955)

The density and power connections to the 3098 in safe and hazardous areas are shown in the following diagrams:

3.5.1 7950 2-wire configuration

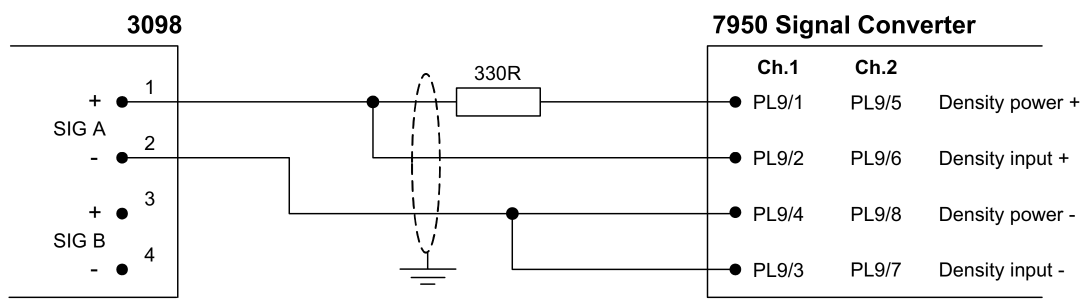


Figure 3-5.9: 7950 Signal Converter and Gas Specific Gravity 2-Wire System (Safe Area)

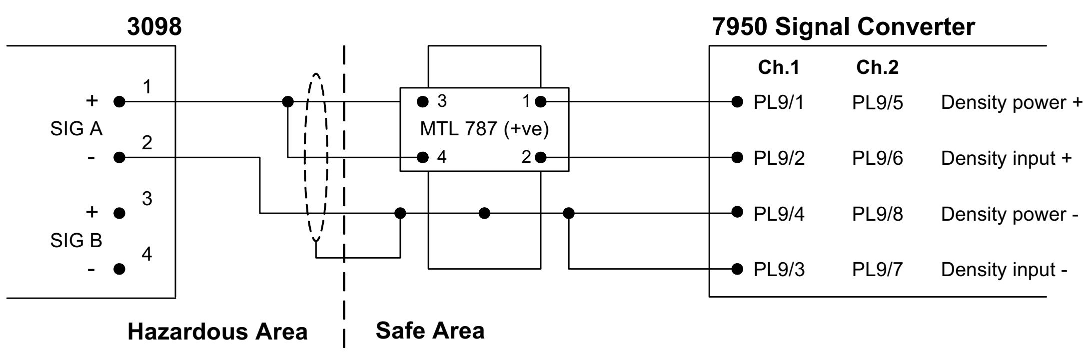
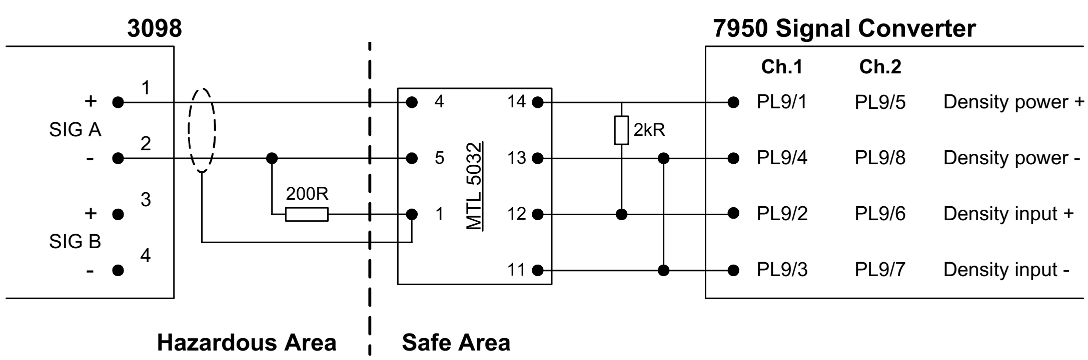


Figure 3-5.10: 7950 Signal Converter and Gas Specific Gravity 2-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)



Note: Switches on MTL5032 should be set to give a threshold voltage of 3 volts.

Figure 3-5.11: 7950 Signal Converter and Gas Specific Gravity 2-Wire System with Galvanic Isolator (Hazardous Area)

3.5.2 7950 3-wire configuration

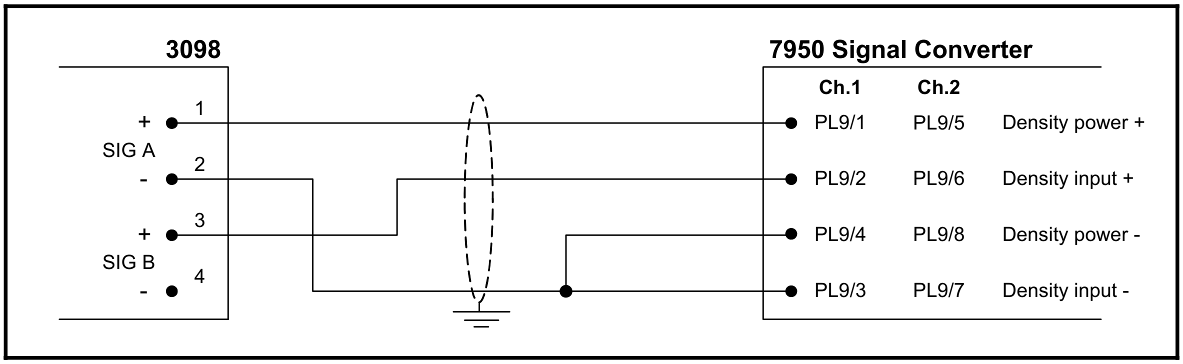


Figure 3-5.12: 7950 Signal Converter and Gas Specific Gravity 3-Wire System (Safe Area)

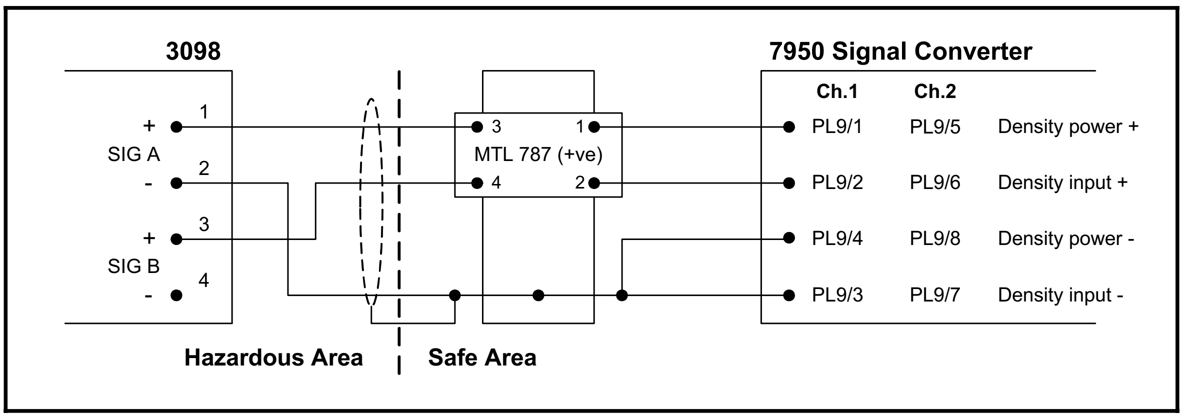


Figure 3-5.13: 7950 Signal Converter and Gas Specific Gravity 3-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)

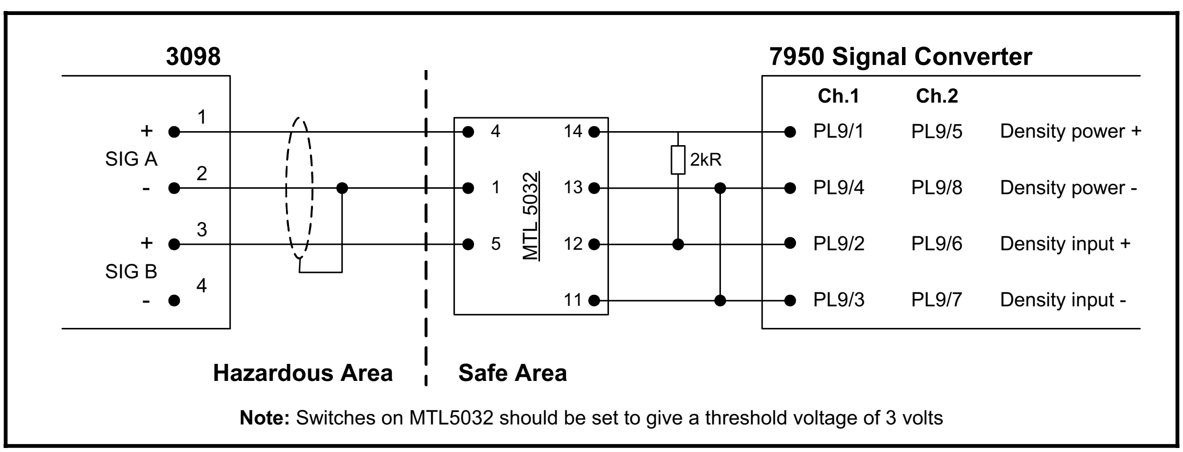


Figure 3-5.14: 7950 Signal Converter and Gas Specific Gravity 3-Wire System with Galvanic Isolator (Hazardous Area)

3.5.3 7951 2-wire configuration

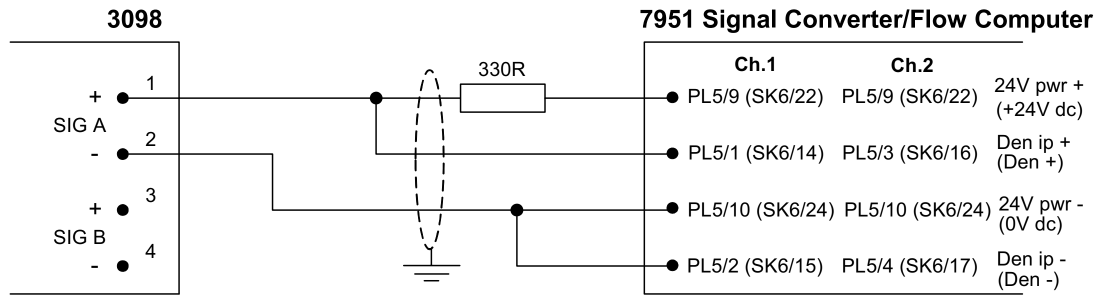


Figure 3-5.15: 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 2-Wire System (Safe Area)

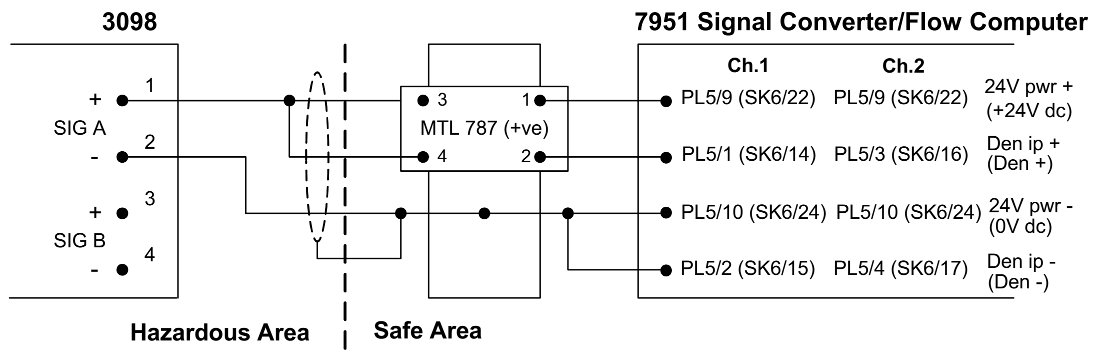
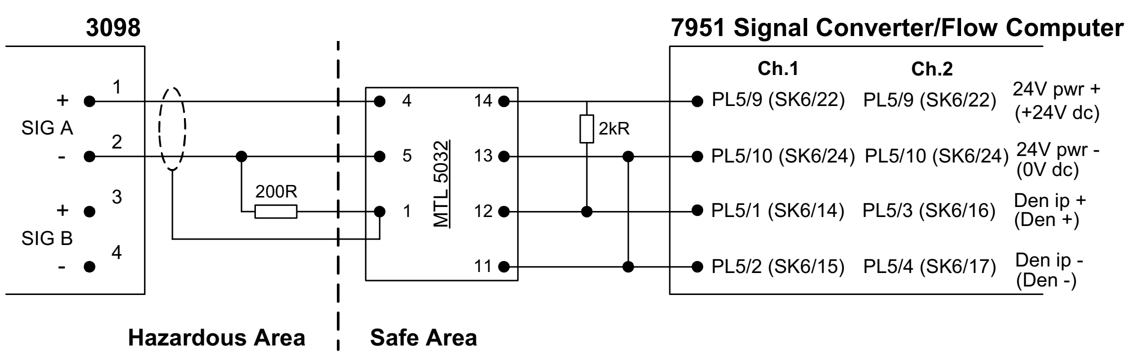


Figure 3-5.16: 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 2-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)



Note: Switches on MTL5032 should be set to give a threshold voltage of 3 volts

Figure 3-5.17: 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 2-Wire System with Galvanic Isolator (Hazardous Area)

3.5.4 7951 3-wire configuration

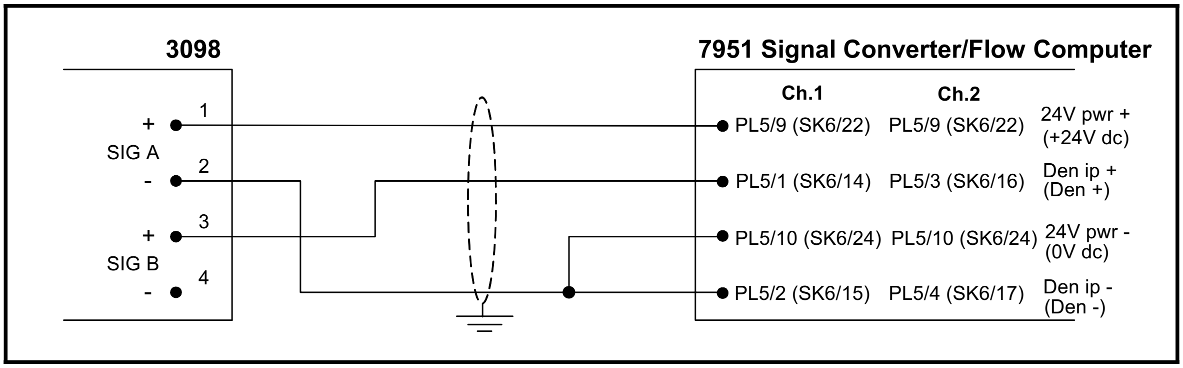


Figure 3-5.18 : 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 3-Wire System (Safe Area)

