DENSITY METERING INSTALLATION METHODS

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SUMMARY

The paper concentrates on density meters which utilize the well established technique of a vibrating element to continuously determine the density of a fluid. A review of 2 primary types of element and 3 methods of installation are used to highlight the benefits of each type and method together with some of the problem areas. The intention of the paper is to help alleviate problems in new metering systems and provide guidelines on trouble shooting existing measurement difficulties.

1.1 THE VIBRATING ELEMENT

This technique is widely accepted as being the most accurate method of continuous density measurement for fiscal duties.

There are two common types of element which are used. The first is a short thin-walled magnetic stainless alloy cylinder often called a spool (or tines). **FIGURE 1** shows a spool mounted in the density meter body which is shown cut away for clarity. The spool is secured so that one end is fixed and the other free and is totally surrounded by the process liquid. The wall thickness varies depending on the required measurement range between 50 microns and 250 microns.

An impulse is supplied by the drive coil from the amplifier which is mounted by a stem on to the density meter body. This causes the spool to vibrate and this movement is detected by the pick up coil and the resulting signal is amplified and supplied back to the drive coil. The spool is therefore maintained in oscillation by this feedback circuit.

The spool vibrates in a hoop mode and this is shown in this section through the spool. Obviously this is very much magnified for clarity and the actual movement is very small indeed. This vibration is of the same type that you get if you rub your finger around the rim of a wine glass.If the wine glass is full it will give a different note from that it gives when empty. This differing frequency of vibration also occurs in the density meter and the spool vibrational frequency varies with the density of the fluid surrounding it.

As can be seen from **FIGURE 2**, the advantage of this approach is the fluid is present on both sides of the vibrating element (which is called the spool). This means that there is no differential pressure across the thin wall of the spool and therefore the spool is not stressed by increasing pressure. The body of the instrument is merely a pressure vessel in which the spool is mounted and this makes the instrument suitable for operation at high pressures. As mentioned previously, the mode of vibration of a spool is circumferential hoop mode. This is shown diagrammatically on the left hand side of **FIGURE 3**. The vibration is always mechanically balanced so that there is no reaction on the point where the spool is attached to the body assembly.

If we look at a different mode of vibration as illustrated on the right of **FIGURE 3**, we can see the second type of vibrating element. Here we have a longer tube that is clamped rigidly at each end. The tube is caused to vibrate in a transverse mode, i.e. the centre of the tube is deflected from side to side. This causes minimal shearing of the fluid and an instrument based on this principle is thus unaffected by the viscosity of the fluid passing through the tube. All the fluid in the tube is forced to take part in the vibration and the measurement is then one of the bulk or average density of the instantaneous sample. This means that non-homogeneous fluids such as slurries can be measured with this technique. By sealing the outside of the tube from the process we can magnetically drive the tube without worrying about the corrosion resistance of the magnetic materials as they need not be in contact with the process fluid. Thus we can use a 316 stainless steel tube with magnetic armatures fixed to the outside of the vibrating tube to give us a magnetically driven density meter with the corrosion resistance of 316 stainless steel. One disadvantage of using this method is that the vibration is no longer dynamically balanced; there is a net reaction on the clamps at each end as the tube is deflected from its rest position.

To look at the practical implications of a density meter using a tube in transverse vibration, as we have just discussed, we must firstly provide a massive clamp at each end of the vibrating tube section to define these points as nodus points of vibration. This limits the energy transfer from the vibrating tube to the holding structure by ensuring there is no movement at the coupling points. This is shown diagrammatically in the top illustration of **FIGURE 4**, where we have a stiff frame welded on to the tube.

One disadvantage with this meter is with the central tube held rigidly when the temperature of the fluid passing through the vibrating tube varies a stress will be generated in the vibrating tube as the clamping structure remains at ambient temperature.

A method of compensating for this effect is to make the frame a part of the fluid path through the instrument. This is shown here where the fluid flows through the instrument in one continuous path. The top and bottom tubes are made with a thicker wall than the central vibrating element, Forming a stiff structure together with the manifolds. As the fluid now passes through the structure as well as the vibrating tube, the whole measuring section reaches fluid temperature. The thermal induced stress on the central tube is then much reduced because the connecting structure can expand and contract with temperature.

1.2 A NEW DESIGN

The design brief for the new transducer was to make a HIGH ACCURACY WITH LONG TERM STABILITY meter. We explored the performance of a whole range of possible ways of making a Ni Span C vibrating tube device, of both theoretically using a mathematical model and building a series of models to measure performance.

We found that the best overall performance was provided by a twin tube device.

The reason for this is in the basic transducer theory. An accurate sensor design only reacts to the required measurement and all other effects (stiffness of tube and mounts, mass of tube) should ideally be constants.

As previously mentioned the tube must be fixed at its ends to define its vibrating length, preferably to an infinitely big mass. In a 3 tube design, this is achieved by 2 thicker outer tubes bracing the ends together. Single tube designs without this bracing can lack the precise definition of vibrating element length and loose out on accuracy and especially long term stability.

Ruling out infinitely large end masses as less than practical, we found by using 2 close spaced tubes and modest end mass the end nodes could be well defined. In using 2 tubes vibrating anti-phase we have perfect dynamic balance with all the shear forces and bending moments nulling out in the end masses.

The twin tube design is not new, it was probably one of the first and best vibrating tube designs. However, we so believe that this implementation is markedly superior to any other liquid density meter.

Before we look at the selection of vibrating element for a type of fluid, we should consider the installation methods. The selection of transducer and element type is often influenced by installation options and the overall design.

1.3 INSTALLATION METHODS

The 3 basic installation options of density measurement currently used worldwide today are:- **'IN-LINE'** **'OFF-LINE'** and **'ON-LINE'** as shown in **FIGURE 5**. The 3 titles are taken from the IP Petroleum Measurement Manual Part VII Density section 2 Continuous Density Measurement and broadly defined as follows:-

Density Meter, **IN-LINE** -	A density meter in which the transducer is located directly within the main line or vessel and measures continuously. No sampling system is required.
Density Meter, **OFF-LINE** -	A density meter separate from the main line or vessel. This requires a discrete sample to be drawn from the line/vessel for analysis.
Density Meter, **ON-LINE** -	A density meter operating on a sample of the fluid withdrawn continuously from a main line or vessel via a sampling system.

Having defined the methods we can now consider the key aspects and examples of each method. All three methods are used on gas applications, generally only **IN-LINE** and **OFF-LINE** are used for liquid applications.

1.4 GAS APPLICATIONS

IN-LINE GAS measurement should always be used when the highest accuracy of measurement is the prime factor. The Direct Insertion Density Meter is still probably the most accurate gas density measurement installation available today as it measures true In-Line density with a high degree of immunity to gas borne dirt and moisture and no potential of pressure or temperature gradients; factors which are often overlooked when the user is making an assessment of an installation's desired accuracy. Good examples of this are to be found in the rapidly expanding number of installations in chemical plants for the density measurement of ethylene, propylene, propane and butane. Here the temperature and pressure coefficients are so large that any alternative method of installation will potentially produce errors in the order of 3 times the Density Meter accuracy. This is due to variations in the pressure and temperature gradient relative to flow rate between the main line and the point of density measurement.

OFF LINE GAS measurement is normally used for 2 prime reasons:

1 To allow the product to be conditioned to ensure the removal of excessive dirt or moisture or elevate the temperature of the density meter and product above the product's dew point. A typical example is a By-pass Density Meter installed in a custom built gas filtering system to measure the density of aggressive dirty and variable composition flare gas; an application where a great deal of expertise and experience in both on-shore and off-shore installation, is needed to ensure reliable measurement.

2 To measure density at a defined pressure and or temperature irrespective of the main line conditions for determination of product quality composition or calorific value. A typical example is a By-Pass Density Meter, used within a relative density (SG) system. The line pressure is reduced to just above atmospheric conditions and absolute pressure of the system is measured using a 0.1% accuracy integral transmitter this combined with a high sensitivity PT100 temperature element determines the relative density (SG) of the gas at near reference conditions. At these conditions compressibility effects can be considered to be negligible <u>for all gases</u>. This method is thus ideal on fuel gas applications where line pressure, temperature, density and most important of all product composition vary therefore, making it almost impossible to accurately correct the compressibility of the gas due to un-identifiable and continual change in product composition.

ON-LINE GAS measurement is a useful combination from both In-Line and Off-Line methods, whilst the insertion Density Meter will always be the ultimate in overall accuracy terms. The Pocket Density Meter has the same transducer calibration accuracy capability. On applications where the temperature changes of the product in the main line are relatively small and fluctuations do not occur instantaneously, then this accuracy can be reflected in the overall installation performance. An ideal application for this method would be a natural gas pipeline where the change in temperature of the gas is only influenced by ambient temperature.

FIGURE 6 is an overview of the most common configurations of installations used for gas applications.

If we now look at each in turn we can identify some of the aspects which are sometimes overlooked.

"G1" (FIGURE 7) is a typical **OFF-LINE** fuel gas. We have started with one of the most difficult system applications. This is used where the gas composition can be anything from Hydrogen to C6 plus heavy ends. In the **"REAL WORLD"** it will often be dirty, corrosive (sour) and "wet". Gas applications normally use the short cylinder (spool) type element. Selection of material is important as Ni-Span C is not suited to sour gas with H_2S present.

To a first order, this type of element does not work on "wet gas". However, "wet gas" should be better defined as gas with liquid droplets. A vibrating cylinder element on gas service will not work if liquid droplets are present on the element. This is recognisable in the field as a very erratic output caused by the liquid droplet rolling up and down the element.

Two methods have been used to reduce this problem. A combination of cyclone and coalescing filters together with a heat tracing technique, usually in the form of an electrical self regulating system as steam tracing is often not available.

It is very difficult to achieve a totally successful design on this type of application from "best estimate composition data often from a design process engineer for a platform yet to be built. However, many successful systems have been custom designed and used mainly where the measurement engineer has been able to obtain real composition data on an established platform or plant. Heat tracing, where the product is maintained at a temperature above the lowest dew point value is the most successful of the two methods. Some systems built by analyzer Companies, with limited experience on density measurement, appear to work satisfactory due to the removal of the heavy ends as well as the dirt and water. The result is a non-representative clean dry light ends only sample.

Accurate quick response, low thermal mass, temperature thermowells are a critical component for this type of application to correct to reference or line conditions. In many cases, we have to design and build our own, due to the low volume throughput dictated by the conditioning system. Attention to any pressure reduction is also needed as this can create more liquid formation. Short well lagged impulse pipe work increases the potential performance of this measurement as well.

The combined cooperation and experience of the user and the supplier is the key to this application.

"G2" (FIGURE 8) is a typical **IN-LINE** density meter with a retractor mechanism for removal under line conditions. As mentioned previously this is the most accurate method of measurement of gas density. The basic design has been available for many years, however. A number of developments have occurred more recently. In the **"REAL WORLD"** it could be said that there is no such thing as a totally clean fluid on a platform or in a pipeline, therefore any direct insertion density meter must have some protection from dirt and liquid droplets on gas applications.

FIGURE 9 shows a successful development in this area.

Ideally a filter should have a large surface area to reduce the potential of undesirable differential pressure due to contaminate. However, by having the inlet on the back face of the transducer and a round profile body very little dirt or liquid droplets ever reach the filter. As both of these contaminates are a heavier mass than the gas the increase in velocity generated by the round profile means they will tend not to be drawn in to the inlet.

The retractor mechanism has often two vent valves. One is normally used to vent the small volume of pressure in the chamber after the main ball valve has been closed. An important point for all gas transducers is to always depressurize the instrument slowly otherwise liquid drop-out can be created from hydrocarbon gases. The second vent valve can be used for purging and installation of a test gas. Oxygen free nitrogen is not only a good test gas, easy to obtain pure grade (99.99% pure), safe, and good data available, but it also is very good at absorbtion of hydrocarbon liquid drop out. This sometimes saves the requirement for demounting the system for cleaning.

Some of our clients prefer to take test point values using pure gases. However, we have never seen a density transducer successfully checked on a simple vacuum test fail on line in terms of accuracy. Therefore we recommend an insitu frequency reading with a vacuum of better than 1mm mercury is both a practable and accurate, on site check. For safety reasons an air driven vacuum pump should be used in hazardous areas. Also we recommend the pump is not left pulling vacuum for more than half an hour as oil within the pump can back stream into the density meter.

The paper, "Experimental Evaluation Of Densitometers In The Presence Of Condensation Or "Wet Gas"" by Dr S Kostic, Dr T M Svartas and G Staurland from the Rogaland Research Institute presented at the 8th North Sea Flow Measurement Workshop in 1990, identified that the direct insertion density meter recovered significantly faster than the pocket density meter after an injection of "wet gas". In general, most gas density meters are subjected to occasional liquid carry over. If the gas is continuously wet then only "G1" should be considered.

Direct insertion density meters with their unique inherent accuracy can be used, particulary as most modern fiscal metering stations now use two transducers with back up PTZ calculation to qualify the transducer's status.

Lube oil mist down-stream of a compressor on Natural gas pipelines can cause problems which are difficult to identify without PTZ back up calculation.

Unlike other liquid carry over which is easily identified by erratic performance, lube oil mist can form a very fine deposit on the element not visible to the eye. Dual density meters have been seen to be more than 2% off specification but still within 0.2% agreement. Where ever possible on new metering installations, it is best to avoid locations immediately down-stream of compressors. Hopefully in the future there will be a filter which can totally remove this. A dimension of how far down-stream this type of mist becomes relatively harmless droplets should be identified.

When used with a retractor mechanism another option is available to the user to improve performance should there be an excessive frequency and volume of liquid carry over. As we have already mentioned, the latest sampling technique is similar to what occurs in the chimney when wind passes over the tip. This draws the sample from the base of the probe. The instrument therefore suffers no loss of response time if the inlet is positioned in the pipe stub away from the contamination. Furthermore, in extreme cases, heat tracing can be applied to the pipe stub to ensure the carry over stays in the vapour phase.

The final comment for this type of installation is applicable to all installations of density meter. When it humanly possible, ensure the density meter is kept off-line or isolated until 24 hours after start up. Flow computers etc can be given "fall back" values to get the system running. More damage is caused to density transducers in this time frame than the rest of the instrument's life time.

"G3" (**FIGURE 10**) is another installation of an **IN LINE** density meter. The density meter is 8D down-stream of the orifice plate and is mounted on a welded flange. This is a cost effective method which is often used on multiple meter tubes where removal from the line whilst not on line is practical. Because the meter is at the point of full recovery, no theoretical correction for the orifice downstream pressure wake is required. The only additional area of caution required is to ensure the metering engineer liaises with the piping engineer for the correct dimensions and orientation of the pipe stub, (normally 80mm (3") diameter.)

