PIPING INSTRUMENTS-I

Introduction
Instruments are critical components in piping systems because they are needed to ensure smooth flow of fluid and maintain desired production levels and quality. Instruments sense, transmit, indicate, record or control process parameters such as temperature, pressure, flow, and level. An instrument must detect a change in a parameter like temperature, pressure or flow to be useful. This change is converted into a signal like current or voltage that is calibrated for interpretation. Often there is the need to change a signal from one energy form to another. For example, a current signal may have to be converted to a pressure signal or vice versa. A transducer is used for this application.

The common types of instruments in piping system include sensors, transducers, alarms, indicators, recorders, regulators, and controllers. Instruments are useful only after they are accurately calibrated. The most common type of calibration is static calibration in which values of the physical quantities during calibration remain constant. Only the magnitudes of the input and output variables are important. Sometimes, dynamic calibration is necessary and standard test signals such as sinusoidal or step signals are used. Accuracy and precision are static instrument characteristics that are very important in their applications. Instrument manufacturers normally state accuracy and precision as a percentage of the instrument output span. Instrumentation is a configuration of an instrument or a group of instruments that can carry out the control of a process variable.

Process Instrument Types
An instrument is a device that can measure, display, monitor, and or control a process variable. These include meters and gauges (measuring or sensing instruments), display devices, controllers, transmitters, and valves. A measuring instrument determines the size of a process variable. Fig. 1 shows a process control loop with basic instruments. According to their functions, instruments may be classified as sensors, transducers, transmitters, controllers, regulators, recorders, alarms, and indicators. Sensors and transmitters are the common measuring instruments in piping systems.

Sensor (Primary Element)
The sensor or primary element in Fig. 1 is the sensing device in the control loop. Sensors are often enhanced transducers. Examples of sensors are thermocouples, pressure gauges, level gauges, and flowmeters. Electronic level sensors include capacitance, ultrasonic, and radiation meters. Electronic flow meters include ultrasonic, turbine, and electromagnetic meters. Strain gauge and piezoelectric devices are electronic pressure sensor-transducers. Thermocouples, resistance temperature devices (RTDs), and thermistors are electronic temperature sensor-transducers. The primary element normally sends its signal to a transmitter.

Transducer
A transducer is a device that converts one form of energy to another. Transducers are used extensively in control systems and are often integral part of sensors and transmitters. Common transducers are pneumatic-current (P/I) or current-pneumatic (I/P) and voltage-pressure (E/P) transducers.

Transmitter
Transmitters are devices that condition a measured process variable into a standard signal range. Common control signals are pressure, voltage, and current. The standard pressure range is 3 – 15 psig; the standard voltage range is 1 - 5 V DC; and the standard range of current is 4 – 20 mA DC. Transmitters sometimes function as transducers and send signals to the controllers, recorders, indicators, and alarms.
Controller
The controller uses the control or error signal it receives to drive the final control element or regulator. It is the brain or decision maker in a control loop. A controller incorporates a comparator, a device that compares the output value of a process with the reference value and generates an error signal. The error signal may be a voltage signal, electrical current, or air pressure. The error signal may be amplified before being applied to the final control element. Controllers have built-in algorithms that determine the corrective action required by the final control element.

Regulator
The regulator is also called the final control element. It uses the control signal from the controller to regulate the control variable so as to minimize or eliminate the error signal. Examples of final elements are control valves, variable-speed drives, relays, pumps, and dampers.

Indicator
An indicator is a device that displays the current value of a process variable. The display may be on a scale in analog or digital form. Digital display is gradually replacing analog display. Sometimes indicators are integrated with sensors, transducers, recorders, and controllers. Indicators normally receive input from transmitters or sensors.

Alarm
An alarm is a device that produces a signal such as light or sound when a process variable value is out of permissible range. Alarms normally receive input from transmitters, sensors, or controllers.

Recorder
A recorder is a device that records the current value of a process variable. The record could be on paper, on computer screens, and electronic storage devices. Recorders normally receive input from transmitters or sensors.

Fig. 2 shows some instruments in a pipe run. Several instruments may be mounted on a pipe branch. Instruments shown include flow valves, pressure valves and gauges, thermometers, level indicators, etc.

Measuring Instruments
Measuring instruments sense and determine the size of process variables by detecting changes in levels. They are calibrated for reading and recording. Measuring instruments greatly extend human senses and may be classified as meters and gauges. Gauges most often refer to pressure and level meters.

