FIELD EXPERIENCE WITH LIQUID DENSITOMETERS

by

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INTRODUCTION

This paper discusses the problems encountered with the measurement of two different types of liquid hydrocarbons. Crude oil is probably metered more than other petroleum products but causes difficulties due to the presence of waxes, sand, sulphur and water.

Liquified hydrocarbons such as LNG, LPG, ethylene or condensate are generally much "cleaner" when metered but tend to be at much more extreme conditions of pressure and temperature. Consequently different techniques are employed to satisfy these differing requirements.

BACKGROUND

There are two main reasons for using liquid densitometers in the North Sea. The measurement of liquid quantities for fiscal purposes is normally calculated in mass units. Hence as there are very few accurate mass flow devices currently available and none of them widely accepted by Government Authorities this means that the flow rate is usually calculated in volume units and the conversion to mass flow with the use of a densitometer.

ie $M = V \times \rho$

The main requirement is to ensure that the density measurement is made at conditions which are as close as possible to those at the metering device, which is usually a turbine.

Current technology does not allow the design of a densitometer within the turbine, so this means that the meter must be placed close to the turbine and corrections made in the computing system to compensate for any differences.

Alternatively densitometers may be used to measure the quality of a product. The meter can be used on the product at any process condition and with a knowledge of the effect of variations of pressure and temperature on the fluid, a calculation can be made of the density at some base conditions, this being a measure of the purity. Sometimes the result can be compared with water at the same conditions and is expressed as relative density or Specific Gravity.

By far the largest use for meters offshore is with the measurement of mass flow.

METHODS OF DENSITY MEASUREMENT

There are several techniques employed in the measurement of density. Because the density of the fluid can constantly change at the metering point, on-line measurement is the only practical solution. Methods include weighing a tube or vessel through which the fluid is passing; measuring the buoyancy of a float totally immersed in the fluid and measuring the absorption of gamma rays from a radioactive source, through the fluid.

The most important class of density measuring devices is the vibrating element type, widely accepted as the most accurate form of on-line electronic density meter. In particular, the vibrating tube and vibrating spool density meters have been used widely, the former for liquids and the latter for liquids, liquid gases and gases.

The vibrating tube density meter maintains one or more tubes, in transverse oscillation by magnetic drive and pick-up coils, together with an electronic amplifier. The ends of each tube are clamped and the magnetic drive is to the centre, the frequency of oscillation being a function of the density of the fluid in the tube.

The vibrating spool density meter uses a shorter magnetic spool that is clamped at one end only. A drive coil causes the spool to oscillate and the movement is detected by a pickup coil, amplified, and the resulting signal applied to the drive coil as in the vibrating tube instrument. The oscillation is circumferential rather than transverse. The frequency of oscillation is again a function of the density of the fluid in the meter.

A development of the mechanical construction of the vibrating spool density meter enables the whole measuring element to be immersed in the process fluid. This is particularly successful in liquid/gas density measurement where it avoids the problems of temperature or pressure gradients that can occur with bypass systems. The meter can be installed through a blank flange or made retractable so that it may be removed without shutting down the process line.

VIBRATING ELEMENT DENSITOMETERS

The two types of vibrating element densitometers lend themselves to two separate applications.

A densitometer that can be inserted directly into the pipeline close to the turbine minimises the effects of any pressure and temperature gradients. If the meter itself has no pressure coefficient and a small temperature coefficient then the unit is best suited for liquified gases LNG, LPG, or condensates where the fluids are generally clean but small changes of pressure or temperature have a large effect on density.

Where the liquid to be measured is perhaps non-homogeneous, contains particles, sand and other impurities then a smooth bore tube is more suitable. The meter has no small clearances for the build-up of deposits on the measuring element. The vibrating tube meter gives a reading of the mass of the tube at any time regardless of its contents provided this is primarily liquid which will oscillate with the tube. Consequently it is less prone to problems with small amounts of bubbles, particules, slurry or mixtures such as oil with water. Crude oil is therefore a natural application for this type of meter.

FISCAL METERING SYSTEMS

When designing a density metering system several problem areas must considered

temperature effects
pressure effects
response time
maintenance
proving
gassing off

Let us consider all these problems on the metering of two completely different products

(a) crude oil
(b) LPG

CRUDE OIL METERING

(a) The vibrating tube densitometer is not currently available in a form which can be inserted in the line and so a suitable bypass loop must be designed. Figures 5, 6 and 7 show simple bypass systems which can be employed. The main difference between them is the method of generation of differential pressure. The greater this pressure the faster will be the response to any changes and so any temperature changes can also be slightly reduced.

A high integrity fiscal metering system often requires redundancy and/or comparison of two densitometers and so the skid may be required to accomodate two complete systems as per Figure 8. It may be necessary to go one stage further and supply a complete package including solvent tank for flushing either of the meters and a pyknometer to prove the meters. See figure 9.

Any difference between the turbine pressure and densitometer pressure is usually very small and hence causes a negligible change in density. However the same is not true for temperature and this should be considered more carefully. The temperature should be monitored at the densitometer to allow for corrections of the temperature effect on the meter itself. This gives accurate calculation of density at the densitometer temperature. If there is a different temperature at the turbine then volume correction factors may have to be applied to correct for this. It may also be a useful feature to generate an alarm on deviation of these two temperatures.

Another useful feature is a flow alarm to indicate if the pumps are running dry and increase their operational life.

Different manufacturers of vibrating tube densitometers suggest different operational positions depending on design. The single tube and double tube device is mounted vertically to allow any bubbles to pass straight through. A three tube system with 'S' shaped flow path is generally mounted horizontally to prevent air locking in any of the 180 degree curves.

LPG METERING

(b) The designer of the LPG measuring system has a much simpler task. As previously mentioned the temperature and pressure gradients between the turbine and the densitometer are kept to a minimum by use of a direct insertion meter close to the outlet of the turbine.

The response time of the meter is related to the flow rate and the type of filter used. The NBS Technical Notes 697 of October 1977 and 1055 of June 1982 evaluated different densitometers on liquid methane and liquid methane mixtures with ethane, propane, butane and nitrogen under cryogenic conditions. The conclusions are that vibrating element insertion densitometers are most suited to these applications and that a faster response is achievable without filters in the meter, bearing in mind that a more frequent maintenance schedule for cleaning would be required.

Removal of the insertion type of meter is available using a retraction device which means that the individual metering lines do not need to be isolated as each meter is fitted with a ball or gate valve.

ETHYLENE MEASUREMENT

The requirements for ethylene measurement are very similar to that of LPG and are best achieved with an insertion densitometer. Several evaluations have been carried out by various companies and institutions. One such evaluation, the "Industry Ethylene Measurement Project - Final Report to the Steering Committee", compared the performance of densitometers with the calculated density using pressure and temperature and the API table 2565. This shows that densitometers can perform accurately over a wide range of densities. Once again consideration is required for positioning of the densitometer as ethylene close to the critical condition has a very large temperature and pressure coefficient.

PROVING OF DENSITOMETERS

At the moment there are very few, proven, accurate and repeatable methods of proving of this 'type' of densitometers although improvements have been made recently in the design of pyknometers. If the product is pure then tables can be used as a first order check.

