INDUSTRIAL PROCESS MEASUREMENT – Industrial Transducer Systems.

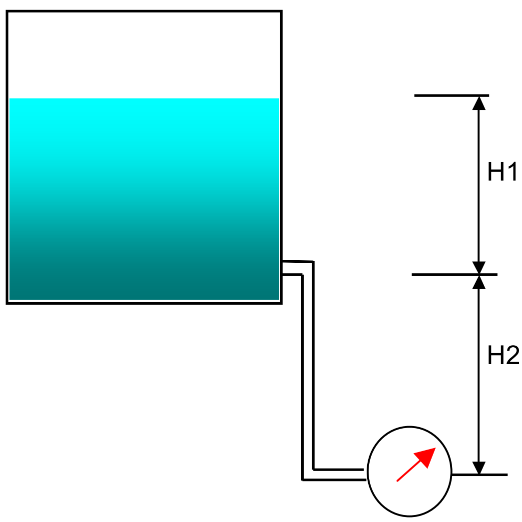
The aim of this unit is to introduce the learner to principles and techniques related to the Performance, Operation and Application of a range of Industrial Transducer Systems.

2 APPLICATION, SELECTION AND OPERATION OF TRANSDUCER TYPES.

Level *– pressure gauges, DP cell transmitters, purged dip pipes, capacitive probes, ultrasonic, nucleonic, load cells, level switches*;

Pressure gauges

Inline with the formula P= ρgh, hydrostatic pressure created by a liquid, is directly proportional to the depth or height of the liquid, assuming that the density of the liquid remains constant. In this case a pressure gauge could be used to act as a very simple level measurement transducer, as shown below;

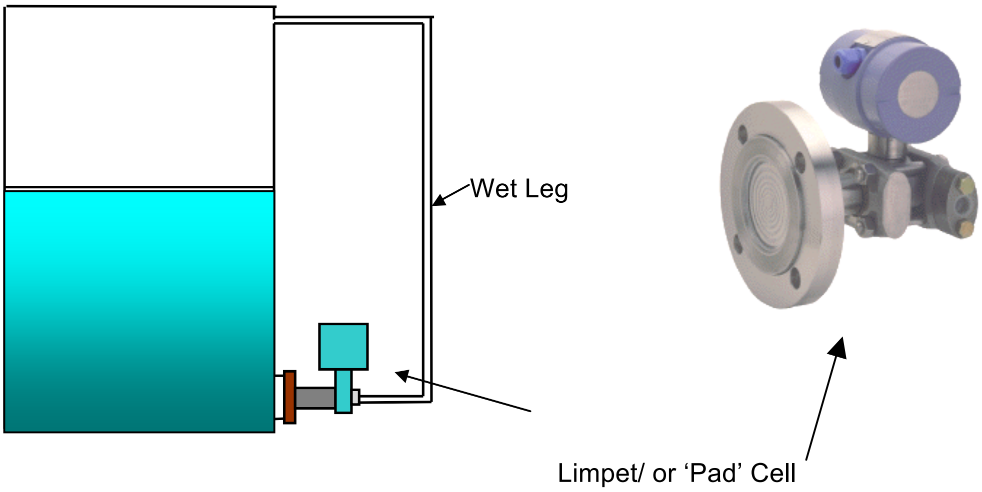


The overall pressure acting on the transmitter is:- H1 + H2, where H2 is the static head pressure and H1 is the actual level in the tank. This error (effect of H2) may be eliminated by suppressing the zero.

In the above example, two potential sources of error exist, firstly not having a precise knowledge of the density, if an exact measurement is required, and secondly, the static pressure acting on the measurement device caused by entrapped liquid in the impulse piping between the measurement device and the process vessel. This method is only suitable were the process vessel is open to the atmosphere, or for closed tanks which are naturally vented to atmosphere. Where the process vessel is closed, a different method is required.

