Group Project On

EXPERIMENTAL AND MEASUREMENT METHODS

By

GROUP 2

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Abstract

This work is a summary of descriptions, operating principles, advantages, limitations, accuracies and the range of measurements of the appropriate instruments for the direct or indirect measurement of temperature, pressure, flow rate and gas quality in natural gas flow systems.

The temperature measuring devices are summarized first. In the chapter for this, an attempt has been made to establish, initially, an essential understanding of temperature measurement by discussing four fundamental temperature scales: Fahrenheit scale, Celsius scale, Kelvin scale and Rankine scale. Consequently, conversion correlations among temperature scales have been stated, in accordance with the International System (SI) measurement, ITS- 1990, and temperature measurement has been broadly classified into Contacted Approach and Non-contacted Approach. Thereafter, the operating methodologies of the temperature measurement instruments were concisely outlined. For the Contacted category of temperature measurement instruments, thermometry types are discussed according to the basic underlying principle that is used by the device for measurement. Consequently, concepts of the Expansion of Solids, Liquid and Gases and the theory of Phase Changes have been discussed. Regarding the Non-contacted class, the underlying principles highlighted include electricity, radiation and optical pyrometry. In addition to the above, the mode of operation and fundamental principles governing the operation of each temperature measurement method/device, and their areas of applications, degrees of accuracy and measurement ranges were summarised in this chapter.

Following the Temperature Measurement chapter is the section which, similarly, summarises the devices for measuring pressure in natural gas systems. This next chapter classifies pressure measurement into Direct and Indirect Measurements. While the former refers to the process of obtaining pressure from the basic definition of “force per unit area” and conversion of the liquid head to pressure, indirect measurement of pressure refers to the use of instruments called pressure gauges to measure pressure. Based on their operating principles, pressure gauges were classified as Liquid Column Gauges or Manometers, Force-Balance Gauges and Pressure Transducers. Different examples of instruments were “x-rayed” from each of those classifications with specific emphasis on their mode of operation, underlying principles, areas of application, pros and cons, precisions and range of measurements.

Flow rate measurement was discussed in the third chapter. Like the previous two sections, this chapter focuses on the principles and devices employed in measuring the gas flow rate in natural gas systems in the gas industry. Flow meters that were treated range from laboratory instruments and domestic meters to those in high-pressure transmission lines used by producers and suppliers. For each device, all specifications, working principle, best-suited tasks, strengths, limitations and range of application are summarised. The devices are presented in two categories according to their operating principles: (i) those that add energy to the flow and; (ii) those that extract energy from it. Up to 12 different flow meters are discussed.

The last section relates to Natural Gas quality measurement. Gas quality is determined by the gas composition, components and key parameters that make up a gas, it is also referred to as the caloric value of the gas, which is the amount of energy obtained by the complete combustion of a unit volume of that gas. Factors such as impurities, Water, Sulphur content through Hydrogen Sulphide (H2S), inert gases, C02 and gas density affect the gas quality. It is worthy to note that; since the consumer is not paying for the quantity but the quality of the gas, referencing conditions do apply in gas sales agreements and national gas grid specifications by different countries. Gas quality measurements, therefore, aim to meet such referencing conditions by establishing the quantity of the earlier-mentioned components that are present in the gas stream. This section, therefore, like the others, summarizes the instruments for measuring the quantity of different natural gas components with emphasis on their mode and areas of operation, pros and cons, precisions and range of applicability.

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Chapter 1 TemperatureMeasurement

In this chapter, we will attempt to establish a basic understanding of temperature measurement. This will feature general temperature measurement methods, identify major temperature measurement systems that are used in the gas industry, explain the principle behind them and state their areas of application.

1.1 Introduction

The sensation of hot and cold are fundamental to the human experience. It is also an imperative parameter in the Engineering field. The methods of measuring temperature have challenged many great minds because it is not easy to define temperature using practical methodologies. Therefore, it tends to be described with words such as cold or hot; such that objects at low temperatures are said to be “cold” while those at high temperatures are termed “hot”. (Nasr & Connor, 2014).

According to Nasr & Connor, 2014, it is not a scientific measurement practice to state that an object is hot or cold. There are scientific methodologies in place that can be used to establish the measurement of temperature accurately by taking advantage of the different responses of different materials to temperature changes.

Nevertheless, since the temperature of an object or a body is a measure of the hotness or coldness of the body, it can be defined as a property that determines the rate at which heat will be transferred from the body or added to it. Therefore, temperature is a measure of the kinetic energy of atoms, molecules or ions of which matter is composed. Units of temperature can be Rankine (R), Celsius or Centigrade (℃), Kalvin(K) or Fahrenheit (°F). (Baierlein, 1999).

1.1.1 Brief History of Temperature Measurement

Currently, it seems natural to express temperature in digits. But, the concept of assigning numbers to temperatures is only a few centuries old. Early thermometers, along with most of those that are in use today, were based on the same principle. For instance, most substances expand as they are heated, but the extent of expansion differs for different materials. For example, glass expands only slightly when it's heated, while mercury and alcohol expend much more for the same increase in temperature. (Baierlein, 1999).

Anders Celsius and Daniel Fahrenheit, are two scientists of the17th century who lived in the same era, although it is not evident that they met each other, they both lived during a time of great scientific opportunity in Europe. Celsius was fifteen years younger than Fahrenheit. These two laid the foundation of temperature measurement in scales; such as the Kelvin scale which is approved and recognised internationally. (Finn, 1986).

The first international temperature scale was established in 1927. Thereafter, a series of temperature range and precision improvement followed up to the adoption of the International Temperature Scale of 1990 (ITS- 1990), in which the Kelvin scale was approved as an international standard for scientific temperature measurement. The letter "K" is the symbol for the Kelvin scale (Sparcklin, 1993).

Figure 1.1: Lord Kelvin (Right), Anders Celsius (Centre) and Daniel Gabriel Fahrenheit (Left). (Bewick, et al., 2016).

1.2 Temperature Scales

The four most common temperature scales in Science and Engineering and correlations for conversion among them are treated in this section.

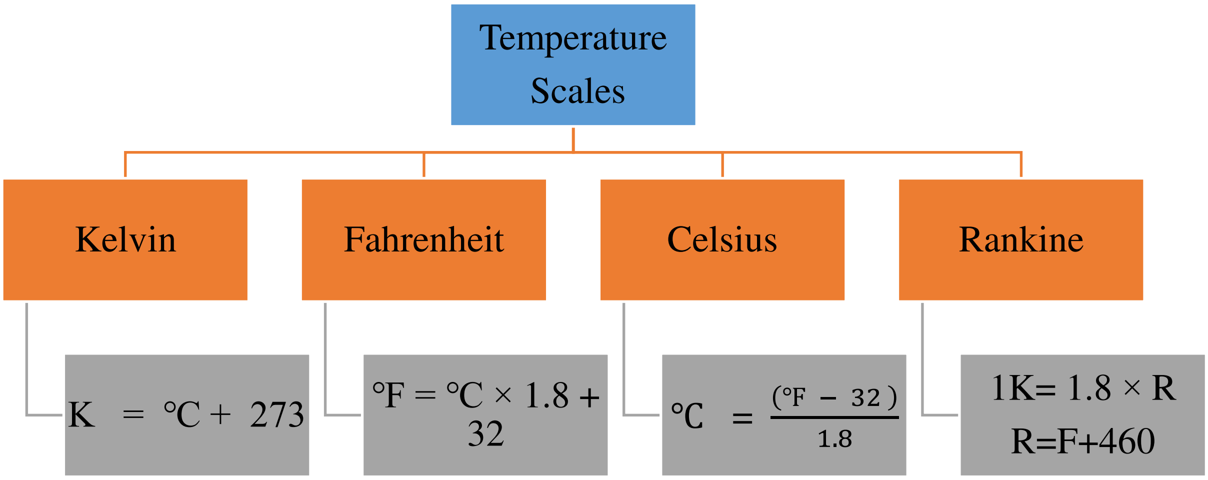

Figure 1.2: Diagram of Temperature Scales.

Figure 1.3: International System (SI) of Measurements. (NLP, 2014).

1.2.1 Celsius Scale

This scale was laid out by Andres Celsius. It is also referred to as the centigrade scale. He used a two-point scale to define the melting point of ice, at atmospheric pressure and the boiling point of water at atmospheric pressure by assigning 0 °C for the melting point of ice at atmospheric pressure, and 100 °C for the boiling point of water at atmospheric pressure. He divided the temperature intervals into 100 units from which he produced the temperature scale illustrated in Figure (1-3). Therefore, the freezing point of water is 0 °C or (32°F), and the boiling point of water is 100°C or (212°F). (Baierlein, 1999).

1.2.2 Fahrenheit Scale

Fahrenheit established three fixed points on his thermometer. The first point, marked zero degrees, was set as the temperature of an ice, water and salt mixture. As he omitted salt from the slurry, the second fixed point was reached when the water-ice mixture stabilised and set as thirty degrees. His third fixed point was marked at ninety-six degrees.

Scientists have gone ahead to recalibrated Fahrenheit's model of the thermometer, after he died, such that water boils at a temperature of 212 Degrees Fahrenheit and the normal human body temperature reading was adjusted and registered as98.6 degrees instead of 96 degrees.

1.2.3 Kelvin scale (Thermodynamics Temperature Scale)

Kelvin temperature scale is in the International System (SI) of measurement as stated in Figure (1-3). It is the temperature scale of thermodynamic temperature measurements. It is an absolute temperature scale named after a British physicist – William Thompson, Baron Kelvin. (BIPM, 2014).

1.2.4 Rankine Scale

Rankine scale is named after the Scottish scientist William Macquorn Rankine. Rankine scale is like the Kelvin scale whereby the zero is absolute zero. Conversion of Rankine temperature values to Kelvin temperature values and other temperature scales are stated in Table (1-1). (NLP, 2014).

Table 1.1: Boiling and Freezing Point of Water from Temperature Scales. (NLP, 2018).

TEMPERATURE SCALE	BOILING POINT OF WATER	FREEZING POINT OF WATER	ABSOLUTE ZERO	TRIPLE POINT OF WATER
Fahrenheit	212 °F	32 °F	- 460 °F	32 °F
Celsius	100 ℃	0 ℃	− 273.15 ℃	0 ℃
Kelvin	373.15 K	273.15 K	0 K	273.15 K
Rankine	671. 67 R	491.67 R	0 R	491.67 R

Conversion between temperature scales can also be done, by using the following expressions:

Celsius (℃) to Fahrenheit, (°F):

$$°F = ℃ \times 1.8 + 32 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1.1)}$$

Fahrenheit (°F) to Celsius (℃):

$$℃ = \frac{(°F - 32)}{1.8} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.2)}$$

Celsius (℃) to Kelvin (k):

$$K = ℃ + 273.15 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.3)}$$

Kelvin (K) to Rankine (R):

$$1K = 1.8 \times R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.4)}$$

1.3 Temperature Measurement Methods

Temperature measurement is an imperative parameter to be physically quantified. Hence, there are different methods of temperature measurement across industries. Principally, there are three major methods of temperature measurement as stated below (NLP, 2014).

1. Mechanical Methods.
2. Electrical Methods.
3. Radiation Methods.

Generally, the three methods of temperature measurement listed above can be characterised into the two categories given below:

1. Contacted Temperature measurement.
2. Non-contacted Temperature measurement.

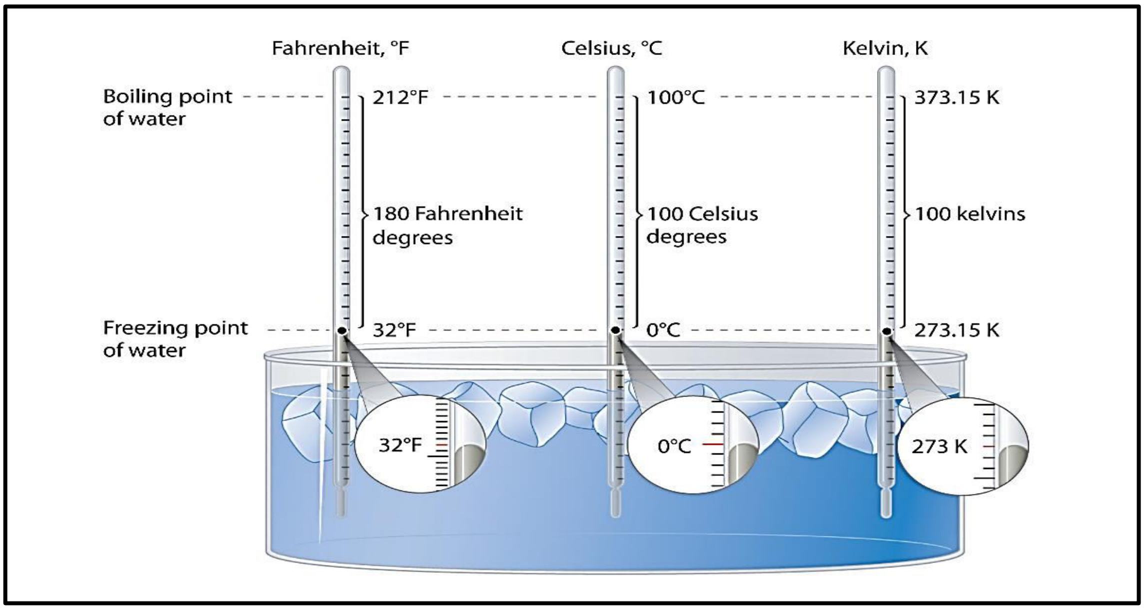

Figure 1.4: Comparison among Celsius, Fahrenheit and Kelvin Temperature Scales. (Bewick, et al., 2016).

1.4 Thermometry

Thermometry is the science and practice of temperature measurement. Several instruments are used in different methods to measure temperature, in industries. A temperature measuring device, or a thermometer, uses the change in the property of a substance with temperature to indicate the value of the temperature of that substance.

1.4.1 Expansion Thermometers

Expansion thermometers can be classified into four categories, namely: solid expansion, liquid expansion, gas expansion and state of gas. The following sections further discuss these four classifications.

1.4.1.1 Solid Expansion Thermometry

Bi-metallic devices are examples of expansion thermometers. See Appendix A-1.

Principle:

Bi-metallic devices measure temperature using two metal strips, each metal having different thermal expansion coefficient. These metals are bonded together and mechanically linked to a pointer. As the metals are heated, one side of the bi-metallic strip expands further than the second metal, the expansion is indicated by the pointer which slides across a calibrated scale. (Areej, 2018).

Bimetallic strips can also be spirally wounded or helical. The type employed depends on the sensor's size and the temperature range that is required to be measured.

Advantages:

- Independent of power supply.
- Portability.
- Inexpensive.
- Rugged.

Disadvantages:

- Usually not accurate as electrical devices.
- Temperature range is limited.
- Impossible to remotely operate.

Application:

They are most commonly used:

- in household thermostats.
- in circuit breakers.

1.4.1.2 Liquids Expansion Thermometers

Mercury-in-glass thermometers are typical examples of liquid expansion thermometers. Many of the current Glass tube thermometers use other fluids rather than mercury due to the hazard of spilling mercury. (Areej, 2018).

Description:

It consists of a glass tube of a very fine bore, joined to a reservoir at the lower-end but sealed at the top. As the thermometer is heated the mercury expands, but the glass is not expanding at the rate of mercury, the mercury is, therefore, forced to rise along fine bore in the calibrated glass tube from which temperature readings are taken. A typical liquid in glass thermometer is illustrated in Appendix A-2.

Range:

- -200°C to 600 °C.

Advantages:

- Inexpensive
- Portability.

Disadvantages:

- Usually not accurate as electrical devices.
- Temperature range limited.
- Reading temperature value impossible to remotely operate.

Application:

Most commonly used:

- In Medicine.
- In Metrology.
- In industry.

1.4.1.3 Gas Thermometers

Gas thermometers utilise gases as their thermometric fluids. Gases used include Helium and Hydrogen. Temperature variations are indicated by measuring the pressure exerted by an exact amount of gas that is enclosed in a constant volume (Areej, 2018).

1.4.2 Electrical Means of Temperature Measurement

Mercury and spirit-filled thermometers have largely given way to electrical instruments, or Thermocouples, in the modern world.

1.4.2.1 Thermocouples

Thermocouples are extensively used in industries for temperature measurement. They measure temperature using differences in voltage since temperature is directly proportional to voltage.

Thermocouples are placed inside metallic, glass or ceramic shields to protect them from exposure to the environment. (Admin, 2018).

Description:

Thermocouples are composed of two dissimilar wires which are welded together in a bead. The junction shown in Appendix A-3 can be large or small depending on its application requirements. The measurement of temperature occurs at the interface between the two different metals shown in Appendix A-3.

Thermocouples are manufactured with a variety of materials. But each material has a different characteristic in terms of the range of voltage and temperature. The voltage produced by thermocouple normally is small, which is measured in the millivolt range.

Types J, T, and K are the most common types of thermocouples that are typically used in the industry. Type J is the most predominant of them. But, in recent years, the type J has been replaced with type T and K due to maintenance issues with iron wires and corrosion of iron connection.

Table 1.2: COMMON TYPES OF THERMOCOUPLES (NPL, 2014)

TYPE	MATERIALS	MIN TEMP	MAX TEMP.	MIN. °C	MAX. °C
J	Iron Constantan (Cu-Ni)	0°C	750°C	0 mV	42.281 mV
T	Copper Constantan (Cu-Ni)	-250°C	350°C	-6.18 mV	17.819 mV
K	Cromel (Ni-Cr) Alumel (Ni- Al)	-200°C	1250°C	-5.891 mV	50.644 mV
E	Cromel (Ni-Cr) Constantan (Cu-Ni)	-200°C	900°C	-8.825 mV	68.787 mV
N	Nicrosil (Ni-Cr-Si) NiSil (Ni-Si-Mg)	-260°C	1300°C	-4.336 mV	47.513 mV
S	Platinum-13% Rhodium Platinum	-50°C	1768°C	-0.236 mV	18.693 mV
B	Platinum-30% Rhodium Platinum-6% Rhodium	0°C	1820°C	0 mV	13.82 mV
C	Tungsten-5% Rhenium Tungsten-26% Rhenium	0°C	2320°C	0 mV	37.107 mV

1.4.3 RadiativeTemperatureMeasurement Device

Radiative temperature measurement devices are classified into two categories:

- Infrared Pyrometers.
- OpticalPyrometers.

1.4.3.1 Infrared Pyrometers

These are infrared radiation devices which are used for measuring temperatures of moving or distant objects using infrared temperature sensors. This type of measurement is advantageous where contacted temperature measurement devices are impossible or impractical to use. For instance, the targeted object may be inaccessible or too hot to be contacted. A typical infrared pyrometer schematic is illustrated in Appendix A-4 and a picture of one is shown in Appendix A-5. (NPL, 2018).

Principle of Operation:

These devices utilize the fact that an object emits an amount of energy which is a function of its temperature to determine the temperature of the distant objects. In other words, infrared temperature sensors determine temperatures by measuring the intensity of energy that is given off by an object.

However, the quantity of energy emitted by an object is not just a function of temperature. Another important factor is the emissivity of the body. This is an intrinsic surface characteristic that fluctuates with the following surface characteristics:

- Modification in oxidisation of surface.
- The texture of the surface.
- Composition.
- Microstructure.

Range:

- Very high temperatures.

Advantages:

- Non-contacted measurement at high temperatures.
- Measurement of temperatures of moving objects.

Disadvantages:

- The high cost of installation.
- Infrared radiation sensitive.
- Inaccuracy occurs due to emissivity of many physical bodies.

Application:

Most commonly used:

- Furnaces.
- In assembly lines.

1.4.3.2 Optical Pyrometers.

In an optical pyrometer, a telescope system is used to focus on the object that the temperature is to be measured. Typical optical pyrometer design Features are illustrated in Appendix A-6 and a typical optical pyrometer is shown in Appendix A-7.

Optical Pyrometers Operating Principles:

Optical pyrometers measure temperature by comparing the brightness of the image produced by temperature sources with that of a reference temperature lamp. ("Optical pyrometer (Disappearing filament Type) " n.d.).

Range:

- High temperatures.

Advantages:

- Accurate
- Non-contacted measurement at very high temperature.

Disadvantages:

- Expensive.
- Infrared radiation sensitive.
- Inaccuracy due to emissivity of many physical bodies.

Application:

Most commonly used:

- In high temperature moving objects, such as industrial of molten steel, molten glass and temperature measurement of flare.

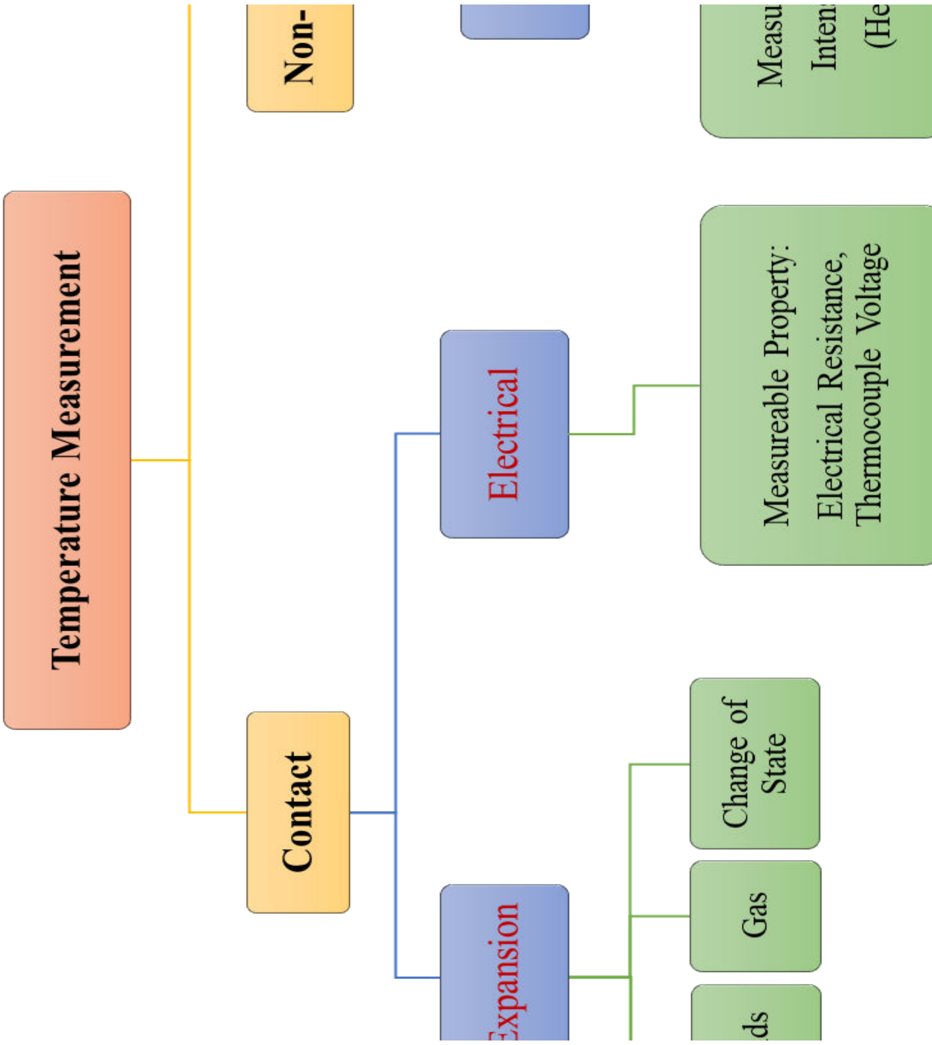

Figure 1.5: Summary of Temperature Measurement Methods (N.L.P., 2005)

Chapter 2 Pressure Measurement

2.1 Introduction

Pressure is the ratio of force to the unit area. In SI, it is measured in Pascal (N/m^2). In Metric Standard Conditions (MSC), it is measured in bar (1bar equals 101325Pa).