"G4" **(FIGURE 11) IN-LINE** installation is 5D downstream of the gas turbine. Gas turbines are becoming increasingly popular especially onshore. Unlike the orifice plate the turbine meter has a small differential pressure drop often preventing the use of the recovery method. However, this does not present a problem when using the direct insertion method. The mounting flange on this installation shows the alternative compression fitting method which permits initial field orientation of the meter.

"G5" **(FIGURE 12)** is the last variance of installation of an **IN-LINE** meter shown. There are an increasing number of small diameter pipe metering installations where the benefits of **IN-LINE** density meters are required. For line sizes greater than 150mm (6") the dimensions of the instrument, ie, blockage factor is not normally a problem.

When the line size is below 100mm (4") we recommend the use of 100mm (4") equal tee with eccentric reducers to suit the actual line size. Problems have occurred with turbines etc when concentric reducers are used due to the pipe work "trough" collecting dirt/liquid and eventually causing slug flow, when there is a significant change in flow rate. From our experience accurate results are achieved as long as the area of the pipe excluding the area of the density transducer body is greater than or equal to the area of the incoming pipe work.

"G6" **(FIGURE 13)** The **ON-LINE** pocket density meter is designed for use on gas applications. The process gas is extracted from the main line via, typically, 6mm Diameter pipe, through an isolation valve and transported to the density meter in a thermal pocket welded into the main line After measurement it is normally returned back to the main line again although, it can be fed to a vent where the differential pressure is small, as often experienced on gas turbine systems.

A differential pressure technique is the most common method used to generated through-flow. Two different d.p. hook-ups are used, which based upon established methods recommended by the Institute of Petroleum.

The preferred method employs a take-off close to the pocket density meter normally 8 diameters down stream of the orifice plate with sample flow return to the low pressure area at the downstream tapping of the orifice plate. This method avoids 'unregistered flow' as all product flows through the orifice plate. The other method is to simply connect the inlet and outlet pipe work across the DP of the orifice plate.

In either method it is essential that the sample lines/valves are fully lagged together with insulation on the pocket density meter to reduce errors due to temperature differences between the sample and main pipeline.

A range of wall thickness on the pockets selectable on the basis of maximum design/operating pressure, ensures thermal mass of the pocket is kept to a minimum, enabling the quickest possible response to a change in the main pipeline temperature.

When using a class 900 lb pocket, a 5 degree centigrade change in temperature could typically take approximately 20 minutes before equilibrium between the mainline and the measuring element is restored. This aspect was more extensively covered by Mr Reidar Sakariassen from Statoil in his paper Installation Details For Gas Densitometers at the 9th North Sea Flow Measurement Workshop.

Finally on the construction The most <u>important feature</u> of any Pocket Density Meter is an integral PT100. Based on years of experience in **IN-LINE** and **OFF-LINE** density and flow measurement we have proven that a custom built integral PT100 unit is a mandatory requirement for any accurate form of density meter installation. It ensures that there is no temperature gradient error between the precise point of density and temperature measurement within the transducer.

Furthermore, on installations operating at extreme temperatures, it allows the user to monitor, correct and/or alarm on any potential temperature differentials between the point of density measurement and the main line. Often where the user is using the density meter as a component of a mass flow metering system, errors due to temperature differential can cause significant offset in the overall system accuracy.

We recommend and always include an external two microns filter to protect the measurement cell. This filter has a large surface area and will therefore, require a far lower frequency of maintenance than an alternative small area integral filter with potentially difficult access. Ideally two filters should be installed in parallel to allow changeout without having to shutdown the stream and depressurise the sample system. For extreme applications coalescing filters can also be used.

A suitably rated variable area flow meter fitted between the filter and the transducer has proved to be a valuable maintenance tool. With experience this can be used to verify filter status. Prevention of errors due to very stable density values the impulse pipe work being blocked with hydrocarbon liquid or as we have seen several times in Scandinavia frozen moisture! Two other points will assist in the prevention of the problem. First avoid impulse pipe work configurations which can become liquid traps, a side tapping rather than the common top tapping can often assist in achieving this. Secondly, the return pipe work should ideally be 12 or 15mm diameter pipe work with no restrictions and a full bore automatic valve included in the valve logic of the shut off valves. Many problems with liquid dropout occur during start up of a meter tube and also rapid depressurization.

Another strange effect we have seen several times in the last few years is dual installations where a density offset is maintained to an installation even when the transducers have been changed over to the other installation. On one occasion manufacturers were also changed and the exact same offset was still present. After changing the lengths and diameters of impulse pipe work the problem was found to be due to use of a common tapping for the return from the density meter and the low pressure side of the DP cell.

To further prove the point, impulse pipe work lengths were changed after providing an individual tapping and all the density meters still maintained their agreement.

"G7" **(FIGURE 14)** As previously mentioned the recovery method can not easily be used with gas turbines. A common technique is to vent the outlet but care should be taken to ensure the turbine hub pressure is maintained within the transducer.

"G8, G9, G10, **(FIGURE 15)** shows **OFF-LINE** and small diameter IN LINE types of installations of density meter. The points previously mentioned apply also to this configuration of installation. Additional points of merit are to always flow vertically downwards to improve the exit of any undesirable contaminators and also to ensure some degree of downstream back pressure to maintain take off pressure, prevent liquid dropout and high velocity noise due to excessive velocity.

All of the above examples of gas installation are based on the totally immersed vibrating element. Whilst there are many complex design aspects, the main reasons for the use of this type of element is the sensitivity required for accurate gas density measurement which restricts the wall thickness of the element. This in turn means that the alternative element with fluid on just the inside could not withhold typical gas application pipeline pressures.

1.5 LIQUID APPLICATIONS

FIGURE 16 As mentioned previously, generally, only 2 of the 3 methods of installation are used on liquid service. Unlike the gas applications, liquid applications utilize both types of vibrating element.

IN-LINE liquid measurement should be used when the liquid has a large thermal expansion coefficient.

Table 1 taken from IP Petroleum Measurement Manual, Park VII Density, Section 2, Continuous Density Measurement, shows 4 good product examples.

TABLE 1. Differences in pressure and temperature that will each cause a change in liquid density of 0.03 per cent.

STABILIZED CRUDE OIL	
Density	0.850g/ml
Temperature coefficient	0.0007g/ml°C
Pressure coefficient	0.00007g/ml/bar
Therefore	
Maximum temperature difference	0.4°C
Maximum pressure difference	4 bar
***LIQUID BUTANE AT 0°C**	
Density	0.580g/ml
Temperature coefficient	0.0011g/ml°C
Pressure coefficient	0.00025g/ml/bar
Therefore	
Maximum Temperature difference	0.16°C
Maximum Pressure difference	1.2 bar
***LIQUID PROPANE AT 0°C**	
Density	0.520g/ml
Temperature coefficient	0.0015g/ml°C
Pressure coefficient	0.0003g/ml/bar
Therefore	
Maximum Temperature difference	0.10°C
Maximum Pressure difference	1.0 bar
GASOLINE	
Density	0.660g/ml
Temperature coefficient	0.00075g/ml°C
Pressure coefficient	0.00019g/ml/bar
Therefore	
Maximum Temperature difference	0.26°C
Maximum Pressure difference	1.58 bar

* NOTE: The above values are specific to the conditions quoted and change dramatically around the critical region.

From this table it can be seen that a 1 degree C difference in temperature between the point of flow measurement will generate <u>0.3% of reading error</u> on propane and almost <u>0.2% of reading error</u> on butane, making an **IN-LINE** density meter essential for these 2 liquids if 0.1% of reading is to be realistically achieved.

The installation position can be upstream or downstream. Upstream disturbances have more effect on the flow meter performance. Upstream distances without any intrusive objects are usually greater than downstream therefore downstream is normally preferable. However, if the flow meter itself causes a significant pressure loss which in itself causes a temperature change then <u>upstream</u> installation is the more obvious choice.

OFF-LINE measurement is the most common method for liquid density measurement, especially for viscous and dirty fluids.

The differential pressure required to induce a suitable flow rate through an **OFF-LINE** density meter can sometimes be provided by such means as a pitot-tube scoop arrangement, or a main stream pipeline restriction device like a part closed valve or orifice plate, or bend in main stream pipeline etc. However, in order to provide a reliable flow rate and any additional pressure for proving, a pumped system is often necessary. We will consider this aspect in more detail as we review the common configuration of liquid installations as seen in **FIGURE 17**.

"L1" **FIGURE 18** is a basic pumped **OFF-LINE** system. This provides a rapid system response time irrespective of flow rate. Some density meter manufacturers design and supply custom built packages based on knowledge and experience of this type of measurement but many are also built by metering companies and end users. Whilst every application has some unique constraints and requirements the following general guidelines can be considered.

A) Inlet pipe work length should be kept to a minimum and thermally lagged to ensure temperature equilibrium.

B) When using a pump a minimum of 180 degrees, ideally 270 degrees, of bends in the pipe work should be placed between the pump outlet and the density meter inlet. Good quality density meters are designed with good immunity to external mechanical vibration even when transmitted via the connecting pipe work. However, the small, pressure pulsation outputted from a typical centrfugal pump can be transmitted via the fluid to the density meter. The frequency range of this pulsation can be the same as the operating frequency or a harmonic resonance of the vibrating element. This can cause an unstable output and under extreme conditions an offset in the performance. 180 degrees of pipe bends will normally eradicate this.

With dual density meters on a typical fiscal metering station the same effect can occur between the 2 density meters if they are operated close together in series. This is not normally a problem as the conventional installation method is to operate them in parallel on identical pipe work configurations to avoid different thermal gradients and maintain operation if one unit is removed.

C) On a few occasions the parallel installations can show a small bias. The installation of a small volume header appears to resolve this effect.

D) When selecting a pump always ensure it will not cause the liquid to cavitate or generate bubbles from dissolved gases. Incorrect sizing of the pump can also significantly elevate the liquid temperature. Different manufacturers and their various models have different recommended flow rates. In general most operate efficiently at around 50 litres per minute. This should be reduced to 20 litres per minute if the liquid has abrasive solid particles, to reduce the effect of erosion. The normal minimum flow rate of 4 to 5 litres per minute should ensure the fluid velocity overcomes the surface tension of bubbles on the measurement element and prevent the deposit of solids.

E) Correct orientation of this type of **OFF-LINE** density meter will enhance the reliability of measurement. 3 tube and some 2 tube types which do not have a straight through flow path should be mounted horizontally to prevent any build up of vapour or particles at low flow velocities. Twin and single tube types with a straight through flow path are best mounted vertically with upwards flow. On dirty applications with significant solid particles the flow should be downwards.

If headroom or pipe work constraints prevent vertical installation other orientations can be used if the previous flow rates can be maintained. Irrespective of orientation on straight through flow path density meters, a minimum of 10 diameters of straight pipe should be used on the upstream pipe work to alleviate effects of flow profile bias on the measurement tube. 90 degree elbows immediately upstream of the density meter have shown to offset the density meter performance under certain conditions which are difficult to predefine.

F) For fiscal measurement using these **OFF-LINE** density meters, especially when they are installed on the common header of a multi tube metering system, pressure and particularly temperature in the density meter should be measured.

These readings should not only be used for correction of any systematic errors due to pressure and temperature coefficients of the density meter. The establishment of powerful flow computers permits continuous comparison, correction and or alarms to be performed relative to the values of pressure and temperature at the point of volume flow measurement.

G) One of the major application problems of density measurement on off shore crude oil is the deposition of high melting point wax on the measurement tube especially when the flow is stopped and the density meter cools down. Anti-waxing agents and sophisticated hot kerosine flushing systems have been previously used to overcome this problem. A new approach has been developed, originating from the even more demanding application of density measurement of Bitumen. Many of these type of **OFF-LINE** density meters are designed and perform like a thermos flask mainly to eliminate the effect of ambient conditions. The adverse effect of this is the density meter is difficult to heat trace. With the fitting of integral heat tracing this design aspect becomes advantageous. Furthermore, the integral PT100 element can be used for precise regulation of heat required by way of a user selected "wax pour point". It can be said that an elevated operating temperature of the density meter could increase the overall uncertainty of measurement but in the **"REAL WORLD"** a wax free density meter, on an annual basis, will provide a more accurate performance.

H) Whilst the liquid should ideally be at a pressure well above its vapour pressure, if you experience an erratic output due to the presence of undissolved gas, often a small amount of back pressure on the downstream side of the bypass pipe work will remove the problem. Like most conventional flow meters, density meters can measure "two phase" flow, but only one phase at a time!

"L2" is mechanically identical to the "G2" direct insertion **IN-LINE** density meter with a retractor mechanism. As previously mentioned, **IN-LINE** should be used when the liquid has a large thermal expansion coefficient. Due to the type of vibrating element this method should not be used when the viscosity of the liquid exceeds 20 centipoise or the location of the measurement is in a pigged line.

"L3" **FIGURE 19** shows the pitot tube scoop method. The response time and thermal and pressure gradient will change with flow rate and condition of product. Therefore this method is only suitable when the span of the flow rate is known to generate sufficient differential pressure. Each application will require specific design based on product composition, line size and flow rate. Under low flow conditions, stratification of density and "vapour locks" can occur in the by-pass pipe work.

"L4" **FIGURE 20** shows the use of a main pipeline restriction to generate a flow around the by-pass pipe work. The operating characteristics are similar to the pitot tube scoop method. Additional care is needed to ensure the potential downstream gas bubbles do not adversely effect any other measurement devices. An advantage of this method can be the ability to fine tune the system on site by use of a partially closed valve as the restriction in the main pipeline. Downstream flow rate reduction must also be reviewed when installing this method of installation onto an existing process plant or pipe line.

"L8" **FIGURE 21** is a pipe work configuration which has been successfully used on 50 to 100mm (2" to 4") diameter lines. Dependant on the flow rate and product condition etc the ratio of pipe diameters of the two lines can be varied. With the 3 valves shown, flow rate, back pressure and isolation for maintenance can be achieved. Using the "pipe splitter" shown, this installation has been particularly successful on applications where the 3 previous **OFF-LINE** installations can have problems in achieving a representative by-pass sample of a non homogeneous liquid.

"L5" **FIGURE 22** is the most cost effective method of liquid density measurement. The selection and operating criteria are the same as "L6", "G3", "G4" and "G5". Caution is required with other liquid density meters where the vibrating element is directly in the main stream flow path. These types of devices are often flow rate sensitive and susceptible to a higher degree of contamination.