Temperature Measurements
Temperature meters may be calibrated to a variety of temperature scales. Temperature sensors operate on the basis that certain material properties respond to changes in temperature. Thermometers are calibrated based on the expansion and contraction of gasses, liquid, or solids due to temperature changes. Hence, there are liquid thermometers, gas thermometers, and solid (bimetallic) thermometers. Electrical and electronic properties also respond to temperature changes, leading to temperature sensors such as thermocouples, resistance temperature detectors (RTDs), and thermistors. Thermal radiation based temperature sensors are called pyrometers.
### Electrical Thermometer

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<tr>
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<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td><strong>Thermistor</strong></td>
<td>High sensitivity</td>
<td>Non-linear response</td>
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<td>Fast response</td>
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<td>Low cost</td>
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<td>Vibration resistant</td>
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<td>• Negative temperature coefficient (NTC)</td>
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<td>• -40 °C to 149 °C (-40 °F to 300 °F)</td>
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<td><strong>RTD</strong></td>
<td>Linear response</td>
<td>Low sensitivity</td>
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<td></td>
<td>Large temperature span</td>
<td>High cost</td>
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<td>Large resistance range</td>
<td>Vibration</td>
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<td>Interchangeability</td>
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<td></td>
<td>• Positive temperature coefficient (PTC)</td>
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<td></td>
<td>• -100 °C to 760 °C (-150 °F to 1400 °F)</td>
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<tr>
<td><strong>Thermocouple</strong></td>
<td>Linear response with a given temperature range</td>
<td>Least sensitive</td>
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<td></td>
<td>• Voltage or current proportional to temperature</td>
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<td>• -207 °C to 2315 °C (-300 °F to 4200 °F)</td>
<td>Reference required</td>
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Table 1: Electrical thermometers

### Pressure Sensors

Pressure sensors are the most common instruments in process plants. Accurate measurement of pressure is very important in industrial plants because of potential explosion from high pressure. An explosion can cause injury to personnel or damage equipments. Often pressurized devices operate within a pressure range and alarms can be set to indicate deviation from the range. Equipment shut down may be initiated by a deviation from a pressure range setting. Another reason for accurate measurement of pressure is that the quality of a product may be influenced by pressure and temperature sometimes. Maximizing efficiency and productivity of processes often requires accurate pressure information.

Pressure sensors are commonly called pressure gauges. They may be classified into liquid, mechanical, and electrical gauges. Liquid pressure gauges are called manometers. Common mechanical pressure gauges include Bourdon, bellows, and diaphram gauges. Common electrical pressure gauges include resistance, capacitance, inductance, reluctance, and piezoelectric sensors. Pressure gauges are sensitive to variations in ambient atmospheric pressure, especially those located in enclosed spaces. Proper installation must be done to minimize this effect which causes loss of accuracy. The reliability and accuracy of pressure gauges is influenced by ambient temperature also. This is because the resistances of the electrical elements in the instrumentation circuits may be directly affected. Temperature effects are reduced by circuitry design and proper maintenance of the gauge which should be used in the right environment. Inspection and re-calibration should be done at regular intervals. Fig. 4 show some mechanical pressure gauges.

![a) Liquid thermometer](image1.png)  
![b) Thermocouples](image2.png)  

Fig. 3: Common temperature sensors
Flow Meters

Flow meters are used to measure fluid flow rate and or velocity. A flow meter is usually a combination of a transducer, transmitter, and a display panel. The transducer senses the flow, the transmitter conditions the flow variable to standard output value and the display panel shows the flow size. Most often the panel records the measurement also. Different services require different types of flow meters so many flow meters are designed for specific needs. There are meters that measure flow velocity and these include turbine, magnetic, ultrasonic, and vortex flow meters. Positive displacement flow meters measure fluid flow rate and there are several of them like the gear meters. The Coriolis and thermal meter are mass flow rate meters. Inferential flow meters are those that are used to infer flow velocity or rate based on the measurement of other variables such as differential pressure. In electronic meters, flow is determined from changes or disturbances of electrical or electronic properties of sensor materials due to fluid flow. These may be temperature, magnetic, or sound properties that can be converted to voltage or current variables.