Absolute Pressure is the prevailing pressure less the pressure in a complete vacuum.

Differential Pressure simply refers to pressure difference.

Gauge pressure refers to the difference between the prevailing pressure and atmospheric pressure. Figure (2-1) classifies pressure measuring instruments in gas systems.

2.2 Liquid-column Pressure Gauges (MANOMETERS)

2.2.1 U-tube Manometers

Description: U-tube manometers measure pressure close to atmospheric pressure. They are basic in design with mercury as the usual manometric fluid because mercury is very heavy and vaporizes at low pressure (Nasr & Connor, 2014).

Mode of Operation: Pressure is indicated as a height difference between the levels of the manometric fluid in two arms of a U-tube glass as shown in the figure below. In Appendix B-1, the pressure in the gas column (ΔP) is given by:

$$\Delta P = P_{gi} - P_{atm} = gh(\rho_{Hg}) \quad \textbf{(2.1)}$$

$Where$:

$\boldsymbol{g}$, $is\ acceleration\ due\ to\ gravity.$, and

$\boldsymbol{\rho_{Hg}}$, $is\ the\ density\ of\ mercury.$

Advantages: They are cheap yet have high accuracy and sensitivity and can be employed to measure other quantities.

Disadvantages: They are temperature-sensitive and parallax errors can easily happen with their usage.

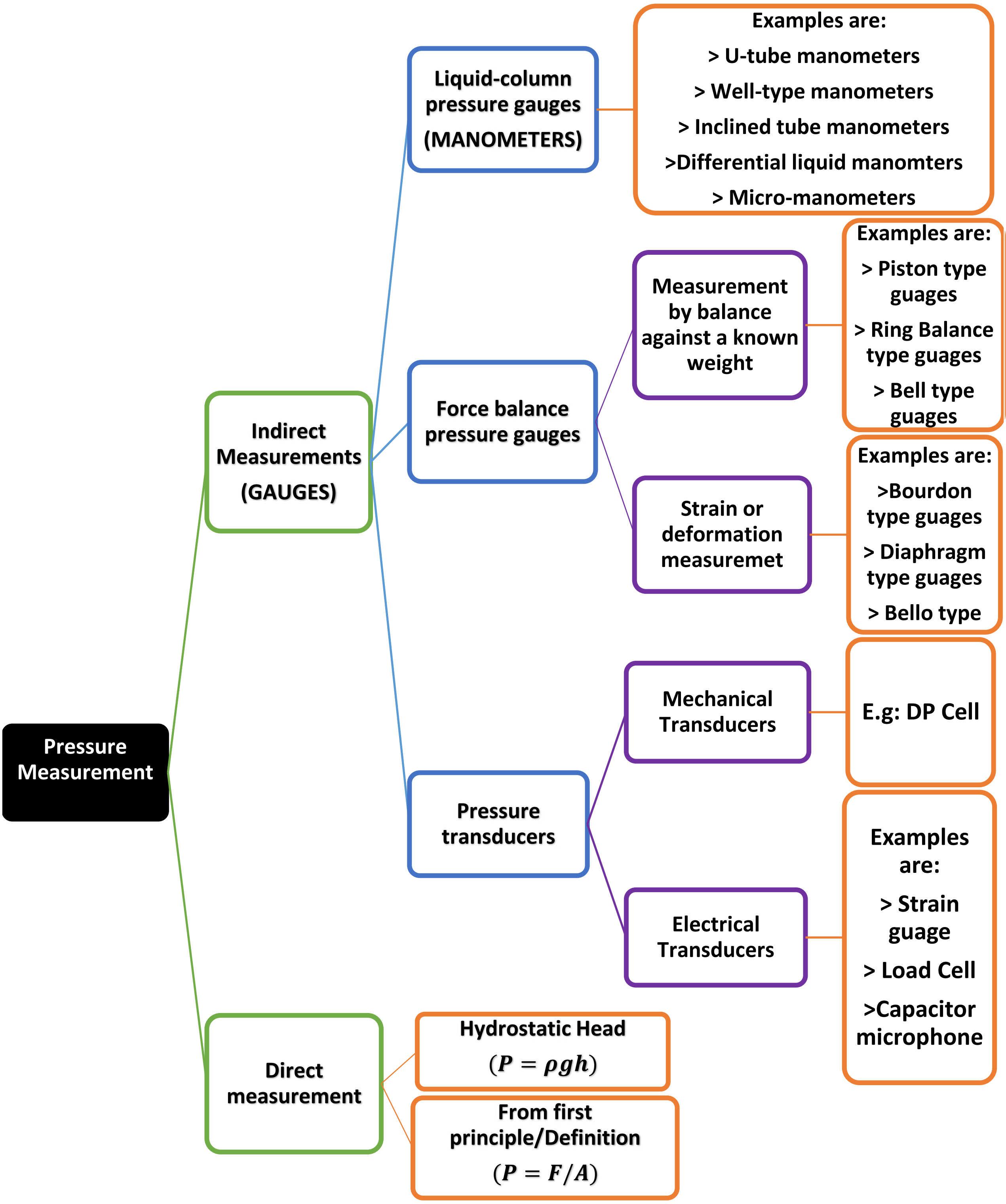

Figure 2.1 Classification Diagram of Pressure Measuring Devices in Natural Gas Systems.

2.2.2 Well-type Manometers

Description:

This consist of a larger diameter, lower section (well) and an indicating tube with a much lesser cross-section but much height than the former (Lipták B. & Welch J, 2003, Nasr & Connor, 2014).

Mode of Operation, Range and Accuracy:

They can measure pressure difference up to 1bar with an error margin of ±0.5 of the smallest calibration (Nasr & Connor, 2014). When the pressure to be measured is applied on the well, as shown in Appendix B-2, the liquid level drops by x and the liquid in the tube rise by $(h + x)$. The liquid stops rising in the tube when the hydrostatic pressure in the tube balances the pressure exerted in the well ("Well Manometer Principle Instrumentation Tools," n.d.). So that the differential pressure is given by:

$$P_g - P_A = (\rho_l)g(h + x) \quad \mathbf{(2.2)}$$

Advantage:

They are also rudimentary in construction, have no mechanical or moving parts and cheap. This device can be used to calibrate other measuring elements and can take more direct reading than the u-tube manometer.

Disadvantages:

The downside is the fact that the pressure to be measured must always be connected to the well.

2.2.3 Inclined-tube Manometer

Description and Mode of Operation:

This is suitable for small pressure difference measurement due to its design. It operates like the well-type manometer. However, as shown in Appendix B-3, the limb is inclined to the horizontal at a slope of 1:20. Therefore, if the liquid in the well rises by xmm, the tube will witness a rise by $20xmm$.

Range and Accuracy:

It can measure pressure as low as $2mmH_2O$ and as high as $40mmH_2O$ with an accuracy of $\pm 3\%$(Nasr & Connor, 2014).

Advantages:

The tube design is flexible (straight or curved). Curved tubes can give direct flow measurements. It is suitable for very small pressure difference measurements.

Disadvantage:

Usage can introduce parallax error in measurement if the fluid meniscus in the tube is not accurately identified.

2.2.4 Differential Liquid Manometer

Description and mode of operation:

Differential manometers consist of a u-tube that terminates with two wells, at both ends, containing two immiscible liquids of different colours and specific gravity as shown in Appendix B-5. The movement of their interface is used to measure pressure (Nasr & Connor, 2014).

Range and accuracy:

If the liquids are appropriately chosen, $h = 5mm\ for\ \Delta P = 1mm$ can be obtained. So that pressure differential range of $0.04mmHg$ can be measured (Nasr & Connor, 2014).

Advantage:

It has a versatile range of applicability including gas pipe flow dynamics measurement.

Disadvantage:

Since fluid density change with temperature, pressure readings may vary at different temperatures. So those calibrations against set temperatures are required.

2.2.5 Micro-manometer

Description:

In Appendix B-4, the leg of the micro-manometer which bears the magnifier is the inclined tube while the second leg is the well. The meniscus in the former is located at a reference level fixed by the hairline that can be seen through the magnifier("Manometer basics & Micromanometer - Field Instrumentation / Pressure Measurement - Industrial Automation, PLC Programming, scada & Pid Control System," n.d.).

Mode of operation:

The well and magnifier are the same pressure initially. When pressure is applied, the well end moves off the hairline which can be restored to the initial position by raising or lowering the well (mercury sump). The pressure is read as the height of the mercury column which is given by the difference in the initial and final micro-meter readings.

Advantage:

It has versatility in applicability; it has high accuracy in small differential pressure measurement. Gauge design and construction ensures that the opposing effects of temperature change on the surface tension and density of the liquid are not felt.

Disadvantages:

It is not portable, and it needs accurate levelling.

2.3 Force balance pressure gauges

These gauges determine pressure by balancing the force generated by the pressure against a known weight or by measuring the deformation or strain caused by the force or pressure in an elastic medium (Nasr & Connor, 2014).

2.3.1 Measurement by Balance against a known weight

These gauges measure the force produced on a piston of known area directly by the weight it can support. Gauges which operate by this principle include the piston type gauge, the ring balance type gauge and the bell type gauge.

2.3.2 Piston type gauges

Description and mode of operation:

"The force produced on a piston of known area is measured directly by the weight it will support"(Nasr & Connor, 2014). In Figure 7, the pressure $P(Pa)$ exerted by the force, $F(N)$, which acts over the area, A (m^2), in the absence of friction is,

$$P = {}^{F}/_{A} \quad \textbf{(2.3)}$$

Advantage:

It can be used to calibrate a wide variety of pressure devices. It is portable and simple in configuration.

Disadvantage:

It can only measure the pressure of static fluid systems.

2.3.3 Measurement of pressure through strain or deformation measurement

These devices measure pressure by balancing the applied pressure against the stress established on an elastic material when the applied pressure deforms the material. Pressure gauges that utilize this principle include bourdon-tube type gauge, the diaphragm type gauge and bellow type gauge.

2.3.4 The Bourdon-type Gauge

Description, Mode of Operation:

This device is made up of an elastic, elliptical, narrow tube which is fixed at one end and attached to a dial that slides across a circular calibrated screen. The applied pressure causes a deformation of the elastic material which expands in proportion to the magnitude of the stress generated. The expansion is expanded and translated to a proportionate displacement of the dial on the screen for pressure reading. A schematic of Bourdon type gauge is illustrated in Appendix B-6

Range and accuracy:

It can measure pressure between 0.1MPa to 130MPa with an accuracy of ± 1% (Nasr & Connor, 2014).

Advantages:

It is highly resistant to corrosion and excellent for industrial applications.

Disadvantages:

They are slow in response, sensitive to vibrations and subject to hysteresis (*Process Instrumentation I Semester IV*, n.d.).

2.4 Pressure Transducers

Pressure transducers incorporate electrical and mechanical mechanisms to detect, evaluate and convert pressure to electrical signals. They are ideal for continuous pressure measurement. They are broadly classified into Mechanical and Electrical pressure transducers (Nasr & Connor, 2014).

2.4.1 Mechanical Pressure Transducer

Description and Mode of Operation:

A mechanical pressure transducer consists of a metal diaphragm capsule which translates applied pressure into mechanical displacement. Typical examples of mechanical pressure transducers are the DP cell shown in Appendix B-8 and the Amerada gauge (Nasr & Connor, 2014, "Pressure transducer technology," n.d.).

Range and Accuracy:

Depending on the design and material used, pressure ranges include (-5mbar to 5mbar) and (0 to 35KPa) with an accuracy of ±1%.

Advantage:

They are ideal for real-time and remote pressure readings and they can work at high temperature and pressure conditions.

Disadvantages:

They have archaic metrological features and they lack surface readouts (SRO).

2.5 Electrical Pressure Transducer

Description and Mode of Operation:

Electrical pressure transducers “convert responses of a pressure-sensing element into an electrical output” (Nasr & Connor, 2014). Types include reluctance gauges, strain gauges, load cells, piezo-resistive silicon chips, bonded-foil gauges and capacitive transducers. “Capacitance transducers have a variable-gap capacitor in which the sensing element is formed by two metallic or quartz plates. As the external pressure increases, the deflection of the sensing plate creates a change in the capacitance that can be mathematically related to the applied pressure” (“Pressure transducer technology,” n.d.)

Range and Accuracy:

Accuracy of electrical transducers ranges from 0.2% FSD (Full-scale deflection) in strain gauges to 0.5 FSD in reluctance gauges.

Advantages:

They are much better for real-time and remote reading; they possess low hysteresis, good stability, repeatability and linearity.

Disadvantage:

Most are highly sensitive to temperature and inclination.

Chapter 3 Gas Flow Rate Measurement

3.1 Introduction

This section is aimed at describing gas flow measurement devices. It encompasses the meters used in custody transfer of Gas between producers and Gas suppliers, meters used on high-pressure transmission systems to domestic type flowmeters up and small laboratory-type instruments.

The measurement of gas flow rate is very paramount to both suppliers and gas consumers. The gas suppliers get to know how much they are selling and can consequently calculate their incomes while consumers know how much they consume and can tell if the charges reflect the quantity consumed.

Based on operating principles, many different types of meters are commercially available; each with advantages and disadvantages for their use. It is on the same basis of their operating principle that meters are classified into 12 major groups. These groups are further categorised in Table 3.1 into those that extract energy from the flow i.e. Causing a pressure drop due to obstruction placed along the flow path and those that add energy to the flow i.e. energy being added in the form of sound, heat or light. The change from a known input value is used to infer flow (Nasr and Connor, 2014).

For gas metering, suitable meters are available for all groups except 6, 11 and 12 that cannot be applied on Liquids. Those meters that apply to the gas industry are not only applied in gas flow measurement but also in other applications such as furnace atmosphere monitoring and air movement in buildings.

3.2 Pressure Differential (DP) Meters.

These are categorised into two groups; Convectional and other types of DP meters. They can be described as meters that consist of a primary element that creates pressure change and a Secondary element that senses the difference in pressure and transmits in analogue or digital form; giving a flow rate using Bernoulli's Equation which relates the pressure difference to velocity for any fluid of constant density flowing in the pipeline (Nasr and Connor, 2014)

Table 3.1: Showing Flow Meter Grouping and Classifications. (Nasr& Connor, 2014).

GROUP NO.	DESCRIPTION	EXAMPLES	CATEGORY
1.	Conventional Pressure Differential (DP) types	Orifice, Venturi and Nozzle meters	Extractive
2.	Other DP types	Pitot, Variable Area, Special Orifices, Elbow and Target meters.	Extractive
3.	Positive Displacement types	Lobe, Vane and gate, Diaphragm	Extractive
4.	Rotary Inferential types	Axial Turbine, Insertion turbine meters	Extractive
5.	Fluid Oscillatory types	Fluidic, Vortex and Swirl meters	Extractive
6.	Electromagnetic types	AC meters, Pulsed DC meters	Additive
7.	Ultrasonic Types	Doppler, Time of Flight	Additive
8.	Direct Mass Types	Coriolis Mass Meter	Additive/ Extractive
9.	Thermal Types	Hot-wire anemometer, Probe meters	Additive
10.	Miscellaneous Types	Lasers, correlation, tracers	Additive/ Extractive
11.	Solid Meter types	Momentum, Belt weightier screw conveyors	Extractive
12.	Open Channel types	Weirs, flumes	Extractive

The DP meters are available in all their varieties of shapes and size with Orifice plate being the most common in high-pressure metering used for very large flows between suppliers and Transmission companies i.e. custody transfer and fiscal metering. These are well documented and are a subject of standards and codes of Practice. The standards such as BS 1042 and ISO 5167 quoted values for C_D under certain flows in standard installations and cover geometric requirements and uncertainty in calculations.

However, for the compressible fluids such as Natural gases, the pressure drop due to flow restriction device is accompanied by a density decrease leading to an increase in Velocity. Considering that the gas at the restriction is under isentropic expansion, the flow rate can be calculated by incorporating the expansibility factor (ϵ) leading to a universal equation for a meter working in any one single-phase fluid. Table 3.2 gives details on description, working principle, ranges and applications for the DP meters.

3.3 Positive Displacement Meters

These are meters that use mechanical parts to displace the fluid at the measure in discrete know volumes. These include; Lobe, Vane and gate plus Diaphragm.

3.3.1 Rotary Displacement Meters

According to Nasr and Connor, 2014, the EEC 71/318 defined them as positive meters in which measurement is affected means of measuring chambers with rotating walls while they are considered as positive displacement meters in which a measuring compartment is formed between the walls of a stationary chamber and a rotating element making a substantially gas-tight contact with the walls by BS1179. These are grouped into two types; the impeller (lobe) and the rotary Vane types.

The Rotary lobed and vane type have been in use for over 70 years and are finally established as reliable meters for large flows of fuel gases for control and sales purposes. The details are discussed in Table 3.3.

3.3.2 Diaphragm Meters

This is another type of displacement meter (Appendix C-27) used commercially to measure the gas used by consumers both domestic and Industrial to determine the charge made to the consumer and thus the revenue of the gas supply company. Due to its importance, it must meet both National and International standards (Nasr and Connor,2014). The details are discussed in Table 3.4.

3.3.1 Wet Gas Meters

This solves the problem of sealing the moving parts in a bath of water during its principle operation as shown in Appendix C-25. The details are discussed in Table 3.4.

Table 3.2 Details on the DP Meters

Instrument	**Description and the operating principles**	**Range and Discharge coefficient**	**Advantages and Disadvantages**	**Applications**	**Figure**
The Orifice Plates	This is a metal disc with a concentric opening placed in the pipe carrying the fluid whose flow is to be measured. Due to pressure drop down the plate, the fluid is forced to congregate through forming a point of maximum convergence (vena contracta) just downstream of the orifice. It is defined by the sharp square edges for setting the separation point and enhancing the contraction making it much easier to maintain the symmetrical similarity (Appendix C-1). These plates are normally stainless steel with an adequate breadth to withstand buckling. It uses tapings at tap vena	It is very difficult to quote the accuracies as so much depends on complete installation and conditions of flow. Discharge coefficient C_d=0.6 constant at numbers	Advantages • Simple and a robust primary element • Well established with comprehensive standards • Calibration not needed for standard designs • Low purchase price of the plate alone • Can be used on liquids as well as gases. • Disadvantages • Low range-ability 3 to 4:1 • Performance changes if the plate is damaged • Affected by swirl and poor	• High-Pressure gas metering on the large flows between suppliers and Transmission Companies and Fiscal Metering (Nasr and Connor, 2014)	Appendices C-1 and C-2.

	contracta for obtaining minimum pressure and at upstream diameter for maximum pressure. There are no bending effects however the position of vena contracta varies with the ratio of the diameters (β) making it one dimensional. The orifice is usually installed centrally during gas measurements although unconventional placements exist for dirty fluid measurements. Viscous fluids are measured by the conical entrance type with a chamfered upstream control and a square downstream edge intended to sustain a constant C_D to much lower R_e than normal types (Connor and Nasr 2014)	greater than 5x $10^{-5}R_e$ The range is 3 to 4:1. Accuracy: o.6 to±0.75%	flow profiles • Output not linearly related to flow • Full installation and secondary costs for high accuracy may be high.		
Venturi Meters	This meter is designed to lessen the pressure loss though at the cost of	The C_D is constant	<u>Advantages</u>	• Not common in gas systems	Appendix

	increased size due to the need for the diffuser to reduce flow by allowing maximum pressure recovery, though the diffuser size can be reduced without affecting the characteristics of the meter. It is designed with an entry cone of 30^0 and an exit of 5^0 (Appendix C-3) accounting for cost and accuracy (Connor and Nasr 2014). The geometry ensures no bend effects at the tapings and allows only one-dimensional flow in the throat due to acceleration. Extra care on the blending radius between the upstream diameter and the throat must be taken during construction to avoid separation effects and throat tapings.	when R_e at the throat is greater than $3x10^5$ Accuracy = ±1%	• High efficiency and good pressure recovery • Good pressure performance at high β ratios • More robust and less affected by internal corrosion. • Less sensitive to upstream disturbances • Less Sensitive to upstream disturbances <u>Disadvantages</u> • Occupies much longer length inline • More expensive to manufacture and install • Large sizes difficult to handle	however used in water distribution systems and laboratory measurements.	C-3
Nozzle meters	This formed by replacing the upstream cone of a classical venturi	The Discharge	<u>Advantages</u>	• Used as DP meters on gas	Appendix

	to form a Nozzle venturi. Its size can further be reduced by dumping the diffuser yet keeping the favourable pressure drop characteristic of a venturi to form a Nozzle meter which is a compromise design between the compact orifice plate and a good pressure drop characteristics of a venturi (Nasr and Connor, 2014). There are two standard designs, the ASME long radius designs and the ISA Nozzle (4). However, there are other designs such as the Dall Tube (Appendix C-4) which makes the use of streamline Curvature at the throat tap to produce a higher differential for the same throat area. Another design is the Sonic Venturi Nozzle made up of a precisely machined venturi tube to allow the pressure drop at the throat up to half of the upstream pressure making the	coefficient is in a range of 0.9 to 0.99 and is a function of both Re and β levels	• The device is small and simple to use • It is insensitive to wear erosion • No sharp edges • higher C_D <u>Disadvantages</u> • Several parallel devices must be used for large flow rates	flow systems. • Critical Sonic nozzles and Sonic Venturi nozzles are used in testing other metres. • Used to check the accuracy of orifice meters • The Dall tube is used in water distribution systems • Can be used as flow limiter in networks.	C-4

	velocity at the throat becoming sonic hence forming a shuddering wave limiting the flow to a maximum value of flow rate.				
Pitot Tubes	This device is very useful in obtaining the temporal measurement of flow by measuring a velocity at a point and then by navigating the pipe at several points making it possible to obtain the mean velocity hence the volume of flow. It works on a principle that if a tube is placed in a gas stream with its open end facing the direction of flow, the encroaching fluid will be brought to rest and its kinetic energy transformed to pressure energy leading to pressure build-up in the tube depending on the square of the velocity of the stream. The static pressure of the stream is measured by tapping the pipe wall or	Accuracy: $\pm 5\%$	<u>Advantages</u> • Used for making Temporally measurements of flow • Negligible Pressure loss • Cheap and Easy to install	• Used as exploratory devices • Can be used to monitor flows in Gas networks • Mostly used by Industrial Gas Engineers for measurement of Velocity and direction during combustion studies and heat transfer work. • A 5-hole tube is used where gas	Appendices C-5 and C-6

	the pitot-static tube Appendix C- 5 itself and the pressure difference between the tube and stream is measured which is equal to the measure of impact pressure, therefore the velocity of the fluid at that point. UK National Physical Laboratory has developed a standard combined type tube with a truly hemispherical end and impact hole cylindrical Appendix C-6			flow patterns are complex especially in furnaces with recirculation and Turbulent zones.	
Elbow Meters	The differential pressure is generated between the outer and inner radii of the elbow bend due to the centrifugal forces of the fluid (Appendix C-7). Due to the very low differential forces in the Gases, a venturi meter section can be incorporated to increase the differential as seen in Appendix C-7	Less accurate and noisier than other types	<u>Advantages</u> • They are small hence saves space • Lesser pressure losses than the orifice plates. <u>Disadvantages</u> • Significantly less accurate and Noisier than other types of meters	• Used in Compression stations with limited space.	Appendices C-7 and C-8

			• More sensitive to upstream conditions.		
Variable Area Meters (Rotameters)	This is a simple device made of a vertical tube with a bore tapered to the top containing a free-piston (float) with a revolving top (Appendix C-9). The flow in this instrument is vertically upwards and the piston rises with the increase in the flow until a steady point id reached. i.e. When the upward shove on the piston due to pressure difference generated by the fluid passing through the annular space is equal to the apparent weight of the system. Its principle of operation is that the differential pressure is kept constant hence the measure of the flow rate is equal to extent of the variation in the cross-sectional area of flow. The displacement of the piston from its initial position is	The flow range depends on the tube size, the Piston Material, permissible pressure drops and nature of the metered fluid, Range: over 10:1 Accuracy: ±0.5%	<u>Advantages</u> • They are very accurate. They are not affected by flow conditions • Good at metering corrosive fluids • Easy to install and calibration is by the manufacturer for intended duty. <u>Disadvantages</u> • Need for corrections if used to meter fluids of different densities.	• Glass Tube Rotameters are very useful in laboratory, development and industrial applications • Used in monitoring Gas flow • Monitoring air supply to burners	Appendix C-9

	directly proportional to the rate of flow for the turbulent condition.				

