Module 2

Measurement Systems

Lesson
8
Measurement of Level, Humidity and pH

Instructional Objectives

At the end of this lesson, the student will be able to:

1. Name different methods for level and moisture measurements
2. Explain the basic techniques of level and humidity measurement
3. Explain the principle of pH measurement
4. Explain the necessity of using special measuring circuit for pH measurement

1. Introduction

Level, humidity and pH are three important process parameters and their measurement find wide application in chemical and manufacturing industries. In this chapter we would provide a brief overview of the different techniques adopted for measurement of liquid level and humidity. The basic principle of pH measurement and the construction of pH electrodes are explained in section 4.

2. Level Measurement

There are several instances where we need to monitor the liquid level in vessels. In some cases the problem is simple, we need to monitor the water level of a tank; a simple float type mechanism will suffice. But in some cases, the vessel may be sealed and the liquid a combustible one; as a result, the monitoring process becomes more complex. Depending upon the complexity of the situation, there are different methods for measuring the liquid level, as can be summarized as follows:

(a) Float type

(b) Hydrostatic differential pressure gage type

(c) Capacitance type

(d) Ultrasonic type

(e) Radiation technique.

Some of the techniques are elaborated in this section.

Hydrostatic Differential Pressure type

The hydrostatic pressure developed at the bottom of a tank is given by:

$$p = h \rho g$$

where h is the height of the liquid level and ρ is the density of the liquid. So by putting two pressure tapings, one at the bottom and the other at the top of the tank, we can measure the differential pressure, which can be calibrated in terms of the liquid level. Such a schematic arrangement is shown in Fig. 1 . The drum level of a boiler is normally measured using this basic principle. However proper care should be taken in the measurement compensate for variation of density of water with temperature and pressure.

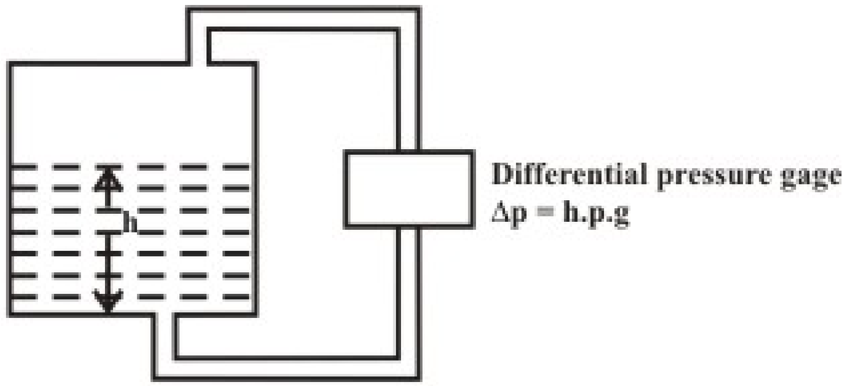


Fig. 1 Level measurement using hydrostatic differential pressure

Capacitance type

This type of sensors are widely used for chemical and petrochemical industries; and can be used for a wide range of temperature (-40 to 200 ^oC) and pressure variation (25 to 60 kg/cm^2). It uses a coaxial type cylinder, and the capacitance is measured between the inner rod and the outer cylinder, as shown in Fig. 2. The total capacitance between the two terminals is the sum of (i) capacitance of the insulating bushing, (ii) capacitance due to air and liquid vapour and (iii) capacitance due to the liquid. If the total capacitance measured when the tank is empty is expressed as C_1, then the capacitance or the liquid level of h can be expressed as:

$$C_t = C_1 + \frac{2\pi\varepsilon_0(\varepsilon_1 - \varepsilon_2)h}{\ln(r_2/r_1)}$$

where, ε_1 is the relative permittivity of the liquid and ε_2 is the relative permittivity of the air and liquid vapour (≈ 1). Hence a linear relationship can be obtained with the liquid level.

The advantage of capacitance type sensor is that permittivity of the liquid is less sensitive to variation of temperature and can be easily compensated.