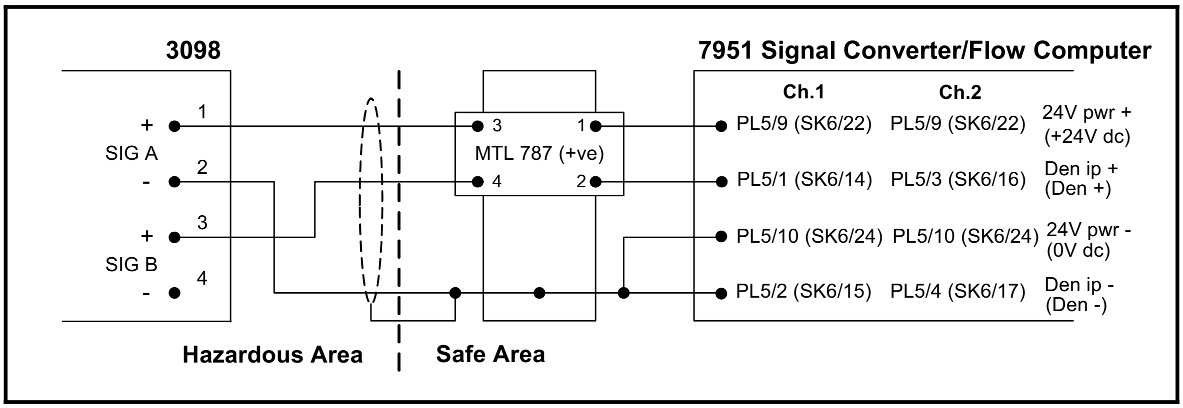
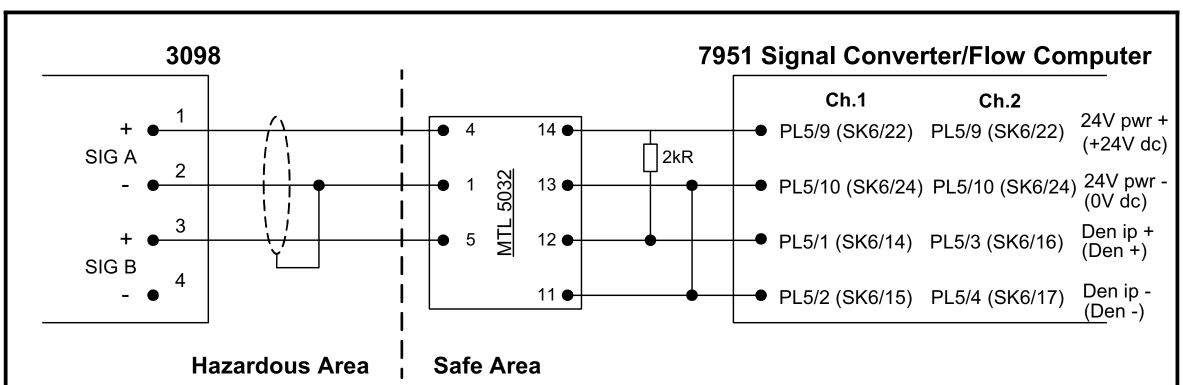


Figure 3-5.19 : 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 3-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)



Note: Switches on MTL5032 should be set to give a threshold voltage of 3 volts

Figure 3-5.20 : 7951 Flow Computer/7951 Signal Converter
Gas Specific Gravity 3-Wire System with Galvanic Isolator (Hazardous Area)

3.5.5 7955 2-wire configuration

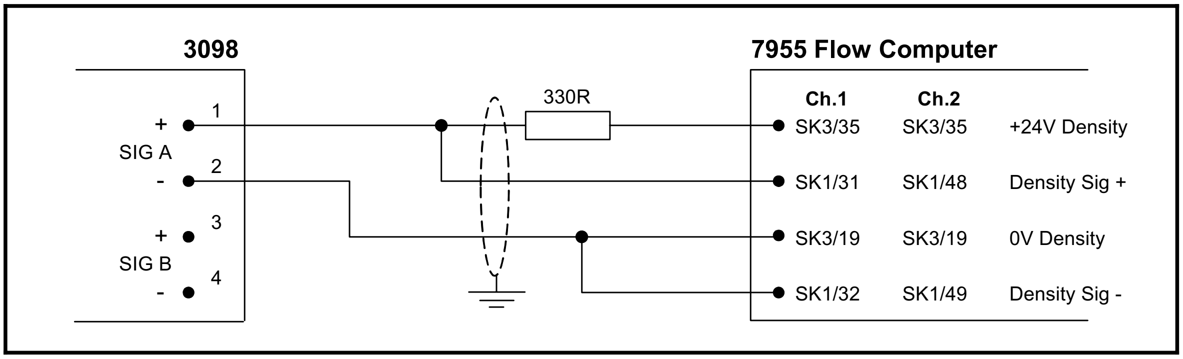


Figure 3-5.21 : 7955 Flow Computer
Gas Specific Gravity 2-Wire System (Safe Area)

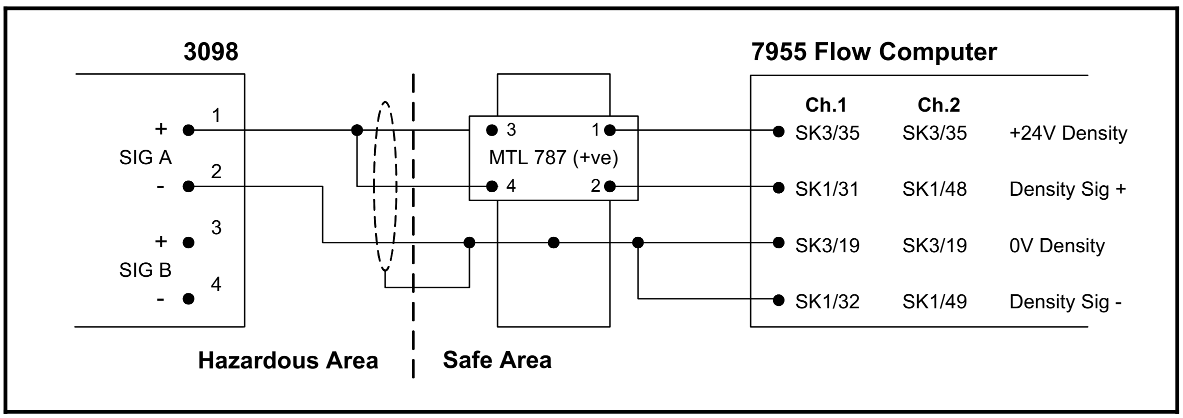


Figure 3-5.22: 7955 Flow Computer
Gas Specific Gravity 2-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)

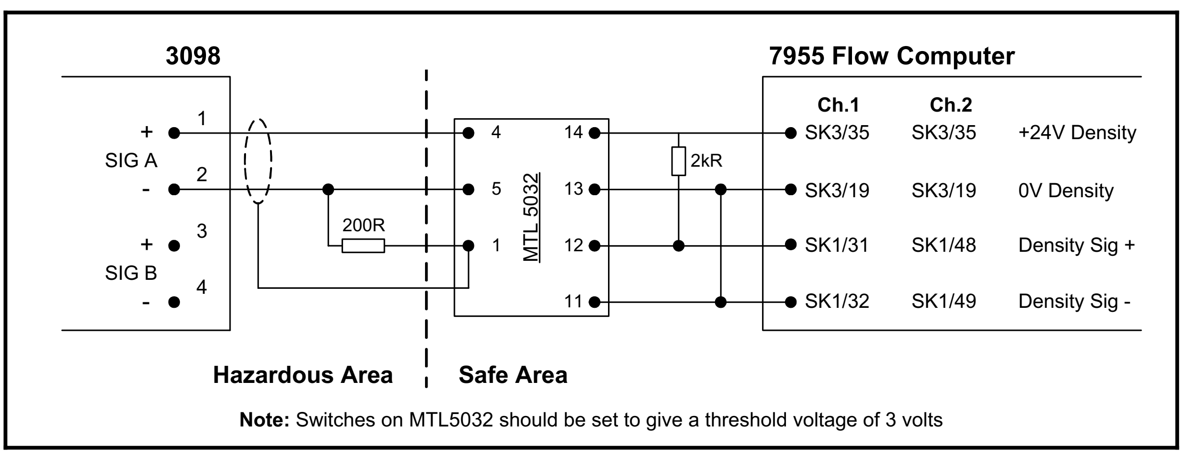


Figure 3-5.23 : 7955 Flow Computer
Gas Specific Gravity 2-Wire System with Galvanic Isolator (Hazardous Area)

3.5.6 7955 3-wire configuration

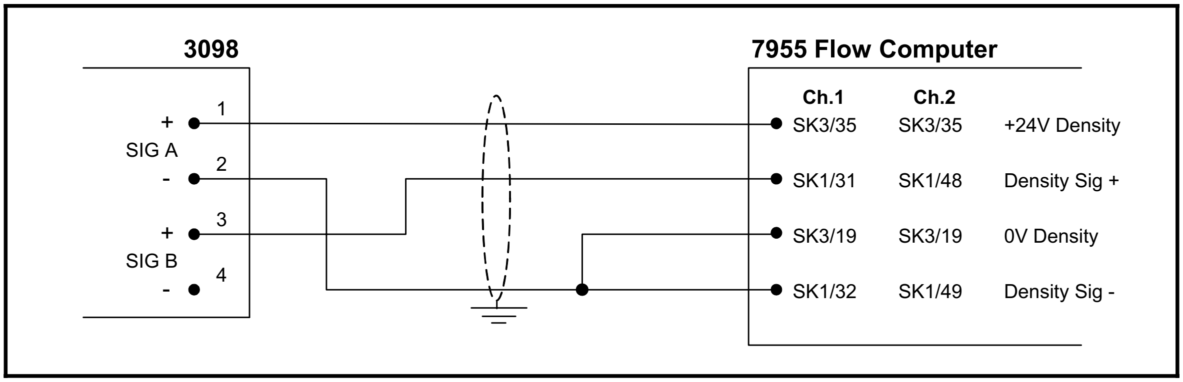


Figure 3-5.24 : 7955 Flow Computer
Gas Specific Gravity 3-Wire System (Safe Area)

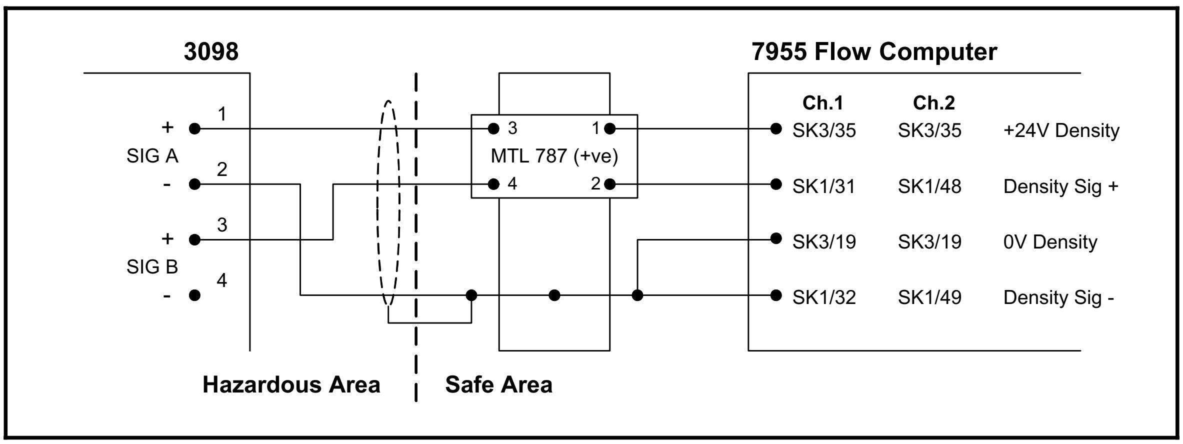
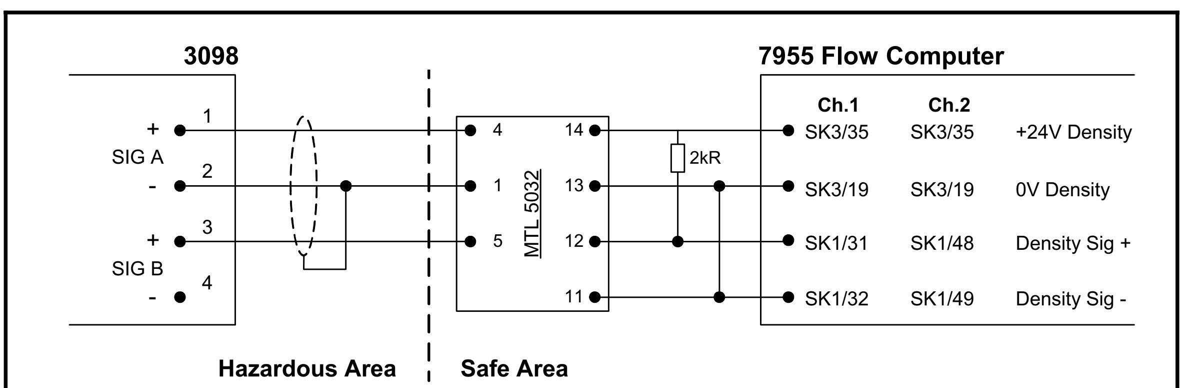


Figure 3-5.25: 7955 Flow Computer
Gas Specific Gravity 3-Wire System with Shunt-Diode Safety Barrier (Hazardous Area)



Note: Switches on MTL5032 should be set to give a threshold voltage of 3 volts

Figure 3-5.26: 7955 Flow Computer
Gas Specific Gravity 3-Wire System with Galvanic Isolator (Hazardous Area)

3.6 System Connections (customer's own equipment)

3.6.1 Non-hazardous areas

Power supply to Density Meter:	15.5V to 33Vdc, <20mA.
Power supply to PRT:	5mA max.