Table 3.3 Details about the impeller and the rotary Vane Positive Displacement Meters

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Rotary Impeller (lobed) Type	This consists of two impellers that are geared together to allow them contra rotate at the same speed while interlinking closely always to ensure that gas only passes forward through the measuring chambers formed between the sides of the impellers and walls of the casing without any contact at any time. The unhinged load on one or the	Its range is up to 30:1 and measures up to 100bar Pressure. Accuracy: ±1%	**<u>Advantages</u>** • It is cheap, accurate and reliable for measuring gases • It has no issues with gas supply security and Safety • All the issues that may arise can be sorted by regular inspection, spin	• They can be applied in viscous, dirty and corrosive fluids measurements • used in the petroleum and agricultural industries due to their rugged	Appendix C-16

	other impeller drives them round when the pressure is applied through the inlet exposing high pressure to the impeller near it than the one at the outlet. The pressure build-up will rotate the impeller anticlockwise; discharging to the measuring chamber, then to the outlet. The work done in causing the impellers to rotate is the energy taken from the gas and is shown as pressure loss.		tests and use of straight flowmeters **<u>Disadvantages</u>** • Pressure losses due to energy needed to rotate impellers • A lot of Corrosion and abrasion hence a lot of noise • Jamming is common due to debris entrapment • Errors due to its dependence on swirl angle	construction	
Rotary Vane Type	This meter is composed of a circular rotor that is mounted inside a round section containing several sliding vanes which isolates fixed volumes of liquid between the rotor and the wall of the section. The centre of the rotor made offset from that of the sections so that they never get in				

	contact.				

Table 3.4 Details about the operation and application of Diaphragm and Wet Gas Meters

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Diaphragm meters	This uses the principle of positive displacement where sliding valves are controls the entry and exit of the gas to the 4 cubicles that fill and empty in turn as shown in the figure 1.3.3 The exact volume of the cubicles are known so the number of displacements gives the volume (Free-stock, 2018).	Usually suitable for pressures up to 5 k pa but special ranges are available; $170m^3h^{-1}$ for 35 k pa Steel case up to $160m^3h^{-1}$ to 20 k pa Aluminium meters up to $280m^3 h^{-1}$ up to 700 K pa	**<u>Advantages</u>** Available in many ranges with very high reliability Can be adjusted for remote data transfer or pre-paid methods. Documented and approved under National and International standards; BS4161 parts (1-5 for specifications), BSCP part 2 for installation ad IGEM other recommendations. (Nasr and Connor, 2014)	Mostly used in residential properties and light commercial buildings. They measure the quantity of natural gas consumer uses and places a charge for the gas distributor to bill for it.	Appendix C-27

			<u>Disadvantages</u> Pressure absorption causing the diaphragm to balloon out. Require Periodic maintenance.		
Wet Gas Meters	It consists of a drum that is divided into chambers of known volume semi bathed into a fluid such as water or oil such that as the drum rotates, the gas enters and leaves the chambers and the fluid through the designed route. It is critical to maintain a low speed of drum rotation so as not to disturb the water level to achieve high accuracy.	Range: 10:1, capacity $0.5m^3h^{-1,}$ with accuracy of up to 0.25%	<u>Advantages</u> High accuracy No problem with sealing moving parts. <u>Disadvantages</u> It is vulnerable to humidity Dry Gas can be saturated if water is used instead of oil	Used Commonly in the Laboratories Used as reference meters for calibration of other types	Appendix C-25

3.3.2 Rotary Inferential Meters

Table 3.5 Details on Operation and application of the Rotary Inferential Meters

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Axial(In-line) Turbine	This is velocity device for measuring the volume of flow as in Figure, 12 in which the direction of flow is parallel to the rotor axis of the meter and the speed of rotation is proportional to the rate of flow. The meter is designed with low non-fluid retarding torques to keep the rotor slip within a flow range during Gas Measurements. A drive and index are also required to convert the velocity of flow directly to volume. To provide for totalization, a commercial meter consists of a body, an internal rotor mechanism with inlet and outlet diffuser, a mechanical index, magnetic drive or pulse counter although the materials used vary according to their applications. The meter derives its energy from	Capacity: up to $300m^3/h^{-1}$ Pressure: 2.5-100 bar Accuracy ±1	They are relatively small with large range-ability. The suitable for large volumes of flow. They can be moved with ease due to their lightweight. Don’t need a big operation space Disadvantage They must be calibrated horizontally since they are one	Used in measuring large flows such as Transmission, distribution and industrial applications.	Appendix C-11

	the kinetic energy of the gas that is caused to increase as it passes through the meter by reducing the cross-sectional area of the flow stream by diffusers. The flow passages can be contoured as in a venturi to keep a low total pressure drop and rotation of the torque depends on torque radius.		dimensional		
Insertion Turbine	With the development of this instrument, the direct measurement of rate and direction of flow in individual mains, validating network analysis models, establishing boundary conditions and identifying blocked mains became possible. The main part of this meter, the motor cage that is of compatible size so that a standpipe and a valve assembly is attached to the mains of 100mm diameter. It should be well-calibrated to avoid being affected by the high range operating densities and still be insensitive to small angles of alignment.	Velocity range: $0.3\text{-}15m^3s^{-1}$	Advantages They are robust, portable, easy to insert in the flow and easy to use This meter gives direct readings Disadvantages If not properly installed can be affected by operating densities	Uses in Validation of Network analysis models Used in measuring the rate and direction of the gas flow in individual mains directly	Appendix C-12

Rotating Vane Gas Meter	This type of meter is an aluminium fan rotating on a vertical shaft as fluid flows and counter mechanism integrates flow. It was designed specifically as a secondary meter for industrial and commercial operations.	Available in size ranges from 4-200m^3h^{-1} at pressure up to 1.7 bar Accuracy: ±2% over 10:1 flow range	Advantages Good for non-corrosive gas Disadvantages Rugged construction hence not suitable for corrosive gases Can only be installed horizontally	Used in Industrial and commercial measurement of flow as a secondary meter.	Appendix C-16
Rotating-Vane Air Meter (Anemometer)	This meter consists of a rotor with a precisely well-adjusted light multi-vane assembly made of aluminium alloy fixed on a shaft made of stainless steel enclosing all friction-free bearings. There are two types of rotors; a cup anemometer consisting of three aluminium light cups of conical shape attached to arms carried by a perpendicular bar and one with jewelled bearings geared to a light counting mechanism and is the most sensitive. The measurement is done by passing Air through linear devices, the	Ranges from 0.13-30ms^{-1}	Advantages Directly measures the airflow rate Disadvantages Not good for corrosive gases	Measurement of flow of air	

	rotation of the vanes causes outputs of electric pulses which are directly picked by a capacitance transducer connected to the outer ring of the anemometer.				

3.3.3 Fluid Oscillatory Types

Table 3-6 Details on operation and application of Fluid Oscillatory Types.

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Fluidic Meters	This type of meter has no moving parts and detects the flow rate by recording the oscillatory movement of gas within the meter by a thermistor located at one of the passages. Using the Coanda effect, the meter introduces the oscillation to the fluid rotating it side to side at a frequency directly to the flowrate where One complete cycle is given by one output pulse This meter has a potential for future domestic gas flow measurement by installing them into house walls and their signals transmitted by already existing telephone companies		**<u>Advantages</u>** • Can be used even on corrosive gas • No pressure losses due to moving parts • **<u>Disadvantages</u>** • Single meters cannot be able to measure the required range • Issues of Overlap ranges • No suitable sensors have been made for them	Very high potential for future domestic application.	Appendix C-14

	if small cheap sensors for oscillations and low flows can be developed.				
Vortex type Meter	The principle of operation is derived from placing a bluff body in the flow with streamlines passing smoothly around the body. With the increase in fluid velocity, the fluid separates from the object to form vortices of low-pressure zones as shown in the fig 16 which are then picked up by sensitive thermistors. At a fixed rate of flow, the rate at which these low-pressure vortexes are directly portioned to the shape of the bluff object.	Accuracies: ±1% Range-abilities of 50:1	Advantages • Frequency is dependant on the fluid used • Easy to calibrate • Less sensitive to dirty water and flow disturbances Disadvantages • Depends so much on the shape and size of the bluff body	Used as alternatives to pressure differential meters Insertion meters under the same principle can be used as single point velocity testers.	Appendices C-15 and C-17
Swirl Meters	The principle of this meter is depicted by fig where the fixed inlet vanes guides the gas to a swirling motion in the meter, then accelerated and		**Advantages** It is very insensitive to upstream conditions	Suitable for light industrial operation due to its insensitivity to upstream conditions.	Appendix C-18

	decelerated through venturi and diffuser respectively causing the swirling gas to process around the pipe centre at a frequency proportional to the gas flow rate. The throat casing consists of a thermistor that detects the passage of coils of the helix. On leaving the meter, the flow expanded is expanded and normalised by further sets of vanes.		Disadvantages Unsuitable for low-pressure metering due to High-Pressure losses		

3.3.4 Ultra-sonic Meters

Table 3-7 Details all the Meters under Ultra-Sonic Meters

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
DOPPLER TYPE	Whenever a known frequency of sound is reflected from a moving object, then the frequency of the reflected beam is altered by a rate that is proportional to the velocity of the moving object. This is the operation principle of the Doppler type meter. For the case of Gas stream containing dust particles, different velocity profiles are expected hence a range of frequencies that are proportional to the existing profile of the flow. These meters are developed commercially for strong signal processing to give result		They are highly reliable with minimal maintenance costs. Easily installed without altering the flow operation **<u>Disadvantages</u>** Accuracy depends on the fluid type and particle distribution in the flow	Applied in the measurement of the flow of corrosive fluids and dirty gases.	Appendix C-19

	proportion to flow rate.				
Time of Flight time	This type operates by calculating the time taken by an ultrasonic pulse flowing within the pipe and the output is proportional to gas velocity. This is illustrated by the fig 20 with the known ultrasound properties of gas, pipe size and minimum gas pressure is determined. To avoid errors due to dependence on the velocity profile, 4 paths are used. A single beam is transmitted axially for the small-bore pipes, this is a design under evaluation for domestic ultra-sonic meters.	Transmission frequency (gas) :100-500 k Hz The range is greater than 100:1 Accuracy: ±1%	Very accurate even above the required flow rate Not affected by the flow conditions **Disadvantages** It consumes a lot of power	Its design is being evaluated for domestic metering	Appendix C-20

3.3.5 Direct Mass Measurement Types

Table 3-8 Showing all the Details on the Direct Measurement Type Instruments.

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Coriolis Mass Meter	Whenever a body is rotated about a fixed point, it changes position relative to that point generating Coriolis force. That is the principle behind the operation of this meter. It is composed of a pair of parallel vibrating tubes anchored at the ends that generate a carioles force that can be measured at distance from the fixed ends. The output is related to mass flow rate, but Newton's second law of motion as shown in Appendix C-21 The maximum angle is proportional to the mass flow rate in the tube.	Very low flow ranges High accuracy of ±0.2%	**Advantages** Very accurate and require low maintenance costs. **Disadvantages** They are very expensive. They have very low flow ranges and acute pressure drop within the meter. High failure possibilities due to tube fatigue	Used in Laboratory for gas testing at high pressures Used in measuring the mass flow rate of liquids. Developed for fiscal measurement though little experience.	Appendix C-21

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Hot Wire Anemometer	This meter relates the heat transfer due to temperature reduction as fluid flows over a heated surface to the rate of flow. Appendix C-22 shows the principle of its operation where the wire placed in the flow is electronically heated and its resistance obtained by the Wheatstone bridge while balancing the current through the wire to maintain a constant temperature. The potential difference across the standard resistance is measured by a potentiometer from the suitable arm of the bridge. This is used to relate the velocity of the flow and the current provided the temperature and resistance of the wire are kept constant	Has a wide range of ±2%	Applied only in low flow rates	Used in laboratory analysis and research Reliable for air/gas flow measurements	Appendix C-22
Probe Type	This meter works on a principle that	The range is up to	Very suitable for	Diameter is being	

Meter	when an alternating current is connected to the thermopile, the change in the direct current depends on the changes in the flow. The device consists of a small hand-held stainless-steel probe which contains the two sensing elements that are heated with the alternating current while noting the variance in the DC output due to changes in the flow. To compensate for heat losses due to ambient temperature changes, another sensor (thermocouple) is added.	30m/s	measuring air movement between 0.05 -0.5 ms^{-1} **<u>Disadvantages</u>** It has a nonlinear scale leading to widely spaced division at low temperatures	used in air velocity measurement on a commercial scale in air conditioning and ventilating systems	

3.3.6 Miscellaneous Techniques

Table 3-8 showing details on other techniques used to measure natural gas flow rate

INSTRUMENT	DESCRIPTION AND THE OPERATING PRINCIPLES	RANGE AND DISCHARGE COEFFICIENT	ADVANTAGES AND DISADVANTAGES	APPLICATIONS	FIGURE
Laser Doppler Meter	This device measures the doppler shift of laser radiations scattered by moving particles in the flowing gas as shown in Appendix C-23. A beam from a laser is split into two components by the splitter and then focused by an optical system to intersect the gas stream. The frequency due to the phase shift due to particles of gas being trapped between the two beams is recorded and is dependent on the gas	Wide range of velocities from 0.1 mm to 3 times the speed of sound Accuracy of ±0.5% obtainable	**Advantages** It is very accurate It doesn't cause any disturbances to the flow Disadvantages They are very expensive, fragile and needs expert operation due to their complexity	Applied in fluid gas combustion research	Appendix C-23

	velocity. This design allows velocity profiles across pipes gotten and are used to calculate the total volume of flow.				
Cross Correlationmeter	This ultra-sonic device uses two traverse beams of ultrasound at a close range. The beam is then modulated by the particles of the gas stream to produce a finger-like print. By tracking the passage of disturbance downstream and comparing the print using the correlator, the time of transit is obtained that is used to calculate the average velocity across the pipe diameter	Accuracy: ±3%	**Advantages** Helps in determining phase velocities, slip and bulky average velocity if used with radioactive tracers Promising device for measurements of two-phase gas stream. **Disadvantages** They are very expensive by industrial standards	Potential for application for two-phase measurements during flaring.	Appendix C-24

3.3.7 Tracers

In this system, a substance is injected into the flowing gas and its flow characteristics measured and used to obtain the flow rate of the gas stream. Two methods are applied under this technique; The Dilute Method and Transit time method. In the former, dilution ration of the trace is measured at a point downstream and then used to obtain the flow rate while in the latter the tracer time of travel across a section of known volume is measured. The technique is ±1% and is used in detecting variations in meter accuracies.

3.3.8 Metering large industrial and commercial loads

The development of the natural gas industries and increased dependence on Natural gas has led to a major increase in the number of large measurement systems in place that can measure high-pressure stream of more than $300m^3/h$.

3.3.9 Statutory requirements and standards

National standards organisation has been set up in every industrialised Nation, recognised and supported by the government. These include BSI (British), ANSI (America), AFNO (France) and DIN (Germany). Industry oriented national bodies like the Institution of Gas Engineering and Institute of Petroleum in the UK have also enveloped.

There are also other three international organisation and one European organisation that issue standards to cover any metering situation related to gas metering;

- The International Standard Organisation (ISO)
- The International Organisation of Legal Metrology (OIML)
- The International Electro-Technical Commission (IEC)
- European Economic Community (EEC).

3.3.10 UK Situation

There is a fundamental legal requirement that all metering systems should meet safety and accuracy aspects as set by the Gas Safety Regulation and Gas Act, and Gas (Meter) Regulations respectively. Only stamped or badged Meters (*by meter examiner based on the requirement of meter regulation for accuracy and pressure loss)* are used, except for a special contract where the customer is provided specific terms by British Gas or another gas supplier.

Only accurate within a range of ± 2% is permitted for badged and maximum pressure drops are stipulated diaphragm though Turbine and rotary displacement meters have no statutory maximum pressure drop. The set standards for British meters have been modified to allow the exchange of meters between EEC countries. International standards for most types of gas meters are produced by OIML except diaphragm, turbine and rotary displacement meters and mechanical volume correctors that are covered by BS4161 and orifice plates by BS1042 and ISO 5167.

According to the Gas Act the Gas Meter regulation, British Gas and other gas suppliers are legally allowed to enter into a special agreement with customers where the volume of the gas consumed can be corrected for the effects of pressure or temperature either employing fixed factor or automatic corrections without meter register or index reading as prima facie evidence of the quantity supplied. The special agreement contracts are based on individual negotiations for all interruptible and amounts supplied on a firm basis though often involve the recording the following parameters;

- Daily or maximum hourly demand rate
- Total demand each day during a charging period
- Hourly demand, to permit the use of tariff terms for charging for differently priced blocks of gas through a single meter
- The period of interruption and its proof
- Gas pressure or temperature at the meter

There are no conclusive recommendations based on metering pressure to design a metering system. There is always needing to consult with the meter manufacturers if an individual item is to be applied beyond the limits set by BSCP 333, IGE comm.750, and IGE GM/1. These limits are set for the following meters;

- Orifice
- Turbine
- Positive displacement diaphragm
- Rotary displacement

Whenever the metering does not exceed 7.5 kPa. reference shall be to BSCP331 and relevant section of ICE comm.750 and for high pressures exceeding 7.5kpa up to 7 MPa. reference be made to ICE GM/1. These are applied for the connection of gas meter at commercial or industrial where gas temperature is -5°C to 40°C.

3.3.11 System Specification

Meters design specification is defined as the function of the flow system and the operating conditions as below;

1. Performance targets
    a. Continuity of measurement.
    b. Security of gas supply being monitored.
    c. Flow rate accuracy.
    d. Integrated flow accuracy.

    e. Maximum flow capacity
2. Operating load profile
3. Upstream and downstream control equipment characteristic
4. Maximum allowable pressure
5. Operating gas pressure and temperature
6. Gas composition limits
7. Readout requirements, including time data for interruptible loads
8. Available power supplies and their specification
9. Space available

Continued measurement is crucial for charging though from 1 hour to 3 days yearly downtime may be required for scheduled maintenance. Therefore, it is also important to integrate a pressure reduction equipment in design a meter system especially for systems where three types of meters are considered for application. These include;

- **Orifice**
- Turbine, and
- Rotary displacement.

Rotary displacement meter that is extensively used in the measurement of low pressure steams has a high turndown ration in order of 30:1 and accuracy of ± 1%. High-pressure operation is only allowed if they are a result of a minor shift of the low-pressure curve. Whenever these types of meters are not correctly installed, the following issues could rise;

I. Jamming: This may rise whenever dust or debris is trapped between the impellers and case stopping the meter hence restricting the flow. A filter placed t the inlet could stop this while an automatic meter bypass ensures continuity in supply.
II. Pulsations and impeller inertia: with rapid change in supply, the required time for the impeller to speed up or slowdown may affect local control equipment causing pressure pulsation at the outlet.
III. Pipe resonance Careful pipework design will be needed to control pulsation frequency generated by impellers from equalling the resonant frequency of the pipework as it could cause acoustic resonance.

The quoted± 1% accuracy of the Turbine meter depends on velocity profile established at the meter inlet and its turndown increases proportionally with the square root of density ratio. For example, at a pressure of 2 MPa, the turndown ratio can increase up to 100:1 compared to the ratio of 15:1 at millibars gauge working pressure which may lead to line debris damaging or stopping the meter. However much the gas still flows through the meter, the following problems below may still arise hence need for regular inspection, tests, spin and use of flow straighteners.

I. Blade damage or change in friction.
II. Flow pulsation, giving high meter readings depending on the pulsations form factors
III. Swirl, producing an error depending on the swirl angle.

Although Orifice meter is yet to be generally approved in the UK, currently all the natural gas is bought, and the largest sales are made using these maters making them extremely very important for the British Gas Industry. Whereas the accuracy of 0.6 to ± 0.75% can be achieved with orifice meters, it is still very difficult to quote their accuracies since it depends on conditions of gas flow and complete installation. Due to the variance in the Reynolds number leading to changes in the discharge coefficient, Flow range-ability has to be restricted to accurately measure the differential pressures generated. Whereas they may not stop the flow of gas, they can be changed once a suitable carrier is used under normal conditions. Flow range-ability above 40:1 can be attained using a suitable secondary instrumentation system. The orifice plate meters are mainly faced with the following problems though they can be reduced by filters and flow straightener and regular check-up of the plate for sharpness;

I. Erosion: This can lead to changes in edge sharpness and pipe wall roughness, giving an error of up to 5%
II. Swirl or pulsation flow due to governors, compressors or bands causing an error of 15% at swirl angle of 40 degree.
III. Collection of debris and dust within the system immediately before the orifice plate.

3.4 Measurement and Correction of Gas Flow Parameters

Whereas only the Orifice meter requires a secondary instrument to give read-out signal to a flow among the three meters, to obtain an automatic corrected result/output, secondary instrumentations are calibrated on all. These include;

I. Differential pressure/ pressure transmitter
II. Temperature transmitter
III. Density meter
IV. Correctors

3.4.1 Differential Pressure/ Pressure Transmitter

These are pressure transmitters for measurement of the pressure of gases and liquids. They also indirectly measure gas flow, speed of water, level and altitude. They are available in different designs at varying costs, need for choice according to application and costs. However, it is necessary to make the right choice and range as the fraction of uncertainty to output increases with the decrease in output.

BS6174 gives specific recommendations for calibration but can also be affected by long operation periods of high differential pressures.

3.4.2 Temperature Transmitter

It is important to accurately measure Temperature to attain accurate gas quantities from PTZ corrections. It is also a requirement if flow variations have a significant effect on the orifice meter bore dimension. Gas temperatures can be determined by Electrical resistance thermometers.

3.4.3 Density Meter

During gas flow measurement, gas density /relative density can be obtained by Vibrating element, inertia or buoyancy meters especially in DP meters where density at line condition is a requirement for calculation of flowrate. A range of inert gases such as nitrogen, argon or gas of similar composition to the service gas with a certified component analysis is used as a basis for Calibration of Density meters by their manufacturers. Density Meters are Very Expensive and often form a significant cost of the system

3.4.4 Correctors

The out-output signal from the meter by direct mechanical link, indirect electromechanical or electronic, correction means is automatically corrected for pressure or temperature and compressibility by the inclusion of fixed factor or actual correction. Their accuracies are up to ± 1 % for mechanical and ± 0.25% for electronic respectively.

Chapter 4 Gas Quality Measurement

4.1 Introduction

Gas quality is determined by the gas composition, components and key parameters that make up a gas, it is also referred to as the caloric value of the gas, which is the amount of energy obtained by the complete combustion of that gas, factors such as impurities, water, sulphur content through (Hydrogen Sulphide) H_2S, inert gases, $C0_2$ and gas density affect the gas quality. It is worthy to note that the consumer is not paying for quantity but quality and as such referencing conditions do apply in gas sales agreements and national gas grid specifications by different countries. The International Organization for Standardization (ISO) which is a body made up of representatives from different standard organizations from different member countries has established standard referencing conditions for natural gas and review is made every 5 years. Most times gas companies and regulators refer to these gas standards example ISO 13443:1996.