"L9" **FIGURE 23** is another cost effective compact method of **OFF-LINE** density meter installation. The differential pressure required to flow the product around the by-pass pipe work is achieved by the inlet being positioned at the external radius, high velocity, high pressure point of a pipe work bend. The outlet is positioned at an angle suited to the lower velocity and pressure internal radius position of the same or downstream bend. This method should only be considered when measuring low viscosity fully homogeneous clean liquids. The centrfugal forces at bends can cause separation where the heavier components move towards the external radius of the bend.

Now we have completed our review of the installation methods, I would like to suggest a simple rule which a metering engineer unfamiliar with density measurement may find helpful.

MASS FLOW SYSTEM ACCURACY WITH DENSITY MEASUREMENT IS DEPENDENT ON YOUR ABILITY TO DEFINE THE TEMPERATURE EXACTLY AT THE POINT OF FLOW AND DENSITY MEASUREMENT.

In most cases the above is a large potential component to the overall uncertainty of accurate mass flow measurement.

SUMMARY

In an attempt to provide guidelines for density measurement there will always be a minority of exceptions. The intent of this paper to improve the performance of density meters by the awareness of problems. From user awareness and supplier knowledge the best solutions and performance of density meters will evolve.

REFERENCES

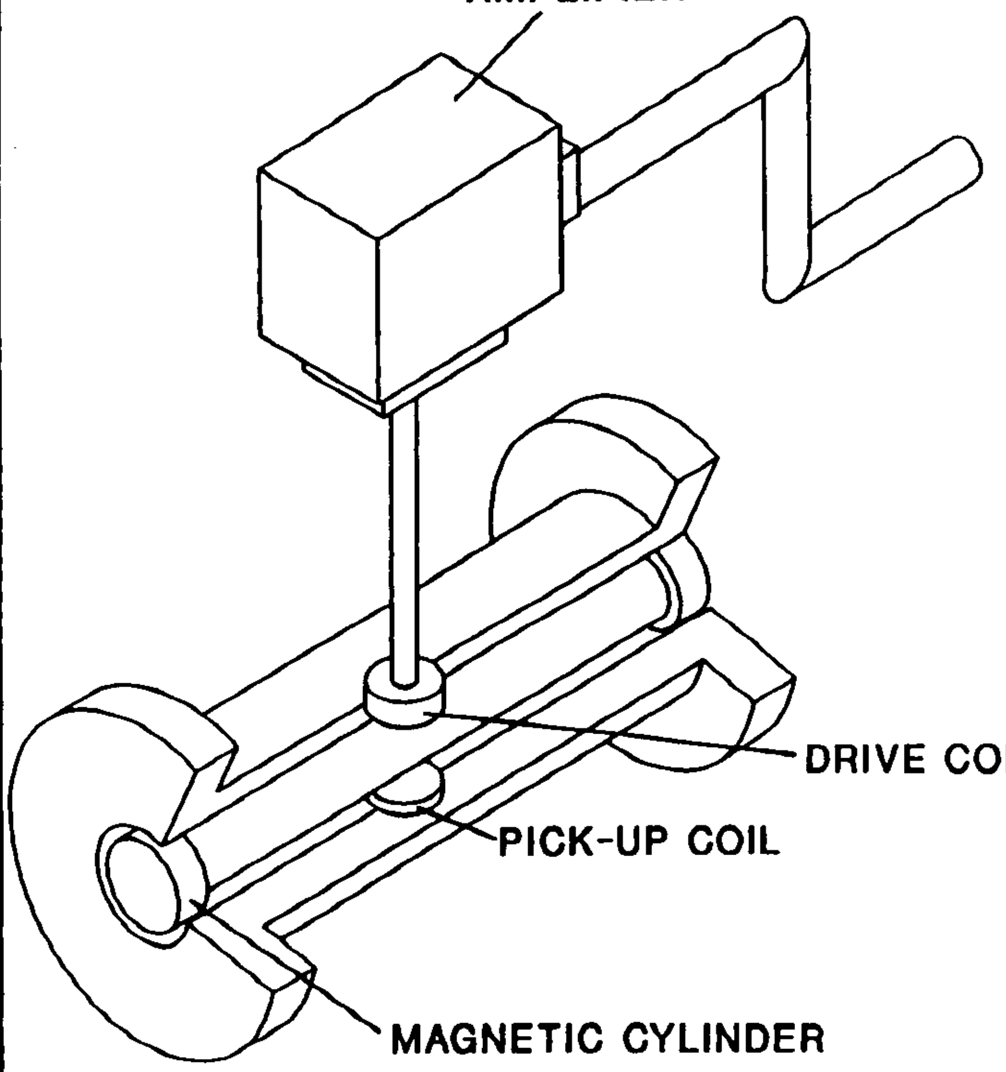
1. The IP Petroleum Measurement Manual, Part VII, Density Section, 2 Continuous Density Measurement.

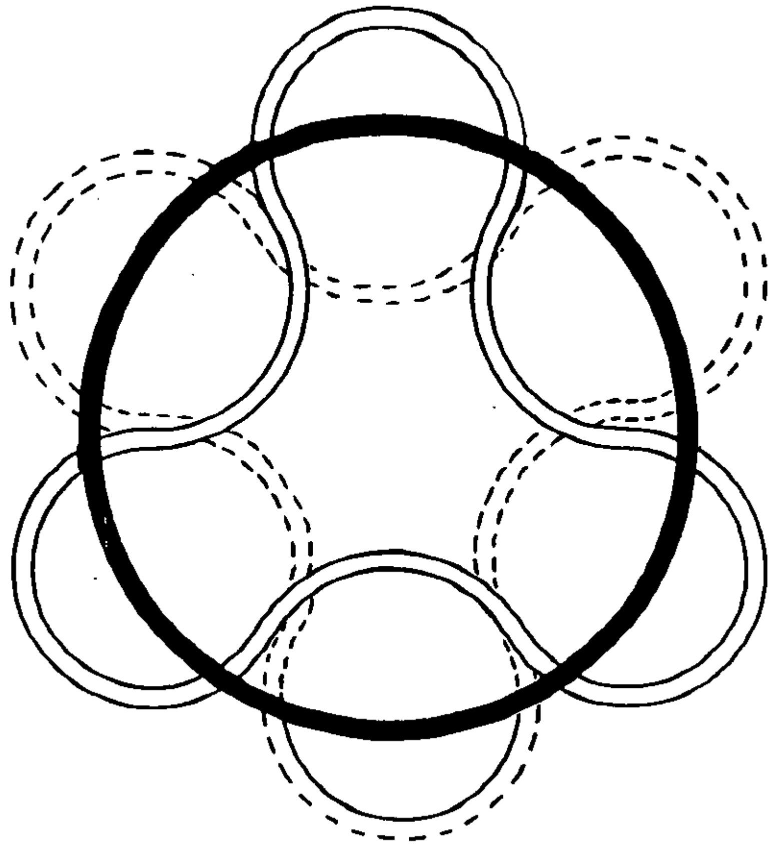
2. Experimental Evaluation of Densitometers In The Presence Of Condensation Or Wet Gas, By Dr S Kostic, Dr T M Svartas and G Staurland from the Rogaland Research Institute presented at the 8th North Sea Flow Measurement Workshop in 1990.

3. Installation Details For Gas Densitometers at the 9th North Sea Flow Measurement Workshop, by Mr Reidar Sakariassen from Statoil.

4. **"REAL WORLD"** at many previous workshops by Mr Brian Henderson from Amoco.

PRINCIPLE OF OPERATION





HOOP MODE VIBRATION

Figure 1

FD700

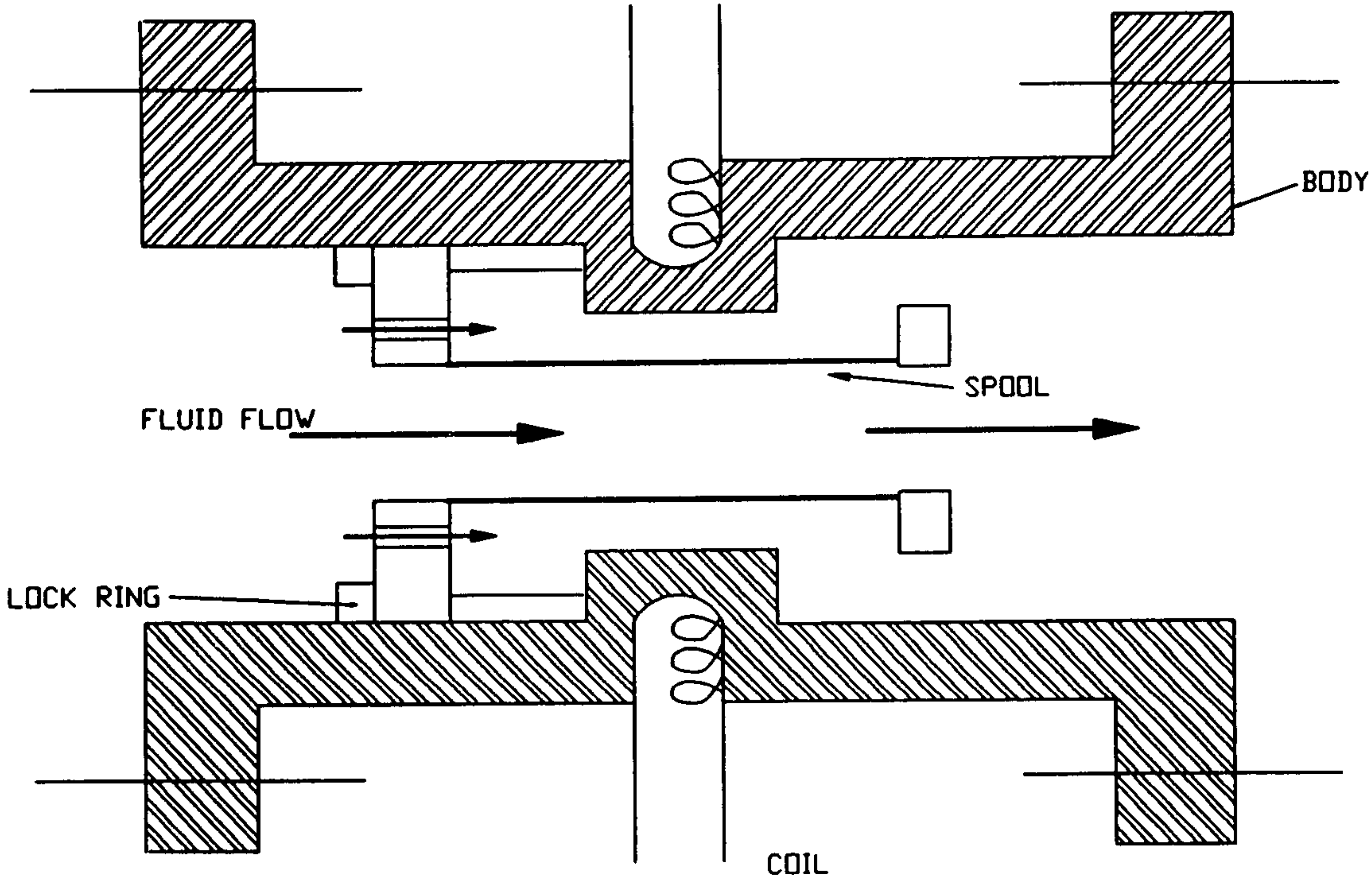


Figure 2

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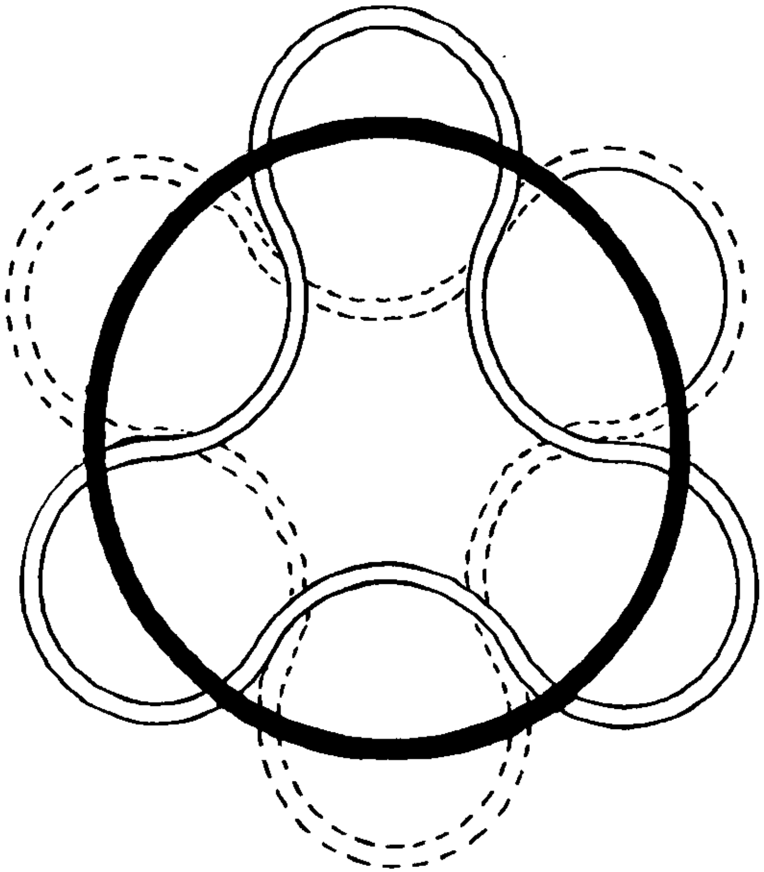
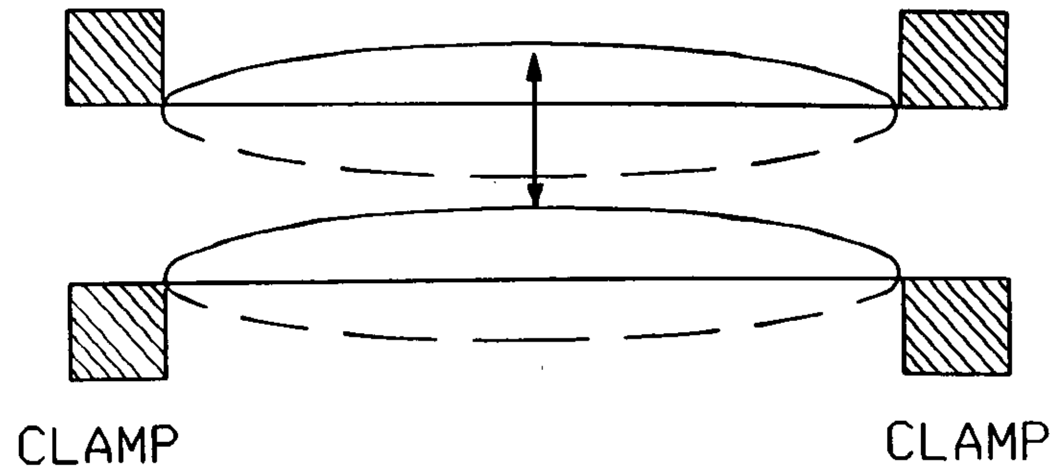
PRIME VIBRATION PRINCIPLES



