Department of Energy
Fundamentals Handbook

INSTRUMENTATION AND CONTROL
Module 3
Level Detectors

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NONE

REFERENCES

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TERMINAL OBJECTIVE

1.0 Given a level instrument, **RELATE** the associated fundamental principles, including possible failure modes, to that instrument.

ENABLING OBJECTIVES

1.1 **IDENTIFY** the principle of operation of the following types of level instrumentation:
   a. Gauge glass
   b. Ball float
   c. Chain float
   d. Magnetic bond
   e. Conductivity probe
   f. Differential pressure (ΔP)

1.2 **EXPLAIN** the process of density compensation in level detection systems to include:
   a. Why needed
   b. How accomplished

1.3 **STATE** the three reasons for using remote level indicators.

1.4 Given a basic block diagram of a differential pressure detector-type level instrument, **STATE** the purpose of the following blocks:
   a. Differential pressure (D/P) transmitter
   b. Amplifier
   c. Indication

1.5 **STATE** the three environmental concerns which can affect the accuracy and reliability of level detection instrumentation.

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LEVEL DETECTORS

Liquid level measuring devices are classified into two groups: (a) direct method, and (b) inferred method. An example of the direct method is the dipstick in your car which measures the height of the oil in the oil pan. An example of the inferred method is a pressure gauge at the bottom of a tank which measures the hydrostatic head pressure from the height of the liquid.

EO 1.1 IDENTIFY the principle of operation of the following types of level instrumentation:

- **a. Gauge glass**
- **b. Ball float**
- **c. Chain float**
- **d. Magnetic bond**
- **e. Conductivity probe**
- **f. Differential pressure (ΔP)**

Gauge Glass

A very simple means by which liquid level is measured in a vessel is by the gauge glass method (Figure 1). In the gauge glass method, a transparent tube is attached to the bottom and top (top connection not needed in a tank open to atmosphere) of the tank that is monitored. The height of the liquid in the tube will be equal to the height of water in the tank.

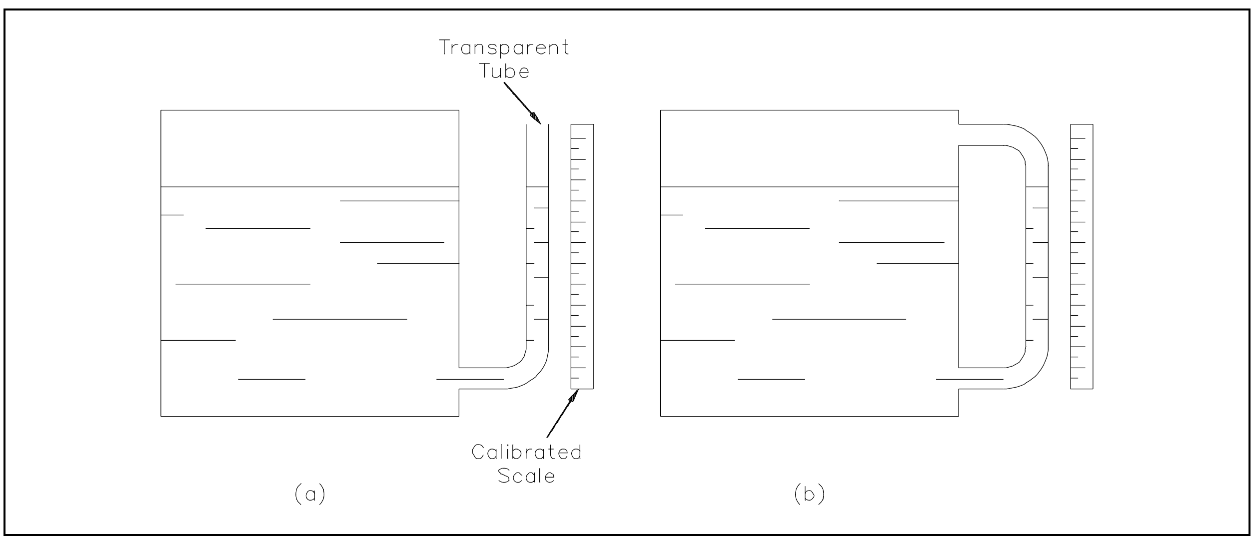

Figure 1 Transparent Tube

Figure 1 (a) shows a gauge glass which is used for vessels where the liquid is at ambient temperature and pressure conditions. Figure 1 (b) shows a gauge glass which is used for vessels where the liquid is at an elevated pressure or a partial vacuum. Notice that the gauge glasses in Figure 1 effectively form a "U" tube manometer where the liquid seeks its own level due to the pressure of the liquid in the vessel.

