UNIT FIVE
CONTROLLING THE PLANT: INSTRUMENTATION

Special Terms

Thermometer: An instrument used for measuring temperature. One type is based on expansion of liquid in a graduated transparent tube.

Thermocouple: An electrical instrument that measures temperature. It is based on the electrical flow that occurs in an electrical circuit made up of two dissimilar metals when the two junctions between the metals are at different temperatures.

Calibrate: A means of standardizing, adjusting, or checking the graduations of a quantitative measuring instrument.

Thermocouple Well: A protective tube that isolates a thermocouple from the material whose temperature is being measured. It is frequently used to protect the thermocouple from corrosive liquids or gases. When a similar tube is used to protect a thermometer, it is called a ***thermometer well.***

Pyrometer: A device that measures temperature by detecting the radiation from a hot object.

Bourdon-tube Pressure Gage: The type of pressure gage most commonly used. It is a curved metal tube, closed at one end and subjected to the pressure being measured at the other end. Internal pressure tends to straighten the tube and this movement is amplified and displayed on the graduated face of the gage.

Manometer: A simple pressure-measuring instrument in which pressure raises the level of liquid in a transparent tube.

Rotameter (Variable-area Flowmeter): A type of flowmeter in which fluid flows upward through a tapered tube and lifts a float or plummet to a point at which the force of the flow counterbalances the weight of the plummet.

Sight Glass (Sight-flow Glass): A transparent tube inserted into a pipeline to enable an observer to see the flow in a pipe.

Indicator (Indicating Instrument): An instrument that shows the measure of a particular variable such as temperature, pressure, or flow.

Recorder (Recording Instrument): An instrument that makes a record of the measure of a particular variable.

Controller (Control Instrument): An instrument that measures a variable and uses this measurement to control a process.

Control Valve: A valve that can be opened or closed (or set anywhere in between) by a control instrument. It is the combination of control instrument and control valve that accounts for most of the automatic operation in process plants.

Control Room: A room in which many of the instruments of a chemical process plant are located. This centralization of instruments enables one or two operators to run the entire plant.

Vocabulary Practice

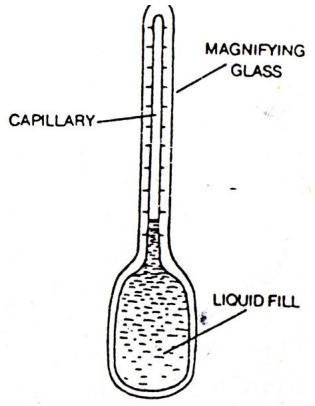
1. What is a *thermometer*?
2. What is a *thermocouple*? How does it work?
3. What does *calibrate* means?
4. What is a *thermocouple well*? Why might one be used in a process plant?
5. What is a *pyrometer*?
6. For what is a *bourdon-tube pressure gage* used? How does it work?

7. What does a *manometer* do?
8. What is a *rotameter*? How does it work?
9. What is meant by *sight glass*? What is another name for a sight glass?
10. What is an *indicating instrument*? By what other name is it known?
11. What is a *recording instrument*? What else is it called?
12. What is a *control instrument*?
13. For what purpose is a *control valve* used?
14. What is a *control room*?

Controlling the Plant: Instrumentation

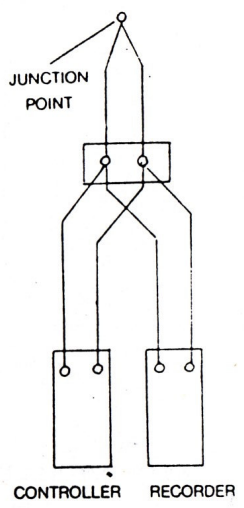
We have seen how important a plant's instrumentation is in enabling it to function properly. Now let us take a closer look at the actual equipment that is used for this purpose. In any process plant the three basic variables to be controlled, if the plant is to operate properly, are temperature, pressure, and flow.