A paper was given at the Norflow 83 symposium in Aberdeen detailing the problems a North Sea operator has using a pyknometer. Once the problems were identified and an operational procedure laid down then a pyknometer when used in this way is a satisfactory method.

Other options are being investigated at the moment by another North Sea operator. This involves a Transfer Standard Densitometer. For it to be suitable for Offshore use the unit that has been supplied by Sarasota is mounted in a purpose-built insulated carrying case with handles. This allows transportation between platforms. For simple coupling up to existing pipework the unit is fitted with quick fit connectors. As a result of these tests on the Sarasota unit (and other manufacturers' also) a decision will be made as to whether the concept is feasible and practical. It is then likely that a procedure will be written and then adopted as an alternative to pyknometers for the proving of densitometers on fiscal metering systems.

FACTORY CALIBRATION OF DENSITOMETERS

An alternative to on-line checking of densitometers is to return the units to the manufacturing factory for re-certification. Consequently the calibration facility must be equipped with certified equipment traceable to the various standards. This subject in itself is worthy of a separate paper.

The normal method is to measure the upthrust on a silica (low temperature coefficient) body totally immersed in the fluid which is flowing through the meter. This means that the temperature must be monitored at both the meter and the measurement tank to ensure no variation. Temperature must be measured to an accuracy of 0.01 degrees C if the density is to be determined to 0.1 kg/m^3. It is desirable to calibrate each densitometer against the silica body so as to avoid any cumulative errors if another densitometer is used as a transfer standard. Mixtures of hydrocarbon fluids are used and a full calibration using a 15 point calibration including hysterois takes nearly three days. This also includes the calculation of the temperature and pressure coefficients of the meter. Consequently the system has to be computer controlled and automatic. Up to six meters can be calibrated at the same time and a temperature controller ensures equalisation and stable conditions. A hydraulic ram allows data to be taken at elevated pressure.

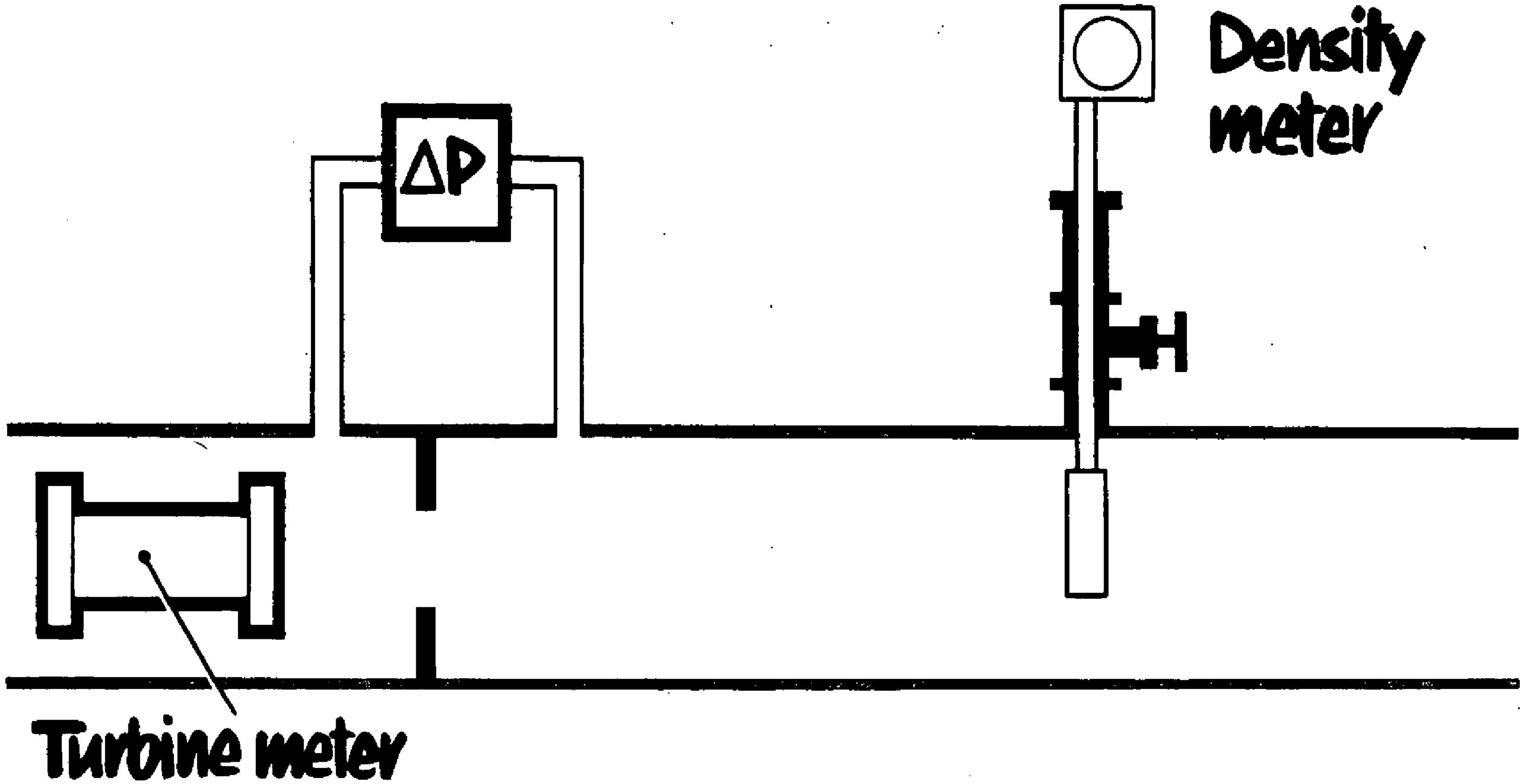
At the end of these tests calibration certificates are produced indicating the calibration data and whether it falls in the specified accuracy.

CONCLUSION

Vibrating element densitometers are an essential part of mass flow metering systems. The system designer must observe the procedures currently adopted by operators which have been developed as a result of many years' experience.

The proving of densitometers in situ is not easy to achieve with a high degree of accuracy. This is borne out by the fact that manufacturers have found it involves a large capital outlay on a suitable laboratory and system to produce accurate calibration.