4.2 Importance of Gas Quality

It is relevant to know the quality of gas for technical, safety and economic reasons, and these reasons directly affect the purpose of usage, for example, domestic and industrial gas equipment is designed to operate at specific gas quality demands different gas quality lean or dry natural is used in power plant, and as feeds for production of fertilizer, while Natural Gas Liquids (NGLs) are used as feeds for petrochemical plants, heating, and blending purposes, Liquefied petroleum gas (LPG) is used for cooking and as fuel for cars. Different gas application has diverse gas quality demand, when we apply the right gas quality to our machines and plants, it helps save maintenance cost, and the lives of people working in such environment are also preserved. In gas contracts, there are severe penalties when gas qualities are not followed which results in financial and manpower loses (J P, Bowers 2012).

4.2.1 Gas quality Parameters

These are factors that assist in determining the gas quality and are listed below with their disadvantages to the gas system. These parameters include physical and chemical characters of the gas.

4.2.2 Wobbe Index or Number

The Wobbe number indicates the heating value of the gas and it is directly proportional to the gas load – like when it is applied to burners. This is the most important parameter in measuring gas quality. Too high Wobbe number will result in thermal overload (overheating) and production of Carbon monoxide (CO), while a low Wobbe index can result in flame instability, poor ignition, and variations in the air-to-fuel ratio that affect energy production.

$$\boldsymbol{Wobbe\ Index\ (I_w)} = {}^{\boldsymbol{V_C}}\!\Big/\!\sqrt{\boldsymbol{G_s}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ \textbf{(4.1)}$$

Where,

$$\boldsymbol{V_C} = \ calorific\ value\ and,$$

$$\boldsymbol{G_s} = is\ the\ specific\ gravity$$

4.2.3 Hydrocarbon Dew Point

This is the temperature at which heavy hydrocarbon gas will start to condense out of gaseous phase, into liquid phase, the disadvantage of this process is that when allowed to accumulate the hydrocarbon liquids can form slugs which may hinder the flow of gases and affect measuring instruments and pipeline.

4.2.3.1 Density and Specific Gravity

An important property of any gas is its density. High-density gas results in high viscosity and incomplete combustion thereby reducing efficiency. To calculate the specific gravity of natural gas, the density of natural gas divided by the density of air at the same pressure and temperature, and this indicates that specific gravity is directly proportional to the gas density.

4.2.3.2 Water Content

Water in the form of moisture in a gas stream can be a problem and can reduce gas quality, for natural gas it must often be dried before it can be distributed to the user. The drying is necessary to prevent hydrate formation and liquid water deposition in the pipeline and compressors which can cause damage to the equipment. Drying is accomplished by using dehydration agents such as Tri-ethylene Glycol (TEG).

Excess water in natural gas can also cause the formation of hydrates which are ice-like mixtures of water and hydrocarbons that can block or cause problems in metering equipment, pressure regulators or the pipeline itself.

4.2.3.3 Methane Number

Methane number in gas is like the octane number in fuel, the higher the methane number the higher the knock resistance of the gas, thereby improving efficiency. Low methane number can lead to detonation and damage to engines.

4.2.3.4 Hydrogen Sulphide

Apart from being toxic, hydrogen sulphide in gases can be flammable and a higher amount of it can lead to corrosion, it is proven that H_2S is a cracking agent for steel pipelines it advisable to reduce the amount of hydrogen sulphide to meet the delivery quality.

4.2.3.5 Oxygen

The amount of oxygen in a gas stream is important to note as it combines with other chemical gases, particularly with H2S, to form acids which eventually leads to corrosion. Excess Oxygen combine with a heat source can cause explosions.

4.2.3.6 Inert

Inerts in natural gas such as carbon dioxide (CO2), nitrogen (N2), helium (He), argon (Ar) and oxygen (O2) are regulated to avoid excess pressure.

4.3 Gas Quality Specification for the United Kingdom

Countries with a general gas transmission network facility such as gas transmission and distribution pipelines, compression and regasification stations have established gas quality requirements for third party users who intend to use such facilities for gas transmission. The essence of the gas quality specification is to ensure a safe working environment, natural gas grid integrity and safety of the equipment. In the United Kingdom, gas quality specifications are in line with the Gas Safety (Management) Regulations 1996.

Table 4.1: Natural Gas Quality Parameters and Measuring Tools.

PARAMETERS	UNIT	TOOLS FOR MEASUREMENT	PRINCIPLE OF OPERATION
Wobbe Index	**(MJ/m3)**	**Calorimeters**	The gas calorimeter works with the principle of burning of a known volume of gas sample with air and the temperature difference between the combustion exhaust gas and the feed air is detected by using a thermocouple, the flow rate of both the sample gas and the air as the differential pressure by using the orifice and converts the differential pressure to the digital signal
		Chromatographs	Gas Chromatography technique separates, detect, and quantify small volatile compounds in the gas phase. The liquid samples are vaporized, then carried by an inert gas through a long, thin column. Analytes are separated based on their chemical affinity with a coating on the inside of the column.
Oxygen	**(mol %)**	**Oxygen Analyser**	Use of material with a strong affiliation to oxygen such as Zirconia. The operating principle of the paramagnetic sensor is the paramagnetic susceptibility of the oxygen molecule, a physical property which distinguishes oxygen from most other gases.
Hydrogen sulphide (H2S) maximum	**(mg/m3)**	**Hydrogen Sulphide Analyser**	When the sample gas is passed through this instrument, an internal pump draws air and any hydrogen sulphide in the sample is absorbed by the sensor which registers a proportional change in electrical resistance.
Hydrocarbon dew point	**kPag**	**dew point analyser**	This method determines the concentration of each component and element after which the condensing point for each element is then

			calculated
Water Content	**(mg/m3)**	**Water Analyser**	Moisture content is calculated based on the weight difference before and after the drying procedure.

Table 4.2 UK Gas Quality and allowable values. (IGEM Regulations 1996, Schedule 3, Part).

GAS QUALITY PARAMETER	ALLOWABLE VALUE
Hydrogen sulphide	≤ 5 mg/m3
Total sulphur content	≤ 50 mg/m3
Hydrogen content	≤ 0.1% (molar)
Oxygen content	≤ 0.2% (molar)
Impurities	Shall not contain solid or liquid material which may interfere with the integrity or operation of pipes or any gas appliance (within the meaning of regulation 2(1) of the 1994 Regulations) which a consumer could reasonably be expected to operate
Hydrocarbon dew point and water dew point	Shall be at such levels that they do not interfere with the integrity or operation of pipes or any gas appliance (within the meaning of regulation 2 (1) of the 1994 Regulations) which a consumer could reasonably be expected to operate
Wobbe Number (WN)	(i) ≤51.41 MJ/m3, and (ii) ≥ 47.20 MJ/m3
Incomplete combustion factor (ICF)	≤ 0.48
Scooting index (SI)	≤ 0.60

Chapter 5 CONCLUSION

We have been able to:

- Mention the importance of accurately measuring four physical properties in Natural Gas systems.
- Categorize temperature measurement into contacted and non-contacted approaches.
- Classify pressure gauges into liquid-column gauges, force-balance gauges and transducers.
- Group flow meters into those that add energy and those that remove energy from the flow system.
- Provide concise descriptions of instruments for measuring pressure, temperature, flow and gas quality in the Natural Gas industry.

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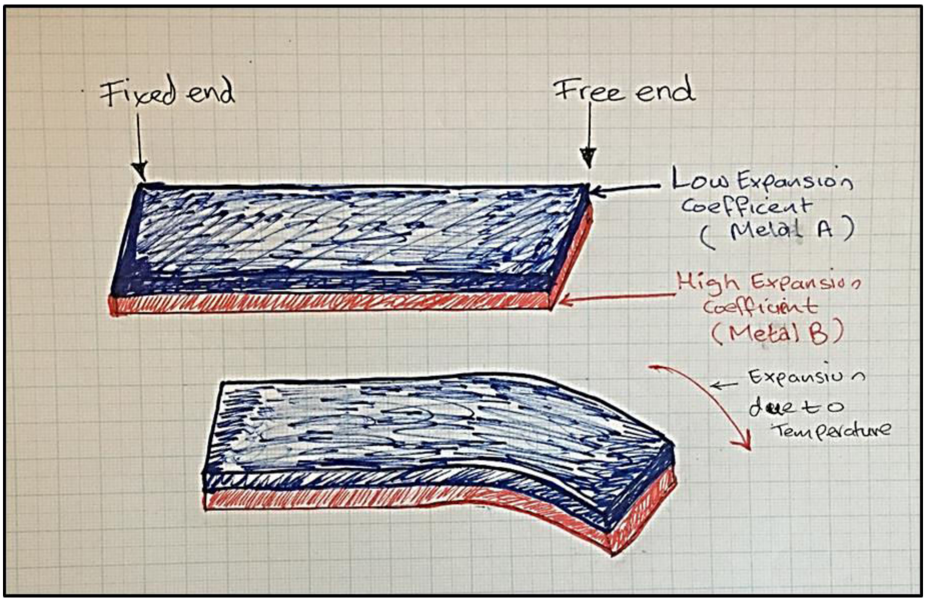
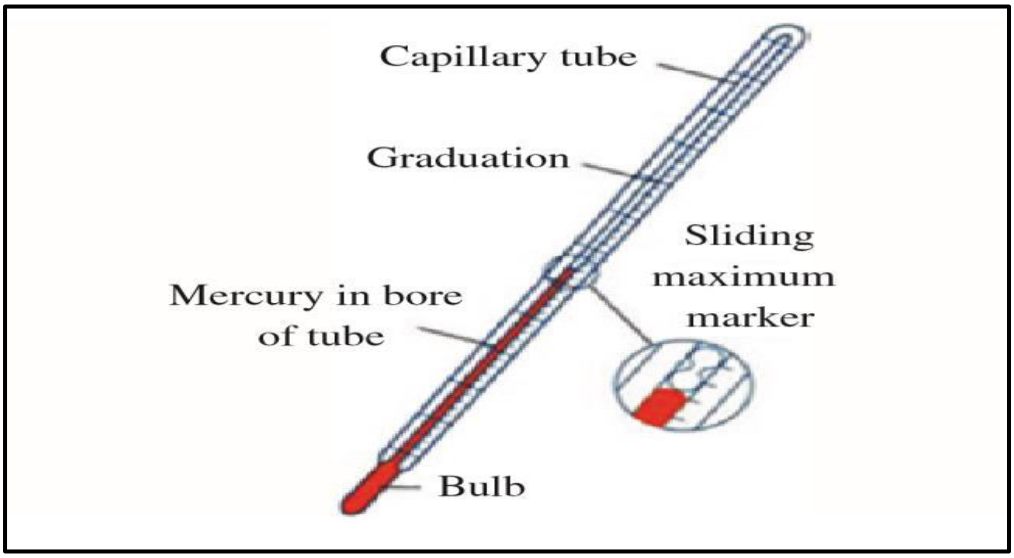
Appendices

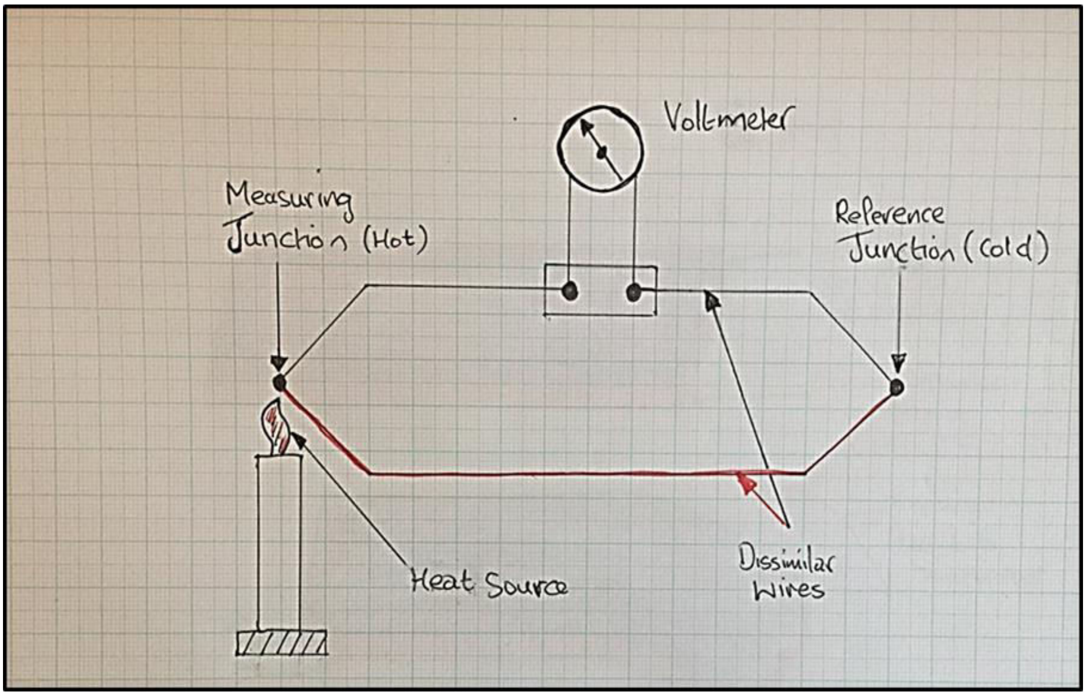
5.1 Appendix A: Temperature Measurement Devices



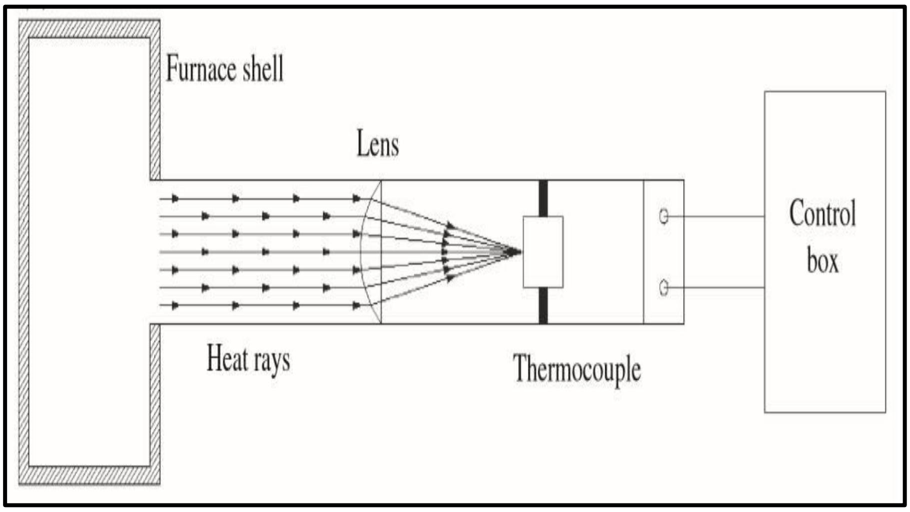
Appendix A - 1:Sketches of Bimetallic Strips



Appendix A-2: Liquid in Glass Thermometer. (Nasr & Connor, 2014).

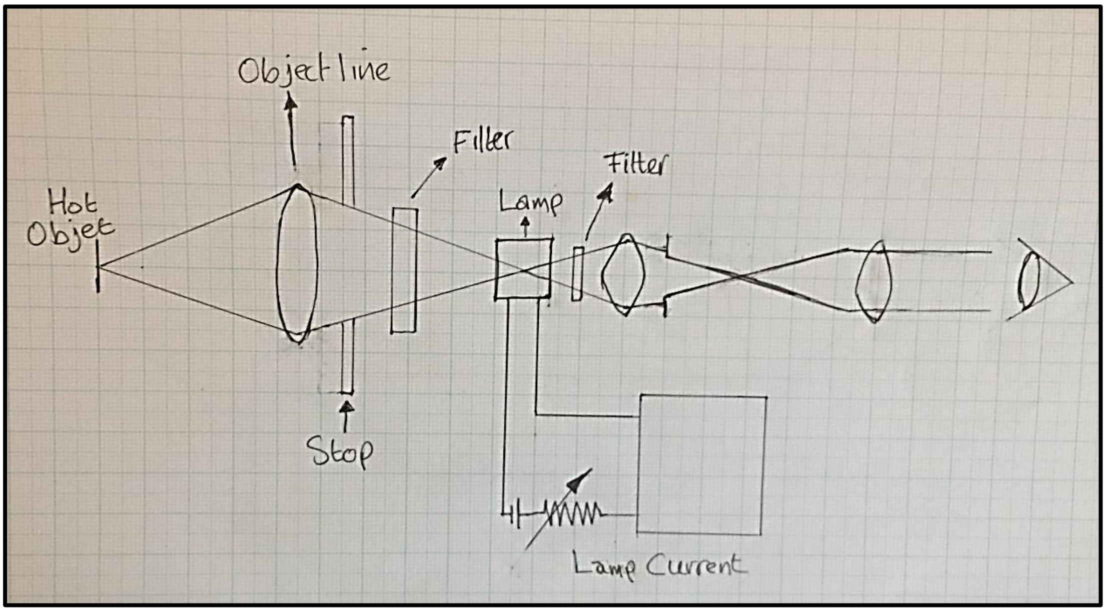


Appendix A-3: Schematic of a Thermocouple. (Nasr & Connor, 2014).



Appendix A-4:Schematic of Radiation Pyrometer Instrument Design Features. (Nasr & Conner, 2014)

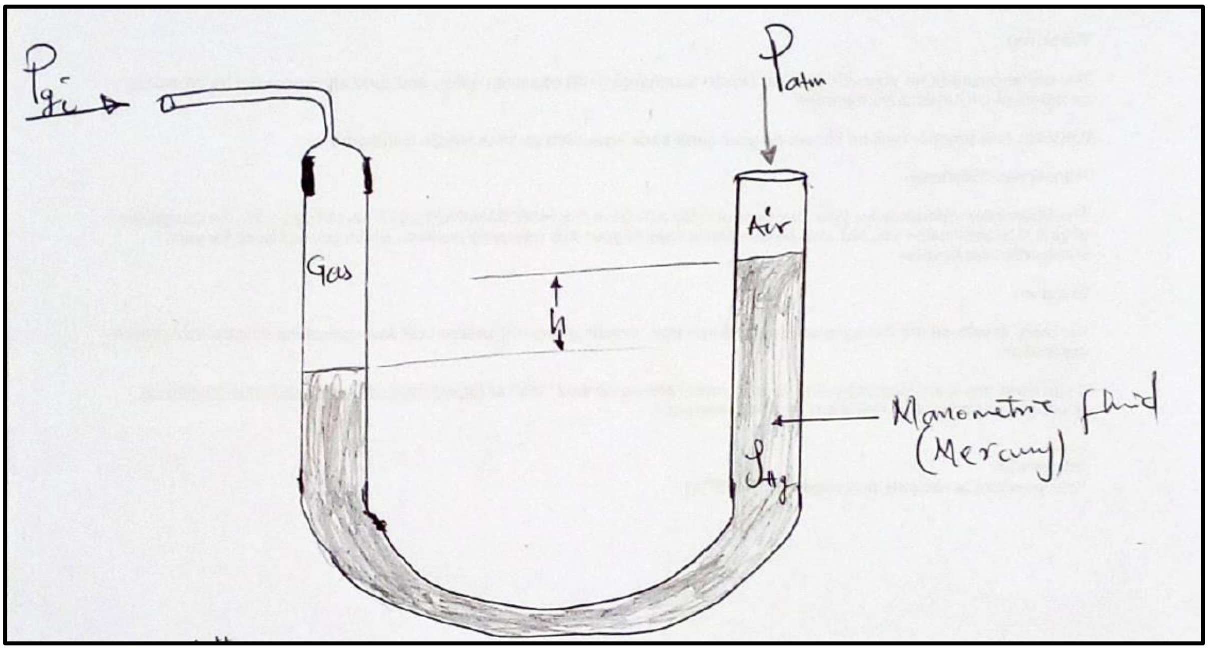
Appendix A-5: Typical Radiation Pyrometer-Continuous Catching Operation (Nasr & Conner, 2014).



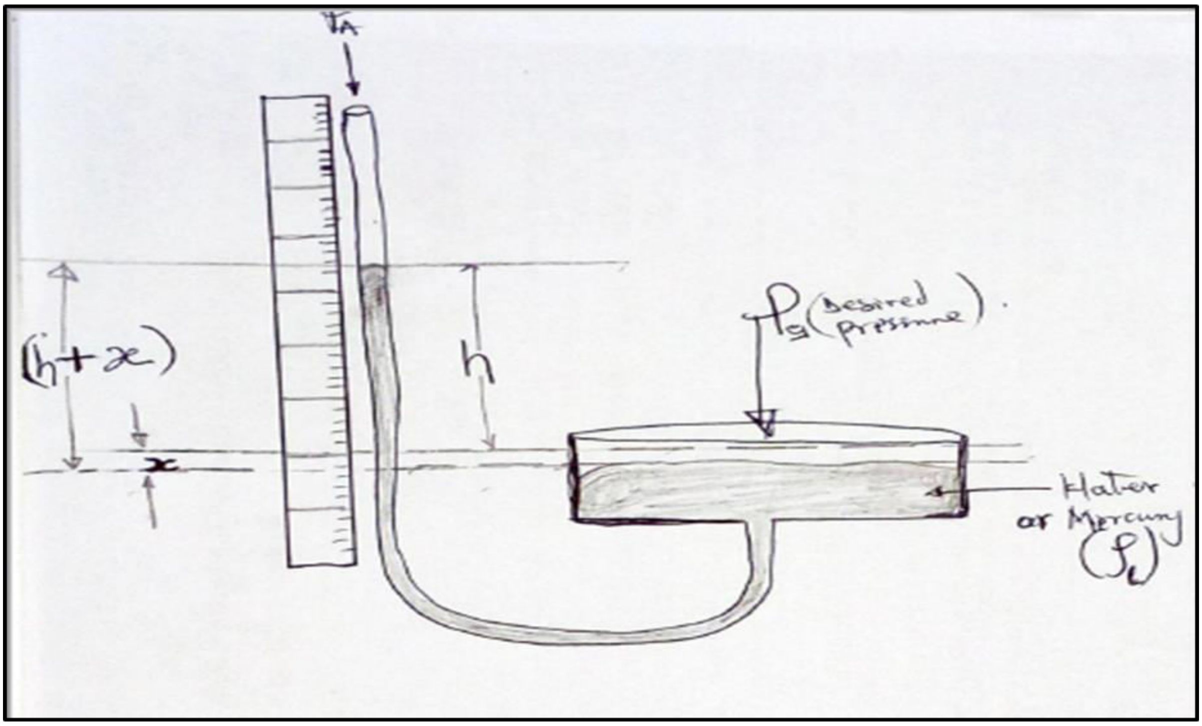
Appendix A-6: Schematic of an Optical Pyrometer (Nasr & Connor, 2014).

Appendix A-7: Optical pyrometer (Nasr & Connor, 2014).