- **Temperature:** The two basic instruments for measuring temperature are the ***thermometer*** and the ***thermocouple***. The basic design of the thermometer is familiar. It consists of a tube, usually glass, which contains a liquid that expands or contracts depending on the temperature to which it is exposed. As it expands it rises in the tube – the height to which it rises is ***calibrated*** to indicate temperature. Depending on the temperatures to be measured, the liquid in the tube is usually colored alcohol or mercury.



Thermometer

The second most common temperature-measuring device is the thermocouple. It is based on the discovery in 1821, by the German physicist, Thomas J. Seebeck, that an electric current flows in a continuous circuit composed of two different metals if the two junctions between the two metals are at different temperatures. One junction is placed at the point where the temperature is to be measured; the other is usually in the instrument used to measure the current. The current that flows in the circuit depends on the difference between the two temperatures. Since the temperature in the instrument is easily found (by using a thermometer, for example), the other temperature can be calculated. Some advanced thermocouple instruments are equipped to do the calculation automatically – on these, the desired temperature can be read directly. Since the output of the thermocouple is electrical, it is frequently chosen to be used with other electrical or electronic instruments.



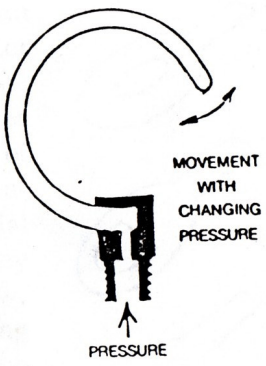
Thermocouple

If a thermocouple is to be placed in a pipe or vessel, it is often necessary to protect it from the corrosive or abrasive material being processed. In such cases, it is placed in a protective tube known as a ***thermocouple well***. Similar wells are used with thermometers and are known as ***thermometer wells***.

Thermometers and thermocouples are not suited to the very high temperatures inside furnace – the heat would destroy them. These temperatures are usually measured with instruments called ***pyrometers***. Hot objects radiate energy and the pyrometer measures this energy. The energy radiated by a hot object varies approximately with the fourth power of the absolute temperature of the object, and the pyrometer is calibrated on this principle. There are some other less common devices used to measure temperature.

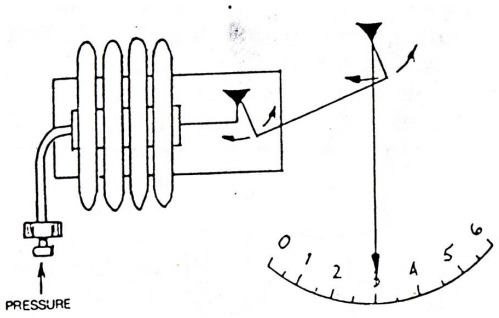
For example, the electrical resistance of a wire varies with its temperature so it is possible to use this effect to measure temperature. Devices based on the variation of resistance are called resistance thermometers. Other types of temperature-measuring devices are based on the expansion and contraction of solids under varying temperatures.

- **Pressure:** There are literally dozens of different types of instruments for measuring pressure. The most common is the ***bourdon-tube pressure gage***. This consists of a curved metal tube that is closed at one end and open at the other. The open end is exposed to the pressure to be measured. As the pressure in the closed tube increases, it tends to straighten the tube. Since the metal of the tube is elastic, the closed end moves as the pressure within the tube changes. This slight movement is amplified by a system of levers and gears, and is used to move a pointer over a graduated scale.



Bourdon Tube

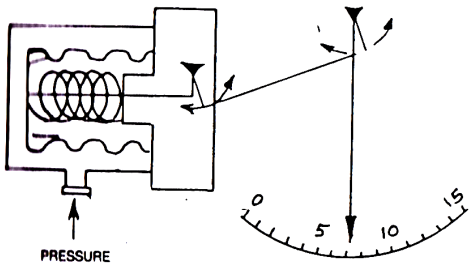
Instead of the bourdon tube, a pressure gage may use a flexible plate, and is called a diaphragm gage. Or a corrugated tube called a bellows may be used to make what is called a bellows gage.