Quantity Measurement



$$M = K\sqrt{\Delta P \times \rho}$$

or $M = V \times \rho$

FIG. 1

Principle of operation

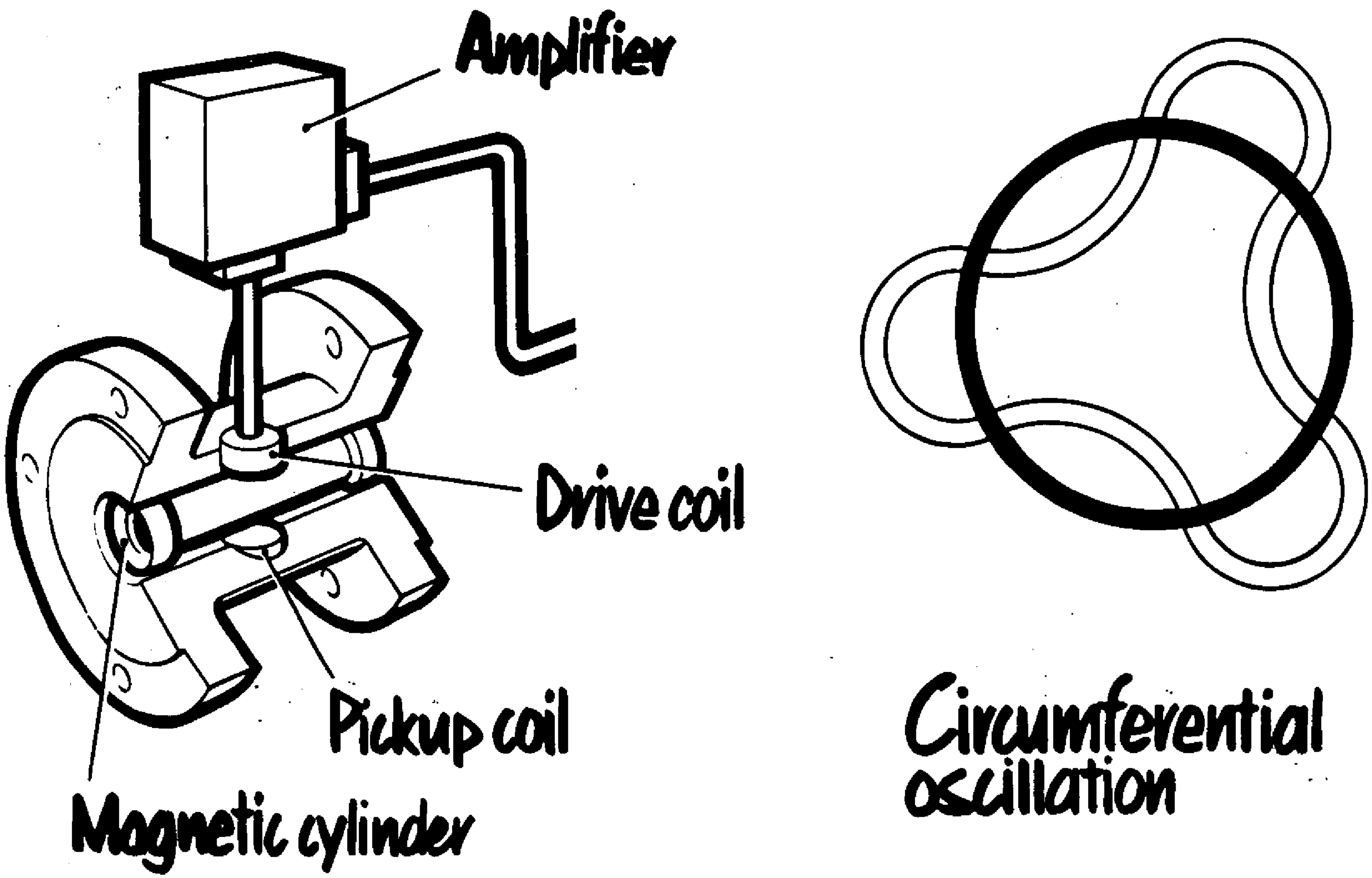


FIG. 2

FD 800 SCHEMATIC

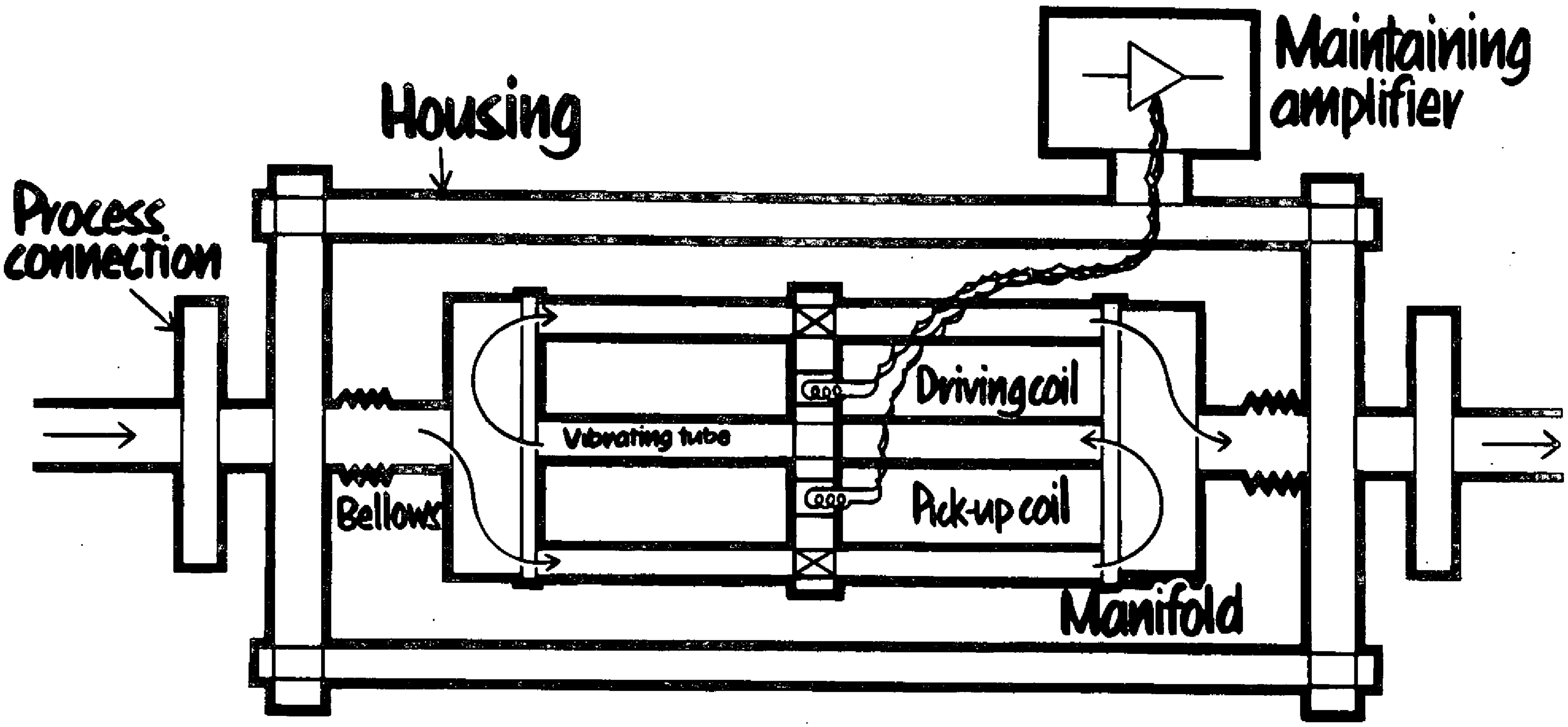
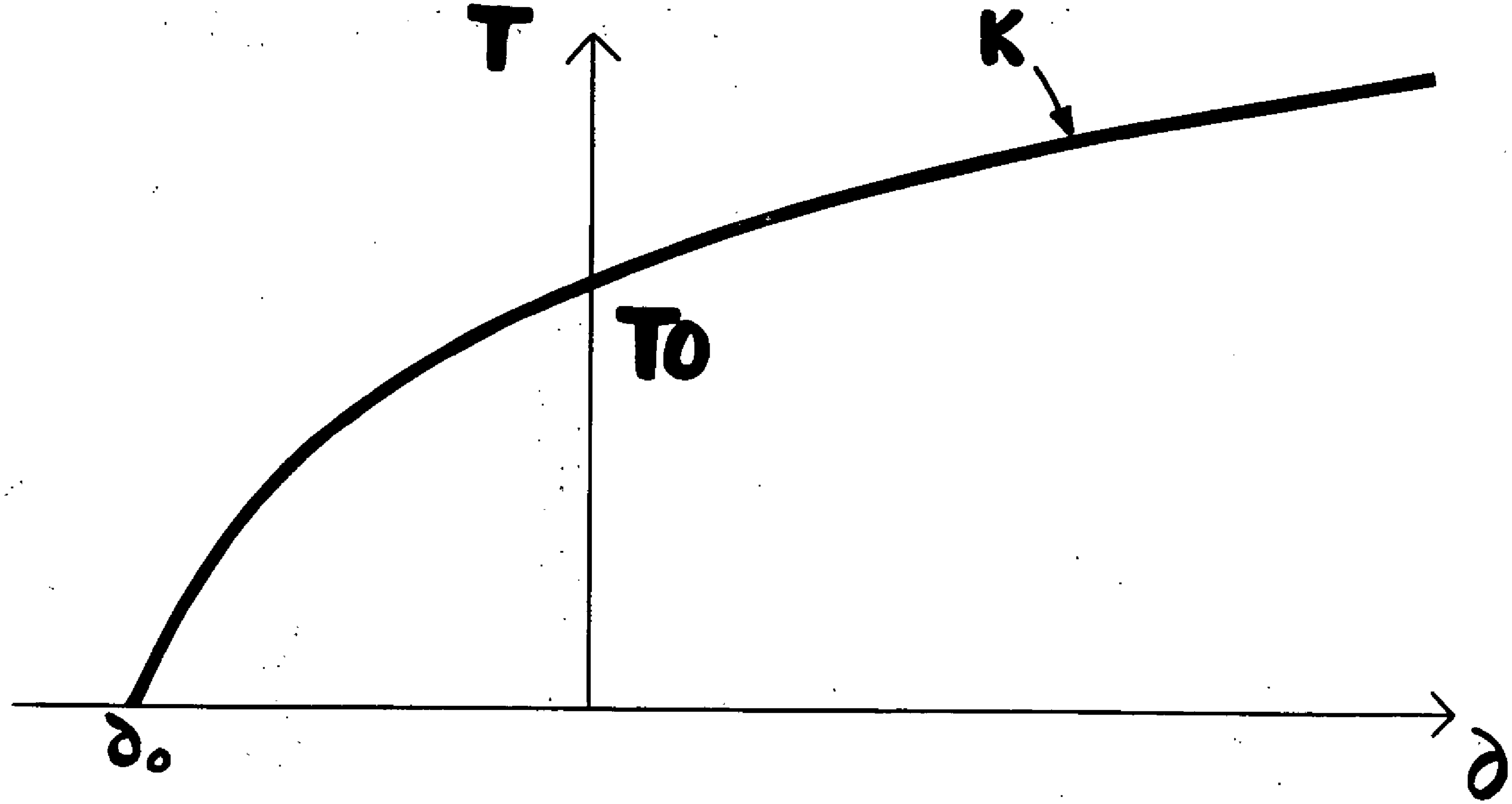