Gauge glasses made from tubular glass or plastic are used for service up to 450 psig and 400°F. If it is desired to measure the level of a vessel at higher temperatures and pressures, a different type of gauge glass is used. The type of gauge glass utilized in this instance has a body made of metal with a heavy glass or quartz section for visual observation of the liquid level. The glass section is usually flat to provide strength and safety. Figure 2 illustrates a typical transparent gauge glass.

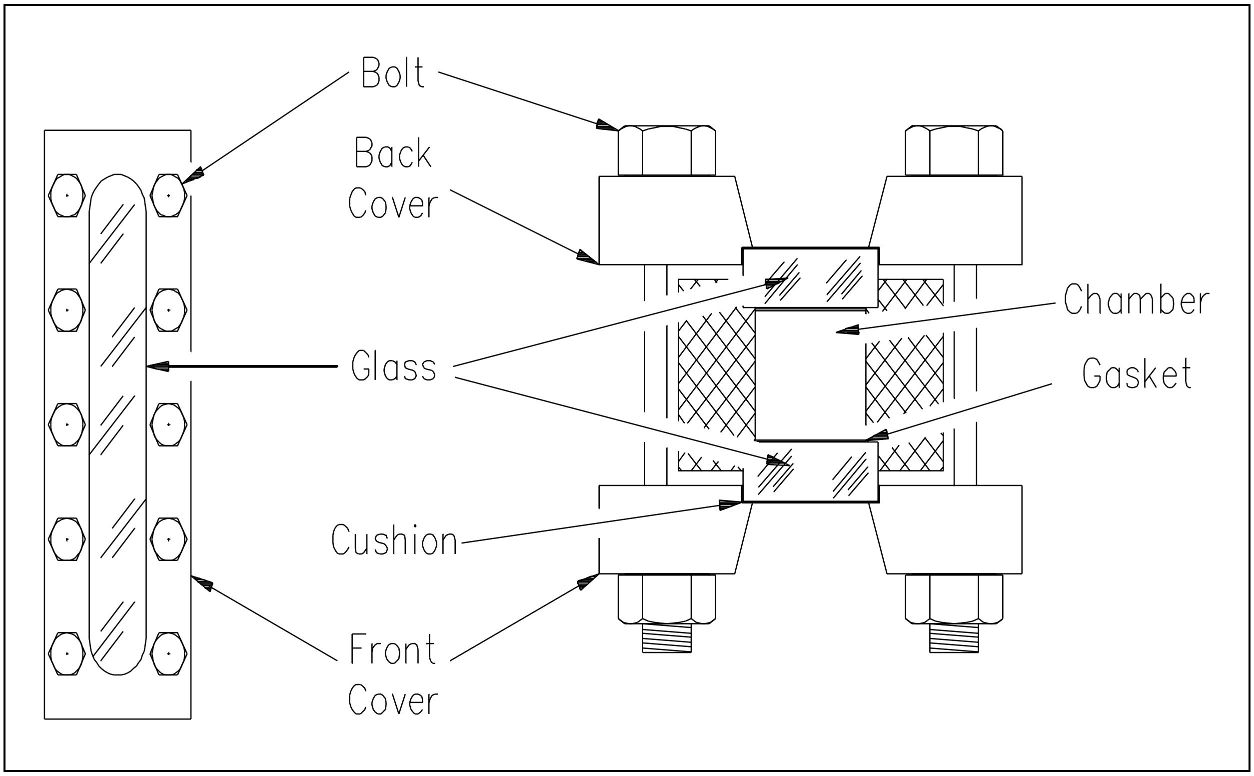

Figure 2 Gauge Glass

Another type of gauge glass is the reflex gauge glass (Figure 3). In this type, one side of the glass section is prism-shaped. The glass is molded such that one side has 90-degree angles which run lengthwise. Light rays strike the outer surface of the glass at a 90-degree angle. The light rays travel through the glass striking the inner side of the glass at a 45-degree angle. The presence or absence of liquid in the chamber determines if the light rays are refracted into the chamber or reflected back to the outer surface of the glass.