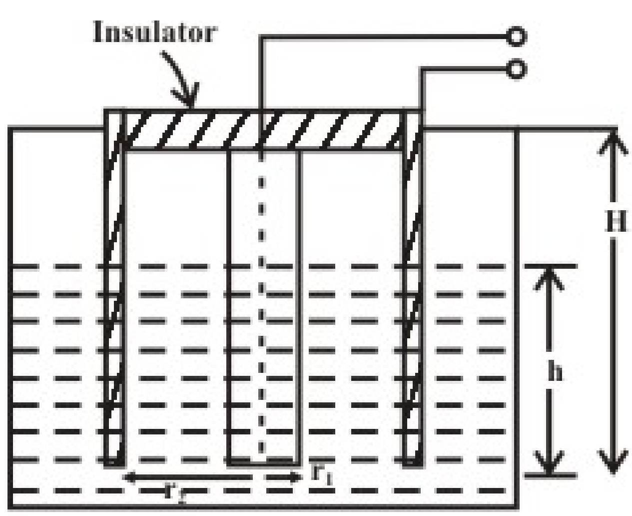


Fig. 2 Level measurement using capacitance technique

Ultrasonic type

Ultrasonic method can be effectively used for measurement of liquid level in a sealed tank. An ultrasonic transmitter/receiver pair is mounted at the bottom of the tank. Ultrasonic wave can pass through the liquid, but gets reflected at the liquid-air interface, as shown in Fig.3. The time taken to receive the pulse is measured, that can be related with the liquid level. For accurate measurement, variation of speed of sound with the liquid density (and temperature) should be properly compensated.

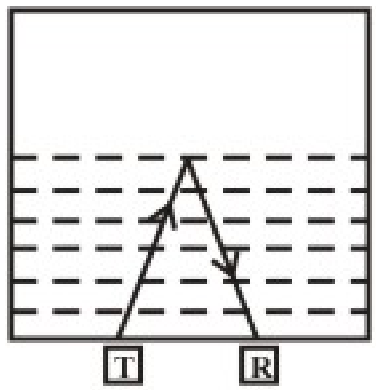


Fig. 3 Level measurement using ultrasonic technique

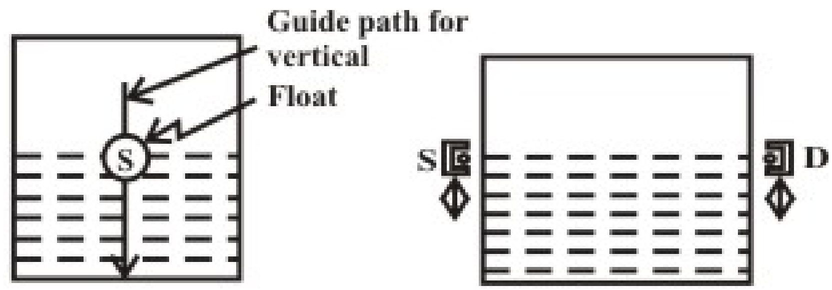
Radiation technique

Radioactive technique also finds applications in measurement of level in sealed containers. Radioactive ray gets attenuated as it passes through a medium. The intensity of the radiation as it passes a distance x through a medium is given by:

$$I(x) = I_0 e^{-\alpha x}$$

where I_0 is the incidental intensity and α is the absorption co-efficient of the medium. Thus if we measure the intensity of the radiation, knowing I_0, and α, x can be determined. There are several techniques which are in use. In one method, a float with a radioactive source inside is allowed to move along a vertical path with the liquid level. A Geiger Muller Counter is placed at the bottom of the tank along the vertical path and the intensity is measured. The basic scheme is shown in Fig. 4.

The method used in a batch filling process of bottles, uses a source-detector assembly that can slide along the two sides of the bottle, as shown in Fig. 5 . As soon as the source-detector assembly passes through the liquid-air interface, there would be a large change in the signal received by the detector. Radioactive methods, though simple in principle, find limited applications, because of possible radiation hazards. However radioactive methods are routinely used for level measurement of grains and granular solids.



Figs. 4 and 5 Radiation techniques for liquid level measurement

3. Humidity Measurement

Humidity measurement finds wide applications in different process industries. Moisture in the atmosphere must be controlled below a certain level in many manufacturing processes, e.g., semiconductor devices, optical fibres etc. Humidity inside an incubator must be controlled at a very precision level. Textiles, papers and cereals must be dried to a standard storage condition in order to prevent the quality deterioration. The humidity can be expressed in different ways: (a) absolute humidity, (b) relative humidity and (c) dew point.
Humidity can be measured in different ways. Some of the techniques are explained below.