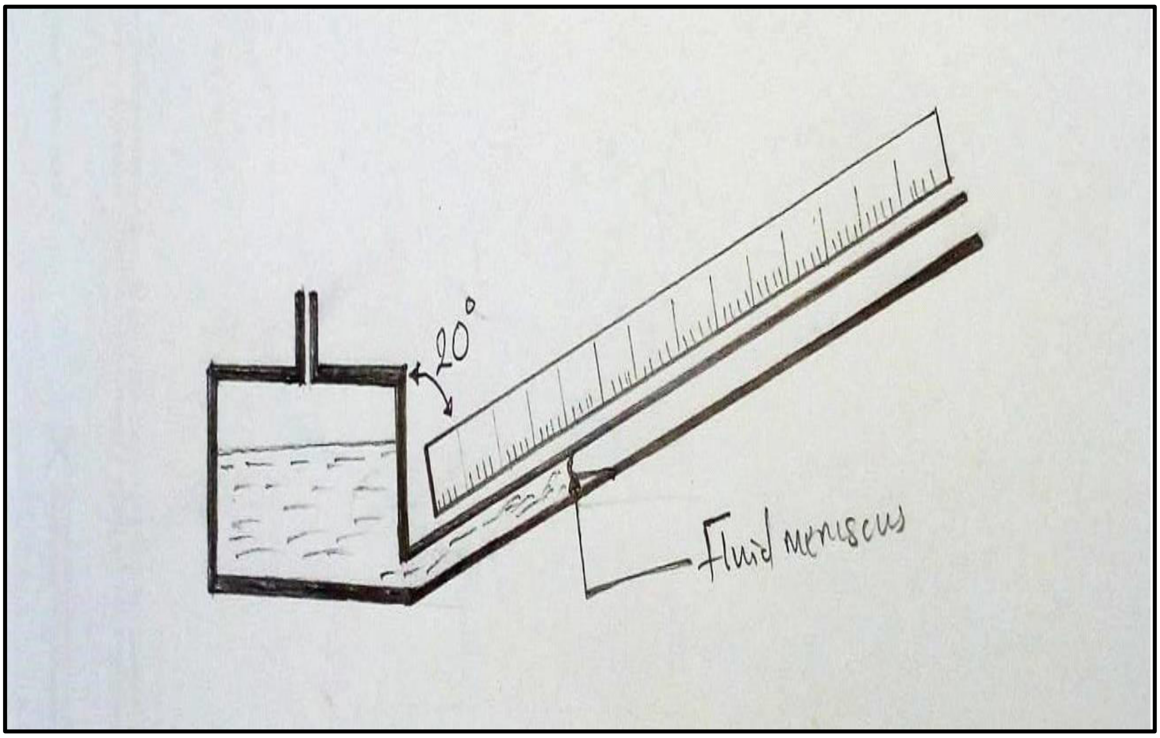
5.2 Appendix B: Pressure Measurement Devices



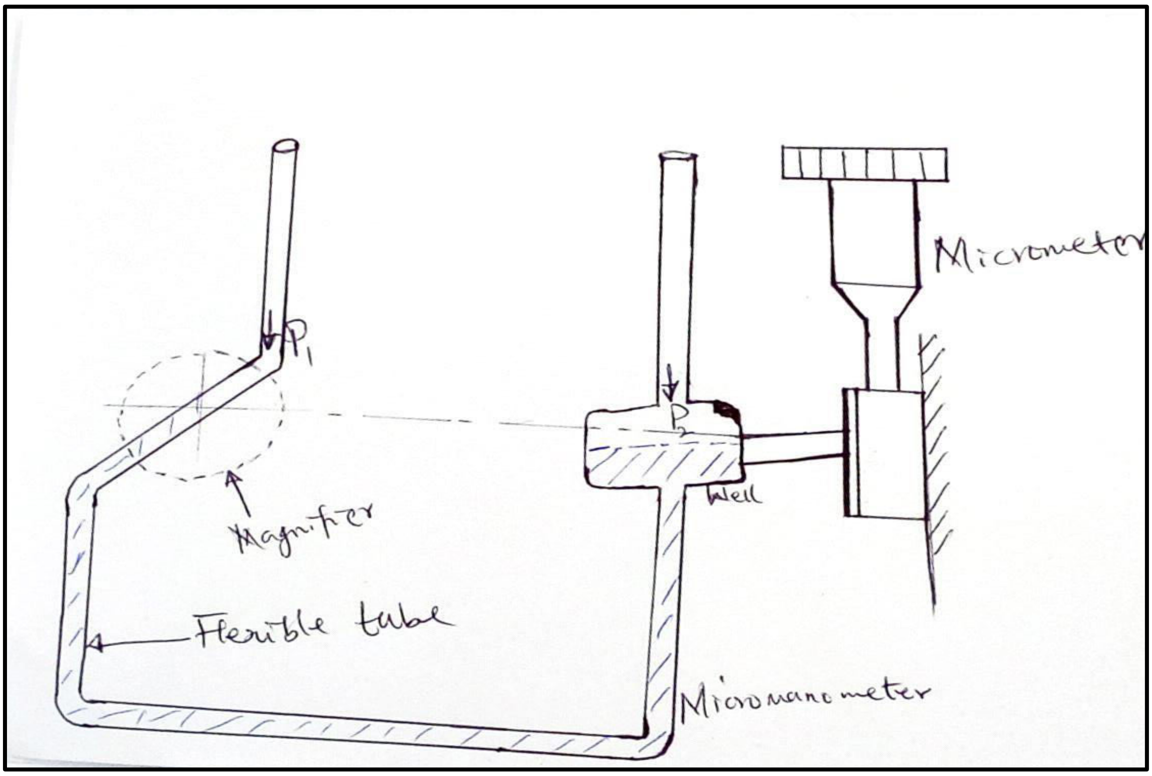
Appendix B- 1 Schematic Illustration of a U-tube Manometer.



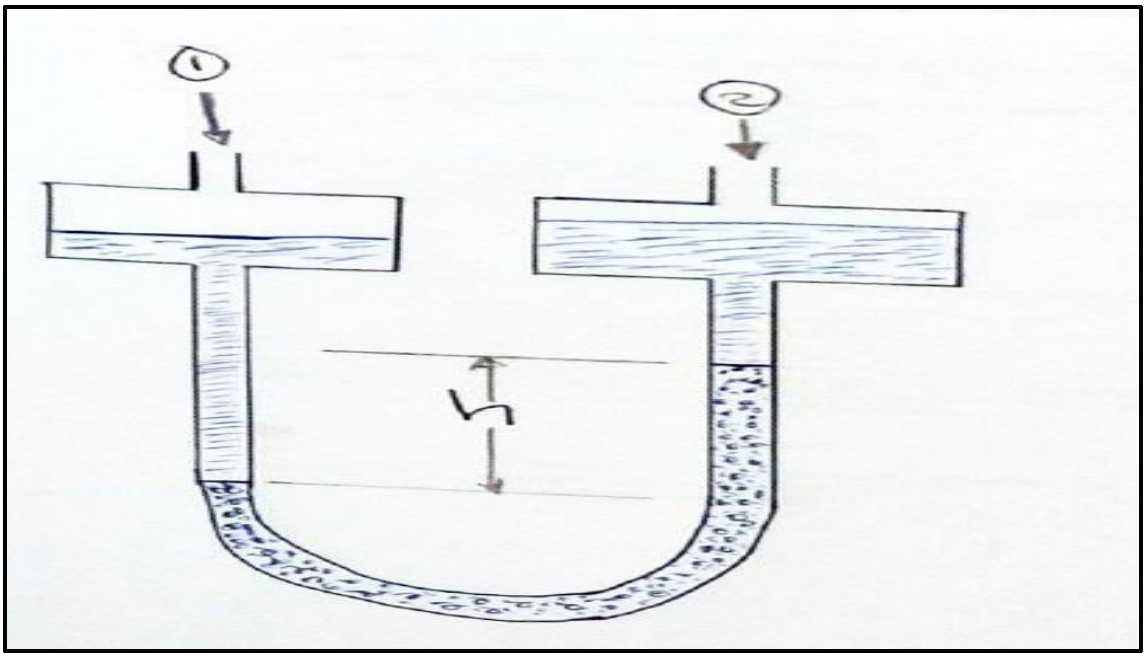
Appendix B- 2 Schematic of a Well-Type Manometer.



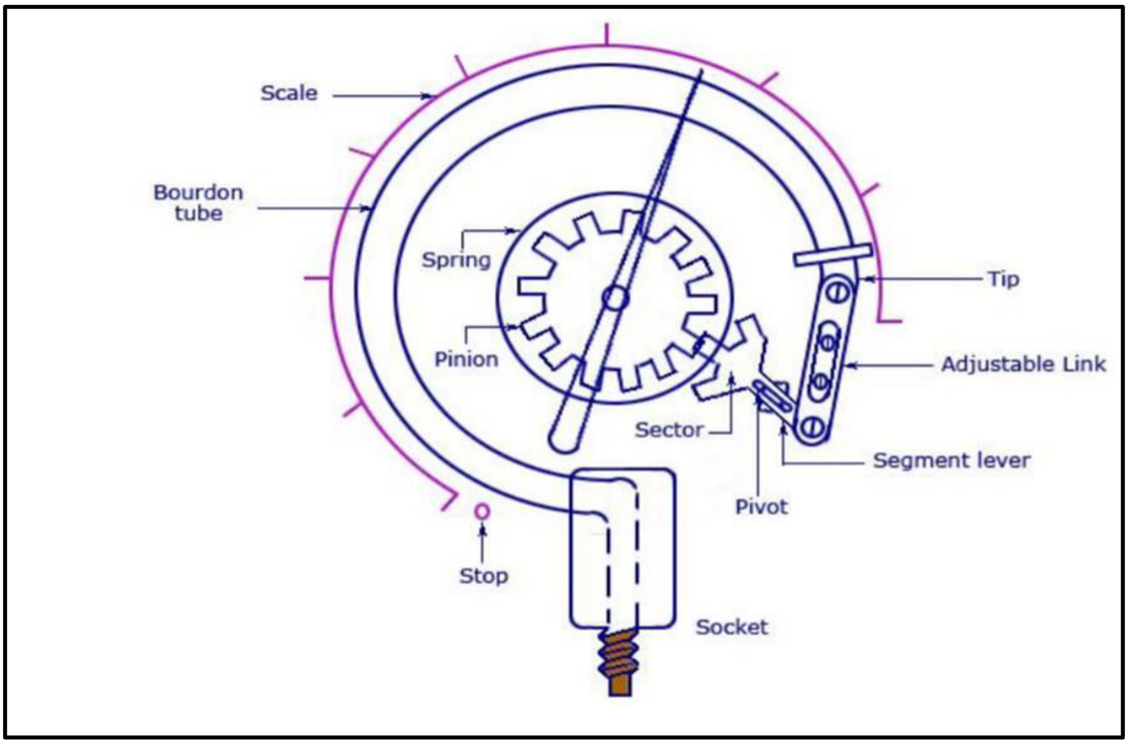
Appendix B- 3 Schematic of an Inclined Tube Manometer.



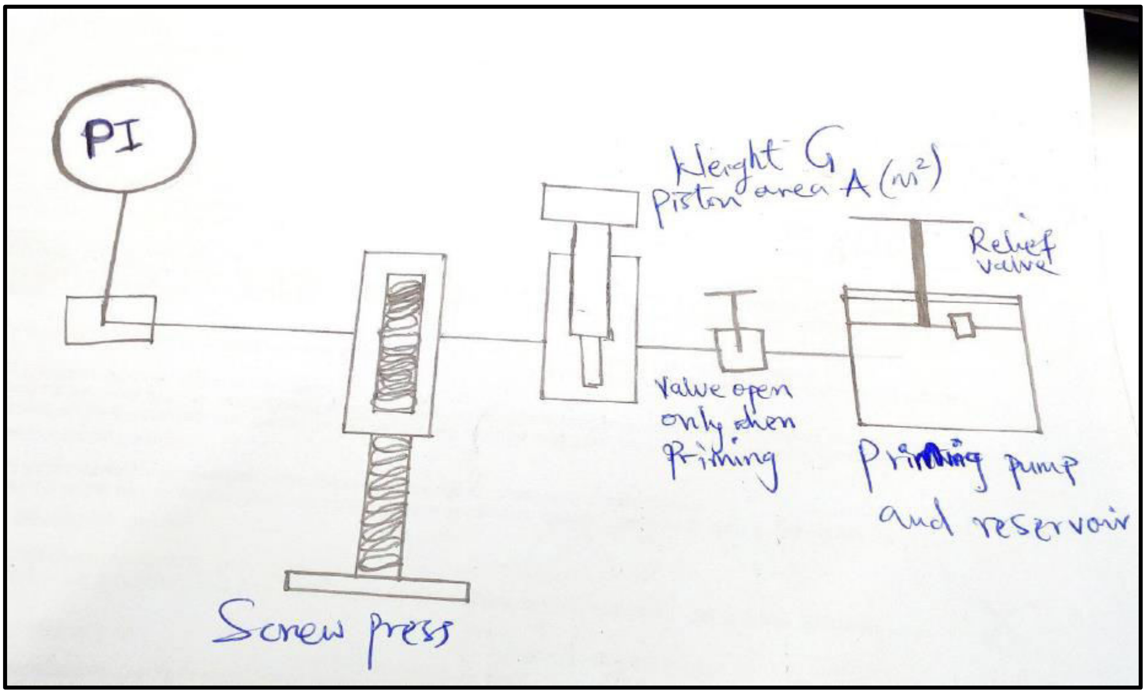
Appendix B- 4 Sketch of Micro-manometer.



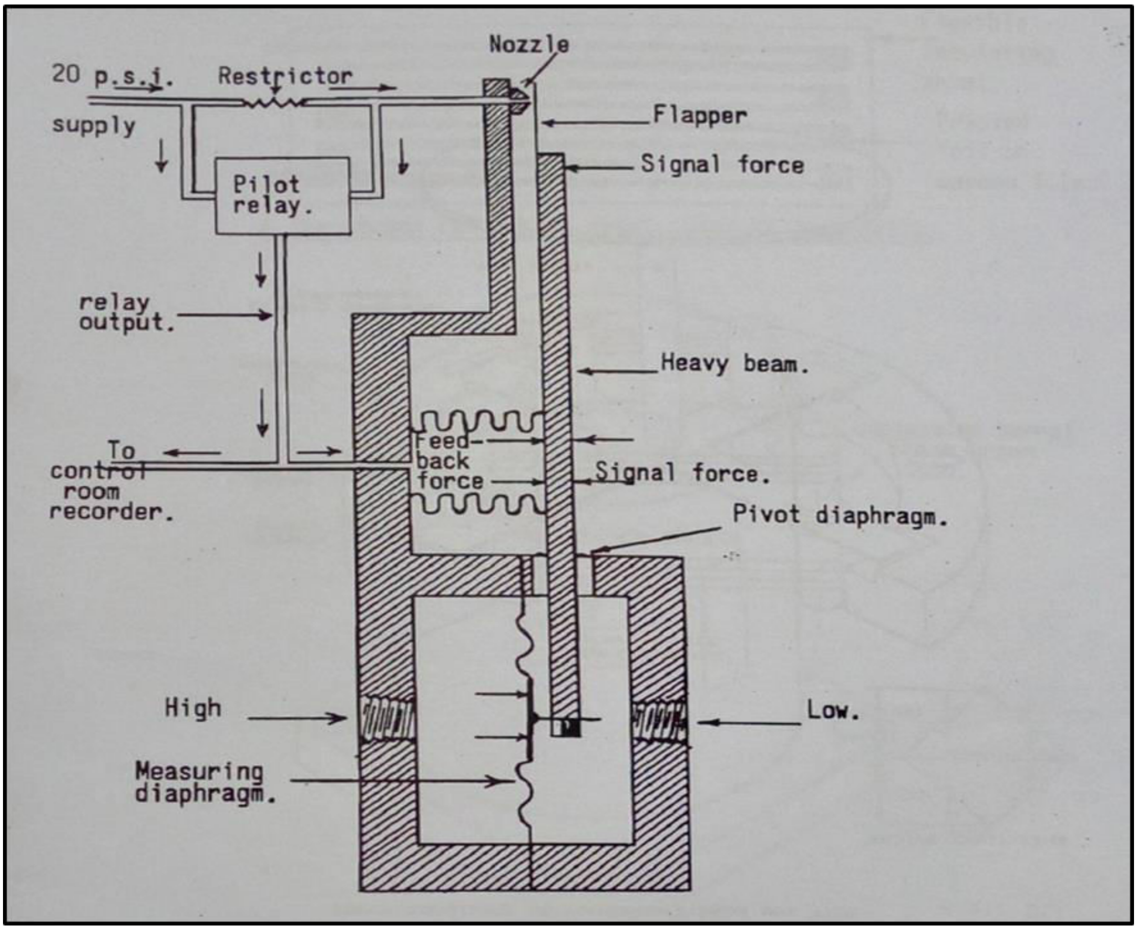
Appendix B- 5 Schematic of a Differential manometer.



Appendix B-6: Bourdon type gauge (: Process Instrumentation I Semester IV, n.d.).

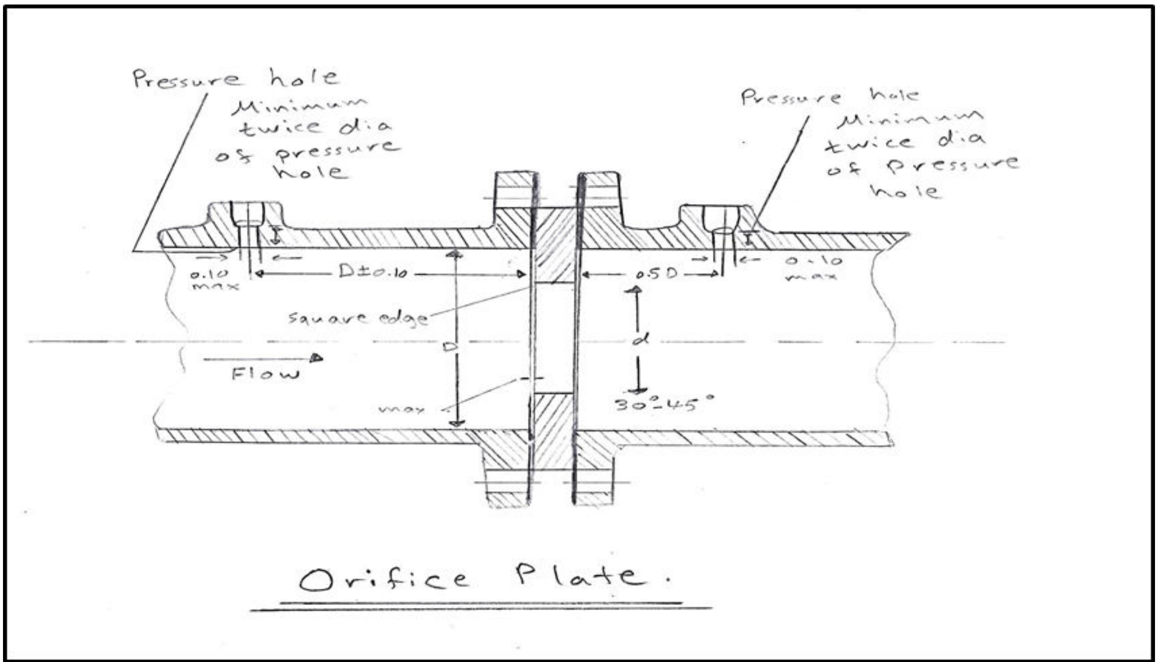


Appendix B- 7: Piston-type Pressure Gauge Schematic.

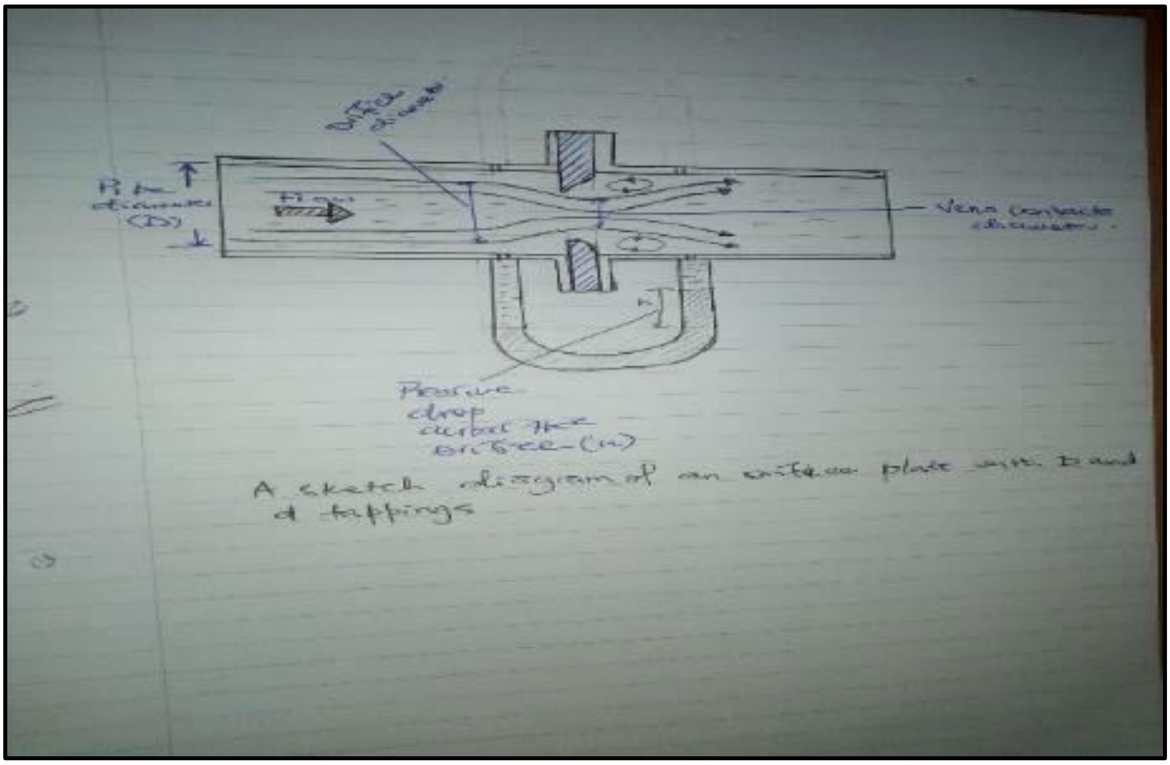


Appendix B-8: of a DP Cell (Nasr & Connor, 2014).