The frequency at which the meter is operating can be detected in one of two ways:

a. For the two-wire option, a 330Ω series resistor should be used in the +ve power line. The electrical connections to be made are shown in Figure 3-6.1. The signal across the 330Ω resistor is greater than 2V peak to peak. The minimum impedance of the signal measuring equipment should be 500kΩ. Where necessary, the 1nF capacitors will block the power supply dc voltage to the measuring equipment.

b. For the three-wire option, the frequency can be measured directly. The electrical connections to be made are shown in Figure 3-6.3.

3.6.2 Hazardous Areas

For details of hazardous area installations, please refer to safety instructions (30985018/SI).

3.6.3 Customer's equipment, 2-wire configuration

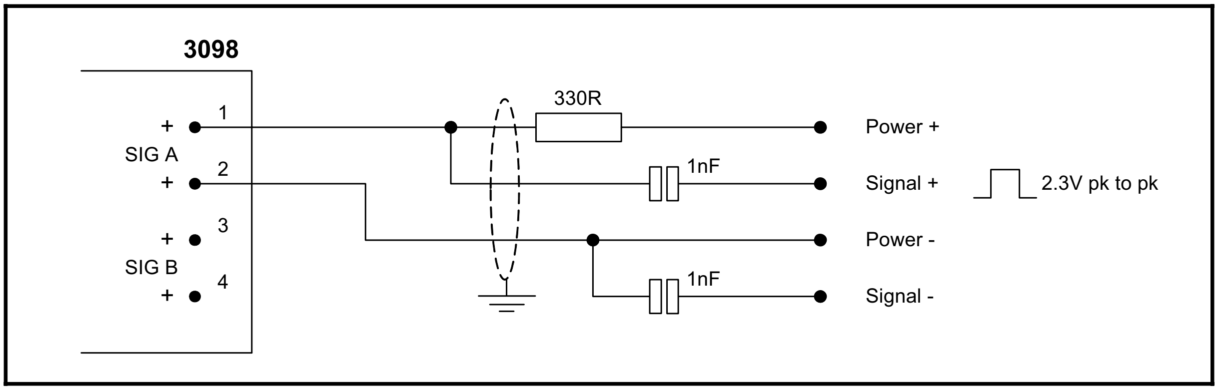


Figure 3-6.1: Electrical connections for meter 2-wire option used with customers' own equipment (Safe Area)

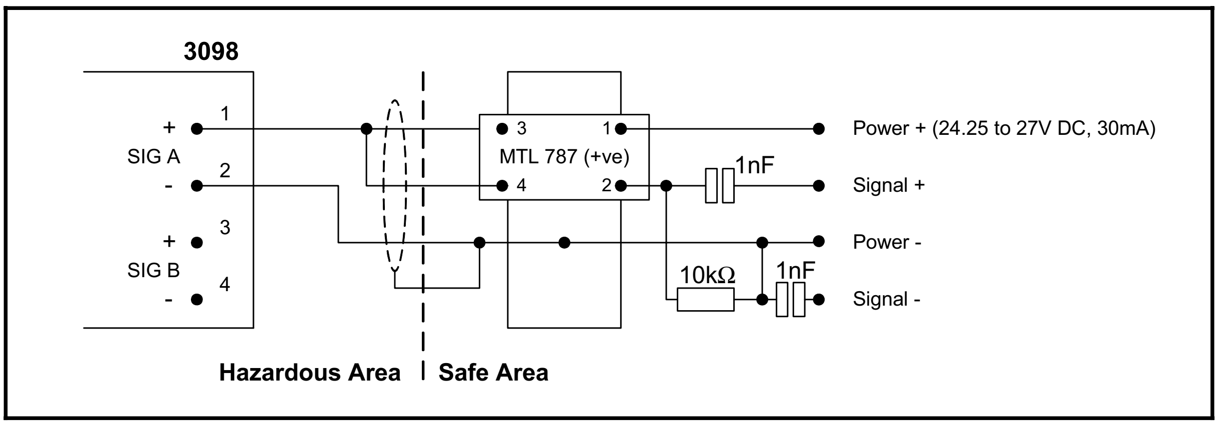


Figure 3-6.2: Electrical connections for meter 2-wire option used with customers' own equipment and Shunt-Diode Safety Barrier (Hazardous Area)

3.6.4 Customer's equipment, 3-wire configuration

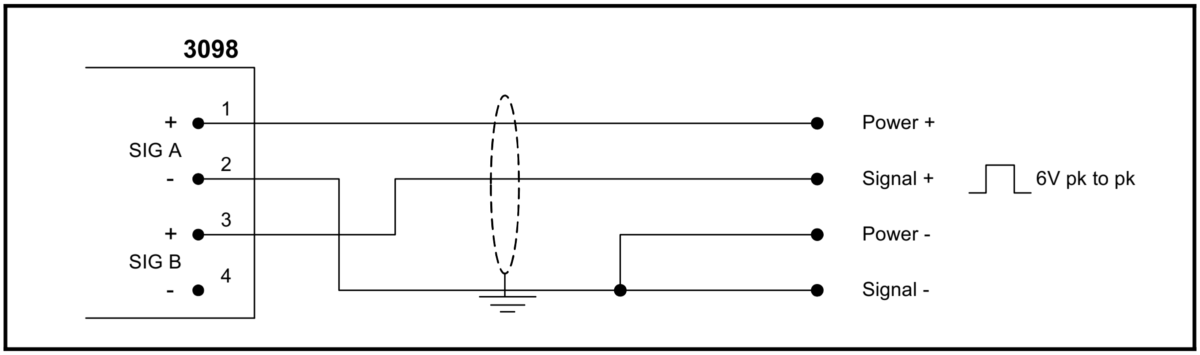


Figure 3-6.3: Electrical connections for meter 3-wire option used with customers' own equipment (Safe Area)

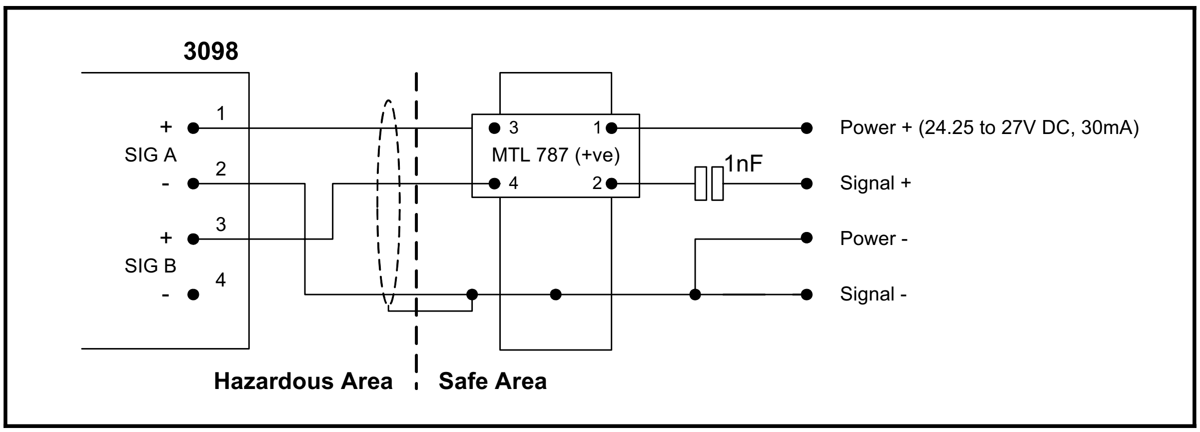


Figure 3-6.4: Electrical connections for meter 3-wire option used with customers' own equipment and Shunt-Diode Safety Barrier (Hazardous Area)

3.7 Post-installation checks

After installation, the following procedure will indicate to a high degree of confidence that the meter is operating correctly.

a. Electrical Check

Measure the current consumption and the supply voltage at the meter amplifier. This should be within the following limits:

15.5V to 33V dc (Safe Areas)
15.5V to 21.5 dc (Hazardous Areas)

17mA ±1mA (Safe and Hazardous Areas)

b. Stability Check

Check the stability of the frequency output signal using a period meter on a 1000 cycle count. The measurement scatter should be within ±2ns. If this value is exceeded, it is likely that dirt is present on the sensing element. This test may be performed at any gas density, provided that the latter is not changing.

Chapter 4
Accuracy Considerations

This chapter

This chapter provides a method for estimating the accuracy of 3098 measurements under various conditions.

4.1 Accuracy Considerations

The 'controlled condition' which establishes a direct relationship between density and the specific gravity of the sample gas is mainly determined by the pressure and the type of gas used in the reference chamber. The choice of reference chamber gas pressure is dependent upon:

1. The span of specific gravity to be measured.
2. The expected change in sample gas supercompressibility, Z.
3. The accuracy required.

The exact choice in reference gas pressure is made after considering all the error sources for that application. To simplify the selection, Table 1 is provided which can be reproduced by the user. In general, unless a pump is used to boost the pipeline pressure, the reference gas pressure at 20°C must be at least 10% less than the minimum line pressure, to ensure gas flow over the operating temperature range.

Example 1

When a gas has a relatively low and reasonably constant specific gravity, and is available at a line pressure greater than 7 Barg (100psig) such as natural gas measurement in the range 0.55-0.8, a very high accuracy is possible using a reference pressure of 7 Barg. (See Example 1 table below for a worked example).

Example 2

If large range specific gravity measurements are to be made, or where changes in the supercompressibility factor of the sample gases become significant, (such as in flare gases or air/CO_2 mixes), a much lower reference gas pressure is required. (See Example 2 table below for N_2/CO_2 mix).

3098 SPECIFIC GRAVITY METER CONTROL PRESSURE SELECTION				
Date: .... Type of Gas: .... Specific Gravity Range: .... to				
3098 Serial No. .... Temperature Coefficient of Density Meter: .... kg/m³/°C				
CONTROL PRESSURE AT 20°C (lb/in² abs.) (bars abs.)	**18 1.2**	**30 2**	**60 4**	**100 7**
DENSITY RANGE AT 20°C (kg/ m³)	**0.79 - .15**	**1.32 - 2.0**	**2.66 - 3.8**	**4.58 - 6.72**
Measurement Errors (% of FS Specific Gravity/°C) due to:				
Density Meter Temp. Coefficient				
Gas Compressibility of Sample Gas				
Velocity of Sound in Sample Gas				
Reference Chamber/Relief Valve	+0.007	+0.007	+0.007	+0.007
Total Error				

Table 1

Calculating the parameters

Density Range at 20°C

Calculated using equation:

$$\text{Density range} = P\rho_{air}G_{\min} \text{ to } P\rho_{air}G_{\max}$$

where

P = Absolute pressure in bars.

ρ_{air} = Density of dry clean air (1.2kgm^{-3} approximately)

$G_{\min}$ & $G_{\max}$ = Specific Gravity minimum and maximum values.

Density Meter Temperature Coefficient Error

Inversely proportional to density (therefore pressure) and is calculated as follows:

Temperature coefficient from calibration certificate = **x** kgm^{-3} /°C

At maximum density value of **y** kgm^{-3} :

Sensor equivalent temperature coefficient = $^{x}/_{y}$ x 100%/°C

Gas Compressibility Error

This describes the deviation in gas compressibility of the sample gas compared with that of the reference chamber gas. The error is taken as 2/3 of the deviation caused by temperature change on the two gases at the reference pressure and is typically proportional to this pressure.
For information on the gas characteristics see the Gas Tables.

Velocity of Sound Error

This error is taken as - 0.0034 G %/°C with G taken at maximum specific gravity $G_{\max}$.

Example 1

3098 SPECIFIC GRAVITY METER CONTROL PRESSURE SELECTION				
Date: 24th June 1997 **Type of Gas:** Natural Gas **Specific Gravity Range:** 0.55 **to** 0.8				
3098 Serial No.: 000124 **Temperature Coefficient of Density Meter:** -0.0003 **kg/m^3/°C**				
CONTROL PRESSURE AT 20°C (lb/in^2 abs.) (bars abs.)	**18 1.2**	**30 2**	**60 4**	**100 7**
DENSITY RANGE AT 20°C (kg/ m^3)	**0.79 - 1.15**	**1.32 - 2.0**	**2.66 - 3.8**	**4.58 - 6.72**
Measurement Errors (% of FS Specific Gravity/°C) due to:				
Density Meter Temp. Coefficient	-0.026	-0.016	-0.008	-0.004
Gas Compressibility of Sample Gas	±0.0003	±0.0003	±0.001	±0.002
Velocity of Sound in Sample Gas	-0.003	-0.003	-0.003	-0.003
Reference Chamber/Relief Valve	+0.007	+0.007	+0.007	+0.007
Total Error	**-0.022**	**-0.012**	**-0.003 to -0.005**	**-0.000 to -0.002**

Example 2

3098 SPECIFIC GRAVITY METER CONTROL PRESSURE SELECTION				
Date: 28th July 1997 **Type of Gas:** N_2/CO_2 mix **Specific Gravity Range:** 1.0 **to** 1.5				
3098 Serial No.: **Temperature Coefficient of Density Meter:** -0.0003 **kg/m^3/°C**				
CONTROL PRESSURE AT 20°C (lb/in^2 abs.) (bars abs.)	**18 1.2**	**30 2**	**60 4**	**100 7**
DENSITY RANGE AT 20°C (kg/ m^3)	**0.4 - 2.16**	**2.4 - 3.6**	**4.8 - 7.2**	**8.4 - 12.6**
Measurement Errors (% of FS Specific Gravity/°C) due to:				
Density Meter Temp. Coefficient	-0.014	-0.008	-0.004	-0.002
Gas Compressibility of Sample Gas	±0.0002	±0.0004	±0.008	±0.015
Velocity of Sound in Sample Gas	-0.005	-0.005	-0.005	-0.005
Reference Chamber/Relief Valve	+0.007	+0.007	+0.007	+0.007
Total Error	**-0.014**	**-0.006**	**+0.006 to -0.010**	**+0.015 to -0.015**

4.2 Calibration (for non-natural gas applications)

The instrument is supplied with its reference chamber empty and thus in an un-calibrated condition. After installation on site it is necessary to decide what reference chamber pressure to use, and then to charge and calibrate the instrument as described in the Installation Procedure (Chapter 2).