FIG . 3

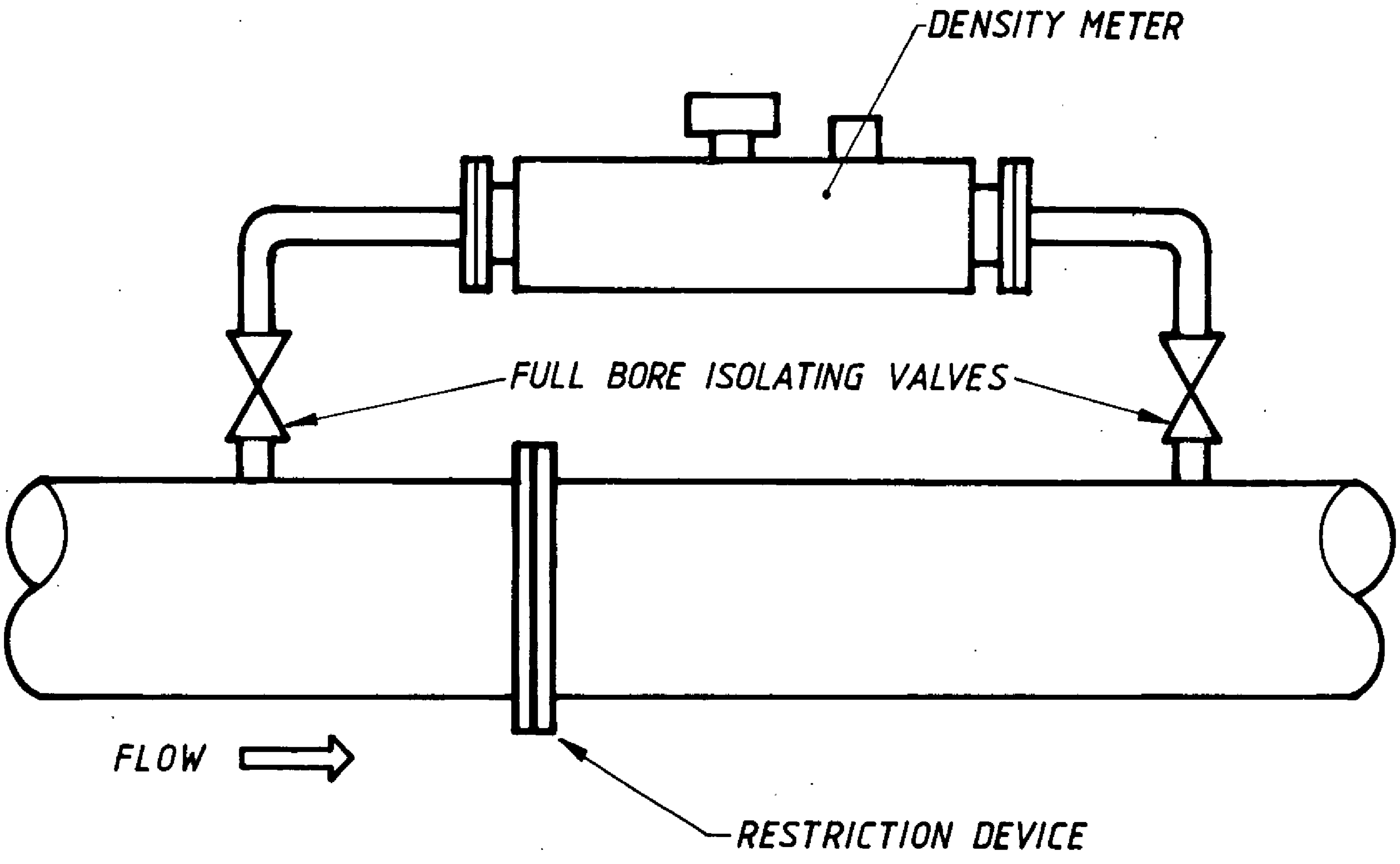
Transducer law



$$\partial = 2\partial_0 \frac{(T-T_0)}{T_0}\left[1+\frac{K}{2}\frac{(T-T_0)}{T_0}\right]$$