DP Cell transmitters

When the liquid in the tank is prone to creating blockage, the liquid may act directly onto the diaphragm in a specially designed transmitter known as a **limpet/ or 'Pad' cell.**



The use of the limpet cell is not restricted to closed vessels only, it may also be used on open tank installations or it may be used to measure density if the level in the tank is kept constant. In this technique, the level transducer is a diaphragm capsule. This method is particularly useful where the liquid is viscous, slurry, or where the liquid in the tank is prone to creating blockage. It can of course be used on clean liquids. In this case, as above, the low pressure side of the transmitter is connected to the pressure above the liquid, and the high pressure side of the transmitter is connected towards the base of the tank. The transmitter measures the differential pressure between the base of the tank and the top of the tank. If the pressure above the liquid changes, this change will apply to both top and bottom equally, and therefore self cancels to leave the differential pressure, which is a product of the level.

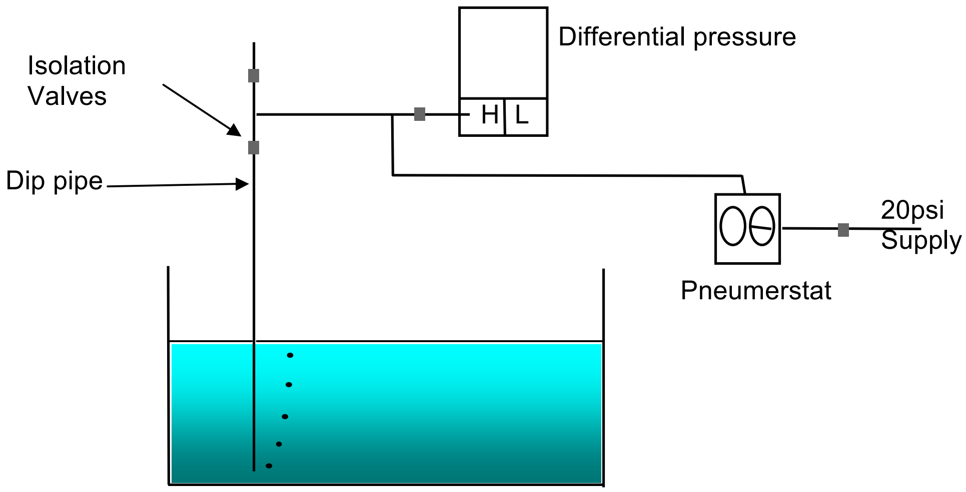
Purged dip pipe systems.

These systems have 3 main components, A gas purge device commonly a Pneumerstat (bubbler), Differential pressure transmitter and a single or double dip pipe arrangement.

Pros

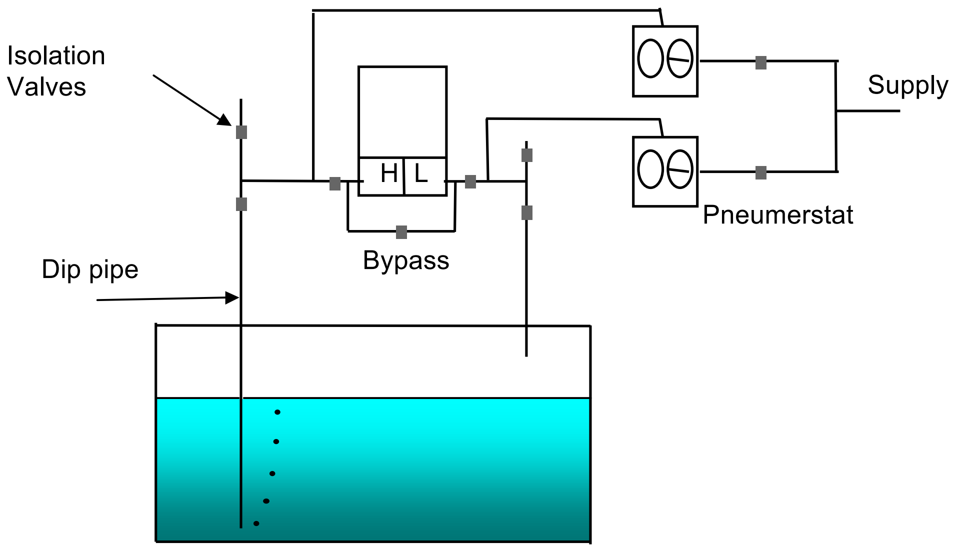
- Very High Accuracy
- Robust and Reliable