Some examples of how to calculate these reference chamber pressures are given in Examples 1 and 2, which show the best pressures for a natural gas and a N_2/CO_2 mix application.

Once this has been done, the gases to be used for calibration need to be defined. The calibration gases to be used must be of known specific gravities and substantially represent the properties of the line gas to be measured (i.e compressibility, viscosity etc.) For example, if measuring a natural gas which is substantially methane and carbon dioxide, then these two gases in their pure forms or at defined specific gravities should be used in the calibration.

With this decided, the 3098 can be calibrated by following the calibration procedure described in Chapter 2, the Installation Procedure.

Note

In the case where only one calibration gas is available, the time period of the density meter at zero density/specific gravity (i.e., vacuum conditions), which is included on the meter temperature coefficient calibration certificate, can be used as time period τ_y. Under this condition, calibration is less accurate due to the non-homogenic condition of a vacuum and its effect on supercompressibility compensation. An example of the meter temperature coefficient calibration certificate is given below.

Once the calibration has been performed, the coefficients can be calculated using equations (1) and (2) in the Installation procedure or by using the calibration certificate shown below. (An Excel program, calcert.xls, to perform these calculations is contained on the 3½" disk which came with this manual).

For more specific details on calibration see Appendix A.

4.2.1 Operation at Low Reference Pressure levels

One of the design features of the 3098 is that two orifice plates are used to control and regulate the flow of sample gas through the unit, one of which is placed at the output port and is used to reduce the stresses placed on the unit's diaphragm. It is important to note that in order to increase the sample gas flow rate, the pressure at the input port must be increased. As this pressure is increased, the pressure across the output orifice increases. If this pressure exceeds that of the gas inside the reference chamber, the diaphragm will not regulate the input gas pressure and hence not allow an SG measurement.

For reference pressures greater than 3 bar absolute (3 bar A), this situation will not occur in the unit flow range of (0.2 - 60cm^3/s). However, it may occur if the reference pressure is less than 3 bar A and the flow rate > 50cm^3/s.

It is recommended that in order to achieve the optimum accuracy when performing SG measurement, the corrections for VOS and compressibility are taken into consideration. This can be done by following the procedure described in Appendix A.

3098 CALIBRATION

Ref. No.: **A1** Date: **24/07/97**

3098 Ser. No.: **xxxxx** Signal Amplifier Ser. No.: **YYYYY** Vibrating Cylinder Ser. No.: **ZZZZZZ**

INPUTS

Sample Gas Type: **Natural Gas** Required Specific Gravity Span: **0.5 to 0.7**

Selected Reference Pressure at 20°C: **7 bars**

Calibration Gas X Type: **Methane** Calibration Gas Y Type: **Nitrogen**

Specific Gravity (Gx): **0.5549** Specific Gravity (Gy): **0.96715**

3098 Output (Tx): **514.798 µs** 3098 Output (Ty): **523.213 µs**

NOTE: Where the output is required in Relative or Standard Density units, simple substitute these values for the Specific Gravity values.

CALCULATIONS

Since the Specific Gravity, $G = K_o + K_2T^2$ 1.

where $K_2 = \dfrac{G_x - G_y}{T_x^2 - T_y^2}$ 2.

= 4.719593X10-5

$K_o = G_y - K_2T_y^2$ 3.

= -11.952

T E M P E R A T U R E   C O E F F I C I E N T
C A L I B R A T I O N   C E R T I F I C A T E

3098 SPECIFIC GRAVITY METER

Serial Numbers:

Instrument	000001
Amplifier	000001
Cyclinder	000001

Pressure Test

Units pressure tested to 300 p.s.i.g.

Datum Periodic Time

Time period with vacuum at 20°C (µs) (zero specific gravity)	504.398

Temperature Coefficients

Cylinder coefficient at 20°C (µs/°C)	0.0013
Density equivalent at 20°C (Kg/m^3/°C)	0.0006

```
  ####    ##    ##      ##  ####    ##      ######
  ####    ##    ##      ##  ####    ##      ######
##      ##  ##  ####  ####  ##  ##  ##      ##
##      ##  ##  ####  ####  ##  ##  ##      ##
  ##    ######  ##  ##  ##  ####    ##      ####
  ##    ######  ##  ##  ##  ####    ##      ####
    ##  ##  ##  ##      ##  ##      ##      ##
    ##  ##  ##  ##      ##  ##      ##      ##
####    ##  ##  ##      ##  ##      ######  ######
####    ##  ##  ##      ##  ##      ######  ######
```

FINAL TEST

3098CERTGEN V1.0

DATE: xx-xxx-xx

Chapter 5
Maintenance & Fault Finding

5.1 Introduction

This chapter deals with the recommended servicing and maintenance that can be carried out under field conditions, including calibration checks, faultfinding procedures and simple maintenance. If a fault is traced to a reference chamber malfunction, it is strongly recommended that the repair of the faulty unit be restricted to a qualified engineer or that the faulty unit be returned to the factory (see Appendix C for Returns Forms).

If a calibration check reveals a significant error, the cause of this error (e.g. reference chamber leak, deposition on the vibrating cylinder) should be thoroughly investigated before any re-calibration attempt is made.

5.1.1 Calibration Check

It is normally good practice to carry out periodic checks on the system accuracy. This is simply achieved by passing a gas of known specific gravity through the instrument as previously detailed under the Calibration section of the Installation Procedure (Chapter 2). It is preferable that the specific gravity of this calibration gas lies within the specific gravity range of the system under test since this will simplify the system check procedure. However, a gas whose specific gravity is outside this range can be used if its characteristics are similar to those of the system line gas.

5.1.2 Fault Finding

If any adverse or suspect readings occur upon checking the calibration, the possible causes for this can be summarised into 4 groups:

- Instrument Over-reads;
- Instrument Under-reads;
- Erratic Instrument readings;
- Meter Faults.

a) Instrument Over-reads

This is generally due to deposition, condensation or corrosion on the vibrating cylinder walls.

The effects of deposition and condensation can be removed from the cylinder by carefully cleaning the cylinder walls (once the density meter has been removed from the 3098) although corrosion cannot be dealt with this way.

If the cylinder is corroded or damaged in any way (i.e. dents, scratches etc.) then it must be replaced with a new unit.

b) Instrument Under-reads

This is most probably due to a gas leak from the reference chamber. Before dismantling the instrument it is desirable to locate the leak, the cause of which may be one of the following:

(i) Reference Chamber to sample gas path

Parts affected are:

- Diaphragm;
- Reference Chamber Valve;
- Reference Chamber metalwork.

This type of leak can be identified by using the following test.

Charge the reference chamber to a high pressure (up to 7 BarA maximum) and then isolate by closing the reference chamber valve. Vent the sample gas path at the instrument's inlet and outlet to atmosphere then seal by closing the inlet and outlet line valves.

If gas is leaking into the sample gas flow path, this will be indicated by the change in output signal from the density meter.

Alternatively, if the leak rate is influenced by whether the sample gas path is at atmospheric pressure or at the line operating pressure, then this is indicative of a leak into the sample gas flow path.

(ii) Reference Chamber to Atmosphere

Parts affected are:

- Diaphragm;
- Sealing gasket (meter);
- Reference Chamber valve pipework;
- Reference Chamber metalwork.

This type of leak can often be traced by the application of a soap solution, or 'Snoop', and bubble observation. Unlike the previous type of leak this will not be influenced by sample gas path pressure.

If the leak is due to a faulty gasket seal, diaphragm or reference chamber valve then a serviceable replacement should be fitted.

If in doubt, advice should be sought from the factory – contact details are on the back page.

(iii) Erratic Instrument Readings

These can be caused by:

a) *Electronic Fault*

This can exist in either the meter or its associated electronics.

If an independent frequency generator is available, this can be used to check the performance of the flow computer/signal converter.

If the fault is in the meter amplifier, this can be changed with no degradation in performance.

b) *Vibrating Cylinder*

If the sample gas flow is stopped by closing the inlet valve, the time period signal should drop slightly to a steady value or, if there is a small leak, continue to drop slowly. Should the reading remain erratic, it is likely that there is deposition on the vibrating cylinder which needs to be stripped, cleaned and re-assembled.

c) *Pressure Control Valve*

If the erratic signal is only present while there is a flow of sample gas through the unit, then the fault is likely to be due to a malfunction of the pressure control valve, brought about by the presence of dirt. In this case the diaphragm (and hence valve mechanism) should be stripped down, cleaned and re-assembled. Any poor seals or damaged parts should be replaced. Alternatively, the gas pressure may be falling below that of the designed input condition.

d) *Meter Faults*

These faults can be found by a few simple tests:

I. *Spoolbody Assembly:* The magnetic drive and pick-up assembly (spoolbody) can be checked visually for problems and also electrically for continuity, by measuring the resistance of the drive and pick-up coils. The resistance of each coil should be (72±10)Ω at 20°C.

II. *Meter Amplifier*: If careful examination of the sensing element and spoolbody assembly does not reveal the cause of the problem, the amplifier should be replaced. This will show whether the problem is with the amplifier.

Note: A check of the amplifier current consumption is a good indicator of the amplifier's health.

A further test to check the amplifier is to change the supply voltage across its operating range and check that the time period does not change.

5.2 Maintenance

Apart from scheduled calibration checks and filter replacements (these being dependent upon the condition of the sample gas) no other routine maintenance should be required.

When a fault is suspected, the 3098 can be easily dismantled to expose the section that needs inspection. A full dismantling procedure to major component level is described below.

1. *Main meter (3098) removal*: removal of the complete unit from its installation, allowing all other servicing to be performed.
2. *Density meter removal*: removal of the sensing element to a clean environment where further dismantling can take place.
3. *Reference Chamber Diaphragm removal*: (performed after stage 1).

General Notes

- All gaskets, O-rings and the diaphragm are to be lightly greased with silicone grease MS4 before re-assembly. Gas connection threads to be sealed using PTFE tape or Loctite 572.
- Loctite 221 is to be applied to all screws during re-assembly.
- New gaskets should be fitted on re-assembly.
- Any re-assembly must be followed by a leak test, procedure 5.2.7.

WARNING: BEFORE ANY SERVICING IS ATTEMPTED THE 3098 MUST BE ISOLATED FROM BOTH THE GAS AND ELECTRICAL SUPPLIES

5.2.1 Main meter (3098) removal (Figure 5-1)

The instructions in this section apply only to *3098* meters supplied with an enclosure (see Important Notice on page 1-1). In all other cases, please refer to the system installer.

1. Ensure that the 3098 has been isolated from the gas and electrical supplies. Vent the instrument to atmospheric pressure.

Note: The reference chamber may remain charged with gas unless a reference chamber diaphragm requires servicing.

WARNING: FOR SOME GASES, E.G. METHANE, IT IS IMPERATIVE TO VENT THE REFERENCE CHAMBER TO ATMOSPHERIC PRESSURE WHENEVER THE 3098 HAS TO BE TAKEN OFF-LINE

2. Disconnect the 3098 externally from the system pipework at the side of the enclosure having vented the reference chamber (if required). Cover all exposed gas connections.

3. The 3098 may be removed from its installation whilst still inside its enclosure, or it can be separated at this stage, leaving the box in situ. If the latter is required then continue from 5.

4. The enclosure can now be removed from its installation by unscrewing the four mounting feet fixings.

5. Once the electrical wiring has been disconnected from the meter and the cable removed from the gland, the instrument can be further dismantled. The 3098 metalwork can be removed from the enclosure as described in points 6 - 8 and transported to a clean area for further servicing.

6. Remove the enclosure door by pulling out the two retaining pins. Undo the three Swagelok pipe fittings that connect the gas lines to the unit at the enclosure wall (item a). When this is done, remove the two recess headed screws that hold the unit's mounting bracket to the rear of the enclosure (item b).

7. Loosen and remove the three bolts at the base of the box that hold the unit's feet (item c).

8. Carefully remove the unit from the enclosure by moving it to the right to disengage the pipes from their fittings. Take the metalwork to a clean area.

9. The 3098 is installed using this procedure in reverse order. All gas pipe connections will require leak testing.

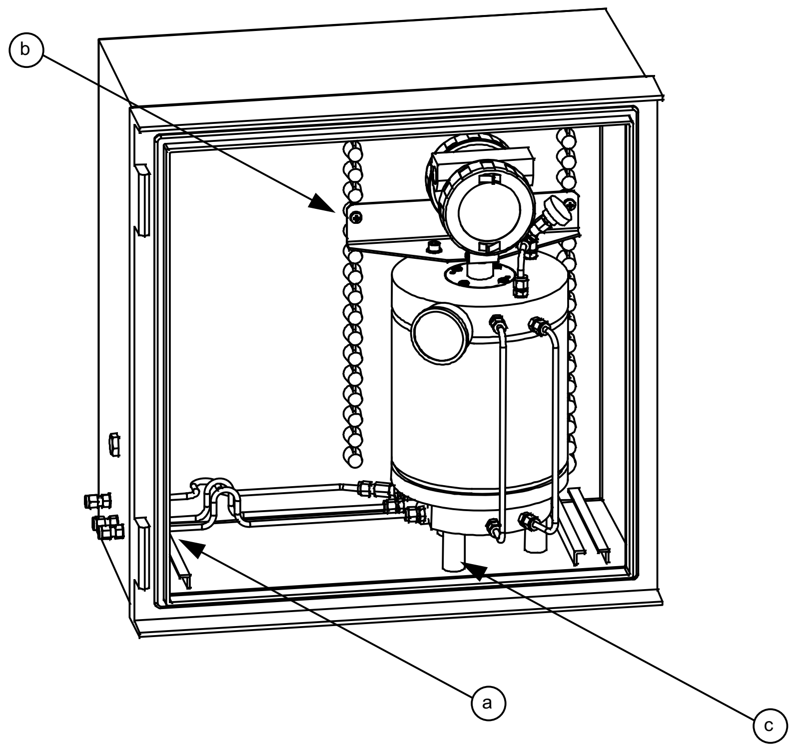


Figure 5-1: 3098 general assembly schematic (typical enclosure)

5.2.2 Density meter removal (Figure 5-2)

1. With the 3098 disconnected and removed from its enclosure, the density meter can be removed from the top plate by undoing the four M6 bolts that hold it in place.