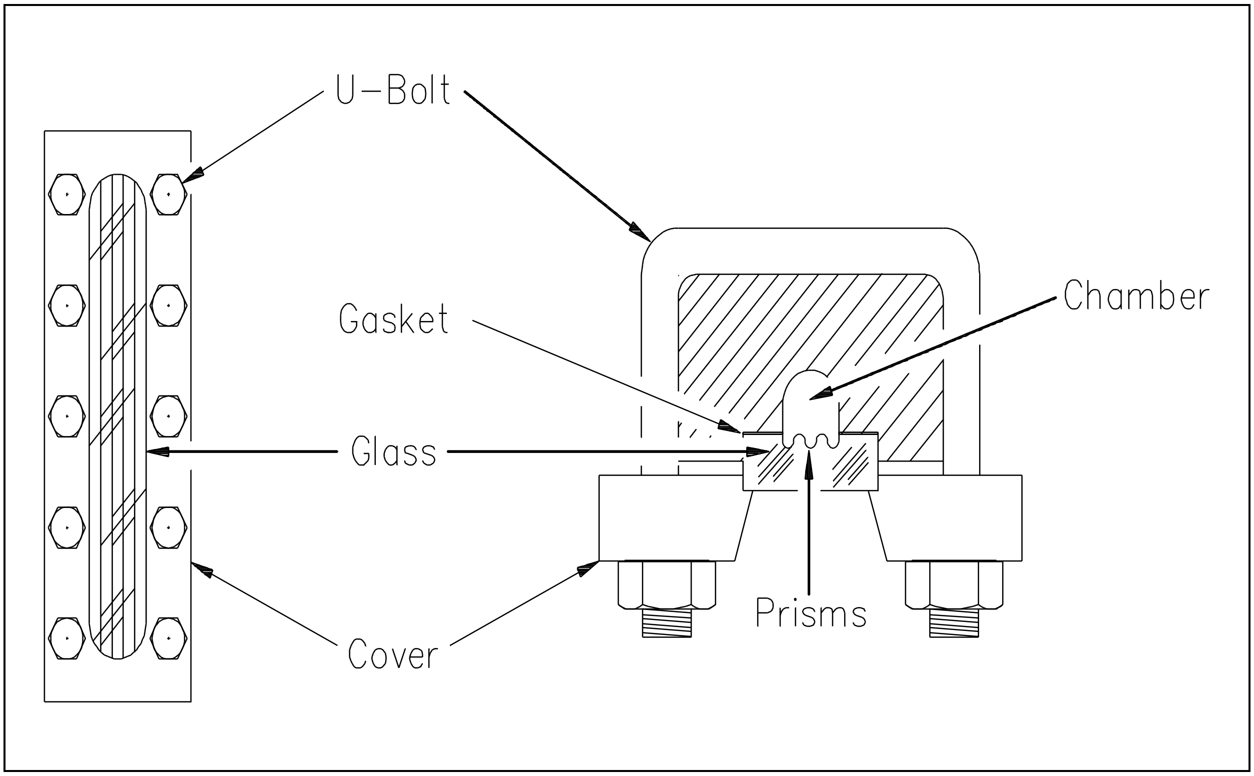

Figure 3 Reflex Gauge Glass

When the liquid is at an intermediate level in the gauge glass, the light rays encounter an air-glass interface in one portion of the chamber and a water-glass interface in the other portion of the chamber. Where an air-glass interface exists, the light rays are reflected back to the outer surface of the glass since the critical angle for light to pass from air to glass is 42 degrees. This causes the gauge glass to appear silvery-white. In the portion of the chamber with the water-glass interface, the light is refracted into the chamber by the prisms. Reflection of the light back to the outer surface of the gauge glass does not occur because the critical angle for light to pass from glass to water is 62-degrees. This results in the glass appearing black, since it is possible to see through the water to the walls of the chamber which are painted black.