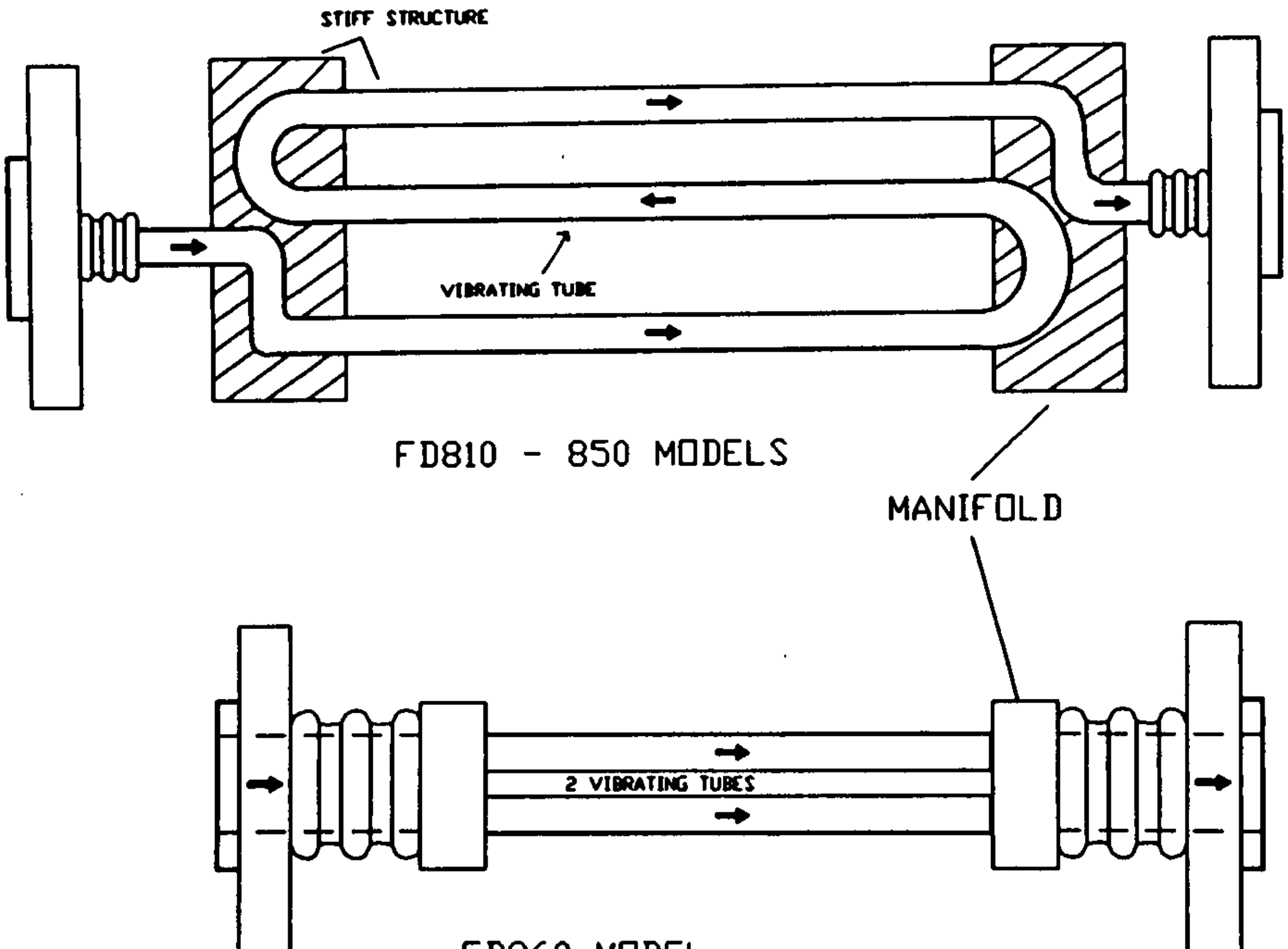
HOOP MODE VIBRATION



TRANSVERSE MODE OF VIBRATION

Figure 3

FD800 SERIES



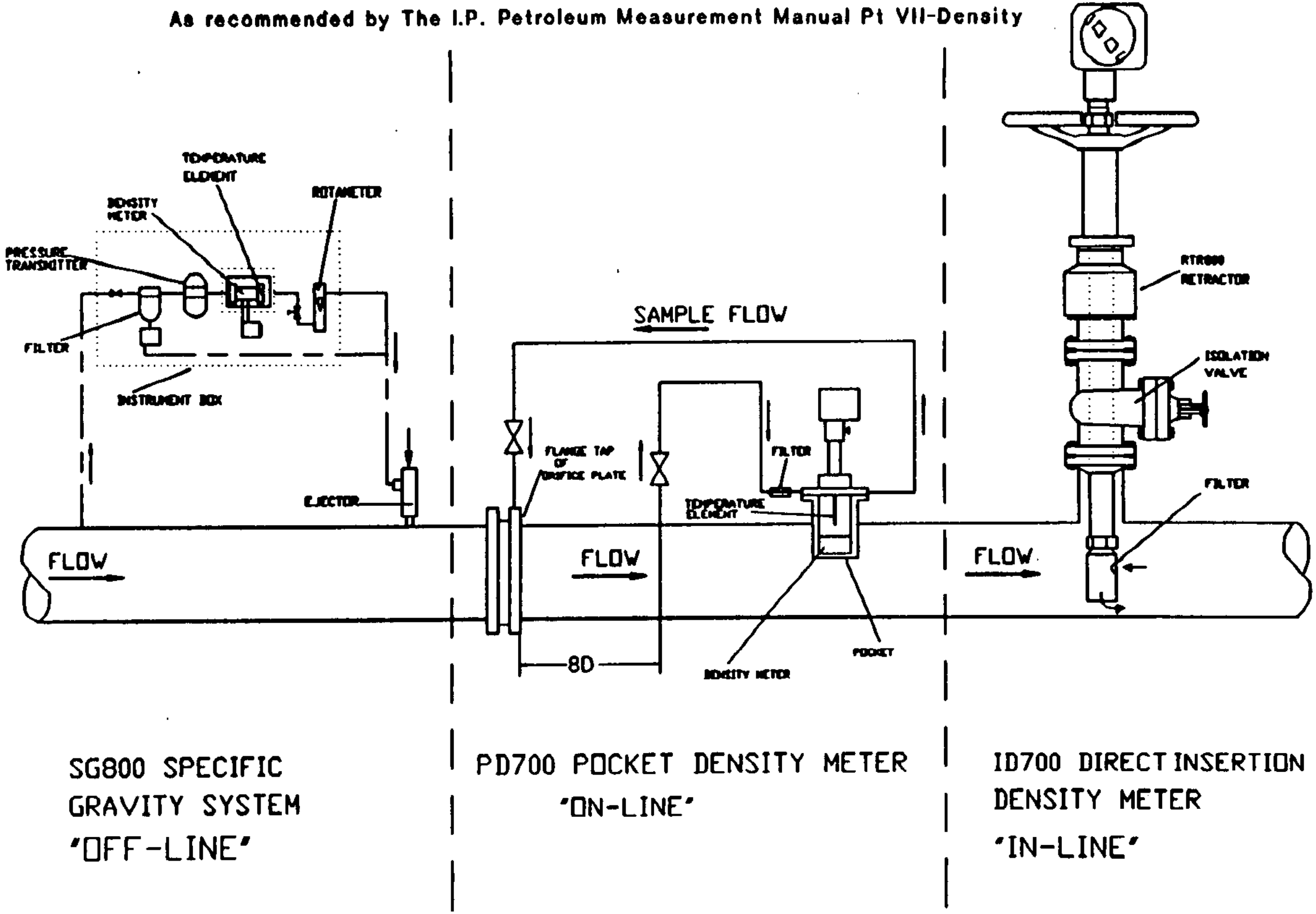
FD810 - 850 MODELS

FD860 MODEL

Figure 5

TYPICAL METHODS OF GAS INSTALLATION

As recommended by The I.P. Petroleum Measurement Manual Pt VII-Density

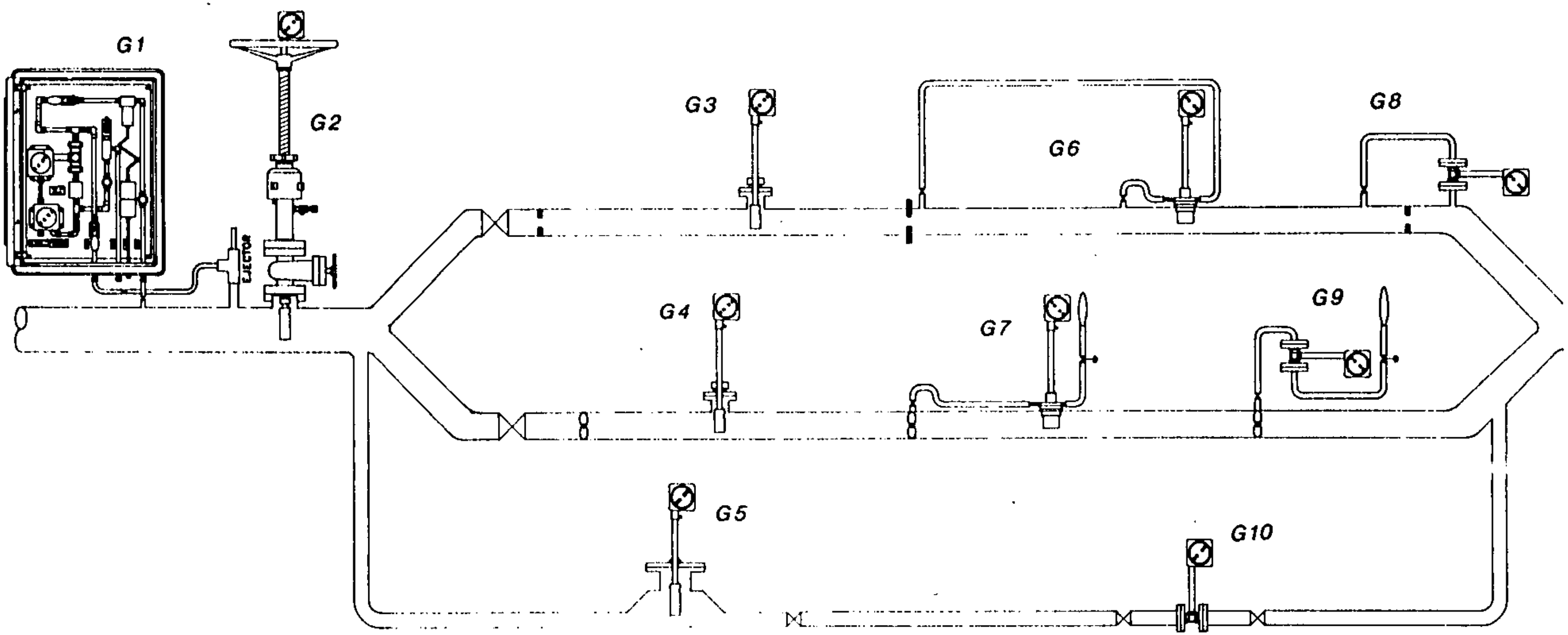


SG800 SPECIFIC GRAVITY SYSTEM 'OFF-LINE'

PD700 POCKET DENSITY METER 'ON-LINE'

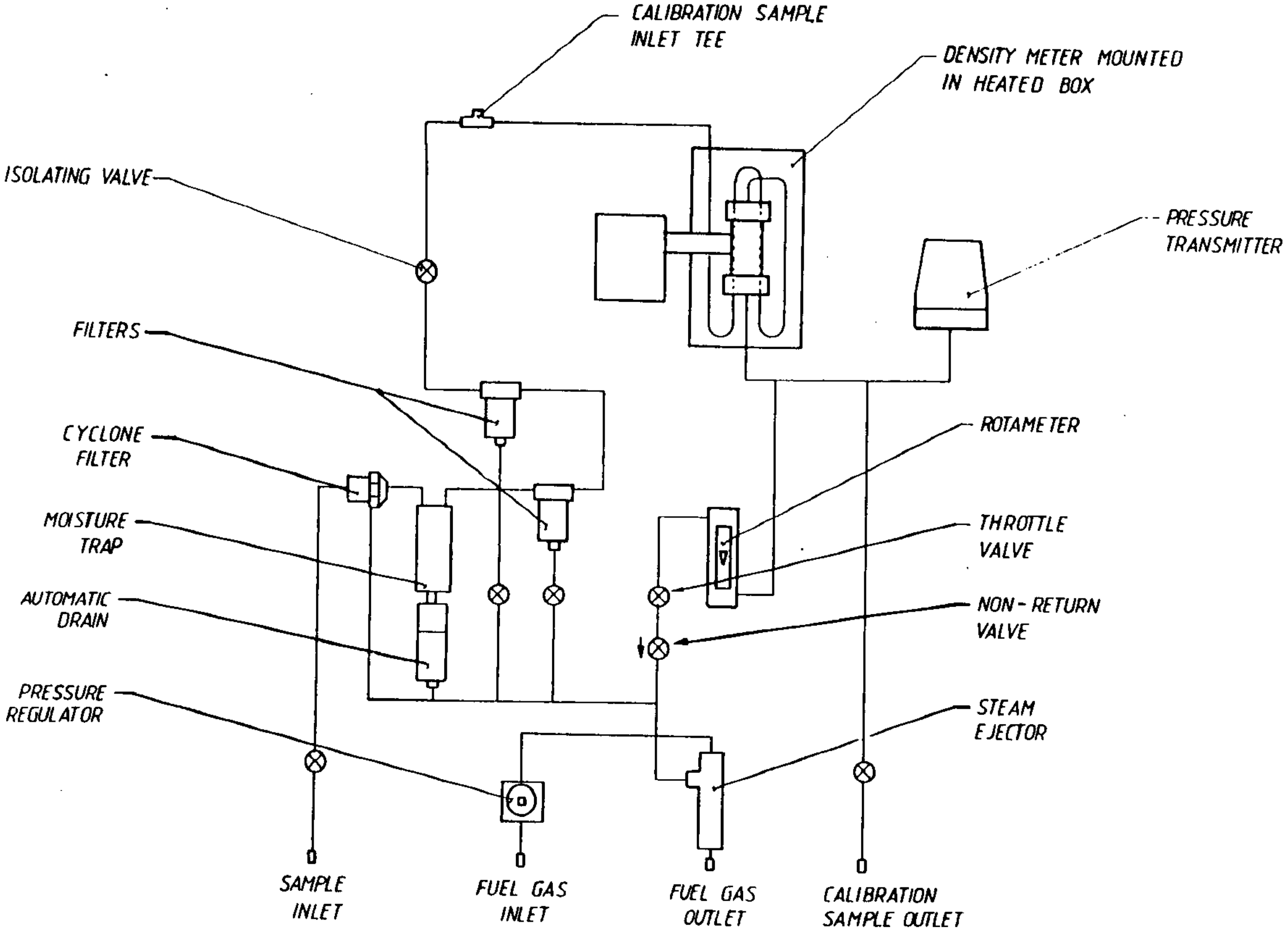
ID700 DIRECT INSERTION DENSITY METER 'IN-LINE'