Hygrometer

Many hygroscopic materials, such as wood, hair, paper, etc. are sensitive to humidity. Their dimensions change with humidity. The change in dimension can be measured and calibrated in terms of humidity.

Psychrometer

Psychrometric method for measurement of relative humidity is a popular method. Two bulbs are used- dry bulb and wet bulb. The wet bulb is soaked in saturated water vapour and the dry bulb is kept in the ambient condition. The temperature difference between the dry bulb and wet bulb is used to obtain the relative humidity through a psychrometric chart. The whole process can also be automated.

Dew point measurement

If a gas is cooled at constant pressure to the dew point, condensation of vapour will start. The dew point can be measured by placing a clean glass mirror in the atmosphere. The temperature of the mirror surface is controlled and reduced slowly; vapour starts condensation over the mirror. Optical method is used to detect the condensation phenomena, and the temperature of the mirror surface is measured.

Conductance/Capacitance method of measurement

Many solids absorb moisture and their values of the conductance or capacitance change with the degree of moisture absorption. Moisture content in granules changes the capacitance between two electrodes placed inside. By measuring the capacitance variation, the moisture content in the granules can be measured. Similarly, moisture content in paper and textiles change their resistance. A schematic arrangement for measurement of moisture content in paper or textiles using Resistance Bridge is shown in Fig. 6.

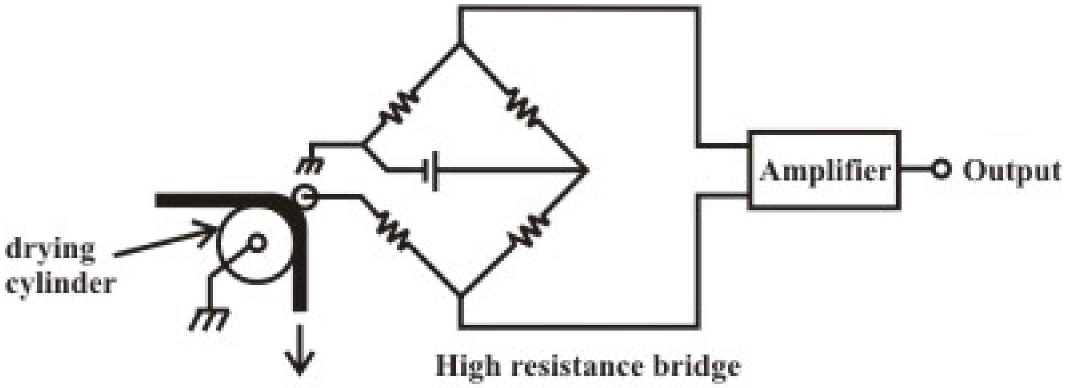


Fig. 6 Moisture measurement using resistive technique

Infrared Technique

Water molecule present in any material absorb infrared wave at wavelengths 1.94µm, 2.95 µm and 6.2µm. The degree of absorption of infrared light at any of these wavelengths may provide a measure of moisture content in the material.

4. Measurement of pH

pH is a measure of hydrogen ion concentration in aqueous solution. It is an important parameter to determine the quality of water. The pH value is expressed as:

$$pH = \frac{1}{\log_{10} C}$$

Where C is the concentration of H^+ ions in a solution. In pure water, the concentration of H^+ ions is 10^{-7} *gm/ltr* at 25^o C. So the pH value is

$$pH = \frac{1}{\log_{10} 10^{-7}} = 7\,.$$

The advantage of using pH scale is that the activities of all strong acids and bases can be brought down to the scale of 0-14. The pH value of acidic solutions is in the range 0-7 and alkaline solutions in the range 7-14.

The pH value of a solution is measured by using pH electrode. It essentially consists of a pair of electrodes: *measuring* and *reference* electrode, both dipped in the solution of unknown pH. These two electrodes essentially form two *half-cells;* the total potential developed is the difference between the individual electric potential developed in each half cell. While the potential developed in the reference cell is constant, the measuring cell potential is dependent on the hydrogen ion concentration of the solution and is governed by *Nernst's equation:*

$$E = E_0 + \frac{RT}{nF} \ln(a\,C)$$

Where:

E= e.m.f of the half cell
E_0= e.m.f of the half cell under saturated condition
R= Gas constant (8.314 $J/^0C$)
T= Absolute temperature (*K*)
N= valance of the ion
F= Faraday Constant = 96493 *C*
a= Activity co-efficient $(0 \le a \le 1)$; for a very dilute solution, $a \to 1$
C= molar concentration of ions.