A third type of gauge glass is the refraction type (Figure 4). This type is especially useful in areas of reduced lighting; lights are usually attached to the gauge glass. Operation is based on the principle that the bending of light, or refraction, will be different as light passes through various media. Light is bent, or refracted, to a greater extent in water than in steam. For the portion of the chamber that contains steam, the light rays travel relatively straight, and the red lens is illuminated. For the portion of the chamber that contains water, the light rays are bent, causing the green lens to be illuminated. The portion of the gauge containing water appears green; the portion of the gauge from that level upward appears red.

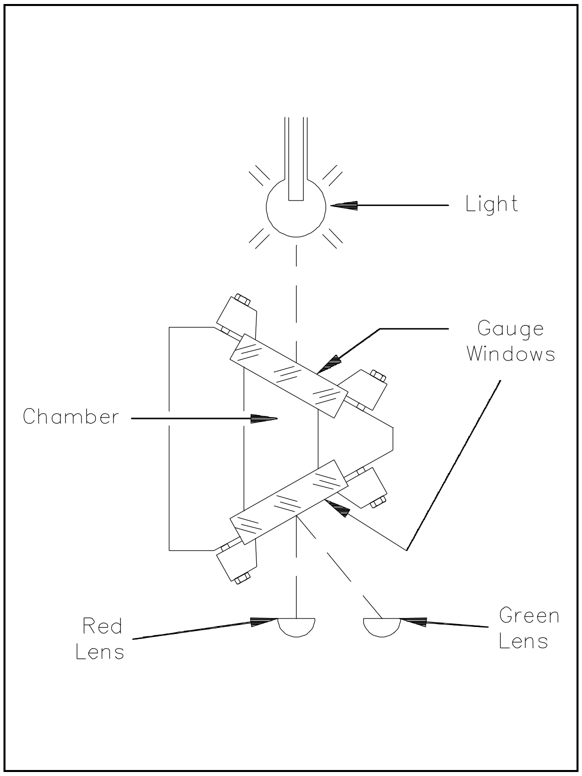

Figure 4 Refraction Gauge Glass
(overhead view)

Ball Float

The ball float method is a direct reading liquid level mechanism. The most practical design for the float is a hollow metal ball or sphere. However, there are no restrictions to the size, shape, or material used. The design consists of a ball float attached to a rod, which in turn is connected to a rotating shaft which indicates level on a calibrated scale (Figure 5). The operation of the ball float is simple. The ball floats on top of the liquid in the tank. If the liquid level changes, the float will follow and change the position of the pointer attached to the rotating shaft.

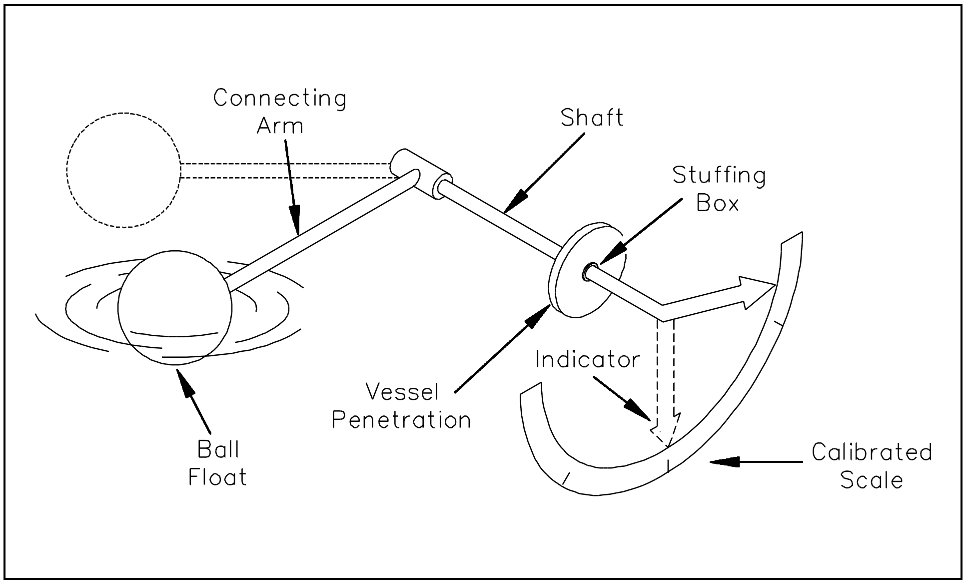

Figure 5 Ball Float Level Mechanism

The travel of the ball float is limited by its design to be within ±30 degrees from the horizontal plane which results in optimum response and performance. The actual level range is determined by the length of the connecting arm.