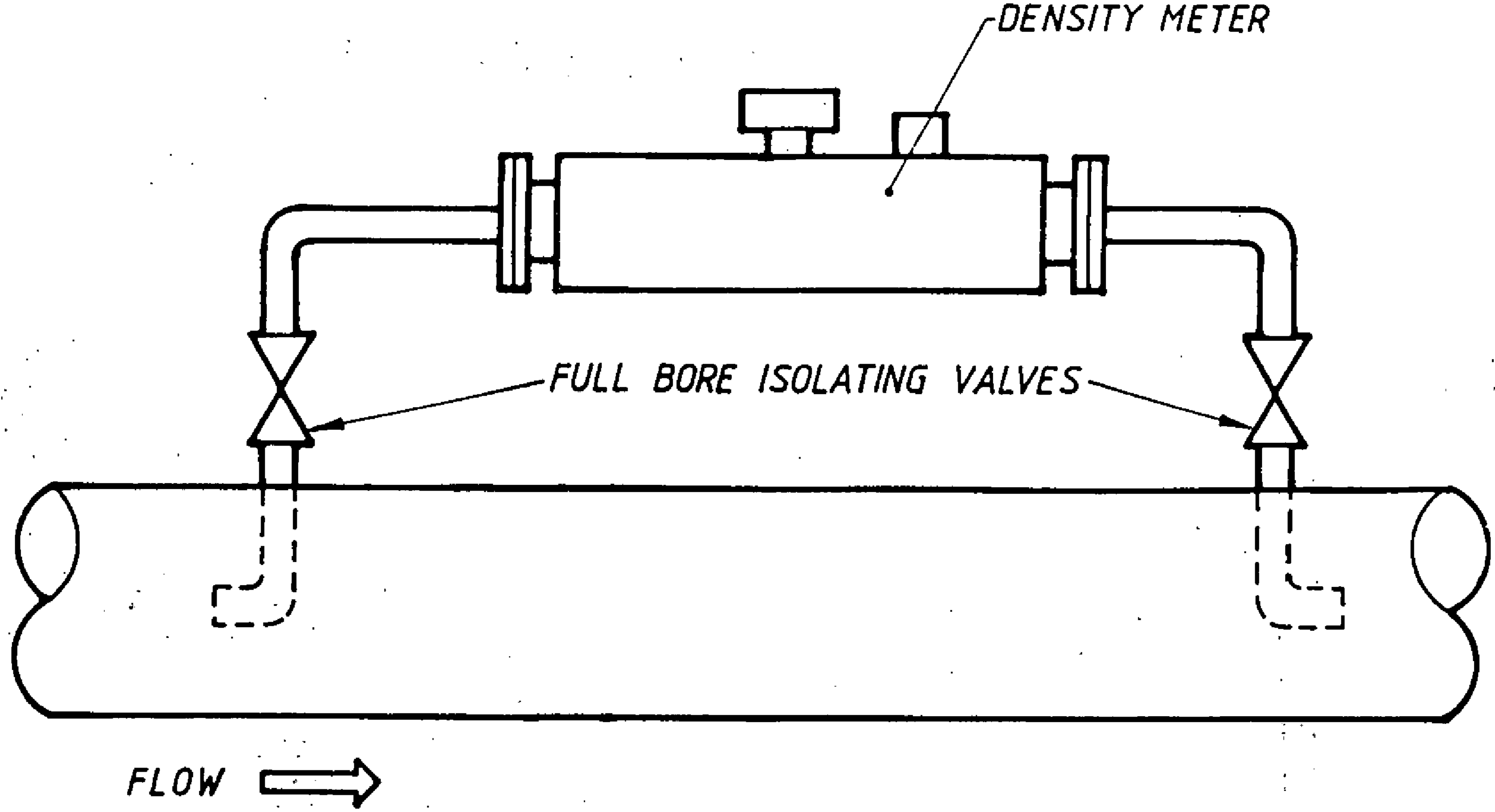
$$\Rightarrow \partial = A + BT + CT^2$$