Diaphragm Gage

Here again, movement of the diaphragm or bellows due to a change of pressure is translated into movement of a pointer on a dial. There

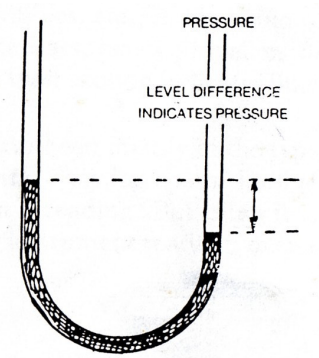
are numerous other types of pressure-measuring instruments. For example, those used for high vacuum may measure the thermal conductivity of the small amount of gas remaining in the space whose pressure is to be measured. Those based on the electrical characteristics of materials in a strained or unstrained condition are



Bellows Gage

called strain gages and are becoming increasingly common with electronic instrumentation.

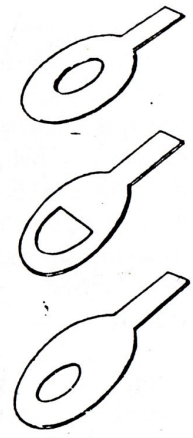
Another common variety of instrument used for pressure measurement is the ***manometer***. This uses a column of liquid (usually water or mercury) which is exposed to pressure at one end. The height to which the liquid rises in the tube is a measure of the pressure. Manometers are used mainly to measure small pressure changes. If the pressure is very low it may be measured by a manometer called a draft gage. Pressures measured by manometers may be shown in the conventional units of pounds per square inch, or in pascals, or they may be simply given as the height of the column of liquid – inches or centimeters of water or mercury.



Manometer

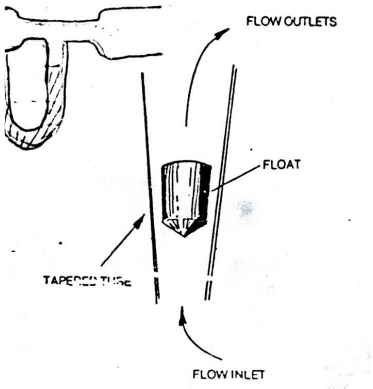
- **Flow:** The most common means of measuring rate of flow of a fluid is based on the principle that if there is a contraction or constriction (a section of reduced diameter) in a pipe, the pressure of

a fluid flowing downstream from the contraction will be lower than that upstream from the contraction. This pressure differential is proportional to the rate of flow. The simplest form of such a flow-meter is known as an orifice-plate meter. It consists simply of a plate with a hole in it, inserted into the pipeline, usually between two flanges. The hole in the plate is called an orifice and is smaller than the internal diameter of the pipe. Small openings, called taps, are made in the pipe on both sides of the orifice plate, and these are connected to some kind of pressure-measuring device – most often a manometer. The manometer reads the differential in pressure on both sides of the orifice and may be calibrated to read in terms of rate of flow. Orifice plates cannot be used if the liquid being measured contains solids because they will be trapped by the plate. The trapped solids interfere with the calibration of the flowmeter and may even clog the pipe. An orifice plate also causes pressure losses and a consequent increase in pumping costs.



Orifice Plates

Instead of an abrupt contraction in the pipe size, as is caused by an orifice plate, the contraction may be gradual. Special fittings (called venture tubes) are used, by which the pipe is gradually narrowed and gradually enlarged. The pressure taps are placed at the largest part of the venturi tube (before it narrows), and at the smallest diameter. These tubes overcome most of the problems of the orifice-plate meter, but the venturi tubes themselves are rather expensive, particularly when they must be made from corrosion-resistant materials such



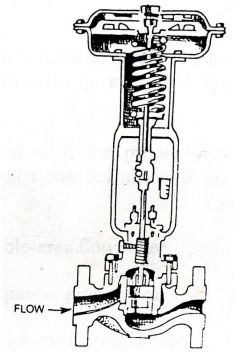
Rotameter (Variable-area Flowmeter)

as stainless steel. Although there is a decrease in pressure at the narrowest part of the venturi tube, the pressure is almost entirely recovered as the liquid passes through the gradual enlargement, so that added pumping costs are minimal. Another type of flowmeter is the ***rotameter***, or ***variable-area meter***. The liquid to be measured is passed upward through a tapered tube with the smallest part of the taper at the bottom. In the tube is a small metal plummet, or float. (Although usually called a float, it is made of metal and is denser than the fluid to be measured.) As liquid flows up the tube, it lifts the float to a position where the weight of the float (a downward force) is exactly balanced by the lifting effect of the liquid in the space between the edge of the float and the inside of the tapered tube.