The stuffing box is incorporated to form a water-tight seal around the shaft to prevent leakage from the vessel.

Chain Float

This type of float gauge has a float ranging in size up to 12 inches in diameter and is used where small level limitations imposed by ball floats must be exceeded. The range of level measured will be limited only by the size of the vessel. The operation of the chain float is similiar to the ball float except in the method of positioning the pointer and in its connection to the position indication. The float is connected to a rotating element by a chain with a weight attached to the other end to provide a means of keeping the chain taut during changes in level (Figure 6).

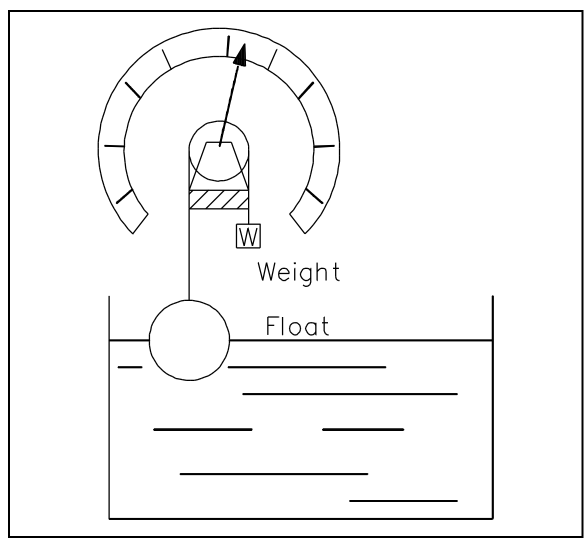

Figure 6 Chain Float Gauge

Magnetic Bond Method

The magnetic bond method was developed to overcome the problems of cages and stuffing boxes. The magnetic bond mechanism consists of a magnetic float which rises and falls with changes in level. The float travels outside of a non-magnetic tube which houses an inner magnet connected to a level indicator. When the float rises and falls, the outer magnet will attract the inner magnet, causing the inner magnet to follow the level within the vessel (Figure 7).

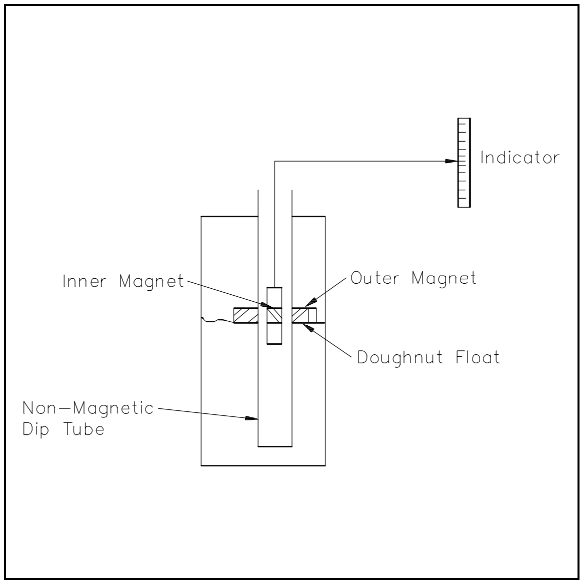

Figure 7 Magnetic Bond Detector

Conductivity Probe Method

Figure 8 illustrates a conductivity probe level detection system. It consists of one or more level detectors, an operating relay, and a controller. When the liquid makes contact with any of the electrodes, an electric current will flow between the electrode and ground. The current energizes a relay which causes the relay contacts to open or close depending on the state of the process involved. The relay in turn will actuate an alarm, a pump, a control valve, or all three. A typical system has three probes: a low level probe, a high level probe, and a high level alarm probe.