Figure 6



Typical GAS Installation Configurations

Figure 7



OFF-LINE Gas Filter System

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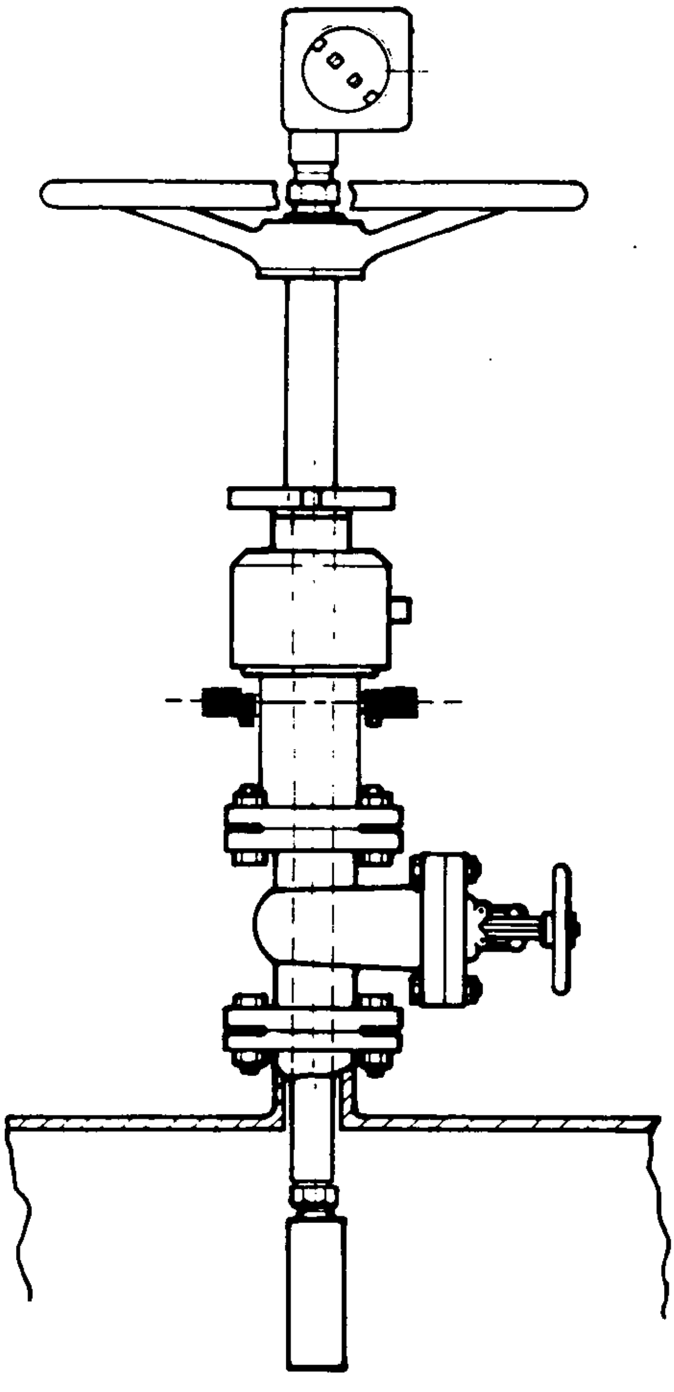

Figure 8

IN-LINE Direct Insertion Density Meter
With High Pressure Retractor
& Calibration Connections

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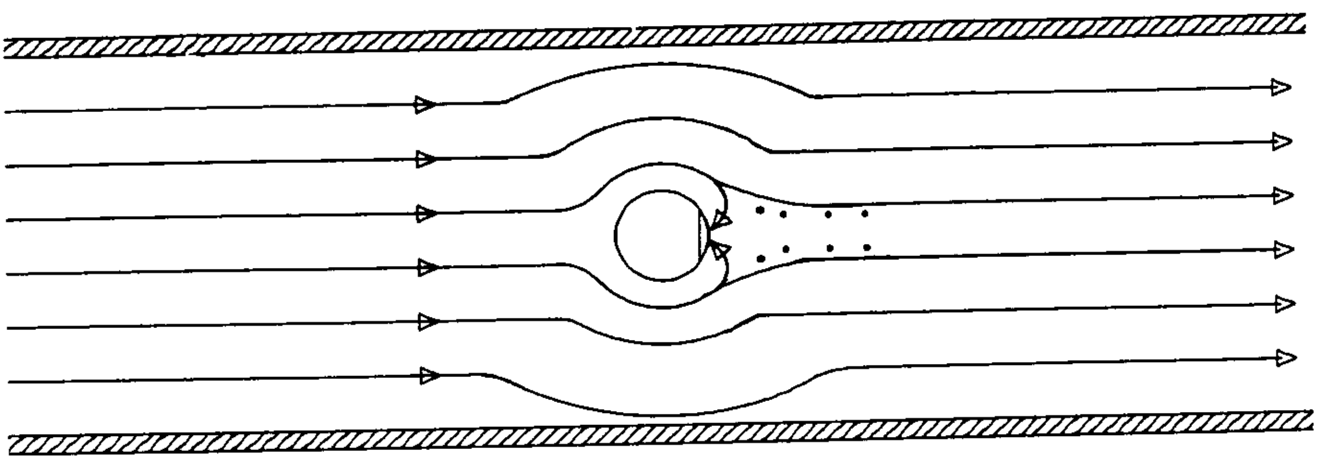
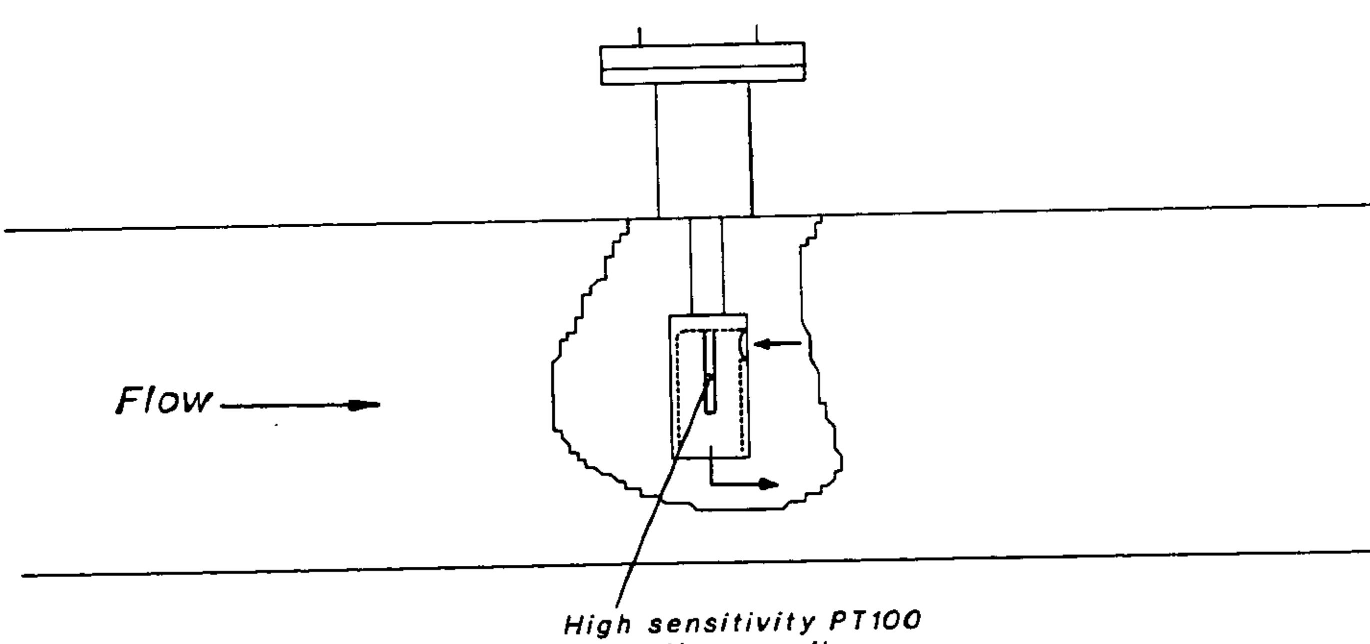
Figure 9





Flow Path Performance of an
IN-LINE Direct Insertion
Density Meter

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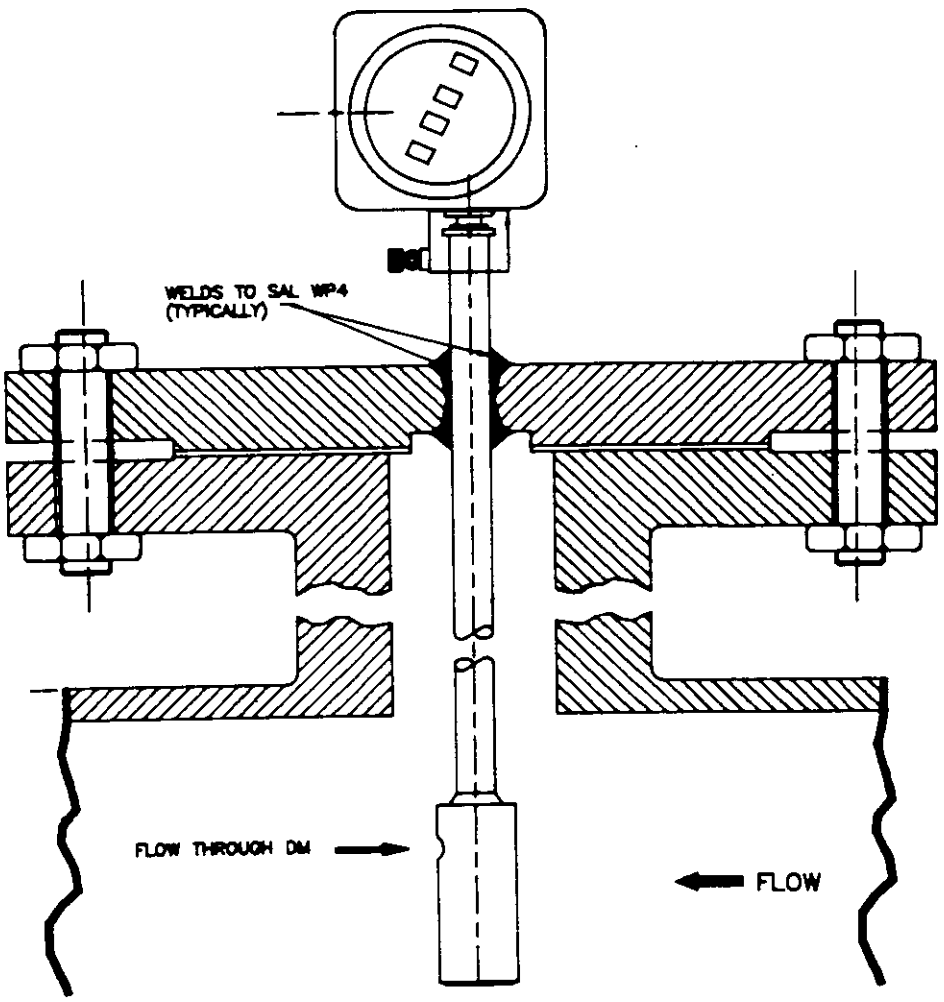