Measuring Electrode

The measuring electrode is made of *thin sodium ion selective glass*. A potential is developed across the two surfaces of this glass bulb, when dipped in aqueous solution. This potential is sensitive to the H^+ ion concentration, having a sensitivity of 59.2 *mv/pH* at 25^0C. Fig. 7 shows the basic schematic of a measuring probe. The buffer solution inside the glass bulb has a constant H^+ ion concentration and provides electrical connection to the lead wire.

Reference Electrode

The basic purpose of a reference electrode is to provide continuity to the electrical circuit, since the potential across a single half cell cannot be measured. With both the measuring and reference cells dipped in the same solution, the potential is measured across the two lead wires. A reference electrode should satisfy the following basic requirements:

(i) The potential developed should be independent of H^+ ion concentration.
(ii) The potential developed should be independent of temperature
(iii) The potential developed should not change with time.

Considering all these requirements, two types of reference electrodes are commonly used: (i) Calomel (Mercury-Mercurous Chloride) and (ii) Silver-Silver Chloride. The construction of a Calomel reference electrode is shown in Fig. 8. The electrical connection is maintained through the *salt bridge.*

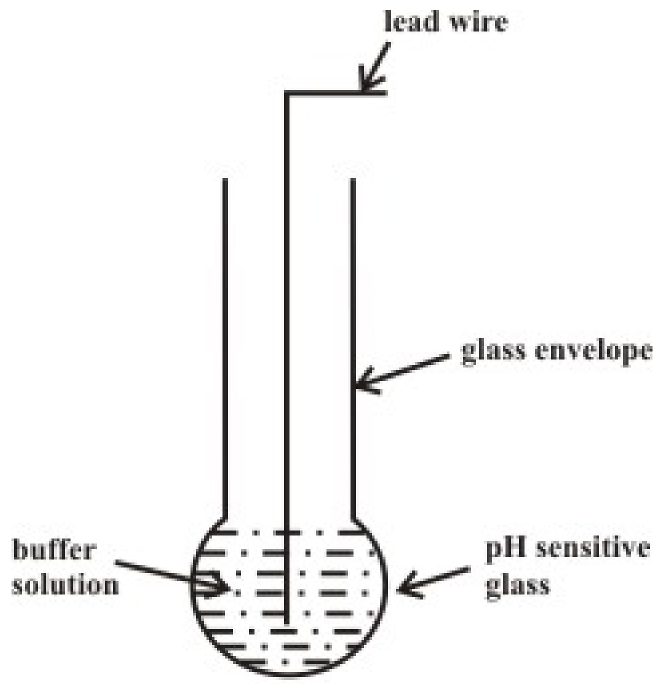


Fig. 7 Measuring Electrode

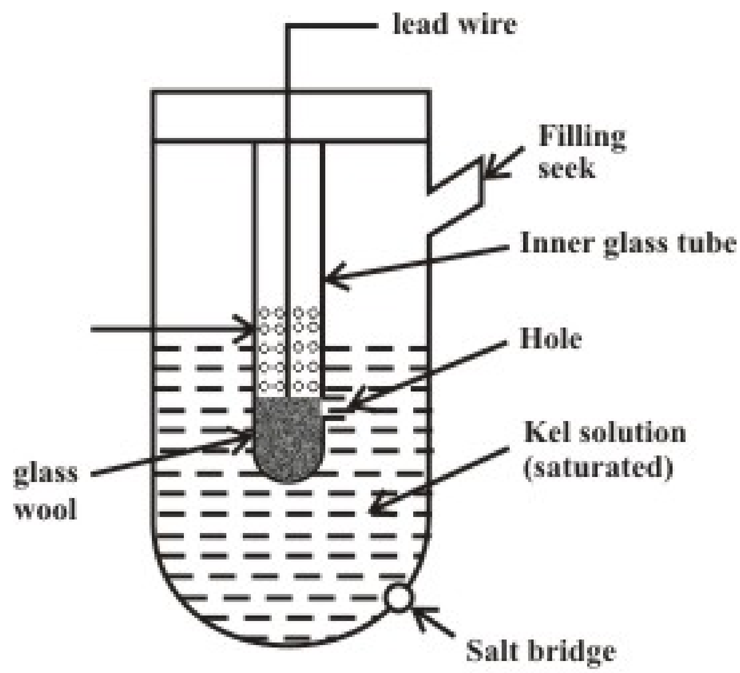


Fig. 8 Reference Electrode

Sometimes the reference and measuring electrodes are housed together, as shown in Fig. 9. This type of electrode is known as *Combination Electrode.* The reference electrode used in this case is Silver-Silver Chloride. The combination is dipped in the solution whose pH is to be measured and the output voltage is the difference between the e.m.f.s generated by the measuring glass electrode and the reference electrode.

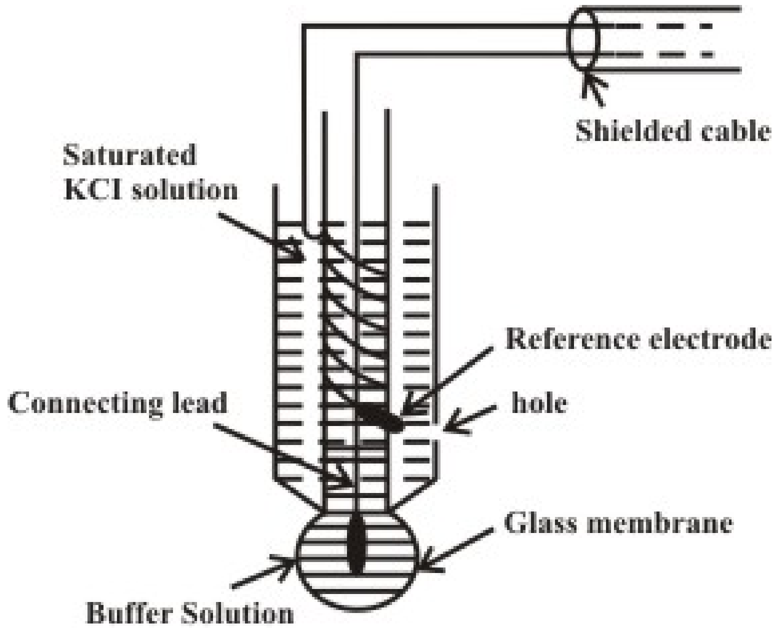


Fig. 9 Combination type pH electrode

Measuring scheme