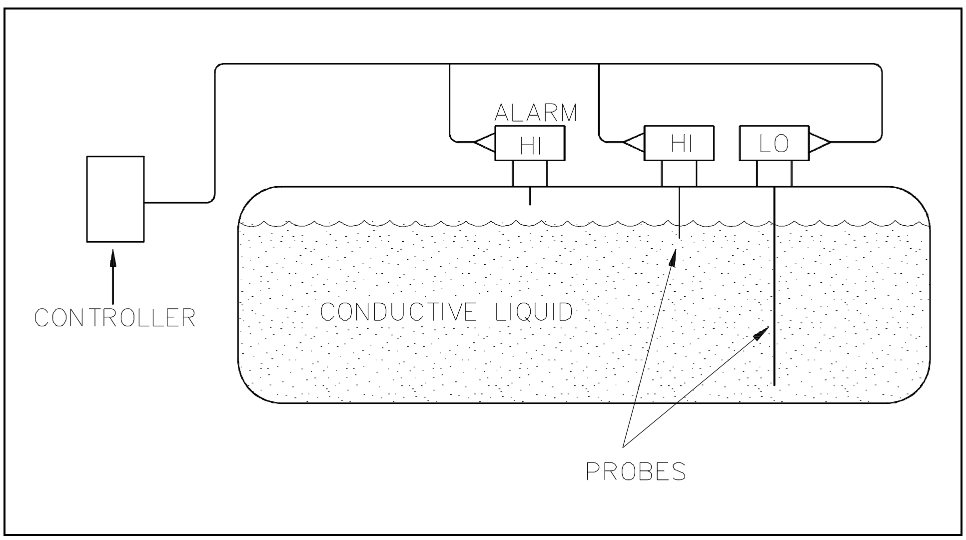

Figure 8 Conductivity Probe Level Detection System

Differential Pressure Level Detectors

The differential pressure (ΔP) detector method of liquid level measurement uses a ΔP detector connected to the bottom of the tank being monitored. The higher pressure, caused by the fluid in the tank, is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the ΔP detector. Figure 9 illustrates a typical differential pressure detector attached to an open tank.

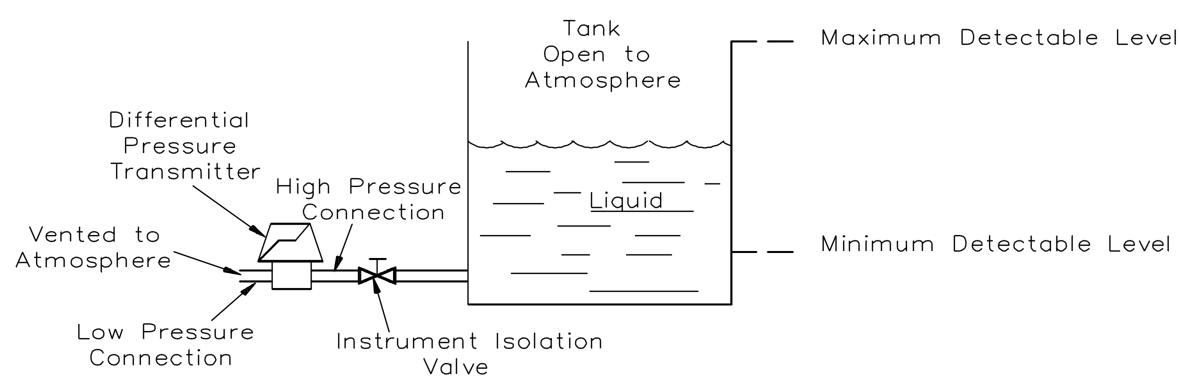

Figure 9 Open Tank Differential Pressure Detector

The tank is open to the atmosphere; therefore, it is necessary to use only the high pressure (HP) connection on the ΔP transmitter. The low pressure (LP) side is vented to the atmosphere; therefore, the pressure differential is the hydrostatic head, or weight, of the liquid in the tank. The maximum level that can be measured by the ΔP transmitter is determined by the maximum height of liquid above the transmitter. The minimum level that can be measured is determined by the point where the transmitter is connected to the tank.