Figure 10

*IN-LINE Direct Insertion Gas Density Meter
With Welded Flange*

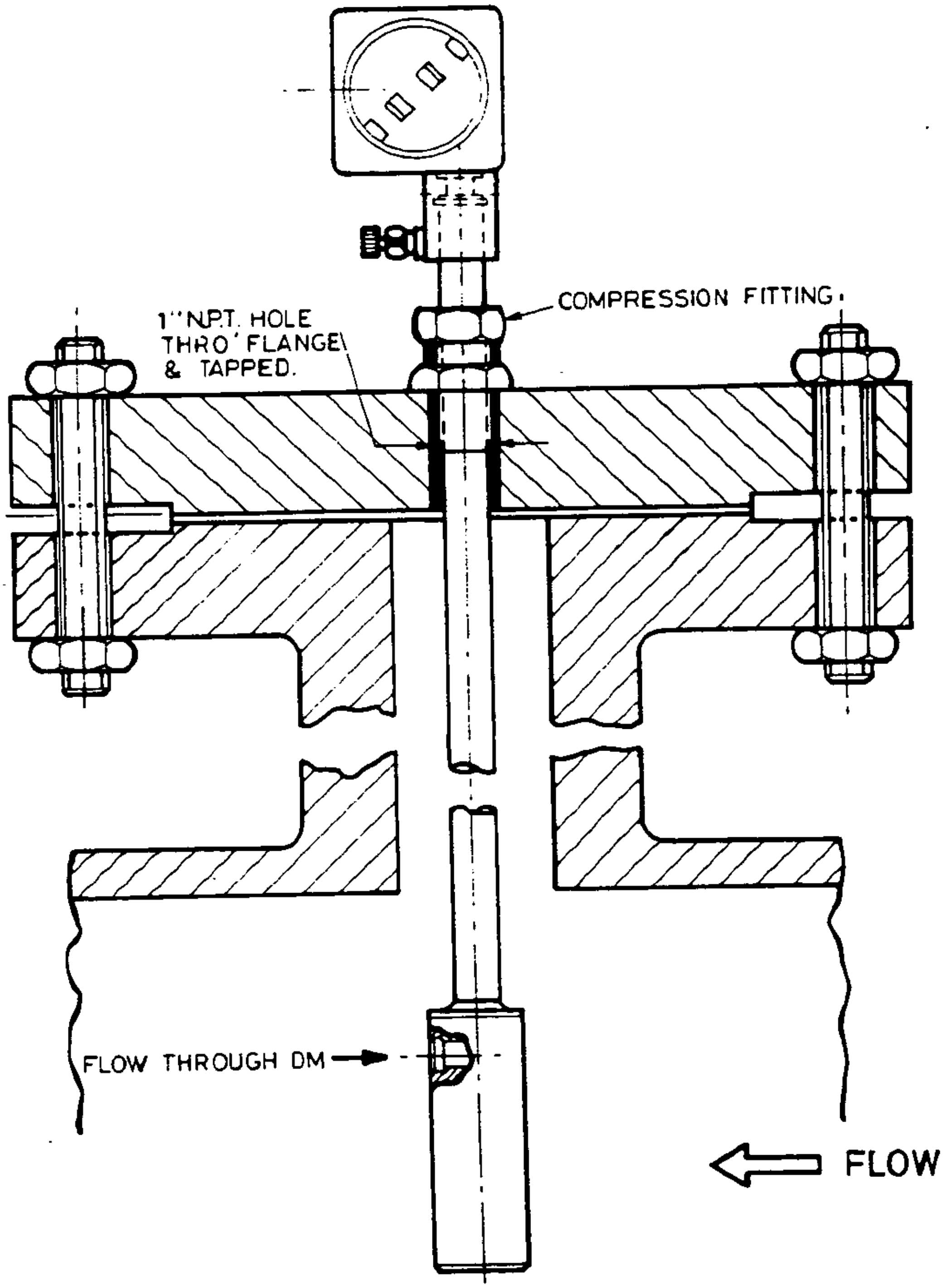

Figure 11

IN-LINE Direct Insertion Density Meter
With Compression Fitting-Type Flange

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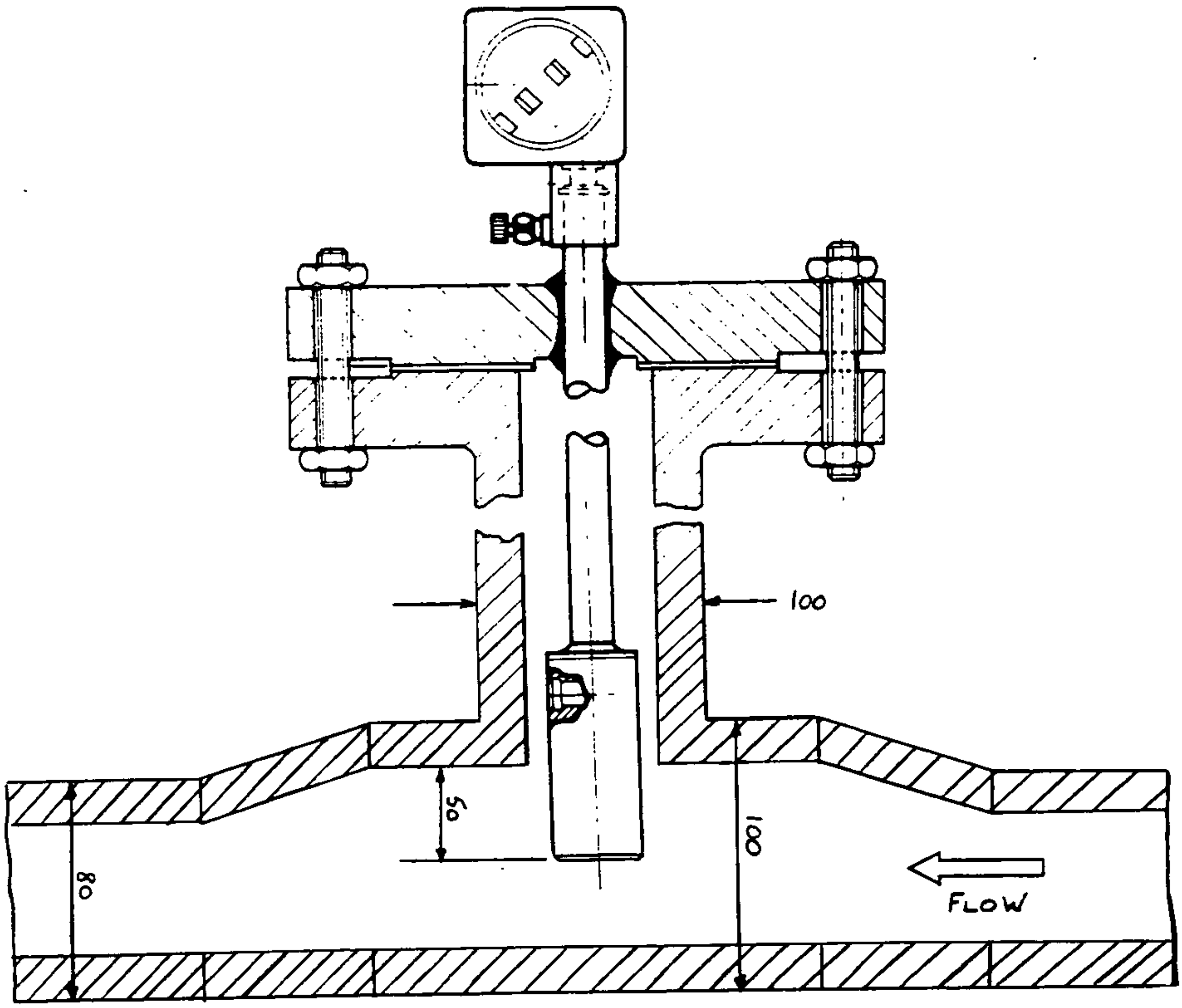
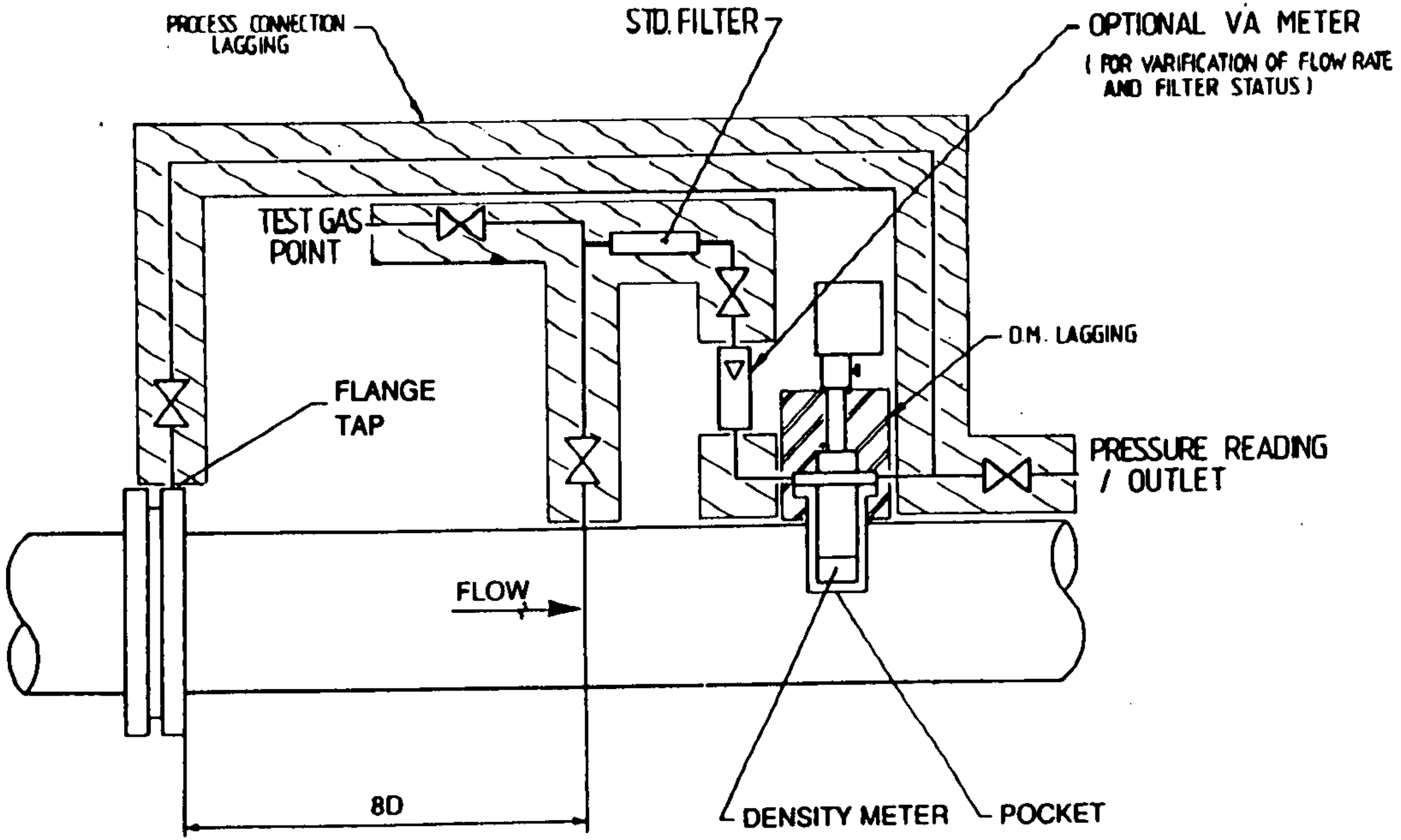


Figure 12

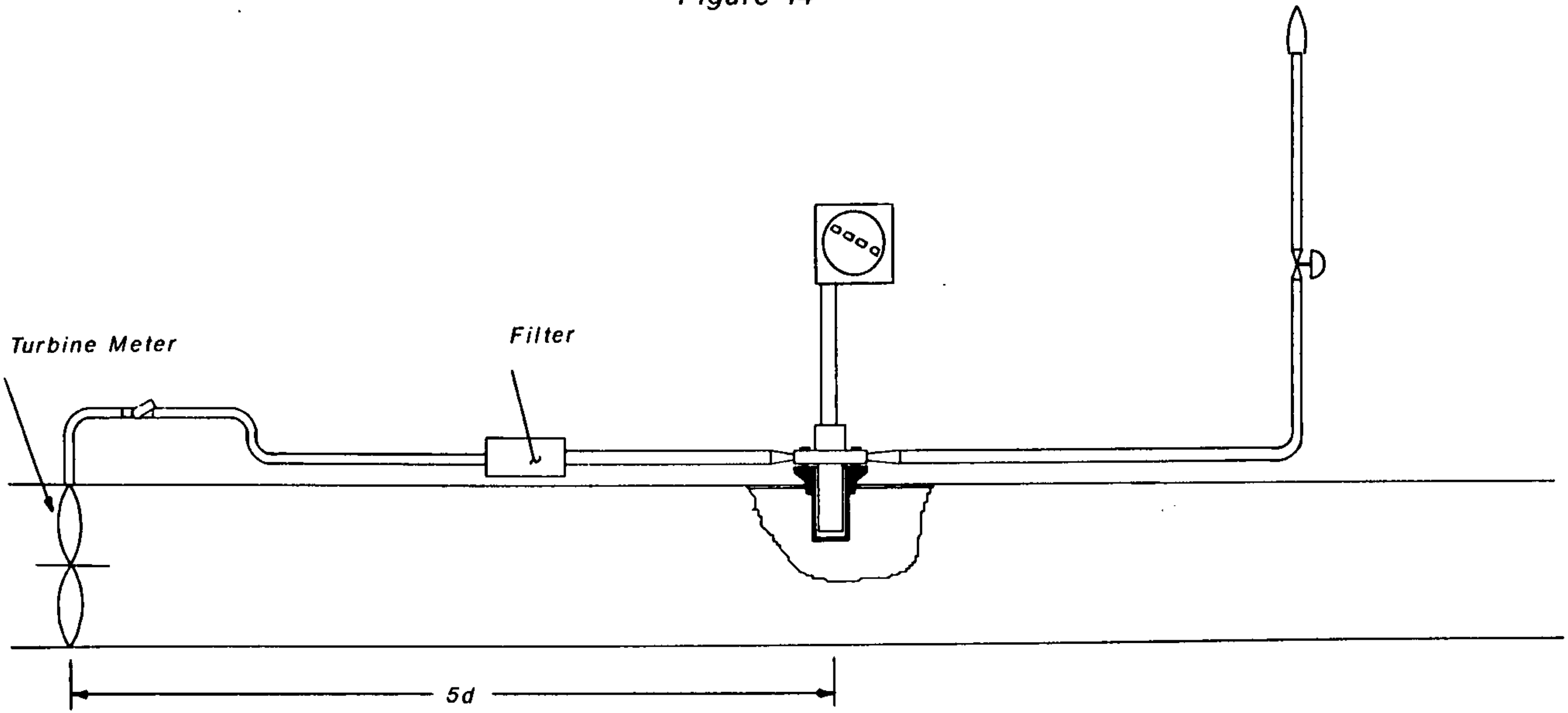
IN-LINE Direct Insertion Density Meter
For Pipes of <100mm Diameter

Figure 13



INSTALLATION OF GAS DENSITY METER ON AN ORIFICE PLATE SYSTEM USING THE PRESSURE RECOVERY METHOD TO AVOID UNREGISTERED FLOW