The following diagram shows a basic open tank dip pipe system:-



Air or nitrogen (the purge gas) is fed to the system via the pneumerstat. The pneumerstat provides a constant flowrate of air to the dip pipe such that when there is no level in the tank the air can freely escape thus not creating a pressure build. When the level in the tank rises it becomes increasingly more difficult for the air to escape and a pressure builds up in the dip pipe equal to the height of liquid, according to the formula $P = \rho gh$. Air bubbles will be seen escaping as the pressure in the dip pipe is kept equal to the pressure created by the liquid level. This build up of pressure is fed back to, and detected by a ‘pressure transducer’. As the level rises and falls so to will the output of the ‘pressure transducer’ or ‘level transmitter’.

The basic principle of operation of the closed tank installation is the same as that for the open tank except that a connection needs to be made to the low pressure side of the transmitter to the gas pressure above the liquid usually at the top of the tank. The next diagram shows this:-



From the previous diagram, when the tank is empty the same pressure acts on both sides of the transmitter therefore creating a zero reading, when the level rises only the high pressure side is affected . If the pressure inside the vessel changes the effect is automatically compensated for. Care should be exercised when operating the isolation valves as the vessel may be under pressure.

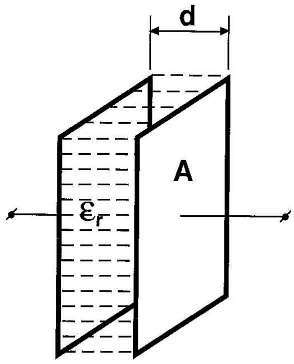
Capacitance probes

In this system it is the 'capacitance' of the fluid which will give rise to the indication of level. A capacitor is an electrical component capable of storing and discharging an electrical charge. A simple capacitor consists of 2 metal plates separated by an insulator known as a dielectric. The capacitance between the measurement probe and the reference probe (which is usually the tank wall) will vary depending on the presence of, the type of, and amount of product between them. If the tank wall is a non conductive material, a second probe of the same length as the first may be used to act as the second plate.

In these systems the process fluid acts as the dielectric. The lower the dielectric constant value, the less able that substance is to conduct electricity.

In the diagram, the capacitance C is equal to

$$C = \frac{\varepsilon r \times A}{d}$$



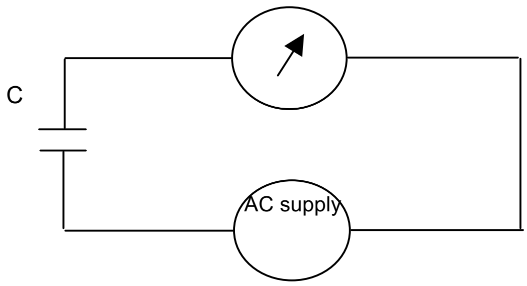
Where:

Ɛr = relative permittivity of the dielectric
C = Capacitance in pF
A = Area of plates in cm
d= distance between the plates in cm

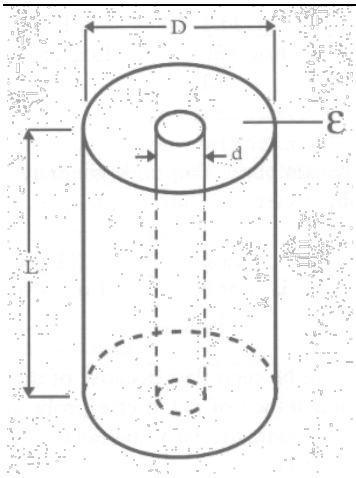
Some show this formula as

$$C = \frac{KA}{d}$$ where K is described as the dielectric constant

The current flowing through the circuit therefore is directly proportional to the value of the capacitance C, as seen in this simple diagram