Not all tanks or vessels are open to the atmosphere. Many are totally enclosed to prevent vapors or steam from escaping, or to allow pressurizing the contents of the tank. When measuring the level in a tank that is pressurized, or the level that can become pressurized by vapor pressure from the liquid, both the high pressure and low pressure sides of the ΔP transmitter must be connected (Figure 10).

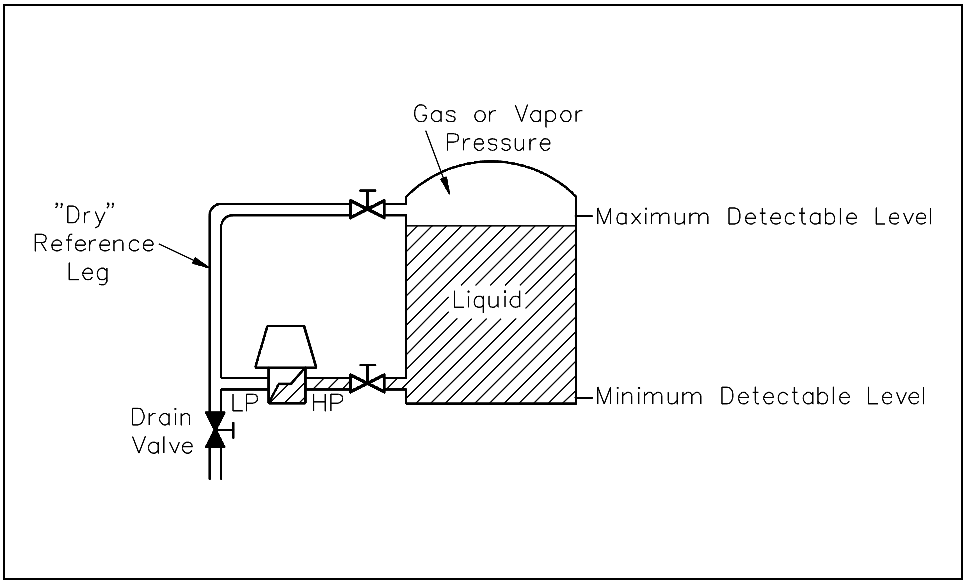

Figure 10 Closed Tank, Dry Reference Leg

The high pressure connection is connected to the tank at or below the lower range value to be measured. The low pressure side is connected to a "reference leg" that is connected at or above the upper range value to be measured. The reference leg is pressurized by the gas or vapor pressure, but no liquid is permitted to remain in the reference leg. The reference leg must be maintained dry so that there is no liquid head pressure on the low pressure side of the transmitter. The high pressure side is exposed to the hydrostatic head of the liquid plus the gas or vapor pressure exerted on the liquid's surface. The gas or vapor pressure is equally applied to the low and high pressure sides. Therefore, the output of the ΔP transmitter is directly proportional to the hydrostatic head pressure, that is, the level in the tank.

Where the tank contains a condensible fluid, such as steam, a slightly different arrangement is used. In applications with condensible fluids, condensation is greatly increased in the reference leg. To compensate for this effect, the reference leg is filled with the same fluid as the tank. The liquid in the reference leg applies a hydrostatic head to the high pressure side of the transmitter, and the value of this level is constant as long as the reference leg is maintained full. If this pressure remains constant, any change in ΔP is due to a change on the low pressure side of the transmitter (Figure 11).