FIG. 4



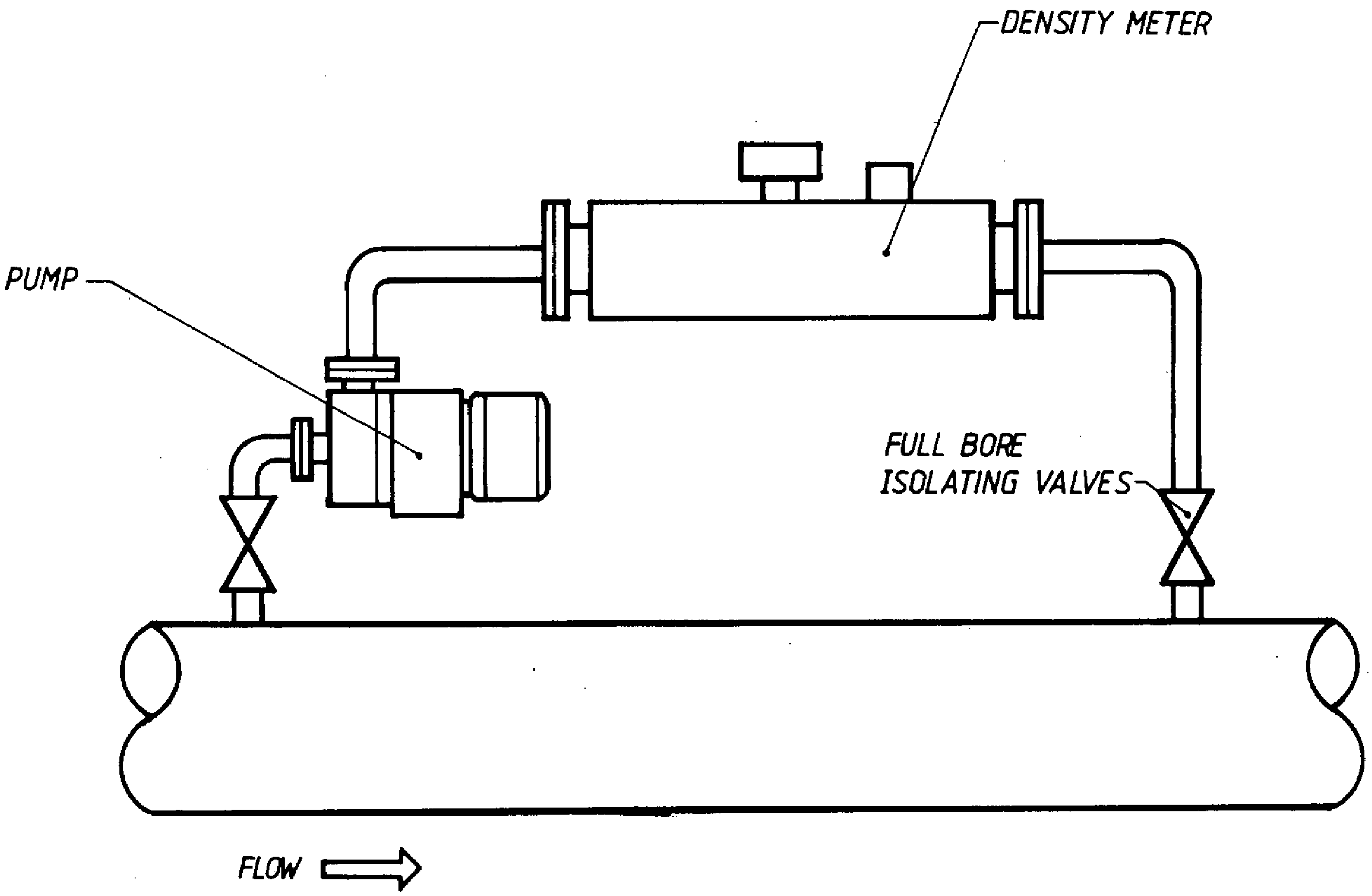
A RESTRICTION DEVICE TO CREATE A PRESSURE DIFFERENTIAL

FIG . 5



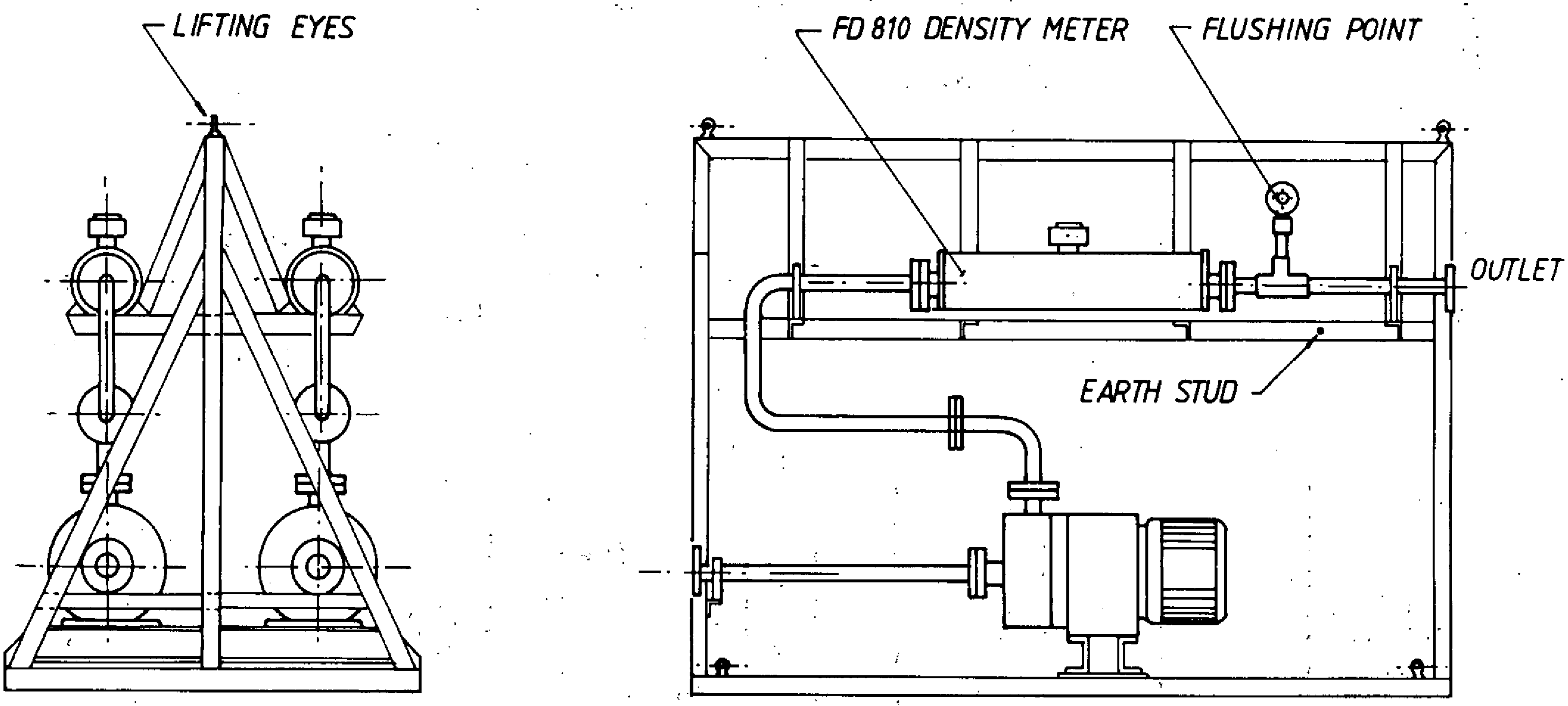
INSTALLATION WITH PITOT TUBE SCOOPS

FIG. 6

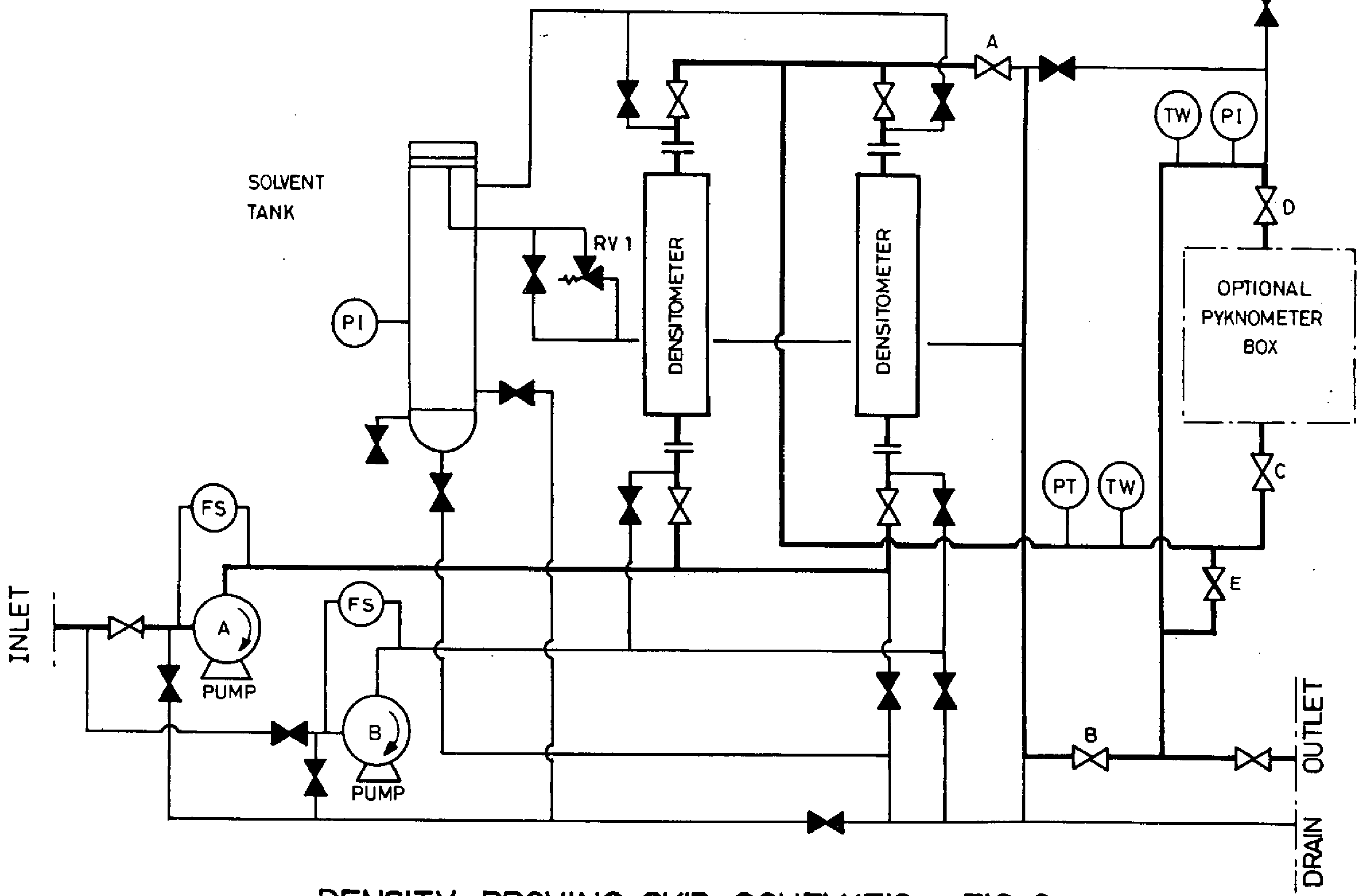