Capacitance level detectors are also referred to as radio frequency (RF) or admittance level sensors. Admittance is a measure of the conductivity in an ac circuit, and is the reciprocal of impedance. Admittance and impedance in an ac circuit are similar to conductance and resistance in a direct current (dc) circuit. AC supply is required, (1) to avoid problems associated with polarization



Using the following formula to work out the capacitance for a cylindrical capacitor, we can see how different things affect measurement.

$$C = \frac{\varepsilon_r \times 24 \times L}{\log D/d}$$ *24 = capacitance of probe*

The capacitance of the probe and the change in product capacitance (ΔC) can be worked out using the above formula.

Where; L = probe length in mtrs, D = tank dia' in mm, d = probe dia' in mm

Using an example where ε_r = 1, and probe length = 1m, tank diameter = 1800mm, and the probe = 12mm

$$C = \frac{1 \times 24 \times 1}{\log \frac{1800}{12}} = \frac{24}{\log 150} = \frac{24}{2.17} = 11pF$$

if the tank diameter was doubled

$$C = \frac{1 \times 24 \times 1}{\log \frac{3600}{12}} = \frac{24}{\log 300} = \frac{24}{2.47} = 9.7pF$$

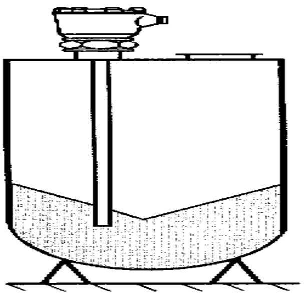
if the substance was changed to Oil (where $\varepsilon_r = 2$)

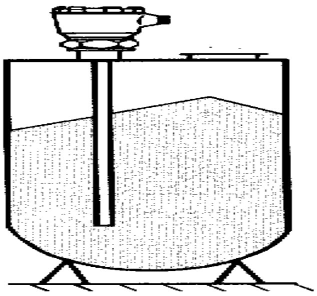
$$C = \frac{2 \times 24 \times 1}{\log \frac{1800}{12}} = \frac{48}{\log 150} = \frac{48}{2.17} = 22pF$$

change in capacitance $$(\Delta C) = \frac{(\varepsilon_r - 1) \times 24 \times L}{\log D/d}$$

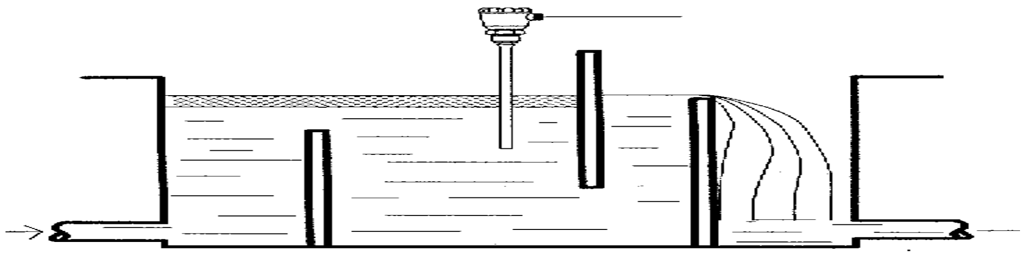
Changes in capacitance as small as 1pF only may be required to register 'point of level' detection, whereas a change of 20pF is the realistic minimum required to begin to detect 'change in level' measurements.

Unlike the conductive system this type may also be used to constantly monitor the changing level in the tank rather than just detection at a preset level, as capacitance (capacity) changes with volume. The next diagram shows the installation of a capacitance system with the level in its low and high state:-





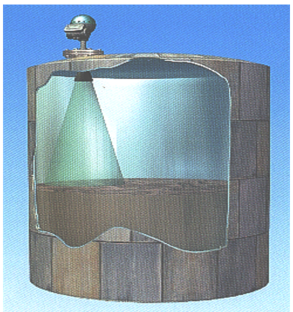
The use of these systems can be similar to the conductive system, however a popular use is to measure liquid interface levels, as the final diagram shows:-



Ultrasonic (echo) level detection.