The sensitivity of pH probe is around 59.2mv/pH at 25^0C. This sensitivity should be sufficient for measurement of voltage using ordinary electronic voltmeters. But, that is not the case; special measuring circuits are required for measurement of pH voltage. This is because of the fact that the internal resistance of the pH probe as a voltage source is very high, in the order of 10^8-10^9 Ω. This is because of the fact; the electrical path between the two lead wires is completed through the glass membrane. As a result, the input resistance for of the measuring device must be at least ten times electrode resistance of the electrode. FET-input amplifier circuits are normally used for amplifying the voltage from the pH probe. Not only that, the insulation resistance between the leads must also be very high. They are normally provided with moisture resistance insulation coating.

The voltage in the pH probe is temperature dependent, as evident from Nernst equation. As a result suitable temperature compensation scheme should also be provided in the measuring scheme.

Review Questions

1. How would you measure level of a liquid inside a sealed tank? Explain with a schematic arrangement any one of the methods.
2. Name different techniques used for level measurement of a liquid. Explain the principle of operation of hydrostatic differential pressure level gage.
3. Name few instances where measurement of humidity/ moisture finds important applications in industry.
4. How the moisture content in solids can be measured? Give an example and show the schematic arrangement.

5. Define pH of a solution. What is the hydrogen ion concentration of a solution if the pH of the solution is 5.0?
6. Explain with simple sketches the construction of measuring electrode and reference electrode. Why two electrodes are required for pH measurement?
7. Why temperature compensation scheme should be provided in pH measurement?
8. What special arrangements are to be provided for amplifying the voltage generated in a pH electrode? Justify.

Source:http://www.nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Industrial%20Automation%20control/pdf/L-08(SS)(IA&C)%20((EE)NPTEL).pdf