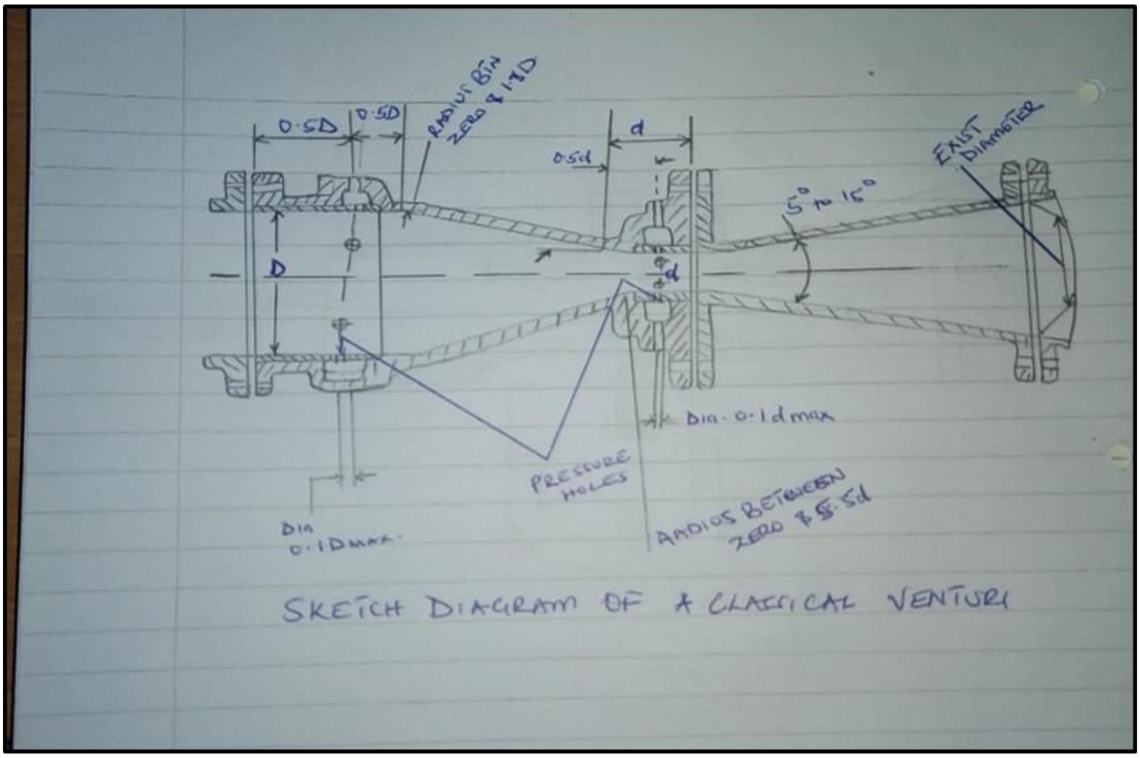
5.3 Appendix C: Gas Flow Rate Measurement Devices



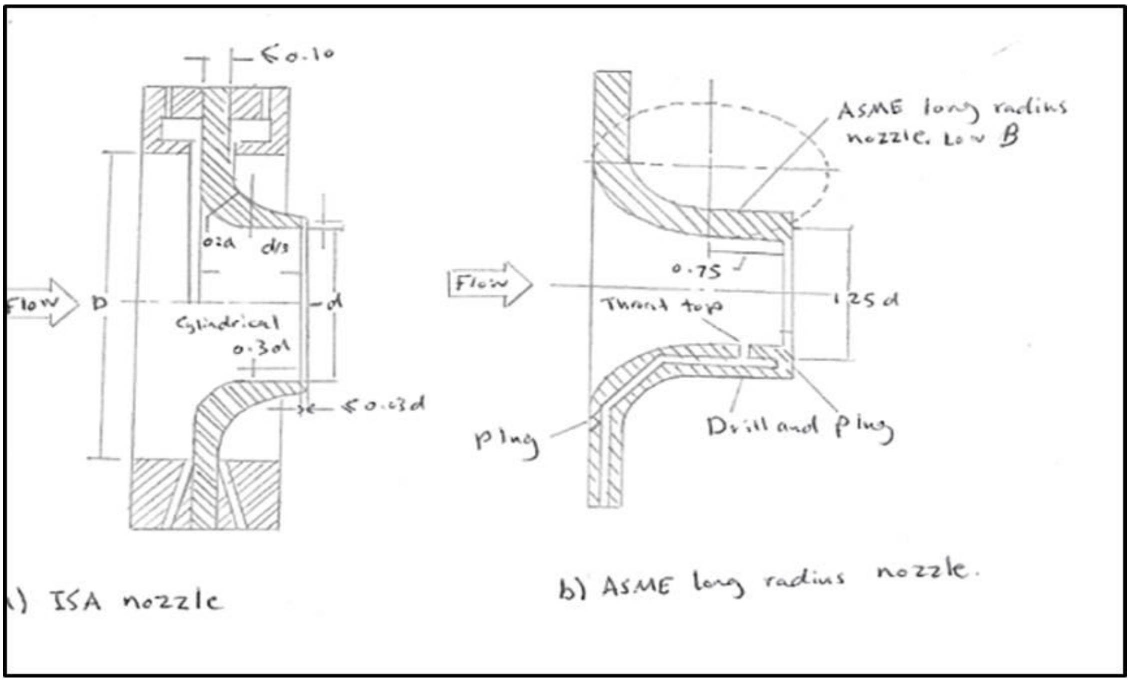
Appendix C- 1 Schematic Sketch of Orifice Plate.



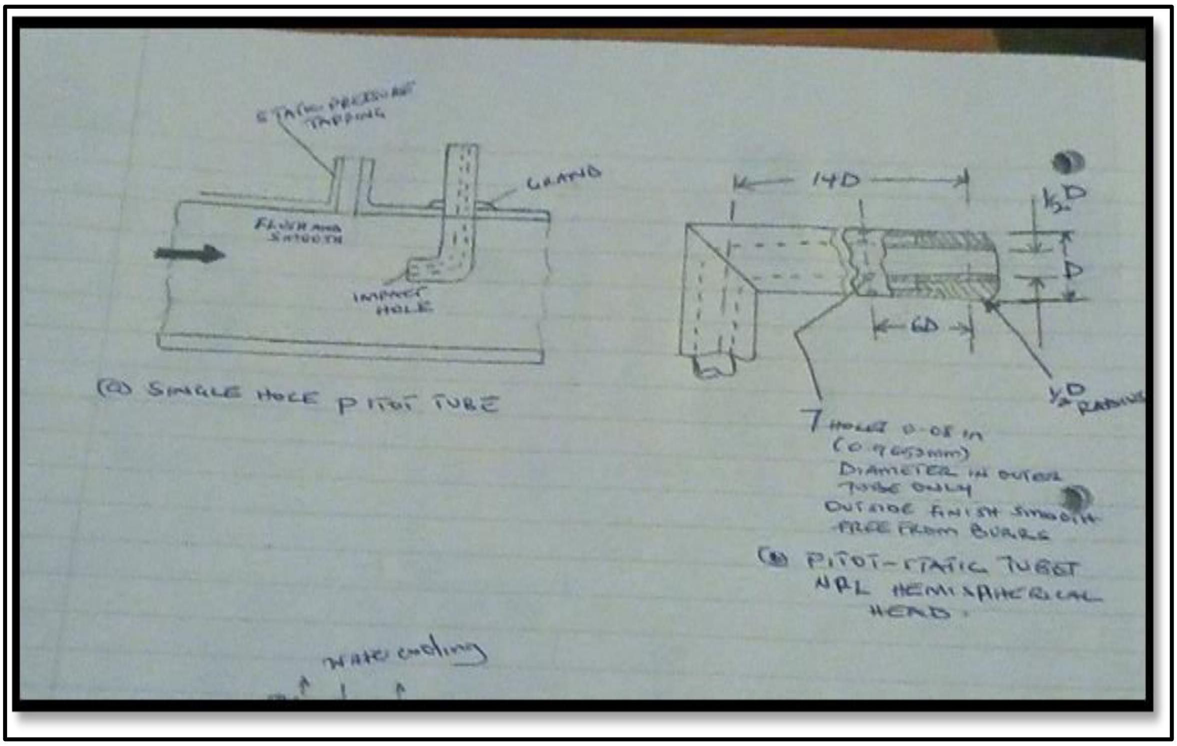
Appendix C- 2 Sketch of Orifice Plated Connected with Taping.



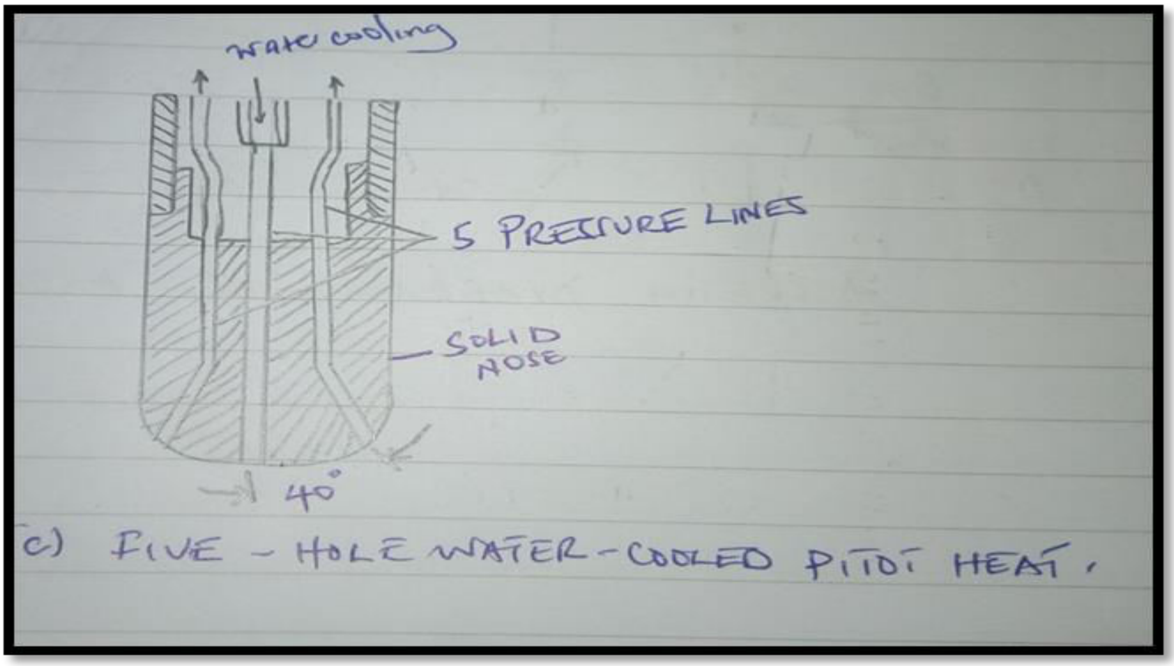
Appendix C- 3 Schematic of a Classical Venturimeter.



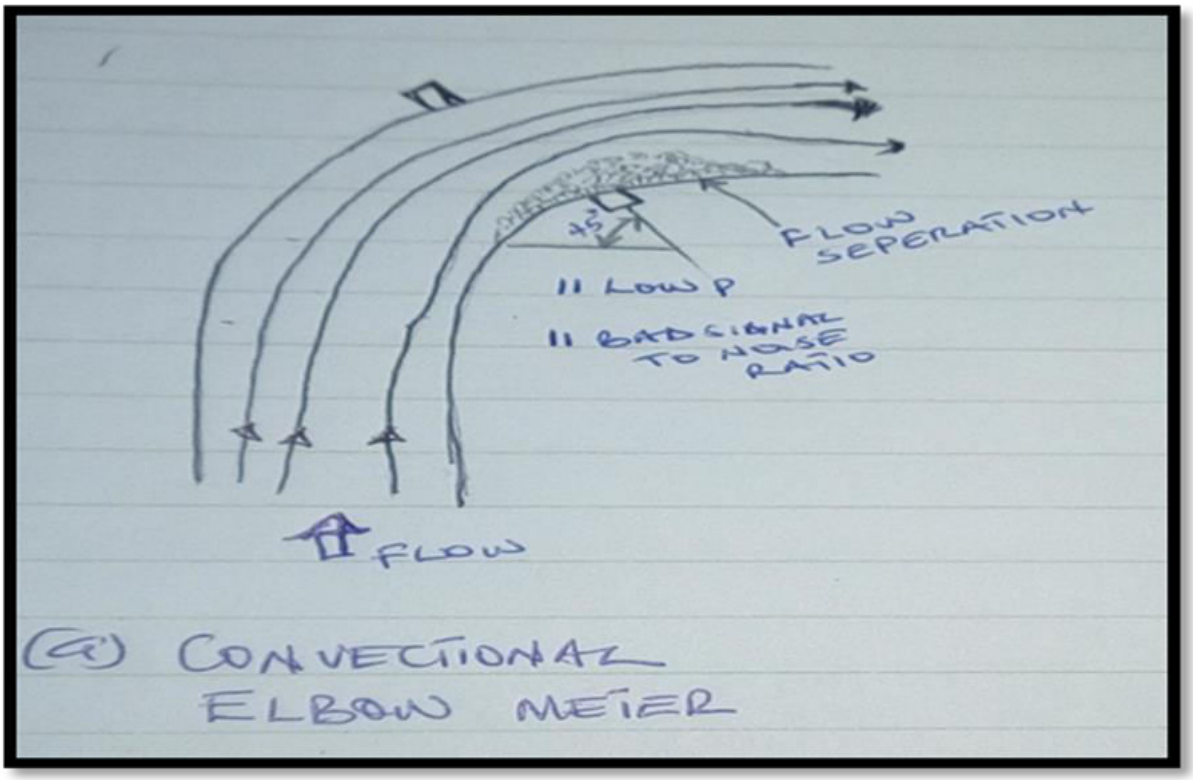
Appendix C- 4: Schematic Sketch of standard Designs Flow Nozzles.



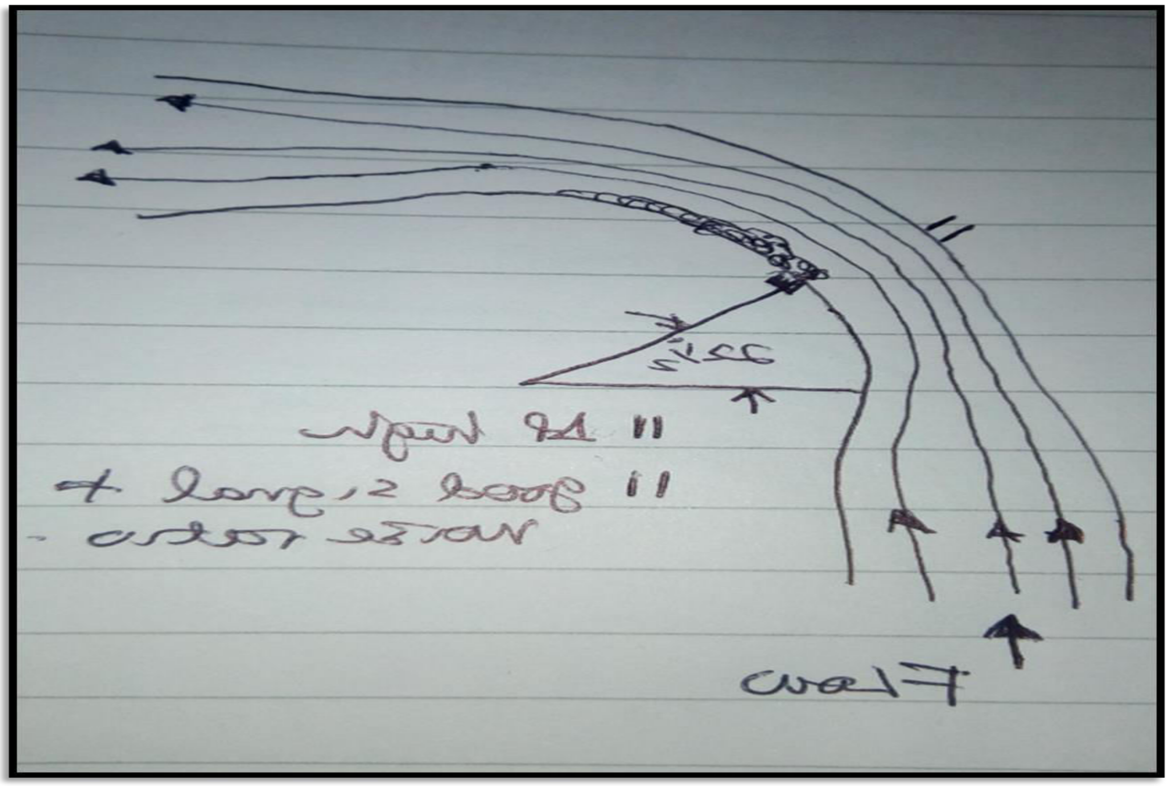
Appendix C- 5: Schematic Sketch of Pitot Tubes.



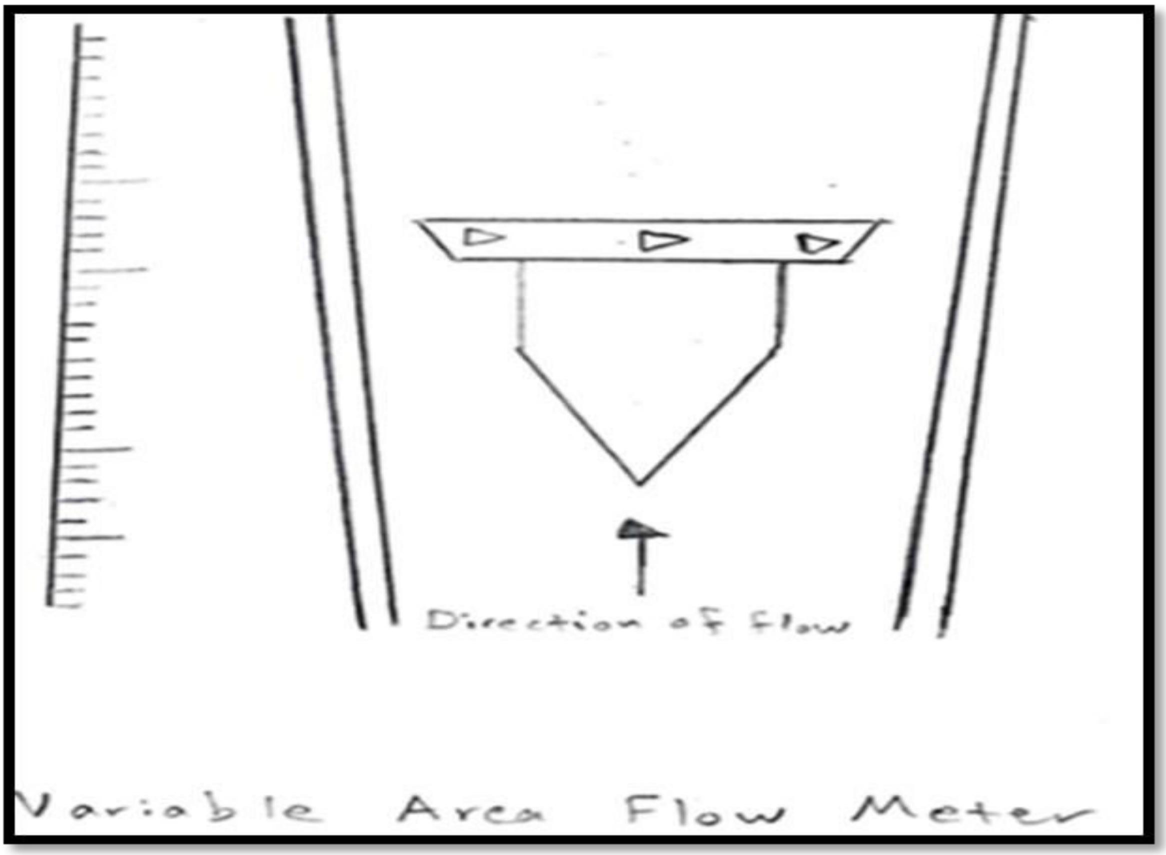
Appendix C- 6: Sketch of Five -hole Water Cooled Pitot Head.



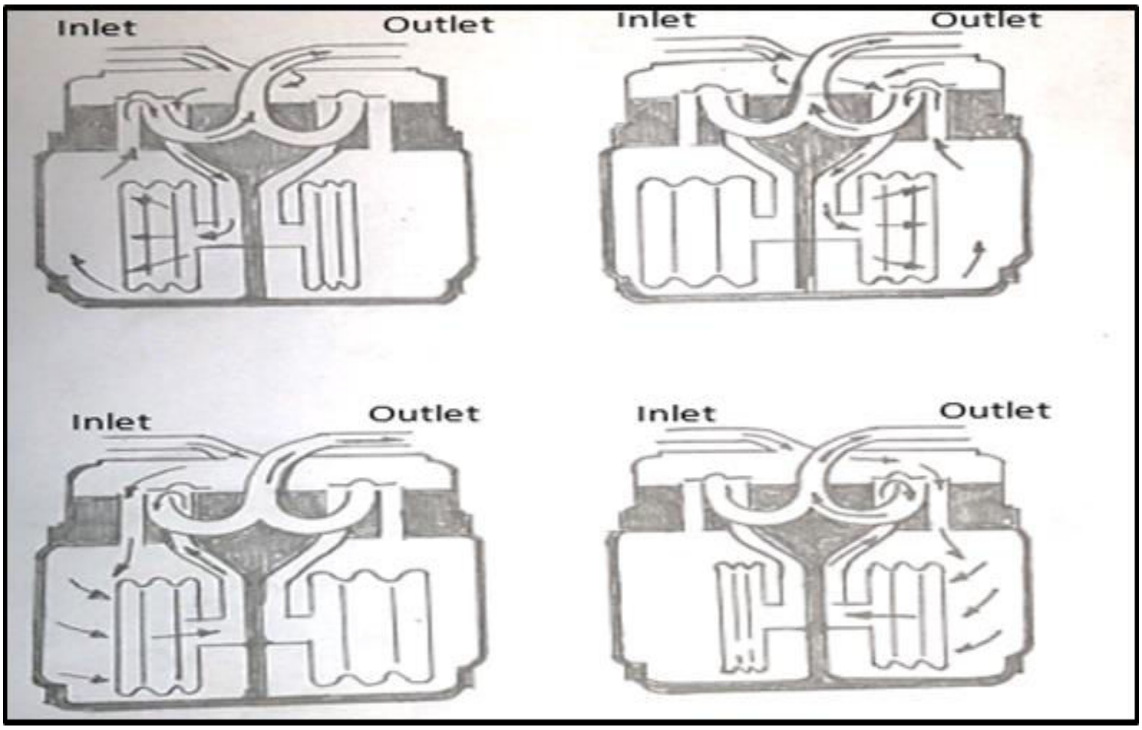
Appendix C- 7: Sketch of Convectional Elbow Meter.



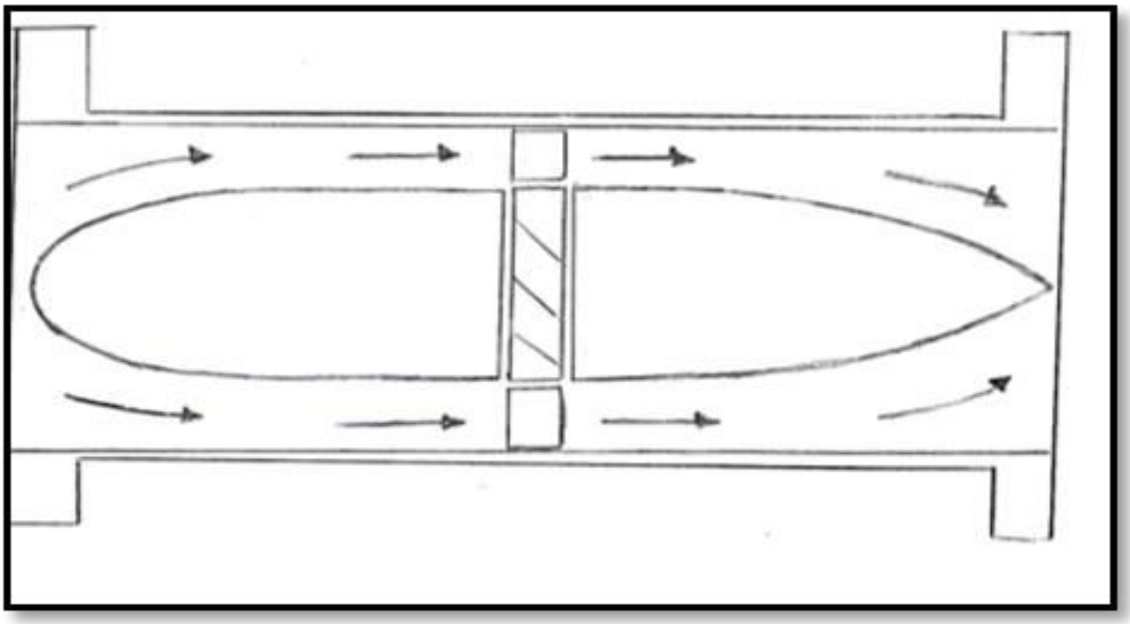
Appendix C- 8 Sketch of a Venturi Elbow Meter.