INSTALLATION WITH PUMP

FIG .7



DUAL SYSTEM SKID FIG. 8



DENSITY PROVING SKID SCHEMATIC FIG. 9

Insertion meter

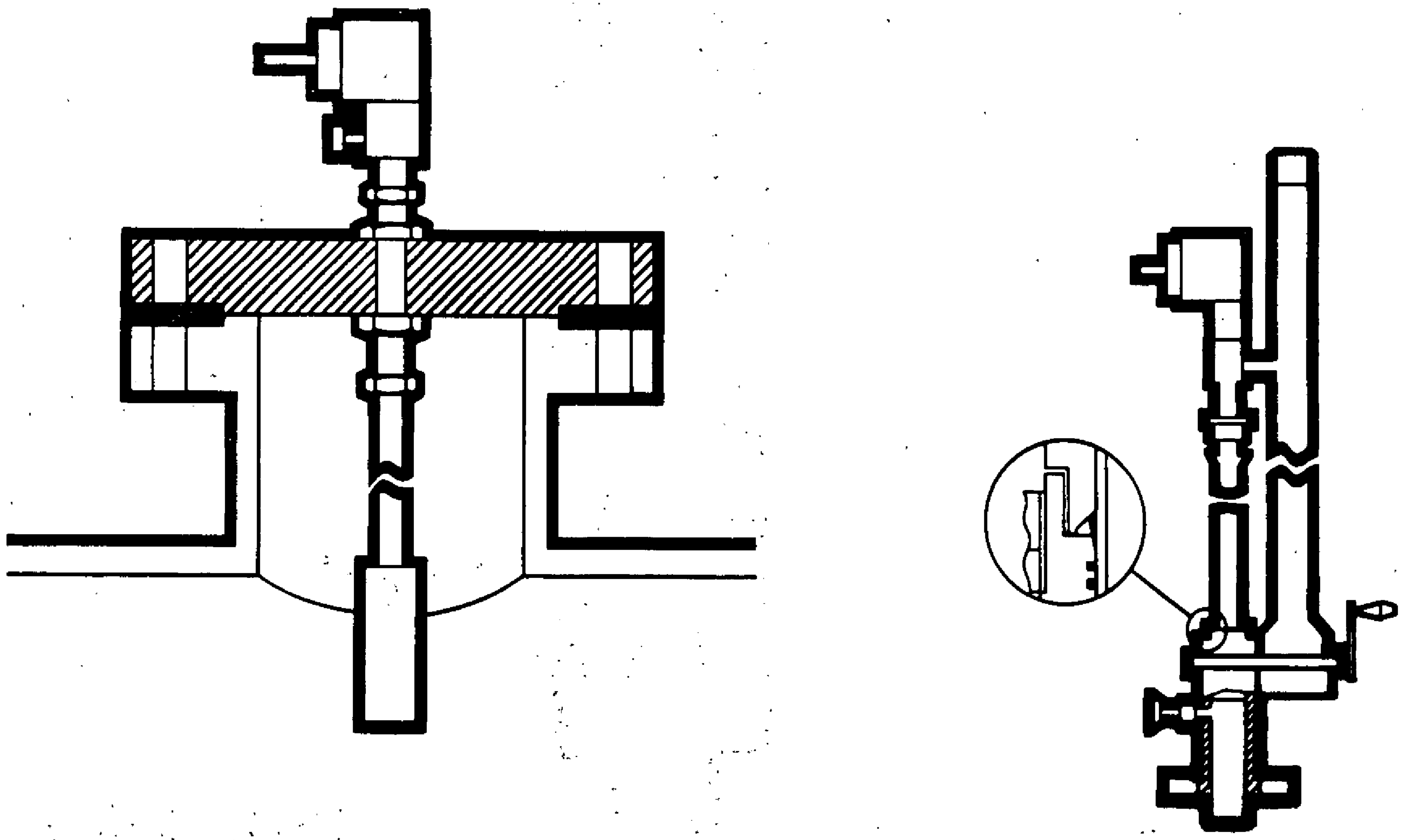
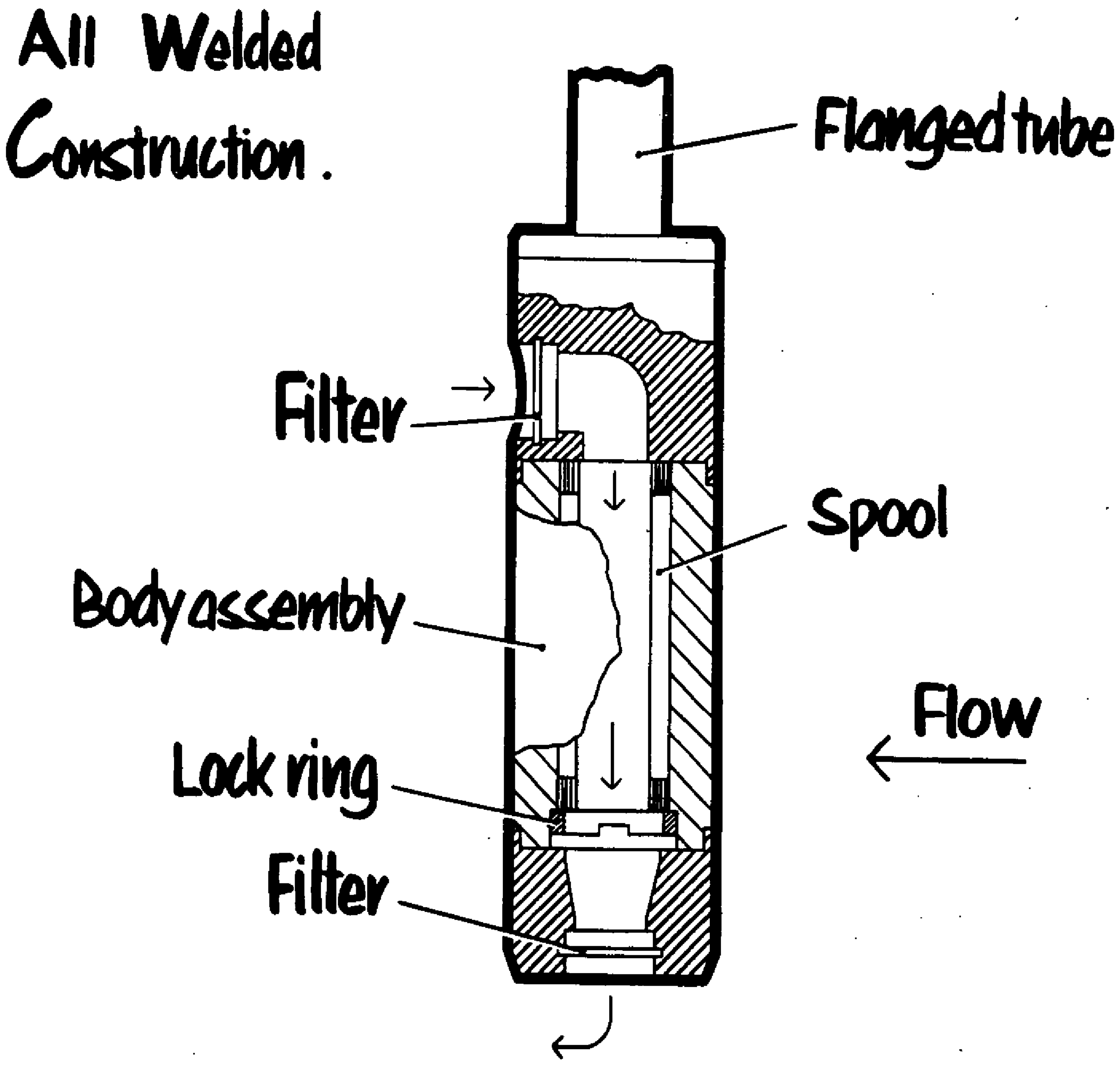
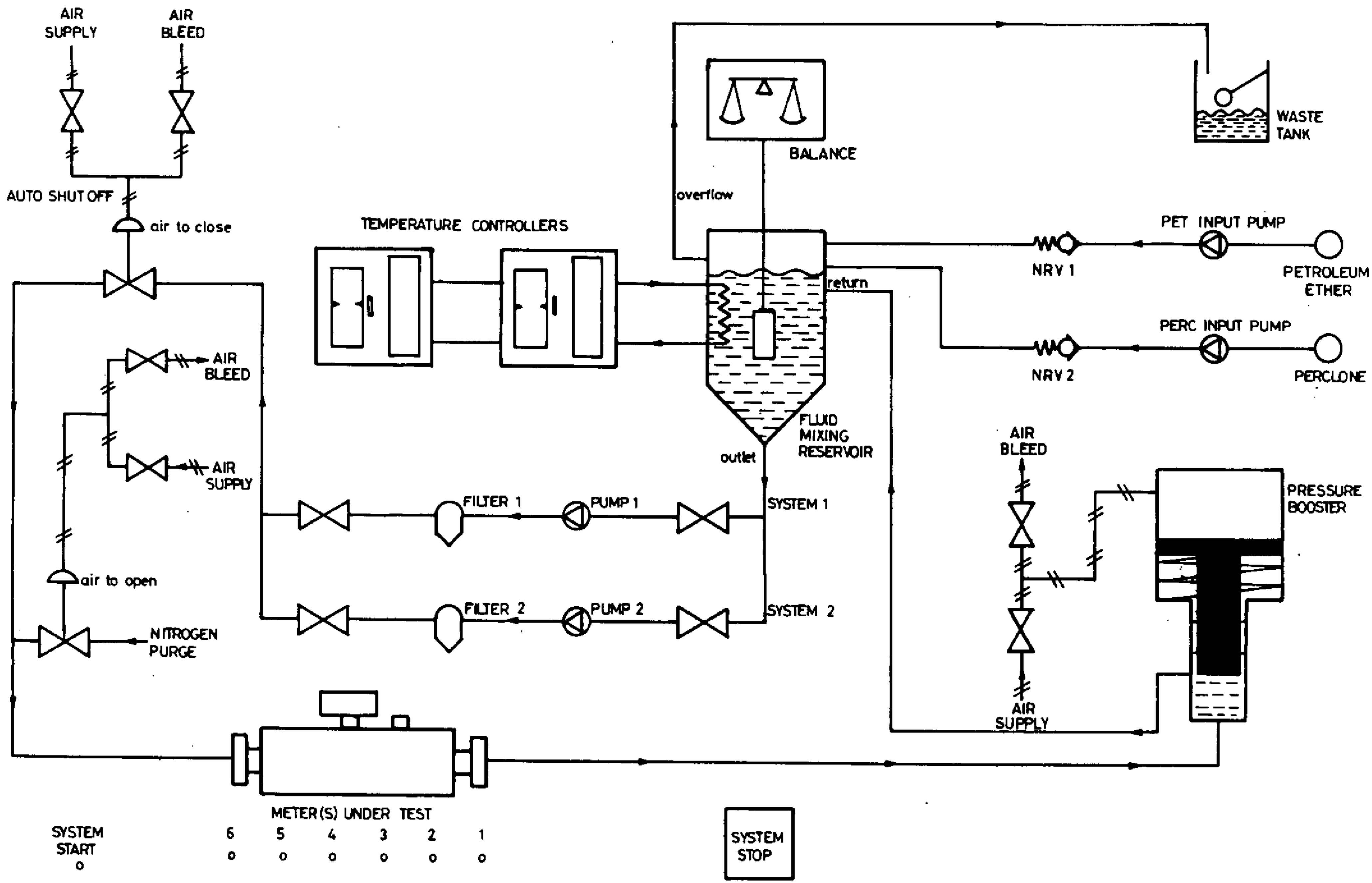


FIG . 10



INSERTION DENSITY METER SCHEMATIC FIG. 11



AUTOMATIC DENSITY METER CALIBRATION UNIT   FIG . 12

References

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

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