The ingenuity of engineers is great, and many other types of flowmeters have been invented and are in use. The types described above are simply the most common.

Sometimes it is important to know whether or not a liquid is flowing in a pipe, without needing to know its velocity. For this purpose, a ***sight glass*** (or ***sight-flow glass***) is employed. This is simply a glass tube mounted between metal fittings so that it can be inserted into a pipeline. If the liquid in the pipe is perfectly clear, it can sometimes be difficult to tell if it is moving, but usually there are enough bits of sediment, small air bubbles, etc., in the liquid to give a clear indication of motion. Sometimes, small propellers or vanes are mounted in the sight glass and their motion indicates fluid flow.

The instruments described so far have been mainly of the type called ***indicators*** or ***indicating instruments***. They have some kind of scale that enables an operator to obtain a reading. But often it is necessary to have a permanent record of instrument readings over a period of time; ***recorders*** are used for this purpose. These ***recording instruments*** make marks on a moving sheet of paper, usually in the form of a graph. The paper is often printed with lines that show



Control Valve

the time the marks were made. Recording instruments frequently include a direct-reading, or indicating, device so that an operator can read the value at any instant. Such instruments are called indicator-recorders.

But instruments can do more than indicate or record measurements; they can also be used to control a process. Let us say there is a tank of water to be held at a certain temperature. If there is a temperature indicator on the tank an operator can see whether or not to open a steam valve to heat the tank or close a valve when the temperature is correct. It is fairly easy to devise an instrument that will automatically open the steam valve if the temperature is too low and close it when the proper temperature is attained. Such an instrument is called a ***controller***, or ***control instrument***. It may also indicate or record, or both. Thus we may have indicator-controllers, recorder-controllers, or indicator-recorder-controllers. There are special types of valves designed to be operated by control instruments rather than by hand. They are called ***control valves*** and are very common in any automatically controlled plant.

In large continuous process plants, most of the plant's instruments are grouped in a special place called a ***control room***. By using these instruments, an operator in the control room can tell what is happening anywhere in the plant. The operator can make adjustments in the process without leaving the control room, and can even shut down the whole plant if it should become necessary.

Discussion

1. What are the two most common instruments used for measuring temperature?
2. Explain how a thermocouple works.
3. What is a thermocouple well used for?
4. What is the name of the instrument used for measuring the temperature inside furnace?

5. What is the most common kind of pressure-measuring device? Explain how it works.

6. How does a manometer work?

7. What is the simplest kind of flowmeter used in process plants? How does it work?

8. What problems are associated with orifice-plate flowmeters?

9. What is a rotameter? What else is it called? How does it work?

10. What is the purpose of using a sight glass?

11. What is an indicating instrument? Name some.

12. What are recording instruments used for?

13. What is a controller? Why are controllers important in the CPI?

14. What operates a control valve?

15. What would you find in a control room? What can be done from a control room?

Review

A. This unit described instruments for measuring pressure, temperature, and flow. From your own knowledge of chemistry, discuss why such measurements would be important in almost any chemical process.

B. Also from your own knowledge, make a list of some of the other properties or variables that might have to be measured in a chemical process plant.

C. Match the terms in the left column with the proper short definition in the right column. Only one definition is appropriate for each term.

1.	Flowmeter	___	Variable-area flowmeter
2.	Recorder	___	Transparent pipe section
3.	Sight glass	___	Any flow-measuring device
4.	Thermocouple well	___	Place from which a plant can be run
5.	Control room	___	Shows the value of a variable
6.	Indicator	___	Makes a record of values of variables
7.	Thermometer	___	Indicates pressure
8.	Rotameter	___	Works by expansion of liquid in a tube
9.	Manometer	___	Operated by a control instrument
10.	Control valve	___	Protects a thermocouple