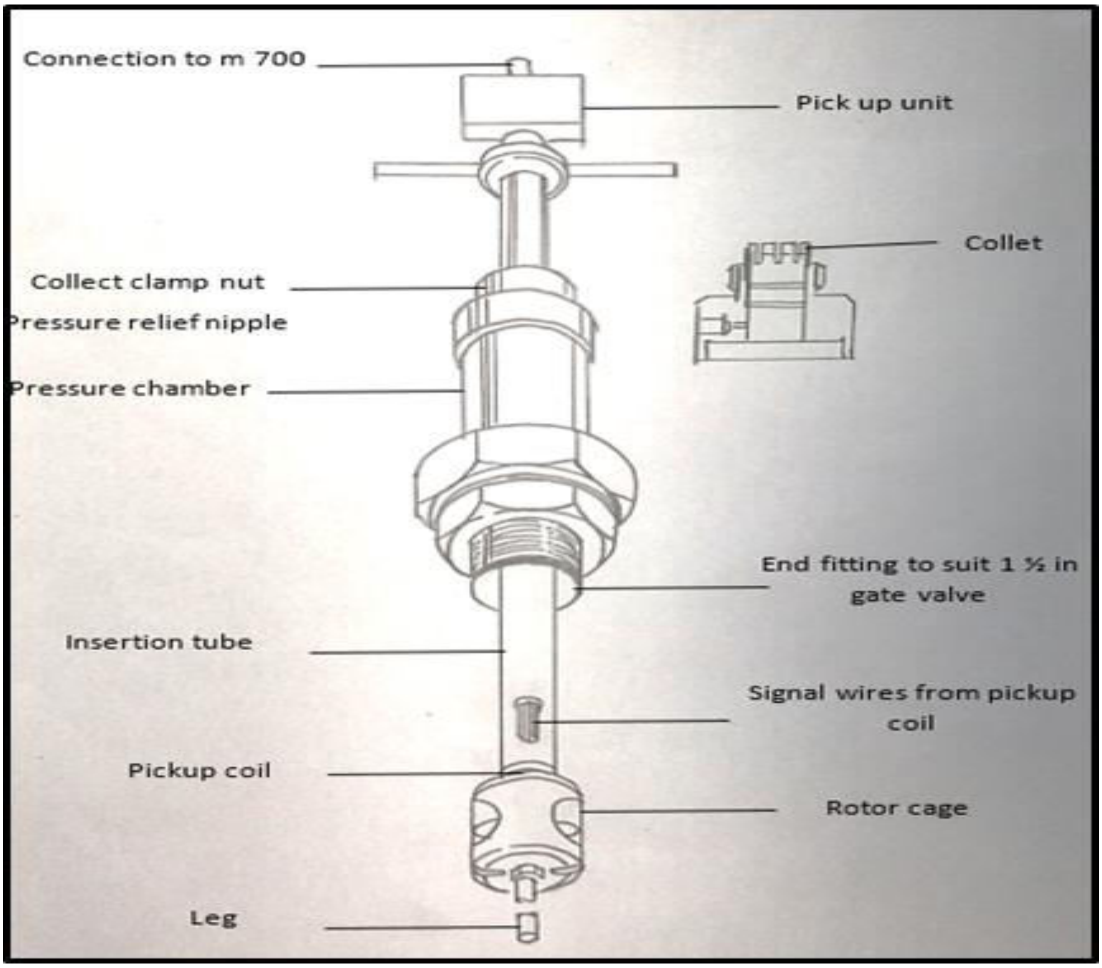
Appendix C- 9 Schematic Sketch of Variable Area Flow Meter.



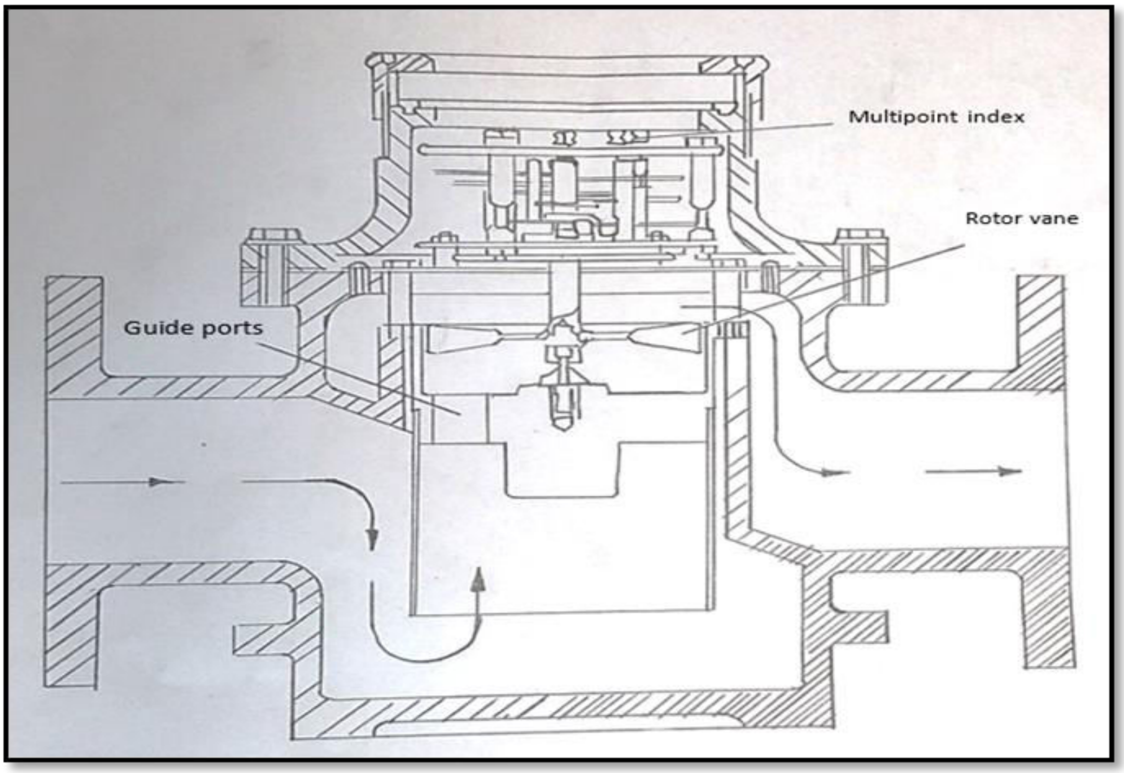
Appendix C- 10 Schematic Diagrams of Sequence Operation of Diaphragm Meters.



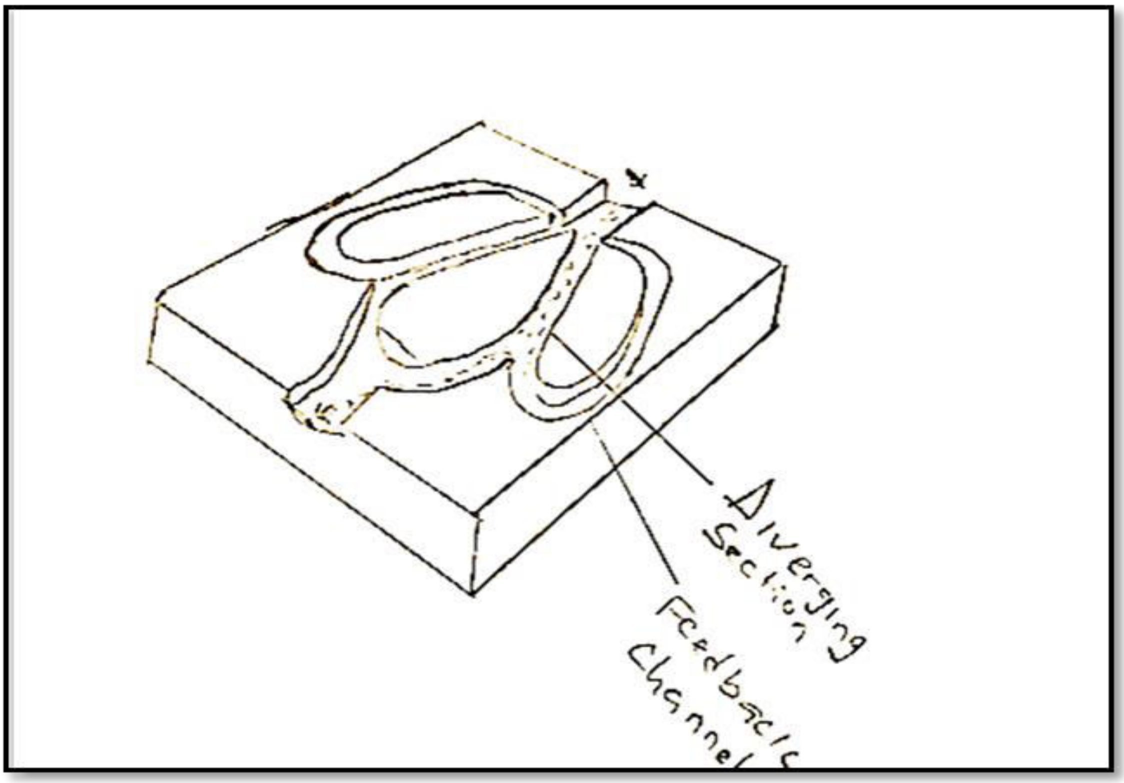
Appendix C- 11 Schematic Sketch of Axial Flow Turbine Meter.



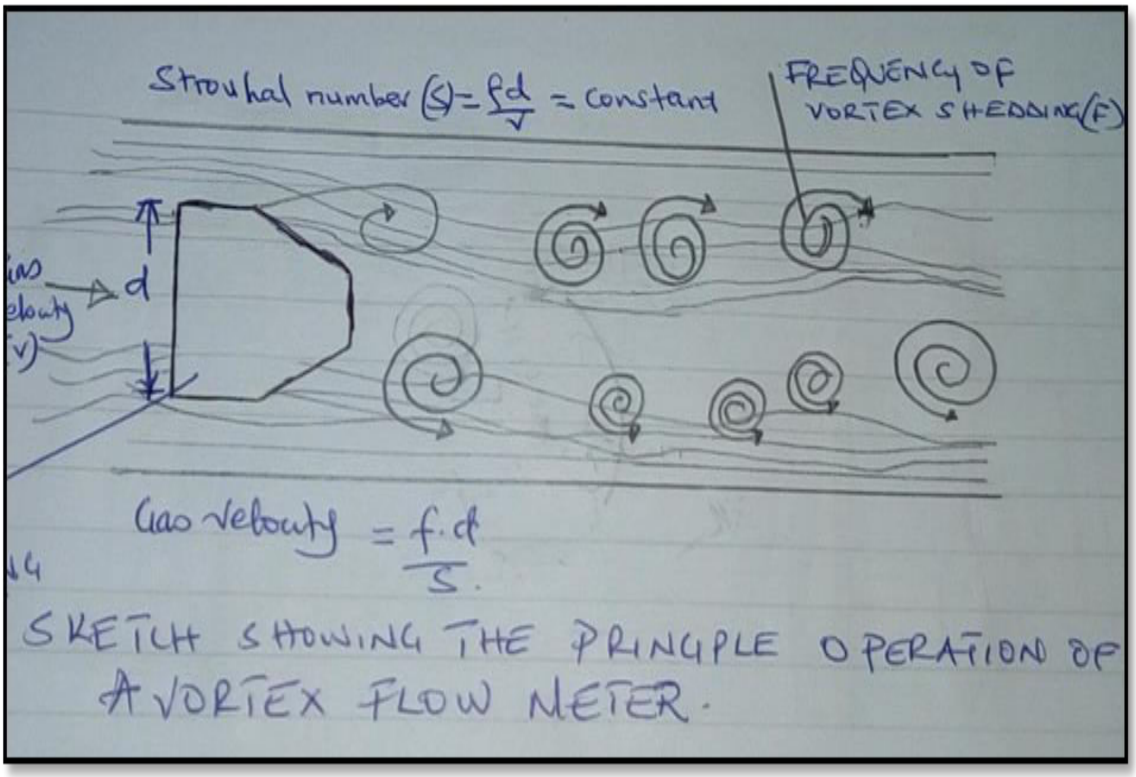
Appendix C- 12 Schematic Diagram of Low Pressure Insertion Turbine Meter.



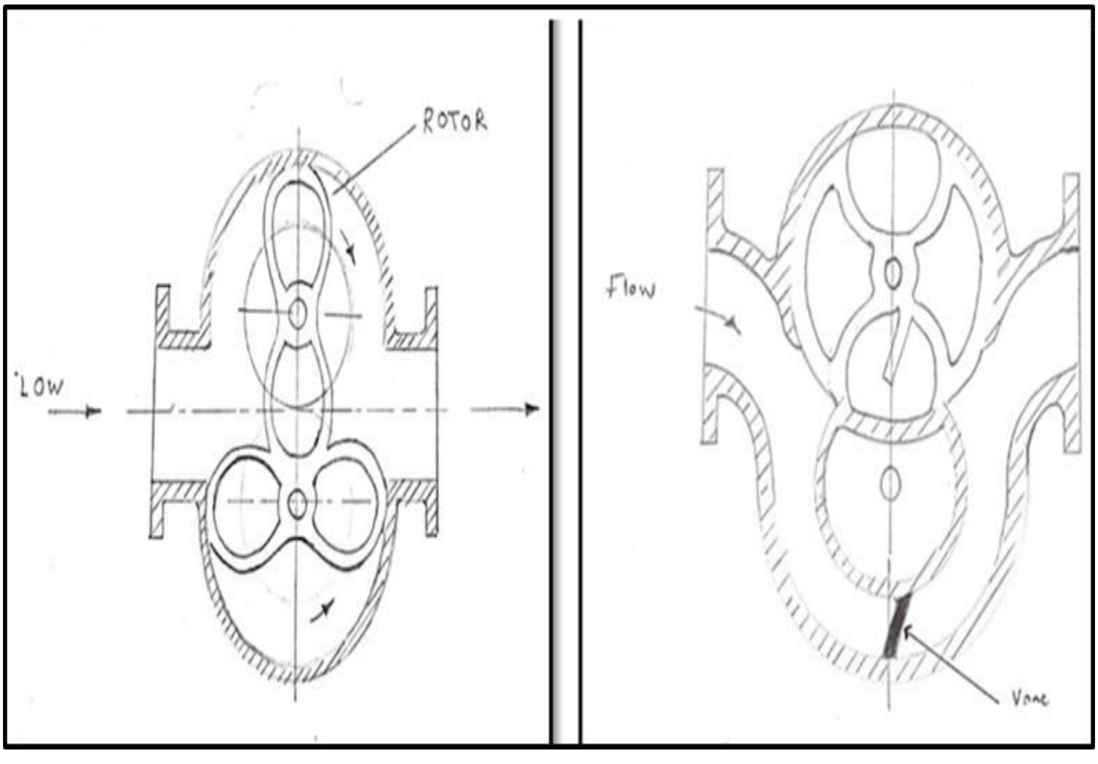
Appendix C- 13 Schematic Diagram Meter Rotary Inferential Gas Meter.



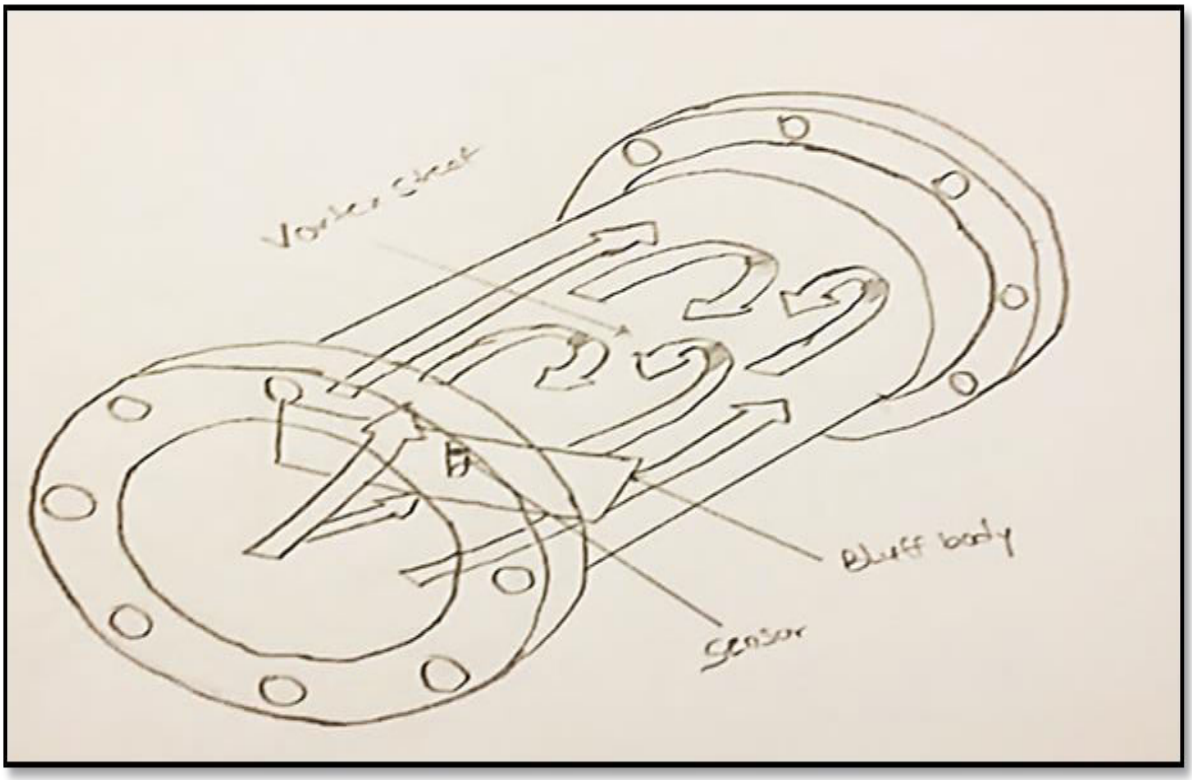
Appendix C- 14 Sketch of Mode of Operation of a Feedback Oscillatory Meter.



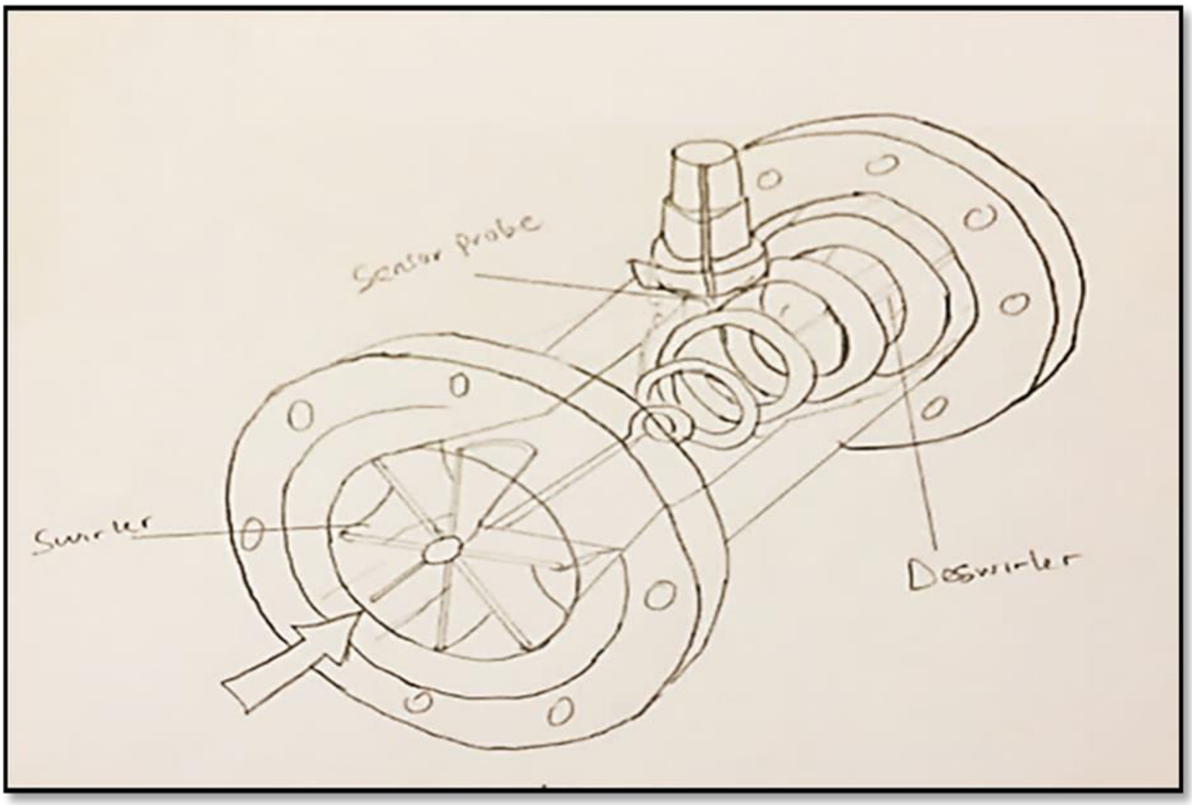
Appendix C- 15 Sketch of Theory of the Vortex Shedding Flow Meter.



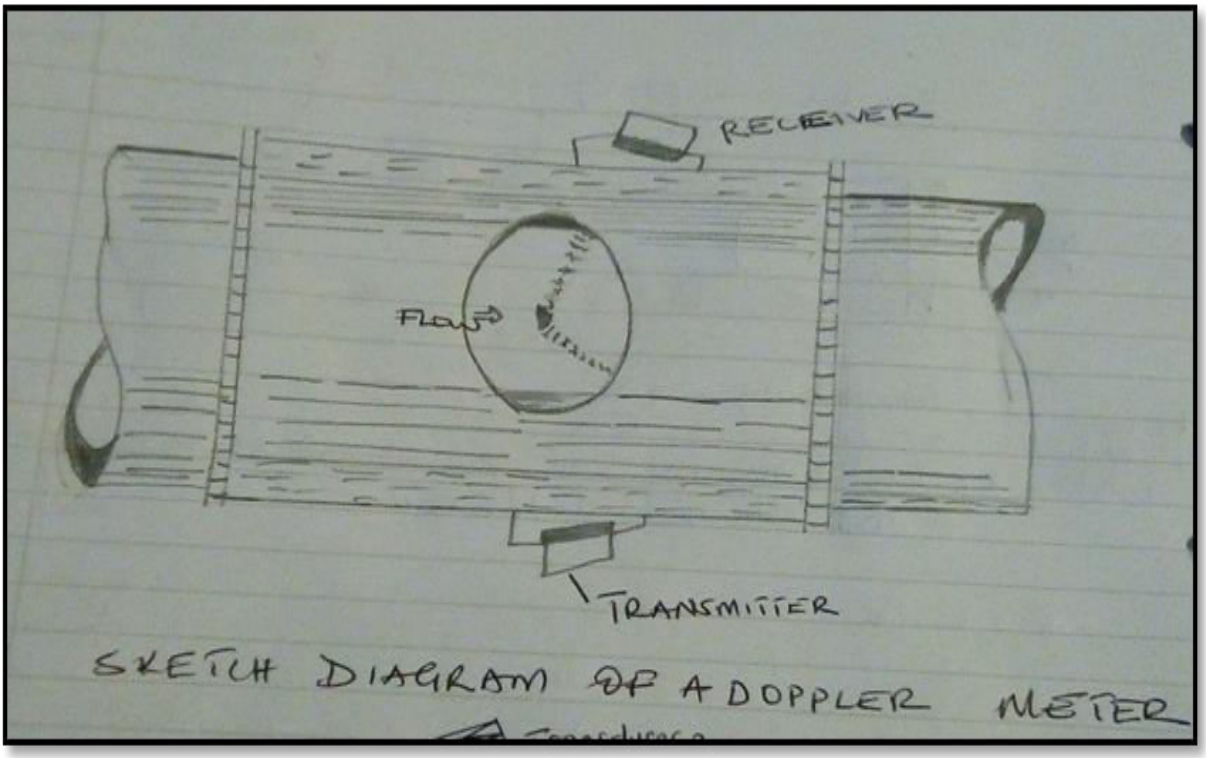
Appendix C- 16: Sketches of Roots Meter and Vane and Gate Meters.