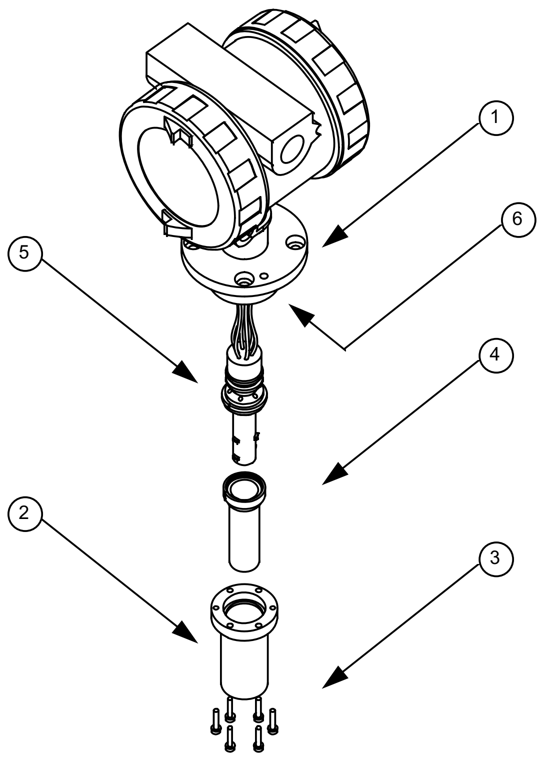


Figure 5-2: Density Meter exploded view

2. Use two of the removed M6 bolts to jack the meter from its housing using the two threaded holes found in the mounting housing (item 6). **DO NOT TRY TO LEVER THE UNIT OUT - THIS WILL DAMAGE THE SEALING 'O' RING AND THE VIBRATING ELEMENT.**

The aperture left in the 3098 by this removal should be covered to stop dust or dirt getting into the meter chamber. The meter itself can now be taken to a clean environment to be serviced further.

The density meter is refitted by locating it in the top plate and lowering it until it sits on the sealing O-ring. **DO NOT FORCE THE METER IN PLACE BY PUSHING DOWNWARDS**. Tighten the four bolts in sequence to gradually ease the meter into place.

Note that the bolts holding the density meter in place should be tightened to a maximum torque of 10Nm and should be treated with proprietary thread locking compound, for example, Loctite.

The meter amplifier housing can be easily removed by releasing the clamp that holds it to the meter body (mounting housing) and undoing the spoolbody wire connections inside. A more detailed description of the electronics inside the housing is given in the Electrical Connections section, Chapter 3.

5.2.3 Reference Chamber Diaphragm removal (Figure 5-3)

The diaphragm that regulates the sample gas pressure to that of the reference chamber is held in between the welded assembly and the base plate. The following procedure shows how to access and service this part.
(The figure below shows two views for clarity with top plate and pipework not shown).

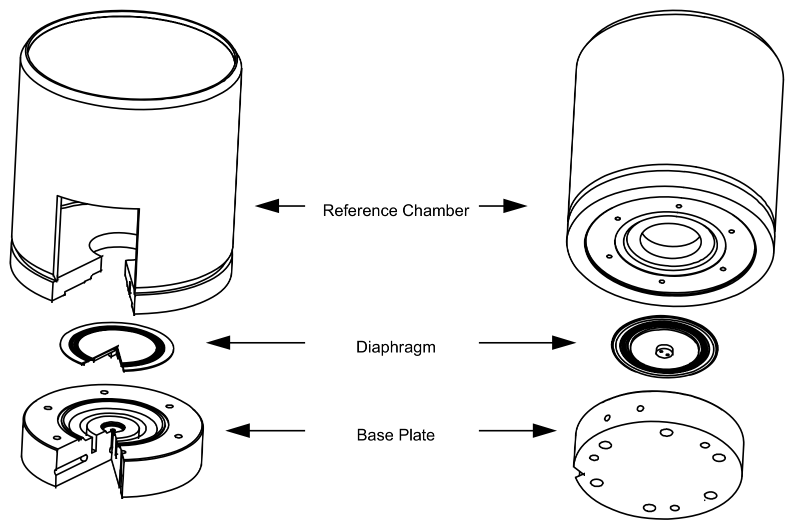


Figure 5-3: Reference chamber diaphragm section

1. As the diaphragm produces a gas tight seal for the reference chamber, before any servicing of this part is done, the **REFERENCE CHAMBER MUST BE VENTED TO ATMOSPHERIC PRESSURE.**

2. With the 3098 out of its enclosure (see procedure 5.2.1) remove the three unit feet and stand the metalwork upright.

3. Using a 9/16" spanner, undo and remove the two gas pipes that connect the base plate to the top plate.

4. Gently rest the 3098 on its side and undo the six M6 bolts that lock the base plate to the reference chamber.

   Note: Care must be taken not to bend or damage the three gas pipelines that originate from the base plate.

5. The diaphragm is exposed once the base plate has been removed.

6. As the diaphragm is a single moulded piece part, servicing consists of either changing the sealing O-ring or changing the diaphragm itself.

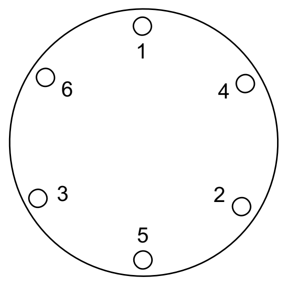
5.2.4 Re-assembly Procedure

1. Invert the 3098 so that the diaphragm counter-bore faces upwards.

2. Locate the diaphragm assembly into the counter-bore housed in the welded assembly - **not** the base plate.

3. Carefully replace the base plate over the diaphragm, making sure that the diaphragm is not moved from its central position in the counter-bore **and** that the connectors line up for the two 'base to top plate' gas pipelines.

4. Place the bolts into their counter-bores and tighten them in ascending order as shown in the diagram below:



5. Replace the two 'base to top plate' gas pipelines and the density meter (if it has been removed) and perform a leak check on all seals described in section 5.2.7.

6. The 3098 can now be replaced in the main enclosure, by reversing the procedure described for 'Main meter (3098) removal'.

5.2.5 3098 Filter Change Procedure

1. Remove unit from installation and enclosure as described in sections 5.2.1 above.

2. Place the unit on its side and loosen the fittings that retain the input gas interconnection pipe.

3. Once this pipe has been removed, loosen and remove the filter fitting that screws into the unit base plate.

4. The filter element cannot be removed from its housing, so the complete fitting must be changed.

5. The new filter should be inserted into the base plate, using PTFE tape to produce a gas tight seal. Care should be taken to ensure that no stray parts of PTFE tape fall into the instrument.

6. Re-assembly is the reverse of points 2 and 1 above.

Note: Once the unit has been replaced into its enclosure, a leak check **must** be performed before on-line operation.

5.2.6 Further Servicing of the Density Meter (Figure 5-2)

Once the density meter has been removed from the 3098 metalwork and the electronics housing removed, the unit can be further serviced by following the instructions below:

NOTE: THE CYLINDER WALL IS FRAGILE. GREAT CARE MUST BE SHOWN DURING THE REMOVAL, HANDLING AND REFITTING OF THE CYLINDER AND ITS HOUSING. HOLD ONLY BY THE CLAMPING SECTION.

1. Referring to figure 5-3, remove the six screws (item 3) which secure the cylinder housing (item 2) to the mounting housing (item 1).

2. Exercising great care, ease off the cylinder housing in an axial direction, allowing access to the cylinder/spoolbody assembly.

3. Carefully lift off the cylinder (item 4) and clean by lightly wiping with a lint-free tissue soaked in an appropriate solvent.

4. Again, exercising great care, ease out the spoolbody (item 5). Clean the spoolbody and examine for corrosion.

If no corrosion or other damage is apparent on any of the piece parts, the instrument may be reassembled in reverse order. During re-assembly of the sensing element, special attention is required to correctly orientate the cylinder/spoolbody combination (see Figure 5-4).

Re-fit the meter to the 3098, by following the operations above in reverse order, making sure that the scribe marks align as shown in Figure 5-4.

Note: It is recommended that O-rings be renewed during re-assembly and **LIGHTLY COATED** with silicone grease.

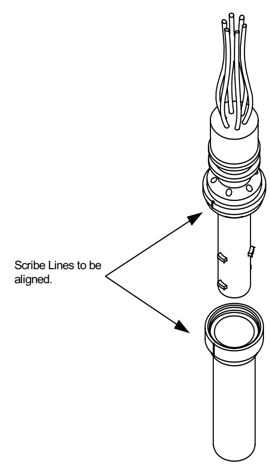


Figure 5-4: Spoolbody/Cylinder alignment

5.2.7 Leak Testing the 3098

Leaks incurred during servicing can be categorised under two main headings:

a) Reference Chamber leaks

1. Charge the reference chamber to 6.5 bar G using any clean dry gas.
2. Pass a gas of constant specific gravity (e.g. nitrogen) through the instrument, and when stabilised, record the time period.
3. Repeat operation 2 every day for three or four days, ensuring that there are no large temperature changes at each reading.
4. A downward drift in the time period indicates a leak.

Note that further tests can be done in order to define the nature of the leak. These procedures are laid out in section 5.1.2.

b) Gas Path to Atmosphere Leaks

1. Apply any clean dry gas at a pressure of 6.5 bar G to the meter.
2. Apply a soap solution or 'Snoop' to all disturbed areas of the meter and observe for any bubble formation.
3. Seal as required and on completion of a satisfactory leak test, vent the meter to atmosphere.

5.2.8 Post Maintenance Tests

A density measurement check on ambient air will verify that the vibrating cylinder is functioning correctly. A full calibration followed by a calibration check preferably using two suitable calibration gases, as previously described, will be necessary to prove the system. This check, when carried out over a period of time acts as a leak detection test.

5.2.9 Worked Example of Calibration Certificate

This example relies on the following criteria being assumed:

Specific gravity span is	0.5 - 0.7
Gas line pressure	15 Bar
Reference chamber pressure	7 Bar G
Calibration gases CH_4 and N_2	SG values 0.5549 and 0.96715

The calibration gases in their pure state are passed through the meter and their respective periodic times measured. From this information, the coefficients are derived.

Chapter 6 Specification

6.1 *3098* Specification

Note: Some parts of this specification (marked with '*') cannot be guaranteed for *3098* meters supplied without an IP-rated enclosure (see **Important Notice** on page 1-1).

6.1.1 Performance

Specific Gravity limits:	0.1 - 3 (typical).
Fluid:	Dry, clean, non-corrosive gases.
Accuracy:	Up to ± 0.1% reading. *
Repeatability:	± 0.02% reading. *
Temperature Coefficient:	± 0.005%/ºF (± 0.01%/°C). *
Temperature range:	-22 to +122°F (-30 to +50°C), or as limited by gas dew point.
Control Pressure at 20°C:	1.2 to 7 bar absolute (17 to 101 psia).
Supply Pressure:	Minimum: Control pressure + 15% Maximum: Control pressure + 100%, **up to a maximum of 12 bar absolute.**
Gas Flow rate:	0.012 to 3.66in^3/s (0.2 - 60 normal cm^3/s).
Response Time:	< 5 seconds upon entry into enclosure with flow at 3.66in^3/s (60 normal cm^3/s). *
Output Signal:	Nominal 6V peak-peak for 3 wire system. 2-3V peak-peak across 330Ω resistor for two-wire system.
Operating frequency range:	(1960 ± 10%) Hz at 0 kg/m^{-3} (1580 ± 10%) Hz at 60 kg/m^{-3}
Built-in Filter:	7 µm.
Calibration:	By gas samples of known specific gravity.

6.1.2 Electrical

Power Supply:	+15.5 to 33Vdc.
Electromagnetic Compatibility:	Approved to BS EN 50081-2 and BS EN 50082-2.

6.1.3 Mechanical *

Gas Connections:	Swagelock compression fittings for ¼" (6.35mm) O/D pipe.
Enclosure Rating:	Meter rated to IP65 when mounted in enclosure.
Enclosure Dimensions:	(See drawings in Section 2.7 of chapter 2).
Enclosure Weight:	Small (3098E): 20lb (9kg) approx. nett, Gross weight (packaged) 53lb (24kg). Large (3098G): 77lb (35kg) (approx.) nett, Gross weight (packaged) 99lb (45kg).
Materials:	Process gas must be compatible with Ni-Span-C902, Stainless Steel AISI 316, Stycast catalyst 11 and 6082 grade Aluminium alloy.

** - only valid for meters supplied with IP-rated enclosure - see Important Notice on page 1-1.*

6.1.4 Safety

See 3098 ATEX safety instruction booklet (30985018/SI) and PED safety instruction booklet (30988002/SI).

Appendix A
Performance Optimisation

A1. Introduction

The 3098 Specific Gravity Meter uses a **vibrating element density sensor** that is located within a pressure regulating system. The arrangement is such that the density output signal can be directly related to the **specific gravity** or **relative density** of the gas.

Operation of the meter involves charging a reference chamber to a defined pressure and then calibrating the output signal by using gas samples of known relative density. In order to reduce the effect of systematic errors associated with the density sensor and the non-ideal behaviour of gases, a number of procedures must be carefully followed. The procedures listed in this document should form the basis for more specific and clearly defined user procedures. Reference should also be made to the calibration details given in Section 2 of the manual.

A1.1. The Density Sensor

The vibrating cylinder density sensor is able to measure the density of gases with very high resolution and accuracy. Its two major potential error sources are temperature coefficient and a gas composition influence due to the effects of the velocity of sound in the gas.