Figure 14



Typical "ON-LINE" Pocket Density Meter installation with a gas turbine meter

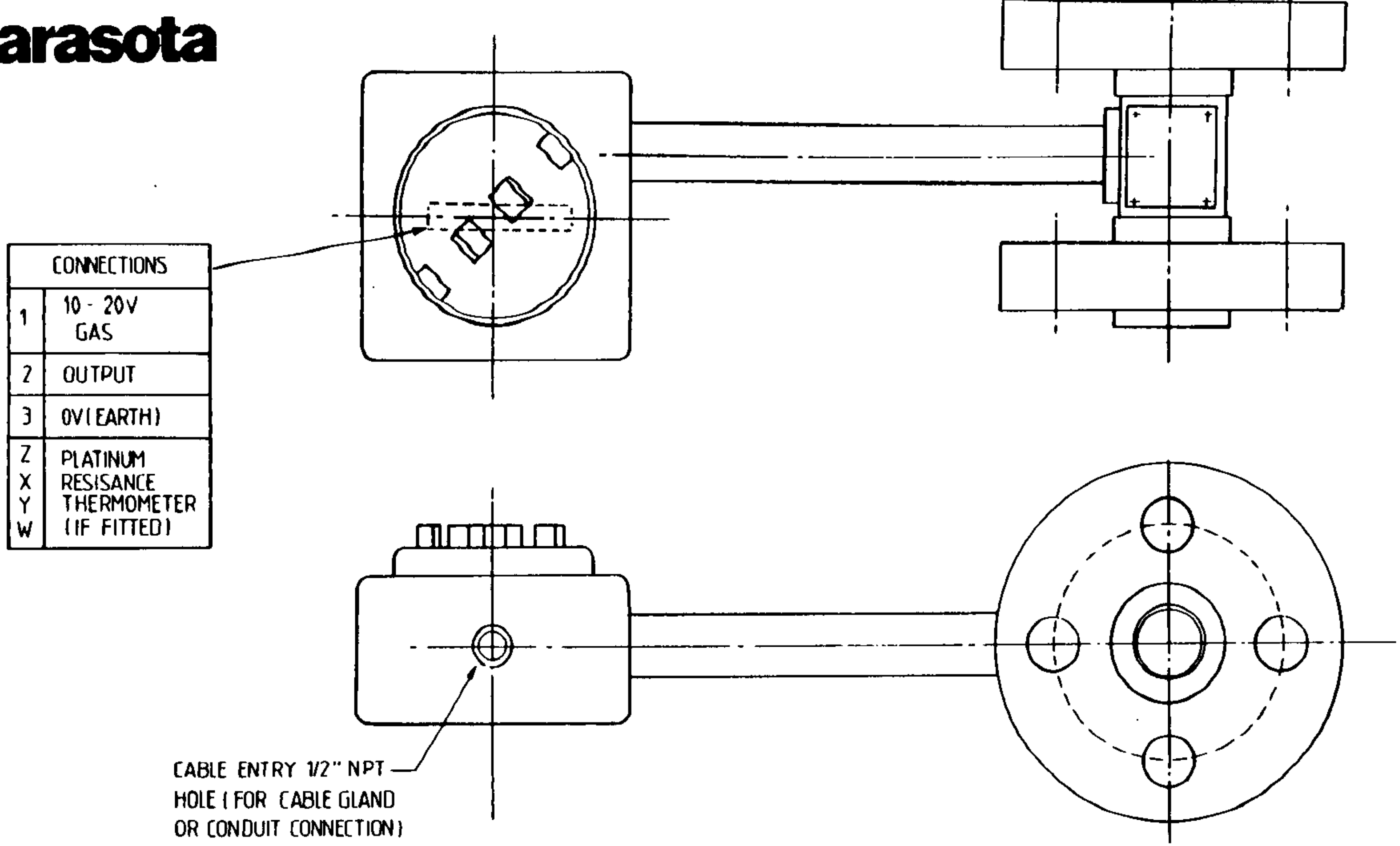


Figure 15

OFF-LINE Flanged By-pass Gas Density Meter

TYPICAL METHODS OF LIQUID INSTALLATION

As recommended by the I.P. Petroleum Measurement Manual Part VII - Density

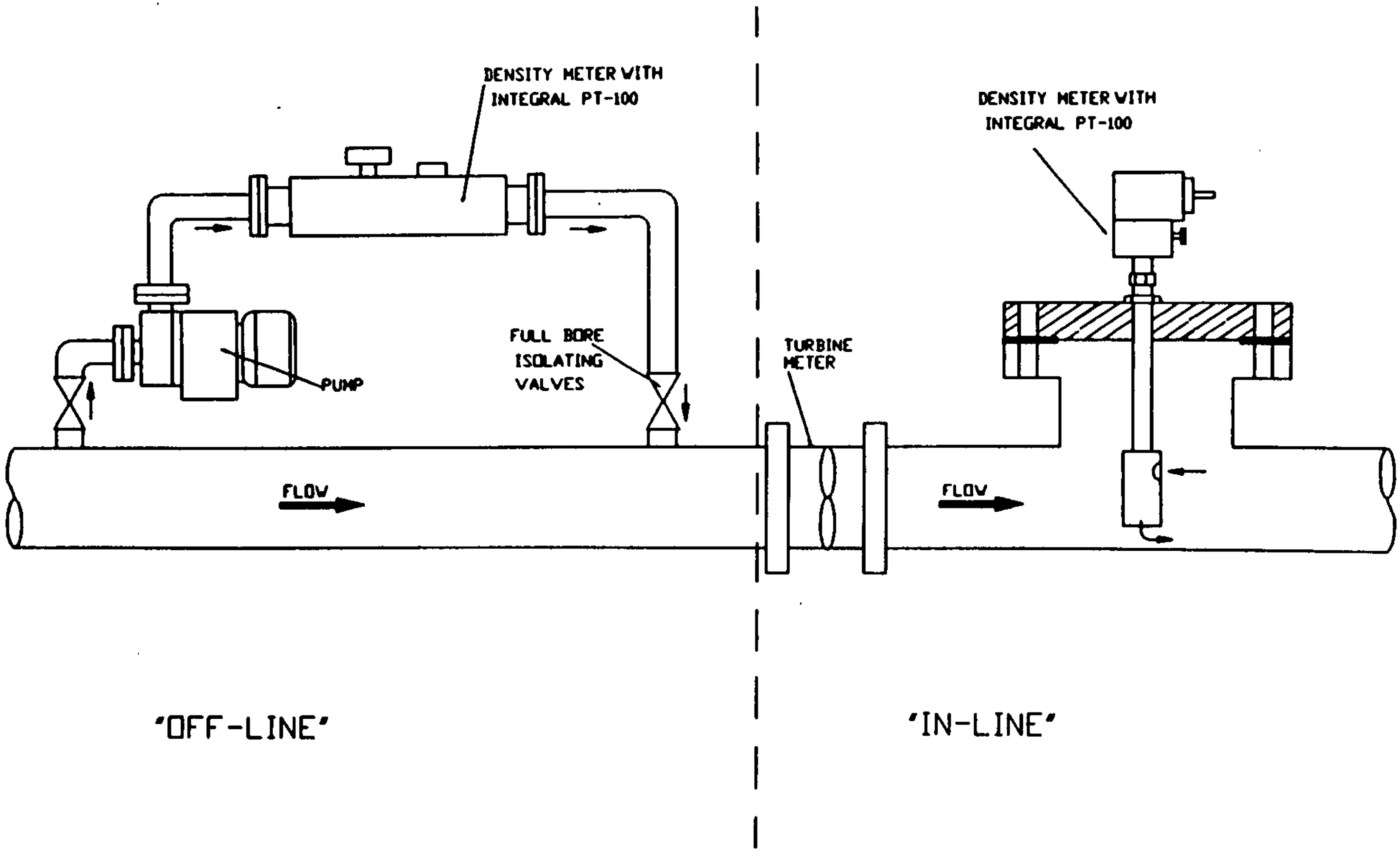
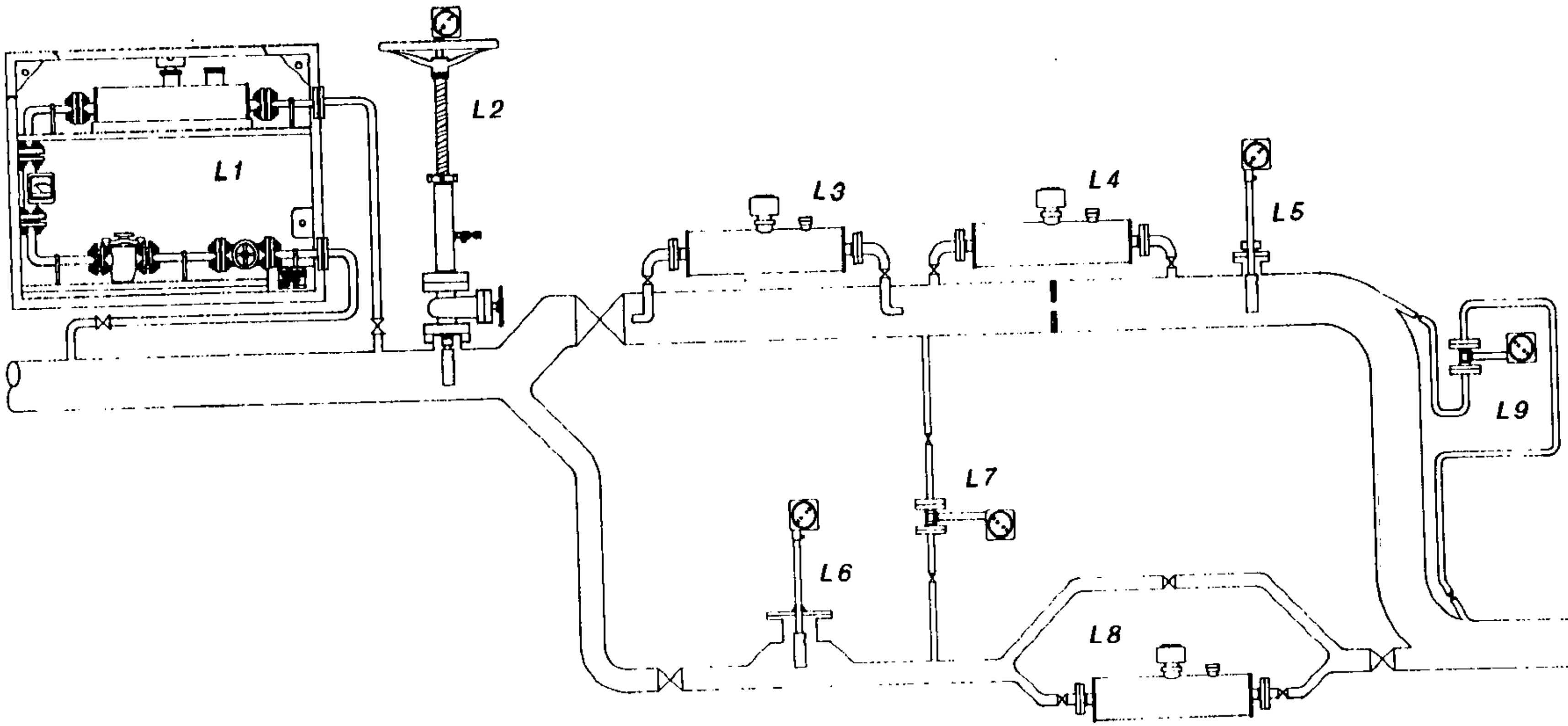
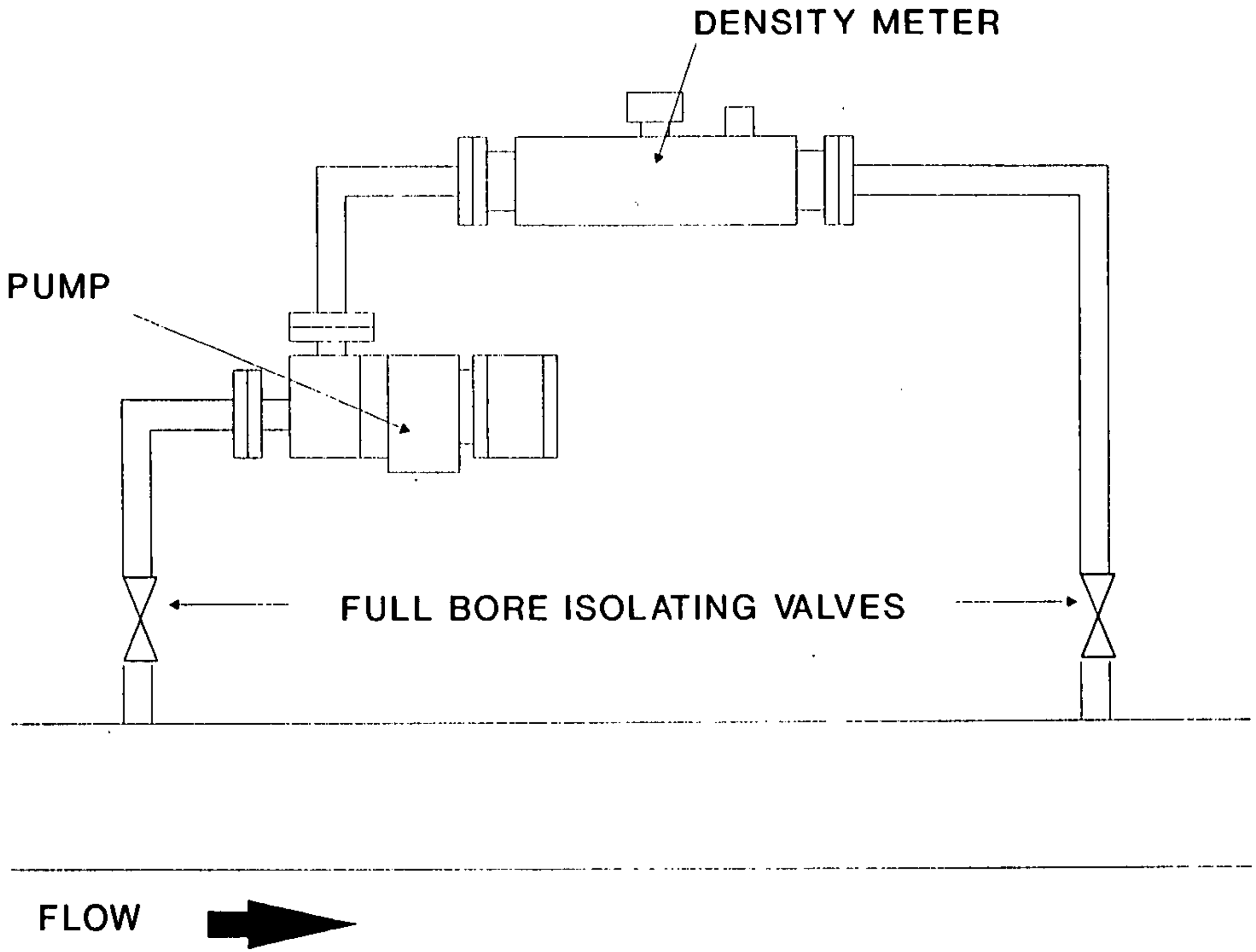