The principle of operation of these devices is based on the 'measurement of the travel time of a sound signal transmitted and received from the same sensor after reflection off a liquid or semi solid product within a process vessel. The time of travel of the signal pulse being a direct measure of the height as the distance travelled by the sound pulse is equal to the travel time in seconds multiplied by the speed travel ie: speed of sound (in m/sec). With sound travelling at 331m/s in air @ 0 degrees C. It is a similar principle to radar on an aircraft determining its height above ground or sea level.

Ultrasonic level measurement utilizes the simple equation D = Va t/2. The distance (D) is a function of the time (t) required for an ultrasonic pulse to travel at the speed of sound (Va) from the face of the transducer to the reflecting surface and back to the transducer. The instrument is performing a timing function to determine the level.



Gas composition can affect measurement, for example the propagation speed of sound waves in air is 343m/s @ 20°C, whereas for nitrogen at the same temperature it is 349m/s

For example

$$\text{Speed of travel} = \frac{\text{2 x distance to be measured}}{\text{Speed of sound}}$$

For an 8m vessel, containing air, the time of travel is

$$C_{air} = \frac{16}{343} = 0.0466s$$

For an 8m vessel, containing nitrogen, the time of travel is

$$C_{nitrogen} = \frac{16}{349} = 0.0458s$$

The Ultrasonic Non-Contact Transmitter electronics sends an electrical signal to the transducer sensor crystal, which causes the crystal to vibrate and emit an ultrasonic pulse. The sound pulse is directed toward the liquid surface where it is reflected as an echo back to the transducer, again causing it to vibrate. The electronics detects when the return echo is received, and converts the time interval into a distance.

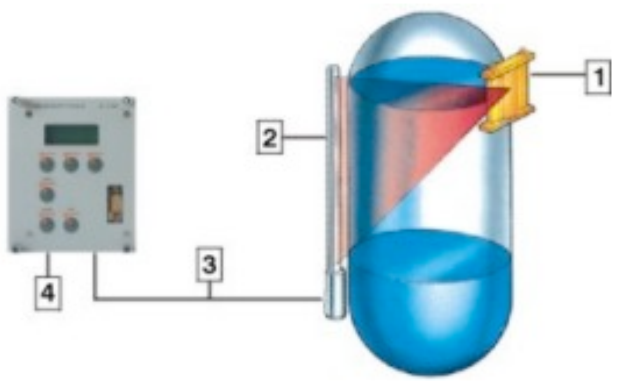
This system works independently of frequency and pressure changes (upto 3bar maximum), but can be affected by temperature.

The typical FM radio frequency range is 88-108 mHz, the typical audible hearing range is 20 Hz - 20KHz, whereas in ultrasonic systems, the sound frequency used is in the region of 20-45KHz.

One particular example of the use of this method is in the paper industry, where the paper pulp is held and moved through plant vessels. This non - invasive method is ideal in these circumstances. Other uses could include in storage tanks, tank farms, and on products such as powders or even petrol and oil. The transducer is mounted above the maximum level of the media to be measured with the ultrasonic pulse directed at the surface of the media.

Nucleonic/ Radiation level detectors.

The use of radiation as a means of detecting level is particularly advantageous where it is not possible to put probes or sensors into a tank or reactor, for example:-



- With very corrosive, viscous or adhesive substances.
- In reactors or furnaces, at high temperatures and pressures.
- With very coarse and abrasive bulk materials, powders or slurries.