The effect of the sensor temperature coefficient is directly related to the operating density and hence the operating pressure. If the operating pressure is doubled, the effect is halved.

The gas composition influence is substantially related to the relative density of the gas and not its operating condition. In consequence, this effect is substantially eliminated by the calibration procedure. However, best results are achieved if the calibration gases are of similar type to that of the sample gases.

A1.2. The non-ideal behaviour of gases

This behaviour will affect the operation of the measurement system since the measurement of density at the operating condition is not only related to the relative density of the gas but also to its compressibility factors. The consequences of this characteristic are as follows:

a. If the operating temperature changes, so will the value of the compressibility factor and this would be seen as an instrument temperature coefficient. However, if the reference chamber contains a similar gas, the Z factor (compressibility) changes are self-cancelling and hence no resultant effect materialises. For this reason, and if a low system temperature coefficient is required, it is important that the reference chamber gas is similar to the measurement gas. Operating at low reference chamber pressure will also reduce this effect.

b. Any compressibility factor differences between the calibration gases and the sample gas will be seen as measurement offsets. In consequence, it is important that the calibration gases do closely represent the major constituents of the sample gas or that the calibration procedure makes allowances for any such offsets. Since compressibility factors are related to operating pressure, it follows that this offset is minimised when operating at low reference chamber pressures.

A1.3. Selection of reference chamber pressure

The reference chamber pressure must always be above the vent pressure to ensure sample gas flow. If venting to atmospheric pressure, this means that the reference chamber pressure should be above 1.2 bar absolute and below the maximum of 7 bar absolute. The actual pressure should be selected to give minimum measurement errors due to temperature changes and calibration method. To summarise:

To minimise density sensor temperature coefficient	-	use high pressure
To minimise Z changes with temperature	-	use low pressure
To minimise Z effect on calibration	-	use low pressure
To minimise errors in readout electronics	-	use high pressure

Note: When sample gas is flowing through the instrument, the reference chamber pressure is indicated on a dial gauge within the insulated enclosure. The indicated pressure is in **bar gauge** whilst the pressures quoted in this text are in **bar absolute**.

A1.4. Selection of calibration gases

The measurement accuracy of the specific gravity meter can be not better than that defined by the quality of the calibration gases. Furthermore, the calibration gases should substantially represent the characteristics of the expected sample gases, especially with respect to their compressibility characteristics.

For example, the use of pure certified methane as one calibration gas and the use of a typical certified gas mix as the other calibration gas would yield good results. However, since it may be difficult to obtain a certified gas mix, and also since some gas mixes will stratify in their containers and hence give unreliable quality, it is often better to use two pure gases such as certified methane and certified nitrogen. In this case it may be necessary to modify the calibration procedure to make allowance for any non-ideal characteristics of the sample gases.

A2. Recommended Calibration Methods

From the previous descriptions it can be appreciated that there is a choice of calibration procedures. These differ in detail to suit the operating conditions, the types of gas to be measured, and the availability of calibration gases. However, all calibrations can be separated into three general tasks as follows:

A2.1. General Calibration Method

Selection of Reference Chamber Gas
This gas should ideally be similar to the sample gas as far as compressibility characteristics are concerned (it is usual for the sample gas to be used in the reference chamber) in order to minimise the temperature coefficient of the instrument.

Selection of Reference Chamber Pressure
This pressure should be set to a value which minimises the temperature coefficient and also any calibration errors which result from using non-representative calibration gases.

Calibration and Sample Gases
Having charged the reference chamber to the selected pressure chamber pressure, then suitable adjustment should be made to the calibration coefficients to ensure minimum error when using the sample gases. These calibration adjustments can be calculated from a knowledge of the compressibility factors of the calibration and sample gases, or by establishing the necessary offsets by measurement experience. Paragraph 2.2 details the procedures which can be adapted to suit any specific calibrations involving gas mixes, and highlights the special problems entailed.

A2.2. Specific Calibration Method

Example for natural gas using methane and nitrogen as calibration gases.

Selection of Reference Chamber Gas
This gas should ideally be similar to the sample gas as far as compressibility characteristics are concerned (it is usual for the sample gas to be used in the reference chamber) in order to minimise the temperature coefficient of the instrument.

Selection of Reference Chamber Pressure
The reference chamber pressure is selected as follows:

a. To minimise the temperature coefficient, see **Section 4.1.4 and Tables 2 and 3**.
b. To minimise the compressibility effect between the calibration and sample gases.

Calibration
Apart from the temperature coefficient characteristics, the major potential error sources are:

a. The velocity of sound effect (*VOS*) of the gas.
b. The compressibility factor (Z) of the gas.

VELOCITY OF SOUND EFFECT

The velocity of sound effect on the sensor is such that:

$$\rho = \rho_i\left(1-\frac{K_3}{(c\tau)^2}\right) \qquad \text{A1}$$

Where: ρ = The line density.

ρ_i = The indicated density assuming infinite VOS.

K_3 = The VOS coefficient, typically $4.41\text{x}10^8$

τ = The sensor periodic time, typically 515µs.

c = The velocity of sound in the gas in metres per second.

The velocity of sound in a gas can be determined as follows:

$$c = \sqrt{\gamma\frac{P}{\rho}} \qquad \text{A2}$$

Where: γ = The ratio of specific heats.

P = The line pressure in bars.

ρ = The line density.

For an ideal gas at 20°C, equation A2 can be simplified to:

$$c = 1562\sqrt{\frac{\gamma}{M}} \qquad \text{A3}$$

Where: M = The molecular weight of the gas.

Therefore, substituting into equation A1 and simplifying:

$$\rho = \rho_i\left[1-\frac{M}{\gamma}\left(6.95x10^{-4}\right)\right]$$

where the term $1-\frac{M}{\gamma}\left(6.95x10^{-4}\right)$ can be referred to as the velocity of sound factor, V_F, i.e.

$$\rho = \rho_i V_F \qquad \text{A4}$$

It follows that the *VOS* factor is substantially related to the molecular weight or base density, the main additional influence being due to unrelated differences in the specific heat ratios. From equation A1, the *VOS* factors (V_F) for the calibration gases and sample gases can be calculated and tabulated, see the example illustrated in Table A2.

COMPRESSIBILITY FACTOR

The normal or base density (ρ_S) is given by the equation:

$$\rho_s = \rho \text{ x } \frac{P_s}{P} \text{ x } \frac{t}{t_s} \text{ x } \frac{Z}{Z_s} \qquad \text{A5}$$

Where:

P_s, t_s & Z_s = Values of pressure, temperature and compressibility at standard conditions.

ρ, P, t & Z = Values of density, pressure, temperature and compressibility at measurement conditions.

The basic operation of the instrument allows the pressure/temperature ratio to be considered constant, hence equation A5 reduces to:

$$\rho_s = \rho K \frac{Z}{Z_s}$$

$$\rho_s = \rho K Z_F \qquad \text{A6}$$

Where: K = The calibration constant.

Z_F = The compressibility factor.

The Z factor for gases or gas mixtures may be obtained from reference sources or may be derived from:

For **Nitrogen** at 20°C:

$$Z = 1.0 - P(2.38x10^{-4}) \qquad \text{A7}$$

Where: P = The gas pressure in bar absolute.

For a **methane**-based gas mixture at 20°C:

$$Z = 1.0 + P\left[1.7x10^{-4} + 6x10^{-5}(M) - 1.13x10^{-5}(M^2) + 7.2x10^{-3}(I)\right] \qquad \text{A8}$$

Where: P = The gas pressure in bar absolute.

M = The mean molecular weight of gas.

I = Volume/mole fraction of inerts, e.g. N_2 and CO_2.

The Z factors of the calibration gases and the sample gases should be calculated at both base and operating conditions in order to establish the compressibility factor V_F and then tabulated as shown by the example in Table A2.

COMBINATION OF V_F AND Z_F

By combining equations A4 and A6, gives:

$$\rho_s = K \rho_i V_F Z_F \qquad \text{A9}$$

The combination of V_F and Z_F should also be tabulated as shown in Table A2. The combined factor E_F can then be used to determine the anticipated measurement errors on sample gases when using the two selected calibration gases. Furthermore, the tabulated results can be plotted to show the error trends and uncover the most suitable calibration gas selection and/or calibration offset to give minimum measurement error on the sample gases, see fig. A1.

Table A1 is provided to identify the variables used in equations A10 and A11.

TOTAL FACTOR CALCULATIONS

Total factors when using calibration gases as reference:

$$E_{1a} = 1 - \frac{X(1-x)}{A} - \frac{(A-X)\left[Y(1-y) - X(1-x)\right]}{A(Y-X)} \qquad \text{A10}$$

E_{1b} = As in equation A10 but substituting B for A

E_{1c} = As in equation A10 but substituting C for A

Total factors when using methane and sample gas *C* as reference:

$$E_{2y} = 1 - \frac{X(1-x)}{Y} - \frac{(Y-X)\left[C(1-c) - X(1-x)\right]}{Y(C-X)} \qquad \text{A11}$$

E_{2a} = As in equation A11 but substituting A for Y.

E_{2b} = As in equation A11 but substituting B for Y.

Note: If sample *B* was used as the calibration gas the equation as in A11 would be used with *B* substituted for *C* and *b* substituted for *c*.

Legend for Table A1

Column		Description of Column Contents
1		Gas type and use i.e. function - calibration or sample.
2	M	Molecular weight of gas.
3	γ	Ratio of specific heats.
4	Z_s	Compressibility factor at base conditions.
5	ρ_s^{true}	Base density of gas.
6	V_F	Velocity of sound factor.
7	Z	Compressibility factor at reference chamber pressure.
8	Z_F	Compressibility correction factor.
9	E_F	Total factor $\left(V_F x Z_F\right)$.
10	$\Delta_F\%$	The value $\left(1-E_F\right)x100\%$.
11	E_1	Calculated total factor using calibration gases as reference.
12	$\Delta_1\%$	The value $\left(E_1 - E_F\right)x100\%$ which is the anticipated error which results from a simple methane/nitrogen calibration. In general these errors are mainly defined by the compressibility factors and in consequence will be reduced in relation to the reference chamber pressure.
13	E_2	Calculated total factor using methane and sample gas as reference.
14	$\Delta_2\%$	The value $\left(E_2 - E_F\right)x100\%$ which is the anticipated error which results from a methane/sample gas C calibration. This is directly equivalent to a methane/nitrogen calibration in which the nitrogen base density Y' is used in place of the true base density, i.e. an offset has been added. Once again the errors can normally be reduced by reducing the reference chamber pressure.
15	$\rho_s^{ind.}$	Values of ρ_s which are anticipated in order to obtain zero error for methane and sample gas C.

SUMMARY

This appendix describes the major systematic errors of the 3098 meters and methods of minimising their effects by correct selection of the reference chamber pressure and calibration procedure to be used. Whether calibration is performed using truly representative calibration gases or whether pure gases such as methane and nitrogen are used will, to some extent, depend upon the availability of each of those gases. If using pure gases for calibration, the method and example clearly show how better accuracy can be achieved on the sample gases by using modified values of base density for the calibration gases. These modified values are as determined from Table A1 Column 15 ($\cdot_{s}^{ind}$) and the resultant errors are as shown in Column 14.

An alternative method of deriving the modified values of base density has been included in the calculations for Table A2. Its results compares favourably with the tabulated result in Column 15 but is not as informative in error identification as Table A2.

Table A1

1	2	3	At base conditions of °C & bars		At sample gas conditions of °C & bars									
Gas Type	Mol. Mass M	γ at sample conds.	4 Z_s	5 ρ_s true	6 V_F	7 Z	8 Z_F	9 E_F	10 Δ_F%	11 E_1	12 Δ_1%	13 E_2	14 Δ_2%	15 ρ_s ind.
Cal				**X**				**x**		**x**		**x**		**X**
Cal				**Y**				**y**		**y**		**E_{2y}**		**Y'**
Sample				**A**				**a**		**E_{1a}**		**E_{2a}**		**A'**
Sample				**B**				**b**		**E_{1b}**		**E_{2b}**		**B'**
Sample				**C**				**c**		**E_{1c}**		**c**		**C'**

Column 2: Data is derived from page x.x or other suitable tables.

Column 3: Data is interpolated from Gas Tables (e.g. IUPAC) at SAMPLE GAS conditions.

Column 4: Data is interpolated from Gas Tables (e.g. IUPAC) at BASE GAS conditions.

Column 5: Calculated using $\rho_s = \frac{P_s M}{0.0831434 x T_s x Z_s}$

Column 6: Calculated using $V_F = 1 - \frac{M}{\gamma} x 0.000695$

Column 7: Calculated using Z=1-0.000238P for Nitrogen.
Z=1+P(0.00017+6E-05xM-1.13E-05xM^2+7.2E-03xI) for CH_4
P is pressure in bars absolute,
I is volume/mole fraction of inert gases

Column 8: Calculated using Z_F= Col 7 / Col 4

Column 9: Calculated using E_F= Col 6 x Col 8

Column 10: Calculated using Δ_F%= (1-Col 9)x100%

Column 11: E_1= x or y or calculated for E_{1a},E_{1b} or E_{1c} (see Eqn. A10)

Column 12: Calculated using Δ_1%= (Col 11-Col 9)x100%

Column 13: E_1= x or c or calculated for E_{2y}, E_{2a} or E_{2b} (see Eqn. A11)

Column 14: Calculated using Δ_2%= (Col 13-Col 9)x100%

Column 15: Calculated using $\rho_s^{ind} = \frac{100 + \text{Col } 14}{100} x\text{Col } 5$

Eqn. A10

$$E_{1a} = 1 - \frac{X(1-x)}{A} - \frac{(A-X)[Y(1-y) - X(1-x)]}{A(Y-X)}$$

$$E_{1b} = 1 - \frac{X(1-x)}{B} - \frac{(B-X)[Y(1-y) - X(1-x)]}{B(Y-X)}$$

$$E_{1c} = 1 - \frac{X(1-x)}{C} - \frac{(C-X)[Y(1-y) - X(1-x)]}{C(Y-X)}$$

Eqn. A11

$$E_{2y} = 1 - \frac{X(1-x)}{Y} - \frac{(Y-X)[C(1-c) - X(1-x)]}{Y(C-X)}$$

$$E_{2a} = 1 - \frac{X(1-x)}{A} - \frac{(A-X)[C(1-c) - X(1-x)]}{A(C-X)}$$

$$E_{2b} = 1 - \frac{X(1-x)}{B} - \frac{(B-X)[C(1-c) - X(1-x)]}{B(C-X)}$$

Note: Use Eqn. A10 with methane/Nitrogen reference gases, Eqn. A11 for methane/sample gas C as references.