A common instrument for pressure and flow measurement is the orifice flow meter. It consists of an orifice plate placed at the middle of two (orifice) flanges- see Fig. 5. Each orifice flange has tapped holes on both sides for attaching pressure sensing devices. A gasket is inserted between the orifice plate and a flange face. The orifice plate has a central hole accurately machined. Standard orifice plates have holes of 1/8, ¼, 3/8, ½, 5/8, and ¾ of pipe nominal diameter. The hole of the orifice plate sets up a well-defined obstruction to fluid flow and its resistance results in a pressure difference on the sides of the plate that is used to measure the rate of fluid flow. The outlet pressure is normally about 60 – 80% of the inlet pressure. The flow rate of the fluid is deduced from the pressure difference between the two pressure taps. An orifice meter must be carefully positioned on a flow line to ensure accurate results- see Fig. 6. So the device must be mounted in a straight run portion on the line, removed from disturbances of flow patterns from pipe fittings and valves. The orifice flow meter is the most common flow meter in process industry. It is estimated that over 80% of industrial and commercial flow meters is orifice flow meter. Fig. 7 shows some common flow meters. Ultrasonic flow meters are shown in Fig. 8.
Careful consideration must be made about the type of flow when selecting a flowmeter. Since the type of flow is determined by the Reynolds number, it does influence the type of flowmeter for specific applications because flowmeters may be designed for laminar or turbulent flow. A flowmeter designed for laminar flow will give erroneous readings if used in a turbulent flow line. Similarly, a flowmeter designed for turbulent flow will give erroneous readings if used in a laminar flow line.

**Level Meters**
A variety of devices can be used to measure and record levels of fluid or solids in a container. The method they use for measurement may be classified into direct and inferred (indirect) methods. Direct methods measure depth or
height of fluid or the space above it. Inferred methods measure variables apart from height or dept, such as pressure from which the level is derived. Level meters may be classified into two groups, namely mechanical and electronic meters. Devices in each group use one or the two methods of direct and inferred measurements. Point and continuous level measurement may be made. Point measurement gives information of material content at defined points in the container. This is quite suitable to high and low limit setup for indicators and alarms. Continuous level measurement allows the tracking of material quantity and is suitable for inventory applications.

Common mechanical level meters include glass gauges, float, displacer, bubbler, and differential pressure meters. See Figs. 9 to 13 for schematic representations. Other type of level meters are represented in Figs. 14 to 16. The glass gauges, float and displacement meters are direct measurement devices while the bubbler and differential pressure meters are inferred measurement devices. The common electronic level meters are capacitance, ultrasonic, and radiation meters. Electronic equipments are sensitive to temperature and humidity. Variation in ambient temperature can affect the resistance of electrical and electronic components which can affect instrument calibration. High humidity can cause moisture to collect in instruments which may lead to short circuiting and damaging of components. Temperature variation effects can be minimized by proper design. Using the instrument in the right environment can minimize or eliminate humidity and temperature problems.
**Analysis and Analyzers**

Analysis is the process of determining the types of substances and their proportion in a sample. There are two types of analysis, namely qualitative and quantitative analysis. Qualitative analysis determines the types of substances in a sample. Quantitative analysis determines the amount of each substance in a sample and may be reported in parts per million (ppm), percent (%), ratio, or in the relevant standard unit. Analysis is extremely important in industrial production. Usually, it is necessary to know the types and quantities of material components used as raw materials, intermediate materials, and final products in production systems. The chemical composition and proportions of the constituents of the materials constitute another aspect of analysis. Generally, a representative sample of the material (gas, liquid or solid) is isolated for analysis. A representative sample has the same composition as the process material. Analysis may be done in centralized laboratories in the production facilities or may be carried out in specialized facilities offsite. Specially designed devices for analysis can be mounted on process lines to monitor the process stream.

Analyzer is the instrument used to carry out analysis on samples of substances. Analyzers are also called meters and are used to monitor various physical and chemical properties of process streams. They are designed to withstand harsh industrial environments. Analyzers can be mounted on-line or off-line on process lines and can be left unattended to continuously monitor process streams. On-line analyzers give best response, provide frequent or continuous monitoring and analysis, but they are more complex. Careful maintenance and attention to calibration are very vital for ensuring functional reliability of analyzers.

Gas analyzers measure concentration of gases in a clean sample at constant temperature and pressure. Several technologies are used in analyzing gasses. These include thermal conductivity, opacity, gas chromatography, radiant energy analyzers, and oxygen. Thermal conductivity analyzers measure conductivity of sample gases. Ultraviolet (UV) analyzers measure the absorption of ultraviolet radiation by different gases. Oxygen analyzers measure the amount of oxygen available for combustion. Humidity analyzers determine the humidity of air. Liquid analyzers measure the properties of liquids such as density, viscosity, turbidity, composition, concentration, solid content, etc. Liquid analyzers use different technologies that include liquid chromatography, radiant energy, nuclear radiation, viscosity, refraction, hygrometers, differential pressure, pH and oxidation/reduction analysis. Solid moisture analyzers measure the moisture content in solids. Solids are analyzed with gravimetric, near infrared, microwave, and electrical impedance analyzers. It is not possible to list all the analyzers employed in the industry, so the listing given above is not exhaustive.