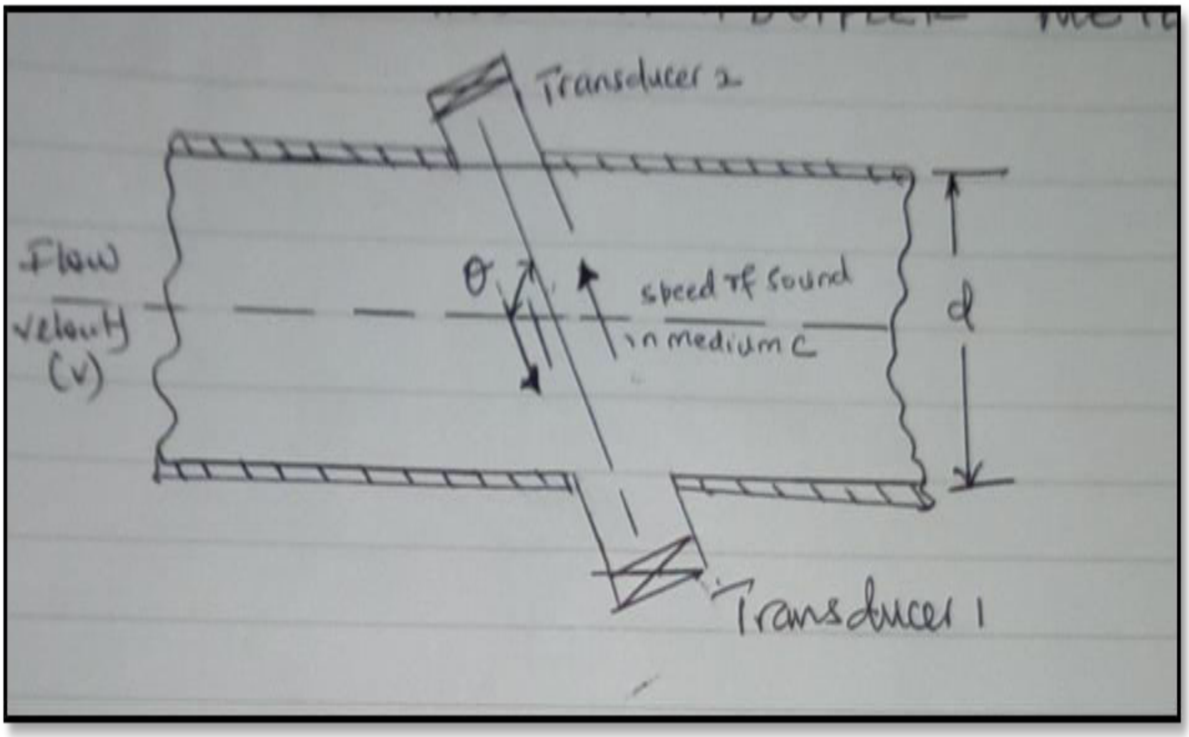
Appendix C- 17: Schematic Sketch of the Vortex Meter.



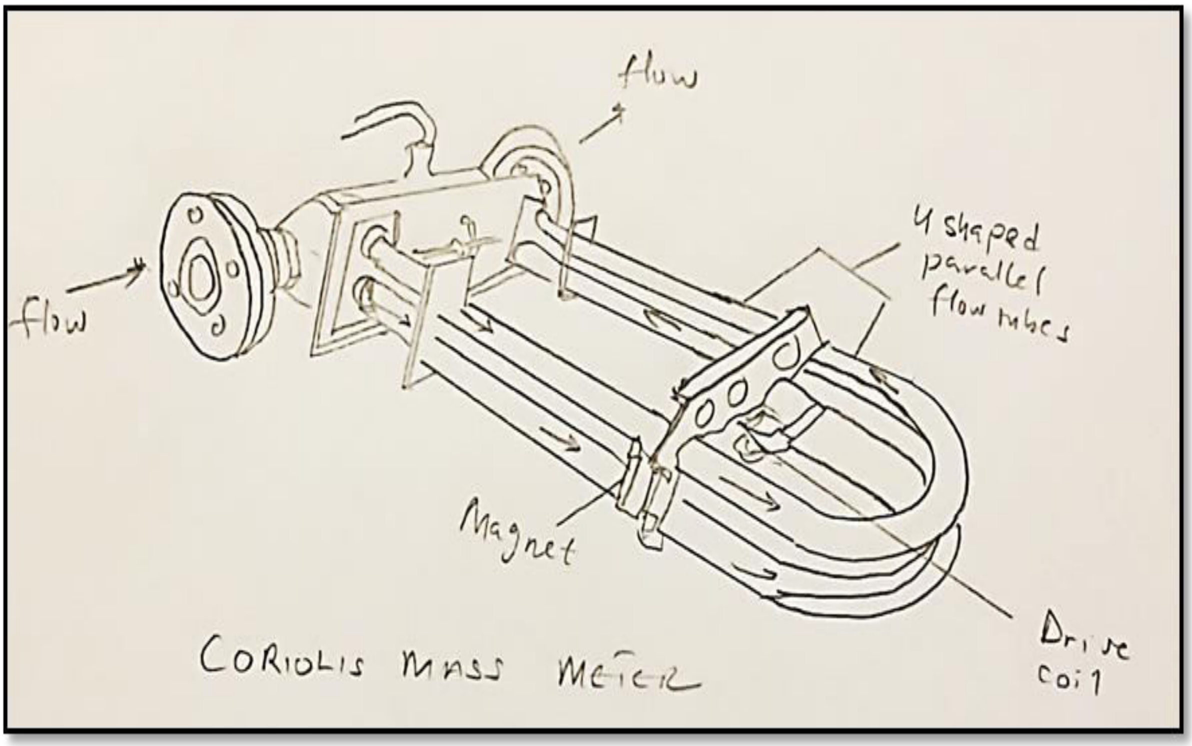
Appendix C- 18: Schematic Sketch of Swirl Meter.



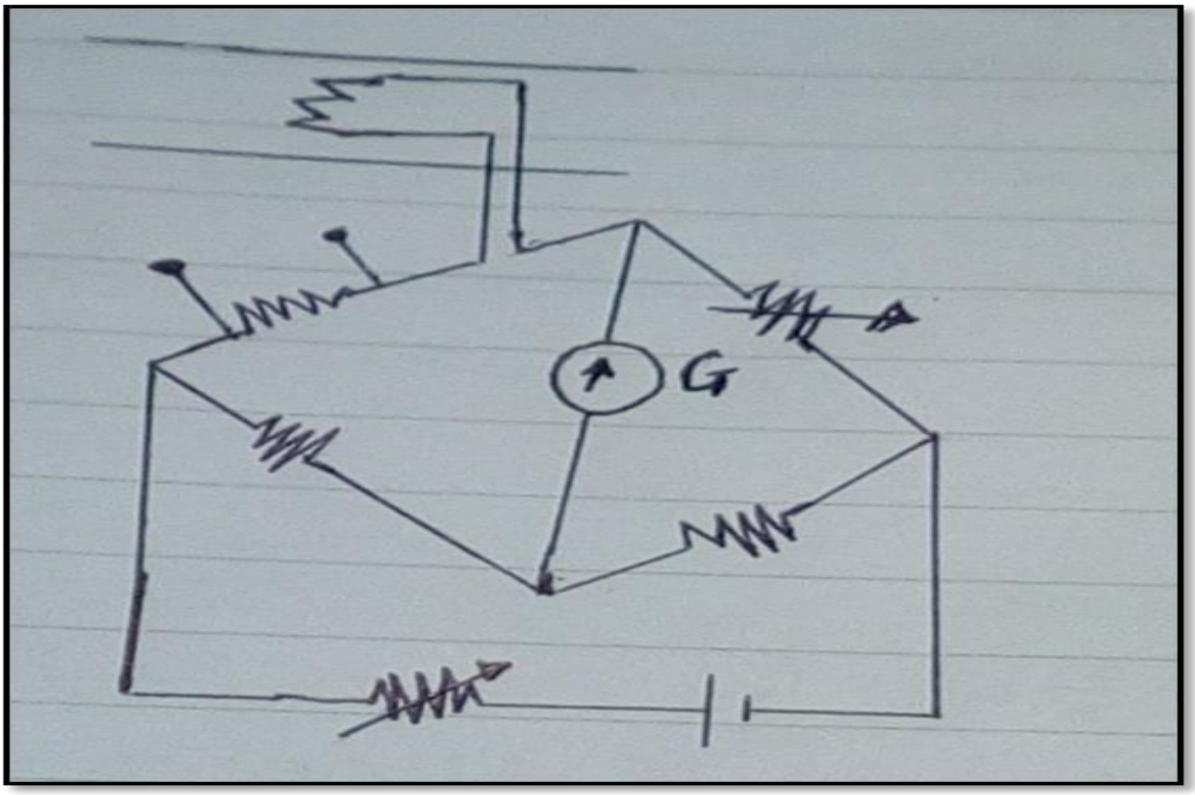
Appendix C- 19 Schematic Sketch of the Doppler Flow Meter.



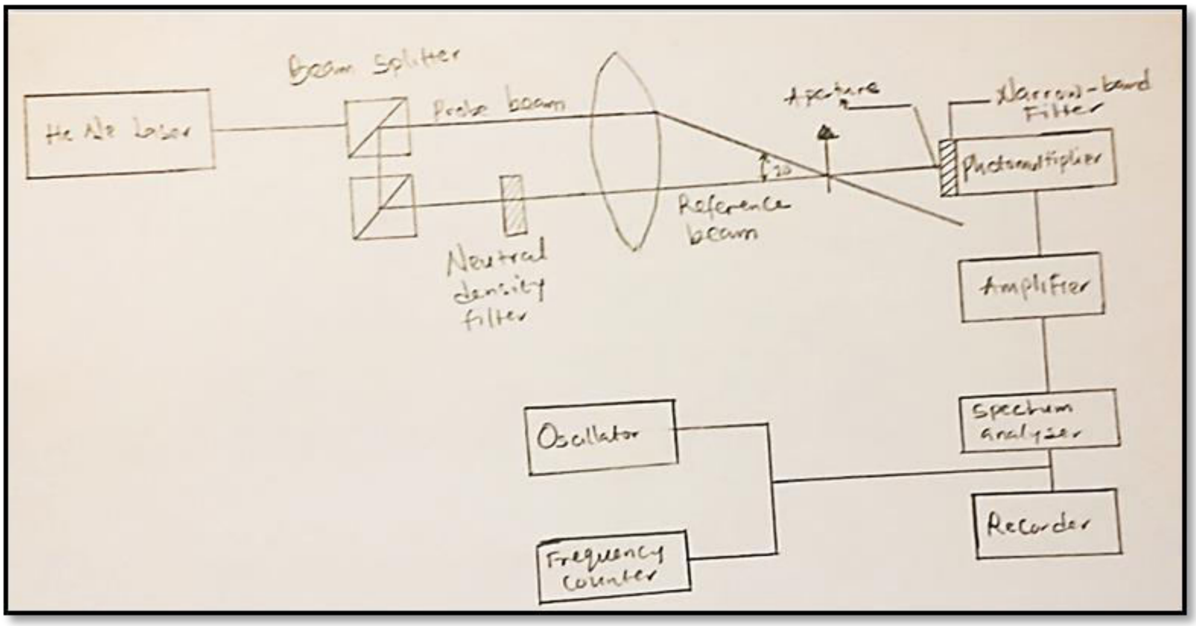
Appendix C- 20 Sketch of Principle of Time of Flight Meter.



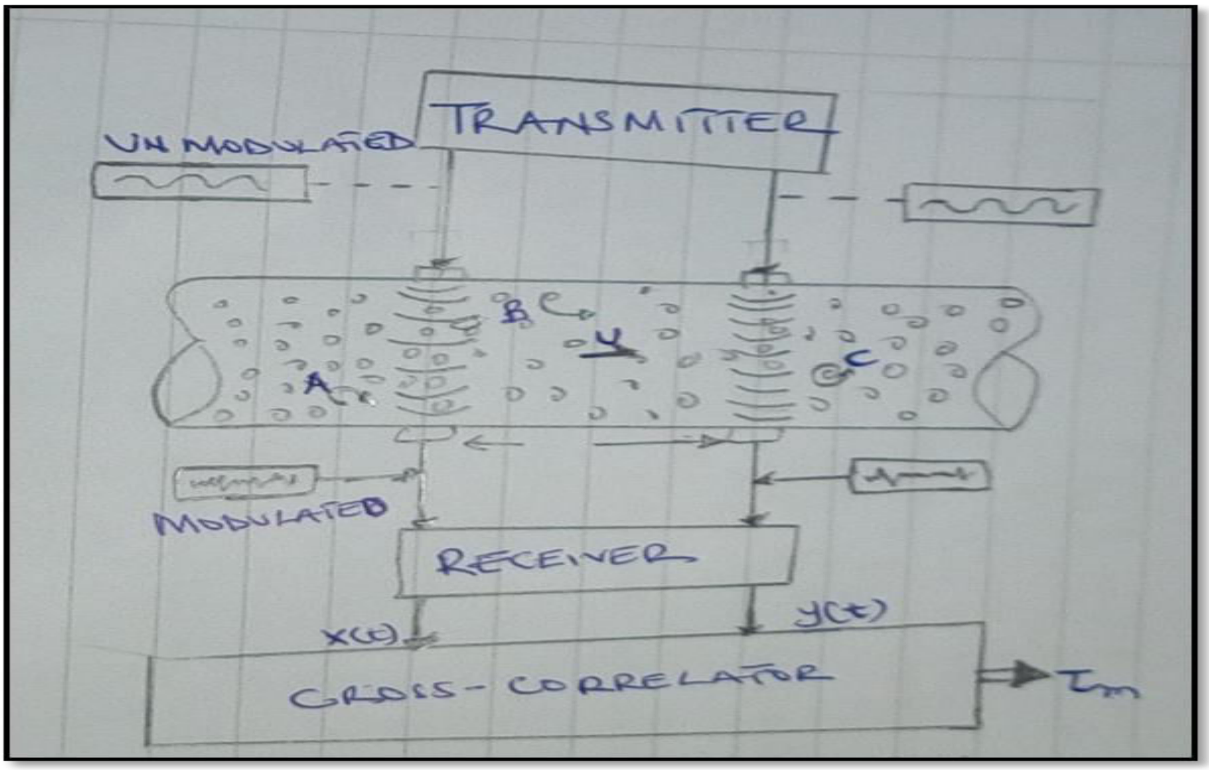
Appendix C- 21 Sketch of a Modern Industrial Coriolis Mass Flow Meter.



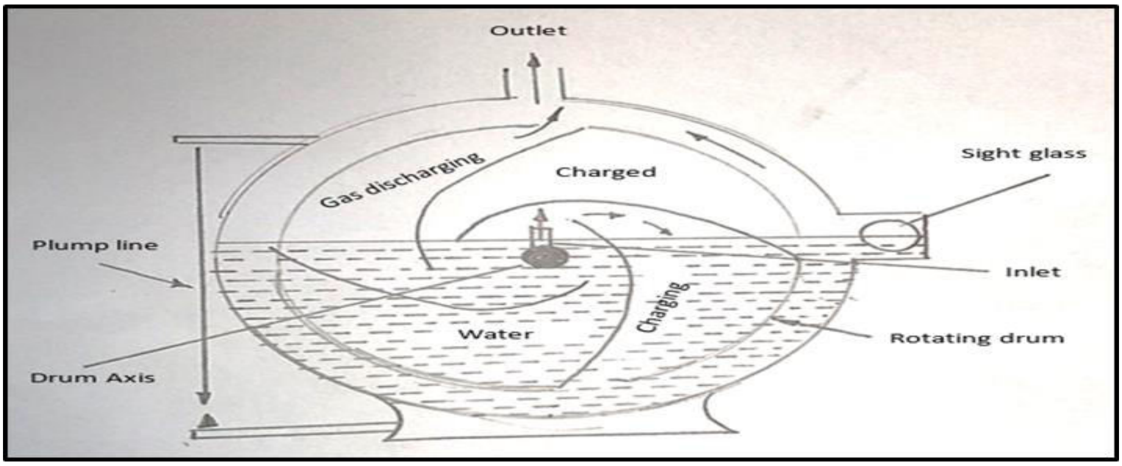
Appendix C- 22 Schematic Sketch of Hot Wire Anemometer.



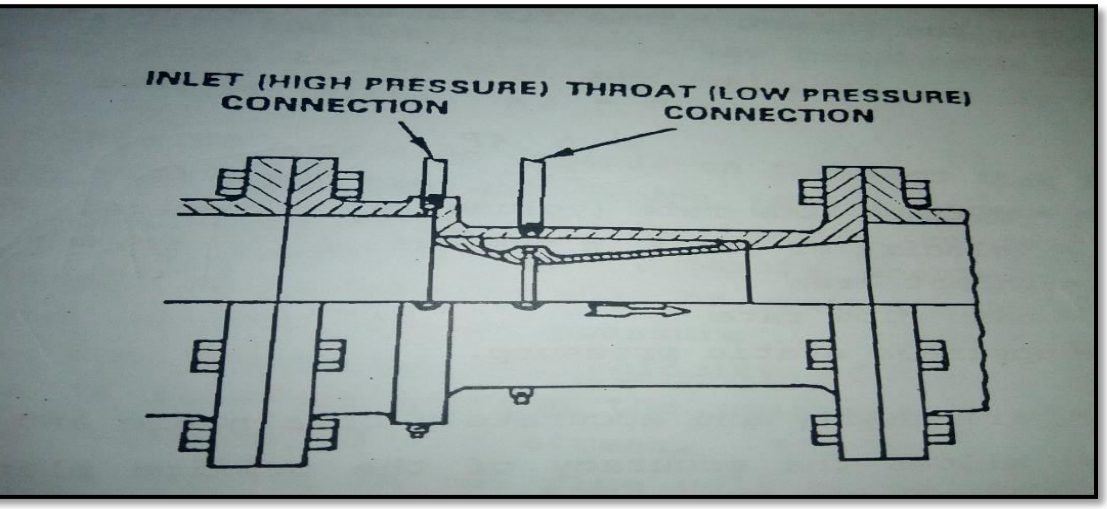
Appendix C- 23 Schematic Sketch of Laser Doppler Meter.



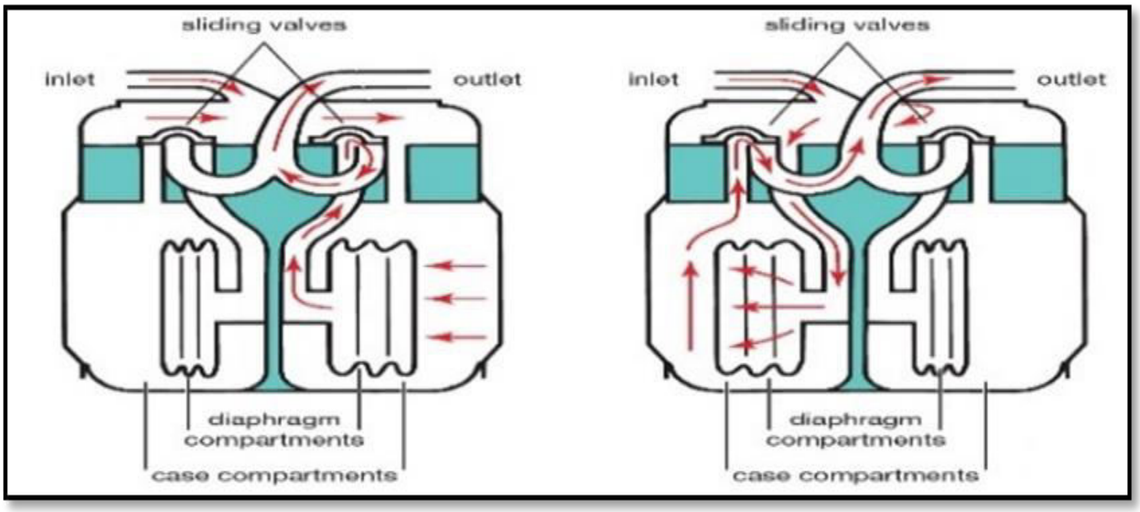
Appendix C- 24 Schematic Sketch of a Cross Correlation Ultrasonic Meter.



Appendix C-25: Wet gas Meters (ResearchGate, 2018).



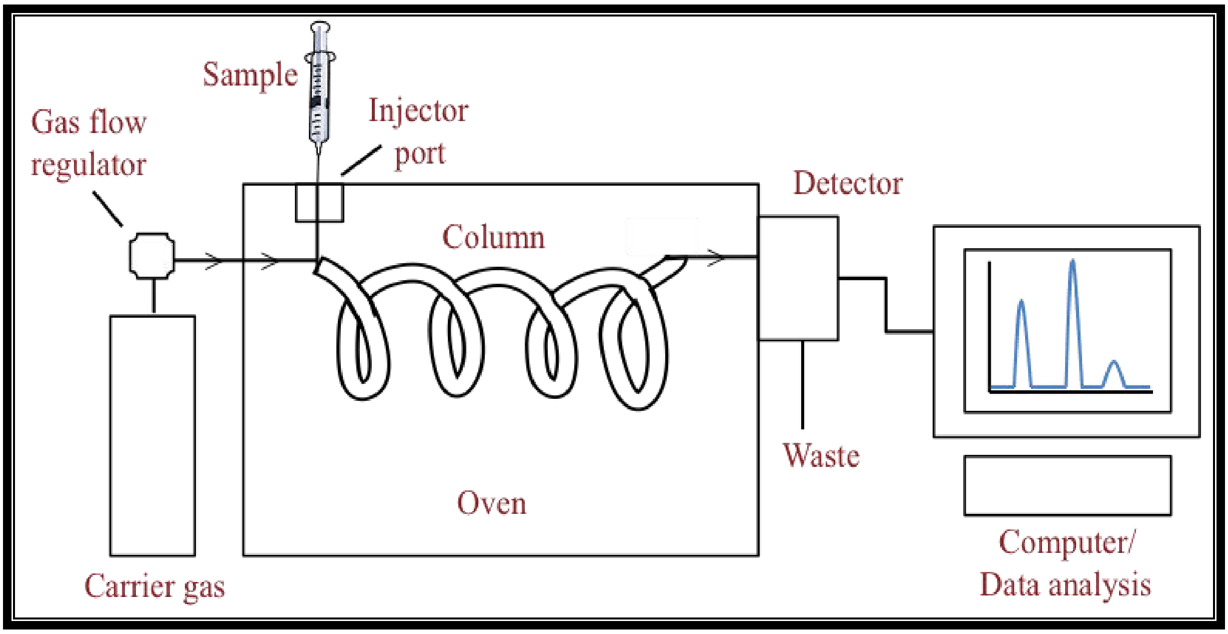
Appendix C-26: Showing a Dall Tube Low Head loss DP Meter (Nasr and Connor, 2014)



Appendix C-27: Showing Diaphragm Meters (Free-stock, 2018).

5.4 Appendix D: Gas Quality Measurement Devices

Appendix D0.1 Gas Chromatography. (Biobase).



Appendix D0.2: Internal Components of a Gas Chromatograph.

Appendix D-0.3: Oxygen Analyser. (CWD).

Appendix D-0.4: Calorimeter. (CWD).

Appendix D-0.5 Hydrogen Sulphide Analyser. (Pem-Tech.).

Appendix D-0.6 Water Content Analyser. (Michell Instruments).