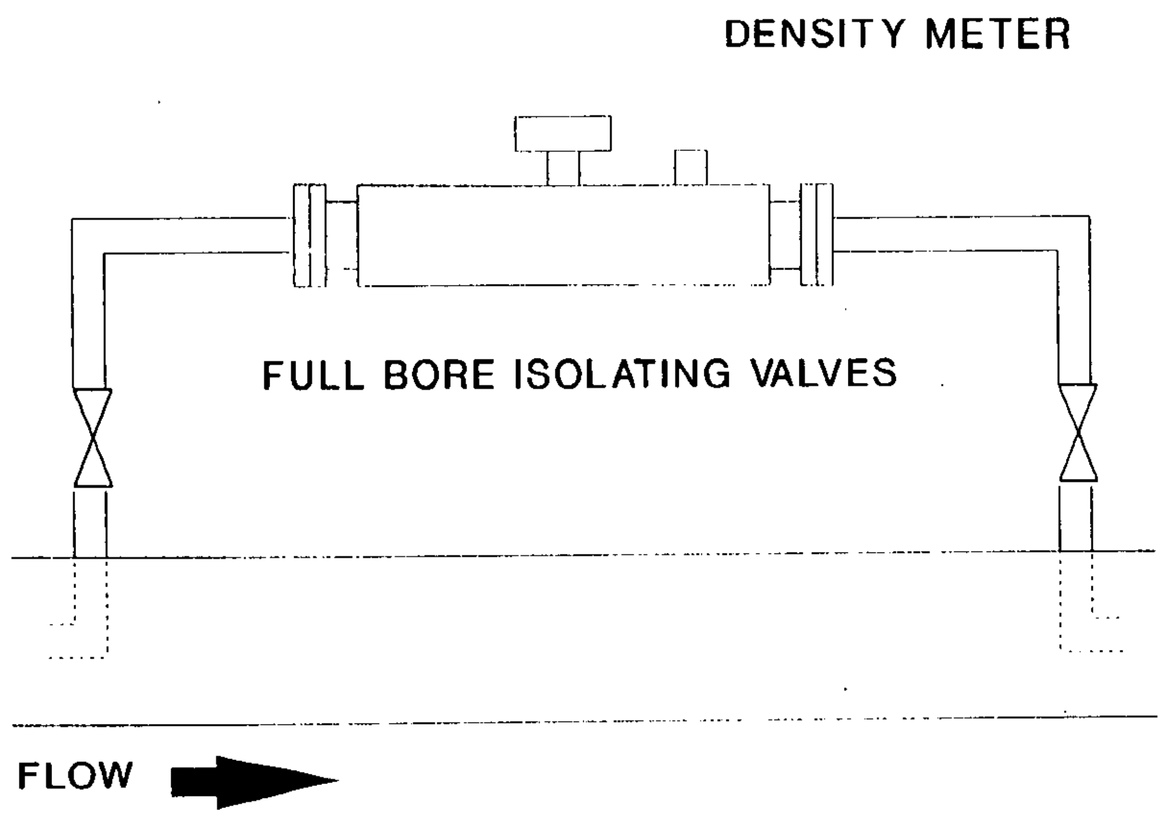
Figure 17



Typical LIQUID Installation Configurations



INSTALLATION WITH PUMP



INSTALLATION WITH PITOT TUBE SCOOPS

Figure 20

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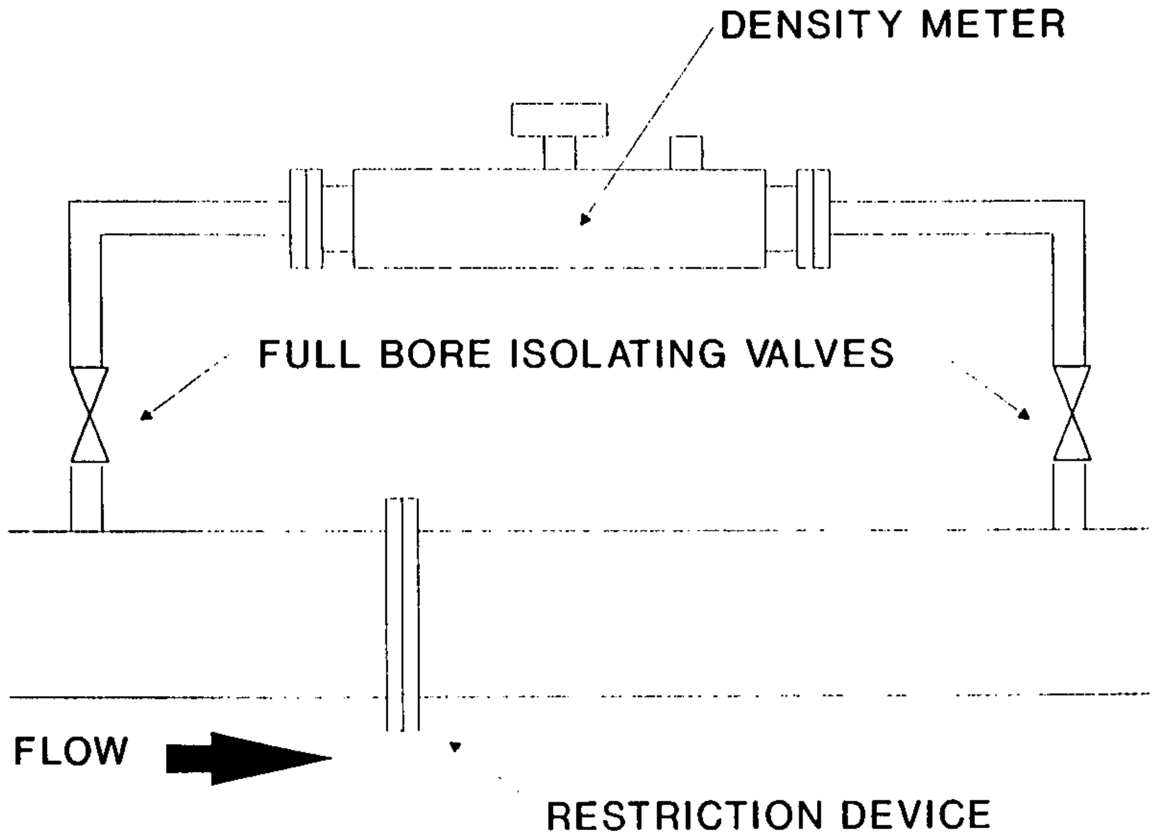
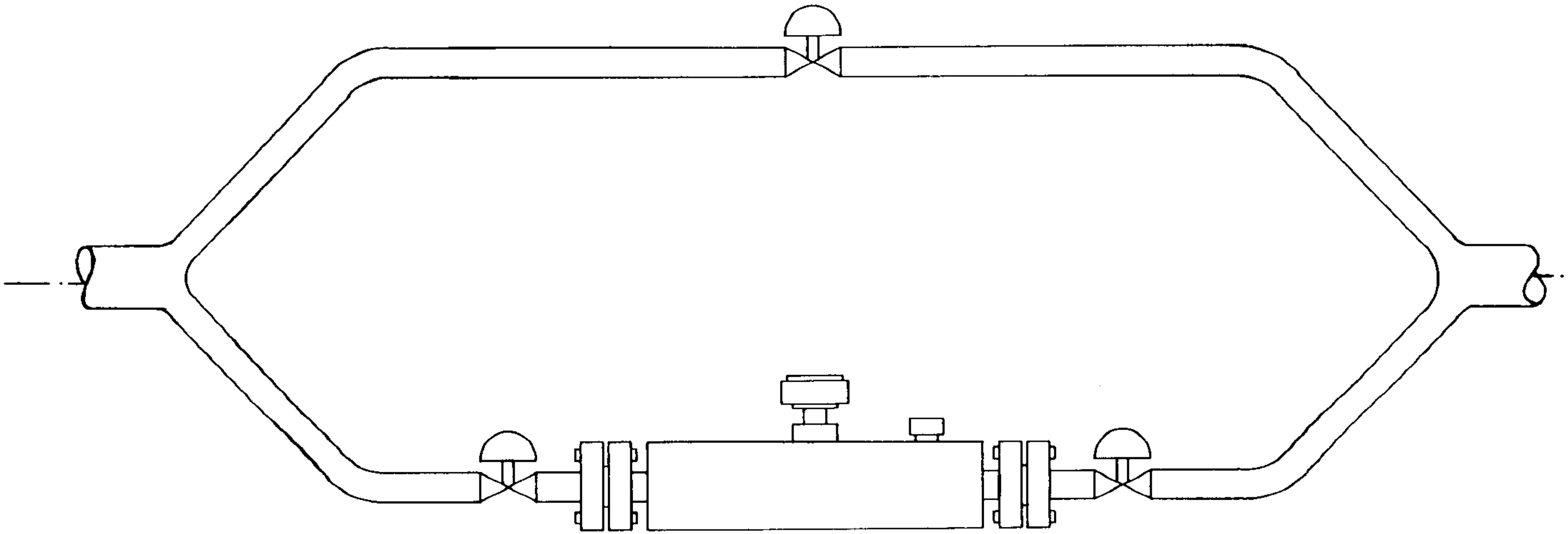


<u>A RESTRICTION DEVICE TO CREATE A PRESSURE DIFFERENTIAL</u>

Figure 21



BY-PASS Configuration for
use with 50 to 100mm Diameter Lines

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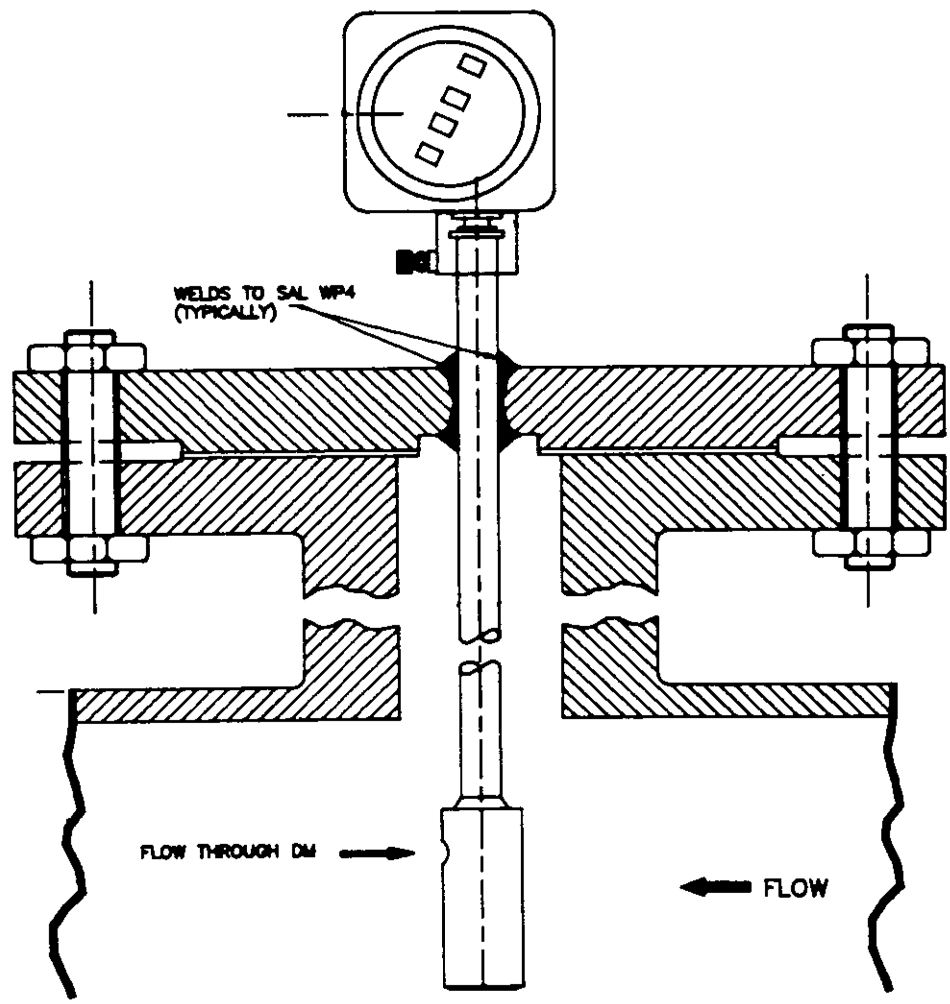

Figure 22

IN-LINE Direct Insertion Liquid Density Meter
With Welded Flange

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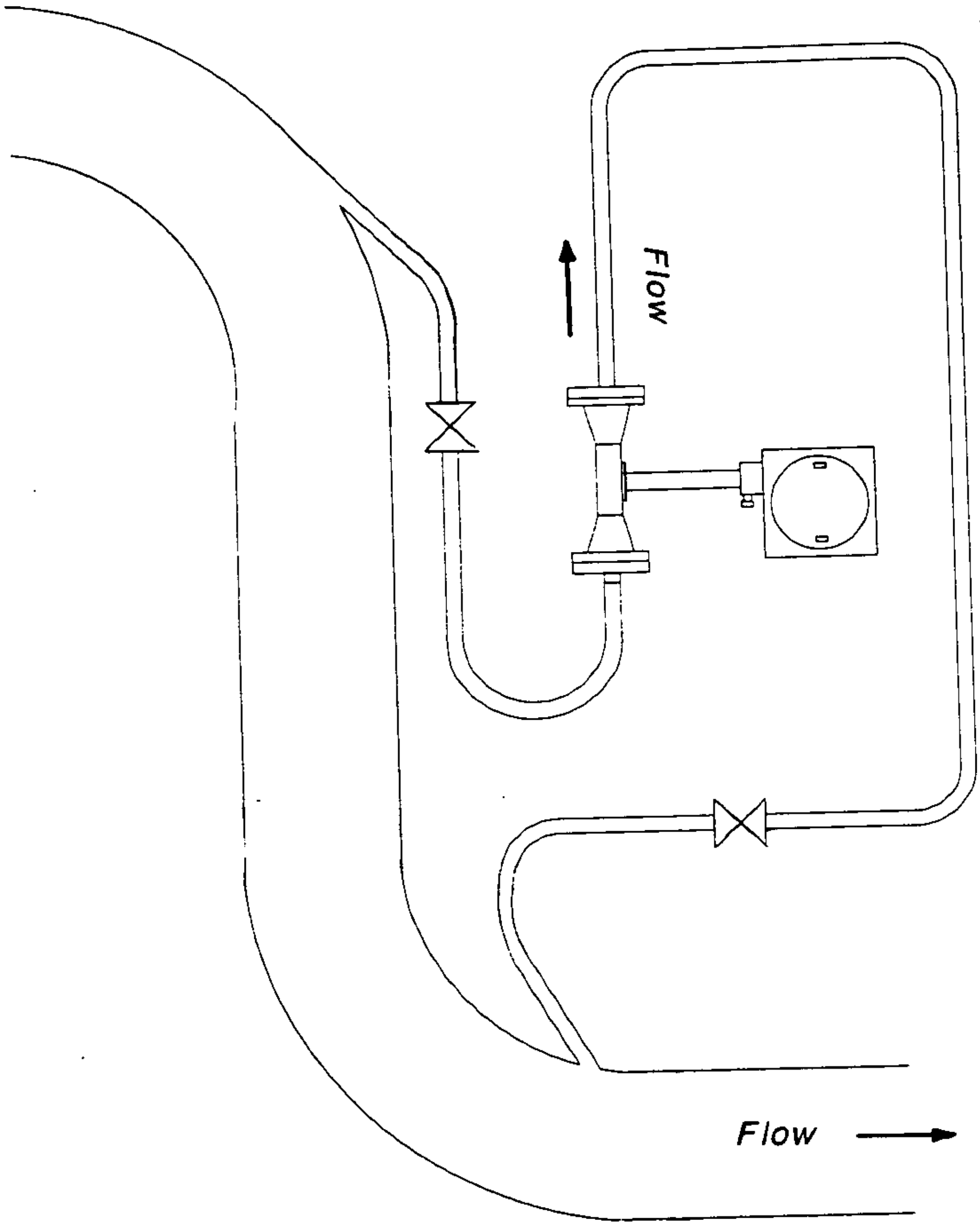
Figure 23



OFF-LINE density meter
utilising the differential pressure
of main-stream bends