**pH Analysis**

The pH is a measure of the molar concentration of hydrogen ions in a solution. It indicates the level of acidity or basicity of a solution. The letters “pH” is an acronym for the “power of Hydrogen ions”. Mathematically, the pH of a solution is the negative of the logarithm of the molar concentration of hydrogen ions. That is:

\[ \text{pH} = -\log_{10}[H^+] \]

\([H^+]\) = molar concentration of hydrogen ions

pH meters measure the concentration of hydrogen ions in an aqueous solution. pH values is in the range of 0 – 14. pH of less than 7 means the solution is acidic, and pH of more than 7 means the solution is alkaline or basic. pH of 7 is neutral, the value for pure water. The pH meter of Fig. 17 works on the principle of electrochemistry like a battery. The meter has three electrodes, namely the sensor electrode, the reference electrode, and thermo-compensator electrode. The sensor electrode is a glass bulb where the liquid sample is placed. The sample electrode measures the small electromotive force (EMF) or voltage across a hydrogen ion in a sample. The detected EMF is compared with the EMF from the reference electrode with a neutral solution and the output voltage is calibrated in pH values. The thermo-compensator uses an RTD circuit to correct for temperature influence on pH values because pH values are very sensitive to temperature. The normal range of pH values for the human blood is 7.35 – 7.45; with a nominal value of 7.4. This is accurately regulated by the human body. A value outside the normal range can be serious and even fatal.

![pH meter](image)
**Chromatography**
Chromatography is the process of separating and identifying molecules of a liquid or gas by means of a tube column with absorptive media. A sample gas is transported through the column of stratified media by an inert carrier stream. Typical inert gas carriers are argon, helium, and nitrogen and some media types are porous silica microspheres, activated alumina, and activated carbon. Porous silica microspheres are often coated with chemically selective compounds to modify their characteristics. As the sample stream goes through the column, each component is absorbed at the level where it has affinity for the medium packing. This allows the components in a sample to be identified and their proportion to be computed on volume basis. Factors affecting analysis are time, temperature, pressure, and flow rate. Temperature, pressure, and flow rates are carefully regulated so that ample propagation time becomes the main discriminating parameter. The sensor is placed at the end of the column so as to detect the separated gas components. A graphic report of the analysis called chromatograph with the separated components have unique peaks, summarizes the results. Chromatography is a popular method of composition analysis. Fig. 18 shows the schematics of chromatographic analyzer.

![Fig. 18: Schematics of chromatographic Analyzer](image)

**Spectroscopy**
Spectroscopy is the process of using the variation in absorption or transmittance of a light spectrum passed through a sample to identify the components of the sample, and determine the proportion of the components. The process can use visible light spectrum, ultraviolet light, infrared light, or near infrared (NIR) as a source and detection measurement. Spectroscope or spectrometer is an analyzer that carries out spectroscopy. A common laboratory spectrometer can detect wavelengths from 2 nm to 2500 nm. A spectrometer consists of a light source, filter, sample cell, and reference cell. The difference in exit energy detected between the sample and reference cells is proportional to the energy absorbed by the sample. Detailed information about the physical properties of objects, gases, or even stars can be obtained from this type of device. A mass spectrometer separates components of a gas mixture by mass and charge. Fig. 19 shows the schematics of spectrometer.

![Fig.4: Block diagram of spectrometer](image)
SUMMARY
Instruments are critical components in piping systems because they are needed to ensure smooth flow of fluid and maintain desired production levels and quality. They sense, transmit, indicate, record monitor and or control parameters like flow rate, pressure and temperature. The five process parameters of flow, level, pressure, temperature, and analysis have special instruments that are designed to sense and monitor them. An instrument must detect a change in a parameter like temperature, pressure or flow to be useful. This change is converted into a signal like current or voltage that is calibrated for interpretation. Console or board mounted instruments have these signals transmitted to control panels. Sometimes the signal is used to activate other devices and effect changes in the process conditions. This is how automatic control is done. Gauges measure the pressure, temperature or liquid level in equipment. Indicators display the level of process parameters. Recorders record the level of process parameters while controllers activate other devices so as to maintain a specific level of a process parameter. Alarms give light or sound signals when operating levels of process parameters are too high or too low. They are also activated when there is no flow or a when back flow occurs.