1. Source, 2. Detector, 3. 2 wire Transmission, 4. 4-20mA output

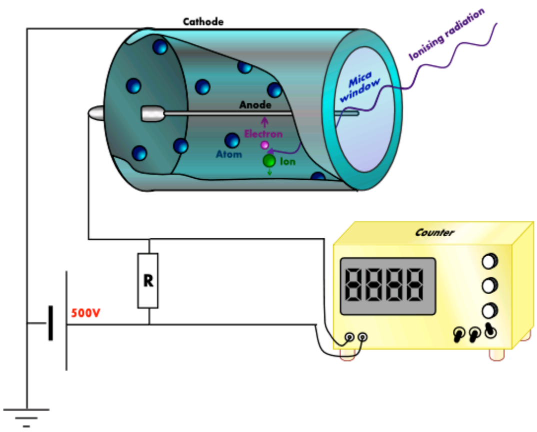
Radiation source.

In application a beam of pure gamma radiation (usually from Cobalt 60 or Caesium 137) is emitted from a source holder, which is often referred to as the *R.A.S* RadioActive Source. This radiation type contains no alpha or beta type radiation

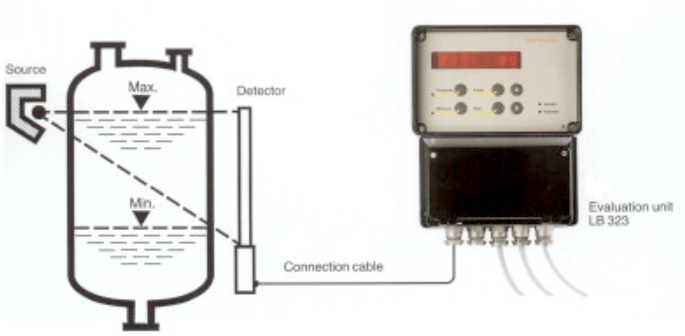
The detector.

Opposite the source is a radiation detector or *R.A.D* , normally a Geiger Muller tube.

The 'Geiger Muller tube', or 'Geiger counter' consists of a tube, with an anode and cathode. (A +ve and -ve connection). The tube is filled with an inert gas, and in some cases a small quantity of Halogen. The tube is connected to a voltage of approx 500V via a high value resistor. When there is no radiation present, the tube material acts as a perfect insulator, and although there is a voltage across the anode and cathode, no current flows between them. When the tube is exposed to radiation, the inert gas becomes ionised, and because of the high energy potential, there is a discharge of electrons, the burst of electrons appears in what is called an electron avalanche, this is picked up between the anode and cathode. The avalanche creates a current pulse, the intense pulse of current passes (or *cascades*) from the negative electrode to the positive electrode and is measured or counted. A signal amplifier is required with the detector unit. The number of pulses produced in the avalanche is a product of the amount, or intensity of the radiation received by the tube. The pulses are often associated with audible clicks.



When there is no level present the radiation strength at the detector will be just less than at the source (due to distance). When the product level rises between the source and detector, it acts as an insulator, or absorbs the radiation and blocks it from the detector. The next diagram shows a common application of level measurement with this technique



The method of measurement is relatively unaffected by:

- High temperature , High pressure or vacuum
- Volatile, corrosive or biohazard material
- Build up on vessel walls
- Physical and chemical properties of the product and the process

Advantages:

- Non-contact, continuous measurement of the filling level
- Adaptable to all vessel shapes
- Level- or volume-proportional arrangement
- Measuring range up to more than 10 m
- On line measurement
- No moving parts
- Reliable technology
- Low maintenance
- Easy to calibrate

Level switches

The simplest way to describe the operation of devices in this section is those which rely on the ability of an object to float on the surface of liquid or those which rely on the displacement of the liquid

One type of device is manufactured by a company called *Mobrey* and hence is called the Mobrey switch, these can be either pneumatic or electrical and consist of a float sensor which is inserted into the tank, an arm is attached to the float which connects via a pivot to a magnet, then via a magnetic coupling a switch can be operated.

The application of these devices is limited to providing measurement only at the point at which they are inserted into the tank, and by the length of the connecting arm, the may be configured to provide either high or low level alarm warnings.