Table A2

1 Gas Type	2 Mol. Mass M	3 γ at sample conds.	At base conditions of °C & bars 4 Z_s	5 ρ_s true	At sample gas conditions of °C & bars 6 V_F	7 Z	8 Z_F	9 E_F	10 Δ_F%	11 E_1	12 Δ_1%	13 E_2	14 Δ_2%	15 ρ_s ind.
Cal methane	16.04	1.32	0.9977	**X** 0.7171	0.9916	0.9876	0.9899	**x** 0.9816	1.84	**x** 0.9816	0	**x** 0.9816	0	**X** 0.7171
Cal Nitrogen	28.01	1.41	0.9995	**Y** 1.2500	0.9862	0.9983	0.9988	**y** 0.9850	1.50	**y** 0.9850	0	E_{2y} 0.9712	-1.38	**Y'** 1.2328
Sample A	16.96	1.32	0.9976	**A** 0.7583	0.9911	0.9871	0.9895	**a** 0.9807	1.93	E_{1a} 0.9820	0.13	E_{2a} 0.9803	-0.04	**A'** 0.7580
Sample B	17.32	1.32	0.9977	**B** 0.7743	0.9909	0.9873	0.9896	**b** 0.9806	1.94	E_{1b} 0.9822	0.16	E_{2b} 0.9798	-0.08	**B'** 0.7737
Sample C	19.28	1.30	0.9972	**C** 0.8624	0.9897	0.9849	0.9877	**c** 0.9775	2.25	E_{1c} 0.9829	0.54	**c** 0.9775	0	**C'** 0.8624

Column 2: Data is derived from page x.x or other suitable tables.

Column 3: Data is interpolated from Gas Tables (e.g. IUPAC) at SAMPLE GAS conditions.

Column 4: Data is interpolated from Gas Tables (e.g. IUPAC) at BASE GAS conditions.

Column 5: Calculated using $\rho_s = \frac{P_s M}{0.0831434 x T_s x Z_s}$

Column 6: Calculated using $V_F = 1 - \frac{M}{\gamma} x 0.000695$

Column 7: Calculated using Z=1-0.000238P for Nitrogen.
Z=1+P(0.00017+6E-05xM-1.13E-05xM²+7.2E-03xI) for CH_4
P is pressure in bars absolute,
I is volume/mole fraction of inert gases

Column 8: Calculated using Z_F= Col 7 / Col 4

Column 9: Calculated using E_F= Col 6 x Col 8

Column 10: Calculated using Δ_F%= (1-Col 9)x100%

Column 11: E_1= x or y or calculated for E_{1a},E_{1b} or E_{1c} (see Eqn. A10)

Column 12: Calculated using Δ_1%= (Col 11-Col 9)x100%

Column 13: E_1= x or c or calculated for E_{2y},E_{2a} or E_{2b} (see Eqn. A11)

Column 14: Calculated using Δ_2%= (Col 13-Col 9)x100%

Column 15: Calculated using $\rho_s^{ind} = \frac{100 + \text{Col } 14}{100} x\text{Col } 5$

Eqn. A10

$$E_{1a} = 1 - \frac{X(1-x)}{A} - \frac{(A-X)[Y(1-y) - X(1-x)]}{A(Y-X)}$$

$$E_{1b} = 1 - \frac{X(1-x)}{B} - \frac{(B-X)[Y(1-y) - X(1-x)]}{B(Y-X)}$$

$$E_{1c} = 1 - \frac{X(1-x)}{C} - \frac{(C-X)[Y(1-y) - X(1-x)]}{C(Y-X)}$$

Eqn. A11

$$E_{2y} = 1 - \frac{X(1-x)}{Y} - \frac{(Y-X)[C(1-c) - X(1-x)]}{Y(C-X)}$$

$$E_{2a} = 1 - \frac{X(1-x)}{A} - \frac{(A-X)[C(1-c) - X(1-x)]}{A(C-X)}$$

$$E_{2b} = 1 - \frac{X(1-x)}{B} - \frac{(B-X)[C(1-c) - X(1-x)]}{B(C-X)}$$

Note: Use Eqn. A10 with methane/Nitrogen reference gases, Eqn. A11 for methane/sample gas C as references

Example Calculations:

Column 5:

Methane $= \dfrac{1x16.04}{0.0831434x273.155x0.9977} = 0.7171$

Nitrogen $= \dfrac{1x28.01}{0.0831434x273.155x0.9995} = 1.250$

Sample A $= \dfrac{1x16.96}{0.0831434x273.155x0.9976} = 0.7583$

Sample B $= \dfrac{1x17.32}{0.0831434x273.155x0.9977} = 0.7743$

Sample C $= \dfrac{1x19.28}{0.0831434x273.155x0.9972} = 0.8624$

Column 6:

Methane $= 1 - \dfrac{16.04}{1.32} x0.000695 = 0.9916$

Nitrogen $= 1 - \dfrac{28.01}{1.41} x0.000695 = 0.9862$

Sample A $= 1 - \dfrac{16.96}{1.32} x0.000695 = 0.9911$

Sample B $= 1 - \dfrac{17.32}{1.32} x0.000695 = 0.9909$

Sample C $= 1 - \dfrac{19.28}{1.30} x0.000695 = 0.9897$

Column 7:

Methane = 1+7(0.00017+6E-5x16.04-1.13E-5x16.04^2+0)
= **0.9876**
Nitrogen = 1 - 0.000238 x 7 = **0.9983**
Sample A = 1+7(0.00017+6E-5x16.96-1.13E-5x16.96^2+0.0072x0.03)
= **0.9871** (I=0.03)
Sample B = 1+7(0.00017+6E-5x17.32-1.13E-5x17.32^2+0.0072x0.05)
= **0.9873** (I=0.05)
Sample C = 1+7(0.00017+6E-5x19.28-1.13E-5x19.28^2+0.0072x0.1)
= **0.9849** (I=0.1)

Column 8:

Methane $= \dfrac{0.9876}{0.9977} = 0.9899$ Nitrogen $= \dfrac{0.9983}{0.9995} = 0.9988$

Sample A $= \dfrac{0.9871}{0.9976} = 0.9895$ Sample B $= \dfrac{0.9873}{0.9977} = 0.9896$

Sample C $= \dfrac{0.9849}{0.9972} = 0.9877$

Column 9:

Methane = 0.9816 Nitrogen = 0.9850 Sample A = 0.9807 Sample B = 0.9806
Sample C = 0.9775

Column 10:

Methane = 1.84 Nitrogen = 1.50 Sample A = 1.93
Sample B = 1.94 Sample C = 2.25

Column 11:

Methane = 0.9816 Nitrogen = 0.9850

Sample A =
$$1 - \frac{0.7171(1-0.9816)}{0.7583} - \frac{(0.7583-0.7171)[1.25(1-0.985)-0.7171(1-0.9816)]}{0.7583(1.25-0.7171)}$$
= 0.982

Sample B =
$$1 - \frac{0.7171(1-0.9816)}{0.7743} - \frac{(0.7743-0.7171)[1.25(1-0.985)-0.7171(1-0.9816)]}{0.7743(1.25-0.7171)}$$
= 0.9822

Sample C =
$$1 - \frac{0.7171(1-0.9816)}{0.8624} - \frac{(0.8624-0.7171)[1.25(1-0.985)-0.7171(1-0.9816)]}{0.8624(1.25-0.7171)}$$
= 0.9829

Column 12:

Methane = 0 Nitrogen = 0 Sample A = 0.13
Sample B= 0.16 Sample C = 0.54

Column 13:

Methane = 0.9816 Sample C = 0.9775

Nitrogen =
$$1 - \frac{0.7171(1-0.9816}{1.25} - \frac{(1.25-0.7171)[0.8624(1-0.9775)-0.7171(1-0.9816)]}{1.25(0.8624-0.7171)}$$
= 0.9712

Sample A=
$$1 - \frac{0.7171(1-0.9816}{0.7583} - \frac{(0.7583-0.7171)[0.8624(1-0.9775)-0.7171(1-0.9816)]}{0.7583(0.8624-0.7171)}$$
= 0.9803

Sample B =
$$1 - \frac{0.7171(1-0.9816}{0.7743} - \frac{(0.7743-0.7171)[0.8624(1-0.9775)-0.7171(1-0.9816)]}{0.7743(0.8624-0.7171)}$$
= 0.9798

Column 14:

Methane = 0 Nitrogen = -1.38 Sample A = -0.04
Sample B = -0.08 Sample C = 0

Column 15:

Methane = 0.7171 Nitrogen = 1.2328
Sample A = 0.7580 Sample B = 0.7737
Sample C = 0.8624

An alternative method for deriving modified values of Y to produce nil error is given over the page.

Alternative simplified method of deriving modified values of Y (the nitrogen SG value used for calibration) to produce a nil error condition for a Methane/Gas C (or Gas B or Gas A) calibration.

$$Y' = X + \frac{\left(\frac{Y}{y} - \frac{X}{x}\right)}{\left(\frac{C}{c} - \frac{X}{x}\right)} \, x \, (C - X)$$

For gases A or B, substitute for C and c in this equation

where : X,Y,C = true base densities of the gases
x,y,c = total factors E_F

For the example:

$$Y' = 0.7171 + \frac{\left(\frac{1.25}{0.985} - \frac{0.7171}{0.9816}\right)}{\left(\frac{0.8624}{0.9775} - \frac{0.7171}{0.9816}\right)} \, x \, (0.8624 - 0.7171) = 1.2328$$

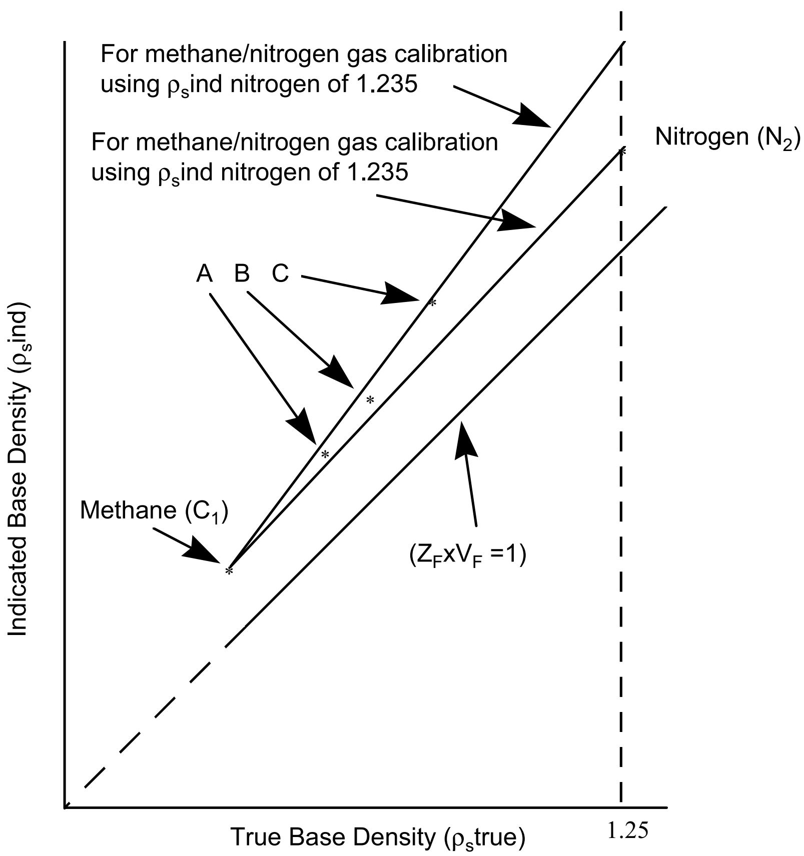


Fig. A1 Illustration of Example Condition

Appendix B
Principles of Operation

B1.1 Theory - Specific Gravity Measurement

By definition:

$$\text{Gas Specific Gravity} = \frac{\text{Molecular Weight of Gas}}{\text{Molecular Weight of Standard Air}}$$

i.e. $$G = \frac{M_G}{M_A} \qquad (1)$$

where M_A is taken as 28.96469

$$\text{Relative Density} = \frac{\text{Density of Gas}}{\text{Density of Air}}$$

i.e. $$\rho_r = \frac{\rho_G}{\rho_A} \qquad (2)$$

at the same conditions of temperature and pressure.

The relative density is numerically equal to specific gravity when the supercompressibility factors of both the gas and the standard air at the measurement conditions are taken into consideration. Therefore:-

$$G = \frac{\rho_G Z_G}{\rho_A Z_A} \qquad (3)$$

Now let the density of the gas sample measured be ρ_1, again by definition :-

$$\rho_1 = \frac{P_1 M_1}{Z_1 R T_1} \qquad (4)$$

By comparing the density of the sample gas with the density ρ_2 of a fixed quantity of a reference gas contained in a fixed volume,

where $$\rho_2 = \frac{P_2 M_2}{Z_2 R T_2} \qquad (5)$$

since conditions of constant volume and quantity exist for the reference gas, its density and molecular weight are constant and from equation 5.

$$\frac{\rho_2}{M_2} = \frac{P_2}{Z_2 R T_2} = K \qquad (6)$$

If now the two gases can be maintained at the same temperature, from equations 4 and 6:

$$\rho_1 = \frac{\mathrm{P}_2 M_1}{Z_1 R T_2} = K M_1 \frac{Z_2}{Z_1} \qquad (7)$$

Finally, by using the sample gas (or a gas having a similar supercompressibility factor) as the reference gas:-

$$\rho_1 = K M_1 \qquad (8)$$

Since $Z_1 = Z_2$

Thus the density of the sample gas, under the stated conditions, is directly related to its molecular weight and therefore directly related to its specific gravity by equation 1.

Appendix C
Returns Forms

The **Returns Forms**, contained in this Appendix, must be copied and completed whenever a meter is to be returned to the factory for servicing, calibration or repair. **This must be done before the product is shipped.**

There are Returns Forms for *New/Unused equipment*, and for *Used equipment*. Please select accordingly**.**

Micro Motion Return Policy

For Use in the U.S.A.
With New and Unused Micro Motion Equipment

Definitions

New and unused equipment

Only equipment that has not been removed from the original shipping package will be considered *new and unused*. New and unused equipment includes sensors, transmitters, or peripheral devices which:

- Were shipped as requested by the customer but are not needed, or
- Were shipped incorrectly by Micro Motion.

Used equipment

All other equipment is considered *used*. This equipment must be completely decontaminated and cleaned before being returned. Document all foreign substances that have come in contact with the equipment.

Before you begin

This document is for returning new and unused equipment to Micro Motion in the United States.

- For instructions on returning used equipment, our *used equipment return policy* is available as a separate document.
- For instructions on returning equipment to Emerson offices around the world, our *international return policies* are available as separate documents.

To obtain any of our return policies, procedures, and forms, contact the Micro Motion Customer Service Department during business hours:

- In the U.S.A., phone **1-800-522-6277** or **1-303-527-5200** between 6:00 a.m. and 5:30 p.m. (Mountain Standard Time), Monday through Friday, except holidays.
- In Europe, phone **+31 (0) 318 495 555**, or contact your local sales representative.
- In Asia, phone **(65) 6777-8211,** or contact your local sales representative.

The latest return policies, procedures, and forms are also available from the Micro Motion web site: **www.micromotion.com**.

Restock fees

Restock fees might apply, depending on the reason for return:

- If you ordered the wrong equipment, a restock fee will be charged.
- If you no longer require the equipment (for example, if your project has been cancelled), a restock fee will be charged.
- If we shipped the wrong equipment, a restock fee will not be charged.

Micro Motion®

EMERSON™
Process Management

GI-00381 (5/07)

Step 1 Obtaining an RMA number

A Return Material Authorization (RMA) number must be obtained prior to returning any equipment to Micro Motion for any reason.

To obtain an RMA number, contact the Micro Motion Customer Service Department at **1-800-522-6277** or **1-303-527-5200** between 6:00 a.m. and 5:30 p.m. (Mountain Standard Time), Monday through Friday, except holidays.

- No product returns will be accepted without an RMA number.
- Each returned sensor must be issued a separate RMA number. A sensor and its associated transmitter may be shipped in the same package with a single RMA number.
- If no sensor is being returned, all transmitters and peripheral devices being returned may be shipped together, in one package, with a single RMA number.

Step 2 Preparing equipment for return

Only equipment that has not been removed from the original shipping package will be considered new and unused. New and unused equipment must be returned in its original packaging.

Before returning new and unused equipment:

a. Clearly mark the RMA number on the outside of the original shipping package(s).
b. Clearly mark on the outside of each package: "NEW AND UNUSED".
c. Complete and sign the "New and Unused Statement" on page 4.
d. Include one copy of the statement inside the original shipping package, and attach one copy to the outside of each package.
e. Close and reseal all packages.

Step 3 Shipping instructions

Required shipping documents

The customer must provide a Packing List and Bill of Lading for each shipment. The Bill of Lading contains information necessary for the carrier to ship the freight, such as consignee of shipment, payment terms, number of pieces in shipment, weight, etc. The Bill of Lading should also contain the following address:

Ship-to Party

Micro Motion Inc.
C/O Veolia Environmental Services
9131 East 96 Avenue
Henderson, CO 80640
Attn: RMA #__________

Document submittal

Submit the following shipping documents inside the shipping container:

- One (1) copy of the Packing List.

Submit the following shipping documents to your Micro Motion customer service representative:

- One (1) copy of the Packing List.
- One (1) copy of the Bill of Lading.

Shipping charges

The customer is responsible for all shipping charges.

Veolia has been instructed to refuse any collect shipments.

Statement of New and Unused Equipment

1) Return Material Authorization (RMA) Number: ____________________

Equipment Identification

2) For each instrument being returned, list a description or model number and its serial number.

Description or Model Number	Serial number

3) Reason for return: ______________________________

____

____

____

Shipping Requirements

4) Clearly mark RMA number and "NEW AND UNUSED" on each shipping package.

5) Include one copy of this document inside the original shipping package, and attach one copy to the outside of each package in a visible location.

6) Ship all equipment to:

Attn: RMA# _____________
Micro Motion Inc.
C/O Veolia Environmental Services
Sensor Department
9131 East 96 Avenue
Henderson CO 80640 USA

Address correspondence to:

Micro Motion, Inc.
7070 Winchester Circle
Boulder CO 80301 USA
Attn: Repairs

Definition and Restock Fees

Only equipment that has not been removed from the original shipping package will be considered new and unused. New and unused equipment includes sensors, transmitters, or peripheral devices which:

- Were shipped as requested by the customer but are not needed, or
- Were shipped incorrectly by Micro Motion.

Restock fees might apply, depending on the reason for return:

- If the customer ordered the wrong equipment, a restock fee will be charged.
- If the customer no longer requires the equipment (for example, if a project was cancelled), a restock fee will be charged.
- If Micro Motion shipped the wrong equipment, a restock fee will not be charged.

THIS EQUIPMENT IS BEING RETURNED AS "NEW AND UNUSED," PER THE DEFINITION STATED ABOVE. I UNDERSTAND A RESTOCK FEE MIGHT BE CHARGED.

By:

______________________________ ______________________________

(Signature) (Print name)

Title: ______________________________ Date: ______________________________

Company: ______________________________

Phone: ______________________________ Fax: ______________________________

Micro Motion Return Policy

For Use in the U.S.A.
With Used Micro Motion Equipment

Definitions

New and unused equipment

Only equipment that has not been removed from the original shipping package will be considered *new and unused*. New and unused equipment includes sensors, transmitters, or peripheral devices which:

- Were shipped as requested by the customer but are not needed, or
- Were shipped incorrectly by Micro Motion.

Used equipment

All other equipment is considered *used*. This equipment must be completely decontaminated and cleaned before being returned. Document all foreign substances that have come in contact with the equipment.

Before you begin

This document is for returning used equipment to Micro Motion in the United States.

- For instructions on returning new and unused equipment, our *new and unused equipment return policy* is available as a separate document.
- For instructions on returning equipment to Emerson offices around the world, our *international return policies* are available as separate documents.

To obtain any of our return policies, procedures, and forms, contact the Micro Motion Customer Service Department during business hours:

- In the U.S.A., phone **1-800-522-6277** or **1-303-527-5200** between 6:00 a.m. and 5:30 p.m. (Mountain Standard Time), Monday through Friday, except holidays.
- In Europe, phone **+31 (0) 318 495 555**, or contact your local sales representative.
- In Asia, phone **(65) 6777-8211,** or contact your local sales representative.

The latest return policies, procedures, and forms are also available from the Micro Motion web site: **www.micromotion.com**.

These procedures must be followed for you to meet governmental requirements. They also help us provide a safe working environment for our employees. Failure to follow these requirements will result in your equipment being refused delivery.

Micro Motion®

EMERSON™
Process Management

GI-00381 (5/07)

Step 1 Obtaining an RMA number

A Return Material Authorization (RMA) number must be obtained prior to returning any equipment to Micro Motion for any reason.

To obtain an RMA number, contact the Micro Motion Customer Service Department at **1-800-522-6277** or **1-303-527-5200** between 6:00 a.m. and 5:30 p.m. (Mountain Standard Time), Monday through Friday, except holidays.

- No product returns will be accepted without an RMA number.
- Each returned sensor must be issued a separate RMA number. A sensor and its associated transmitter may be shipped in the same package with a single RMA number.
- If no sensor is being returned, all transmitters and peripheral devices being returned may be shipped together, in one package, with a single RMA number.

Step 2 Cleaning and decontamination

All equipment being returned must be thoroughly cleaned and decontaminated of all foreign substances, including all substances used for cleaning the equipment, prior to shipment. This requirement applies to the sensor tubes, sensor case exterior, sensor case interior, electronics, and any part that might have been exposed to process fluids or cleaning substances.

Shipping equipment that has not been decontaminated may cause a violation of U.S. Department of Transportation (DOT) regulations. For your reference, the requirements for packaging and labeling hazardous substances are listed in DOT regulations 49 CFR 172,178, and 179.

If you suspect that the sensor case interior may be contaminated, the case must be completely drained and flushed to remove contaminants.

Contents of sensor case may be under pressure. Contents of sensor case may be hazardous. Take appropriate measures to avoid the hazards associated with gaining access to a contaminated case interior. Avoid exposure to hazardous materials.

Decontamination/Cleaning Statement

A blank Decontamination/Cleaning Statement is provided on the final page of this document. You may copy and use this form to return any Micro Motion sensor.

- A Decontamination/Cleaning Statement is required for each sensor being returned.
- Each form must be fully completed and include a signature. If the statement is not completed, the customer may be charged for decontamination and cleaning.

If the equipment has been exposed to a known hazardous substance with any characteristic that can be identified in the Code of Federal Regulations, 40 CFR 261.20 through 261.24, the chemical abstracts number and hazardous waste number/hazard code must be stated in the space provided on the form.

Two (2) copies of each Decontamination/Cleaning Statement must be provided:

- One (1) copy must be attached to the outside of the package.
- One (1) copy must be provided inside the package.

Step 3 **Material Safety Data Sheets (MSDS)**

Included with the returned equipment, you must provide a Material Safety Data Sheet (MSDS) for each substance that has come in contact with the equipment being returned, including substances used for decontamination and cleaning.

An MSDS is required by law to be available to people exposed to specific hazardous substances, with one exception: if the equipment has been exposed only to food-grade substances or potable water, or other substances for which an MSDS is not applicable, the Decontamination/Cleaning Statement form alone is acceptable.

Two (2) copies of each MSDS must be provided:

- One (1) copy must be attached to the outside of the package.
- One (1) copy must be provided inside the package.

Step 4 **Packaging**

Shipping a sensor and transmitter or sensor only

To meet DOT requirements for identifying hazardous substances, ship only one sensor per package. A sensor and its associated transmitter may be shipped in the same package.

Shipping a transmitter or peripheral device without a sensor

If no sensor is being returned, all transmitters and peripheral devices being returned may be shipped together, in one package.

Equipment installed on a portable cart, in a protective cabinet or with special wiring and process connections

Micro Motion is equipped to repair sensors, transmitters and peripheral devices manufactured by Micro Motion only. Our repair department cannot work on equipment installed in a customer-supplied cabinet, on a portable cart as part of a system, or with any wiring or piping attached. Any returned equipment other than Micro Motion sensors, transmitters and peripheral devices will be considered the responsibility of the customer.

Step 5 **Shipping**

Required shipping documents

The customer must provide a Packing List and Bill of Lading for each shipment. The Bill of Lading contains information necessary for the carrier to ship the freight, such as consignee of shipment, payment terms, number of pieces in shipment, weight, etc. The Bill of Lading should also contain the following address:

Ship-to Party

Micro Motion Inc.
C/O Veolia Environmental Services
9131 East 96 Avenue
Henderson, CO 80640
Attn: RMA #__________

Document submittal

Submit the following shipping documents inside the shipping container:

- One (1) copy of the Packing List.

Submit the following shipping documents to your Micro Motion customer service representative:

- One (1) copy of the Packing List.
- One (1) copy of the Bill of Lading.

The address is listed as follows:

Micro Motion, Inc.
Attn: (Your customer service representative)
7070 Winchester Circle
Boulder, CO 80301 USA
RMA# __________________

Shipping charges

The customer is responsible for all shipping charges.

Veolia has been instructed to refuse any collect shipments.

Sensor Decontamination/Cleaning Statement

Refer to *Micro Motion Return Policy for Use in the U.S.A. with Used Micro Motion Equipment*

1) Return Material Authorization (RMA) Number: ____________________
2) Equipment to be returned Model Number: ____________________ Serial Number: ____________________
3) Reason for return ____________________

Process and Decontamination/Cleaning Fluids

4) List each substance to which the equipment was exposed. Attach additional documents if necessary.

Common name	CAS# if available	Used for hazardous waste (20 CFR 261)	EPA waste code if used for hazardous waste
		[ ] Yes [ ] No	
		[ ] Yes [ ] No	
		[ ] Yes [ ] No	
		[ ] Yes [ ] No	
		[ ] Yes [ ] No	
		[ ] Yes [ ] No	

5) Please circle any hazards and/or process fluid types that apply:

Infectious	*Radioactive*	*Explosive*	*Pyrophoric*	*Poison Gas*	
Cyanides	*Sulfides*	*Corrosive*	*Oxidizer*	*Flammable*	*Poison*
Carcinogen	*Peroxide*	*Reactive – Air*	*Reactive – Water*	*Reactive-Other (list)*	
Other hazard category (list)					

6) Describe decontamination/cleaning process. Include MSDS description for substances used in decontamination and cleaning processes. Attach additional documents if necessary.

Shipping Requirements

Failure to comply with this procedure will result in the shipment being refused

7) Ship only one sensor per box. RMA number must be noted on the shipping package.
8) Include inside the package: one copy of this document and all required Material Safety Data Sheets (MSDS).
9) Attach to the outside of the package: one copy of this document, and all required Material Safety Data Sheets (MSDS).
10) Ship equipment to:

Micro Motion Inc. Attn: RMA# _____________
C/O Veolia Environmental Services
Sensor Department
9131 East 96 Avenue
Henderson CO 80640 USA

Address correspondence to:

Micro Motion Inc.
7070 Winchester Circle
Boulder CO 80301 USA
Attn: Repairs

EQUIPMENT HAS BEEN CLEANED AND DECONTAMINATED OF ANY HAZARDOUS SUBSTANCES AND MEETS DOT AND EPA REGULATIONS.

By: ____________________ ____________________
(Signature) (Print name)

Title: ____________________ Date ____________________

Company: ____________________

Phone: ____________________ Fax ____________________

Micro Motion® 3098

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