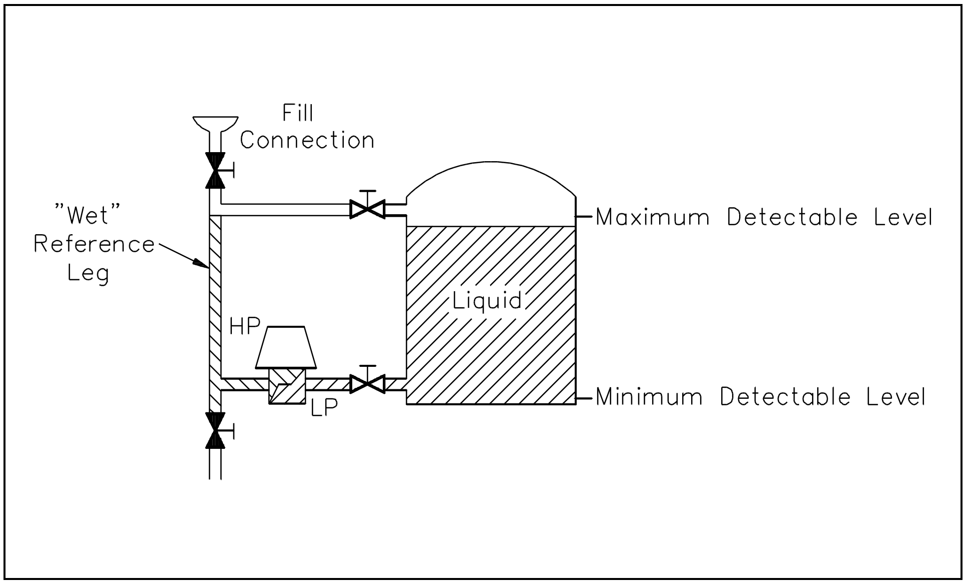

Figure 11 Closed Tank, Wet Reference Leg

The filled reference leg applies a hydrostatic pressure to the high pressure side of the transmitter, which is equal to the maximum level to be measured. The ΔP transmitter is exposed to equal pressure on the high and low pressure sides when the liquid level is at its maximum; therefore, the differential pressure is zero. As the tank level goes down, the pressure applied to the low pressure side goes down also, and the differential pressure increases. As a result, the differential pressure and the transmitter output are inversely proportional to the tank level.

Summary

The different types of level instruments presented in this chapter are summarized below.

Level Instrumentation Summary

- In the gauge glass method, a transparent tube is attached to the bottom and top (top connection not needed in a tank open to atmosphere) of the tank that is monitored. The height of the liquid in the tube will be equal to the height of water in the tank.

- The operation of the ball float is simple. The ball floats on top of the liquid in the tank. If the liquid level changes, the float will follow and change the position of the pointer attached to the rotating shaft.

- The operation of the chain float is similar to the ball float except in its method of positioning the pointer and its connection to the position indication. The float is connected to a rotating element by a chain with a weight attached to the other end to provide a means of keeping the chain taut during changes in level.

- The magnetic bond mechanism consists of a magnetic float that rises and falls with changes in level. The float travels outside of a non-magnetic tube which houses an inner magnet connected to a level indicator. When the float rises and falls, the outer magnet will attract the inner magnet, causing the inner magnet to follow the level within the vessel.

- The conductivity probe consists of one or more level detectors, an operating relay, and a controller. When the liquid makes contact with any of the electrodes, an electric current will flow between the electrode and ground. The current energizes a relay which causes the relay contacts to open or close depending on the state of the process involved. The relay in turn will actuate an alarm, a pump, a control valve, or all three.

- The differential pressure (ΔP) detector uses a ΔP detector connected to the bottom of the tank that is being monitored. The higher pressure in the tank is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the ΔP detector.

DENSITY COMPENSATION

If a vapor with a significant density exists above the liquid, the hydrostatic pressure added needs to be considered if accurate transmitter output is required.

EO 1.2 EXPLAIN the process of density compensation in level detection systems to include:
a. Why needed
b. How accomplished

Specific Volume

Before examining an example which shows the effects of density, the unit "specific volume" must be defined. Specific volume is defined as volume per unit mass as shown in Equation 3-1.

$$\text{Specific Volume} = \text{Volume/Mass} \tag{3-1}$$

Specific volume is the reciprocal of density as shown in Equation 3-2.

$$\text{Specific Volume} = \frac{1}{\text{density}} \tag{3-2}$$

Specific volume is the standard unit used when working with vapors and steam that have low values of density.

For the applications that involve water and steam, specific volume can be found using "Saturated Steam Tables," which list the specific volumes for water and saturated steam at different pressures and temperatures.

The density of steam (or vapor) above the liquid level will have an effect on the weight of the steam or vapor bubble and the hydrostatic head pressure. As the density of the steam or vapor increases, the weight increases and causes an increase in hydrostatic head even though the actual level of the tank has not changed. The larger the steam bubble, the greater the change in hydrostatic head pressure.

Figure 12 illustrates a vessel in which the water is at saturated boiling conditions.

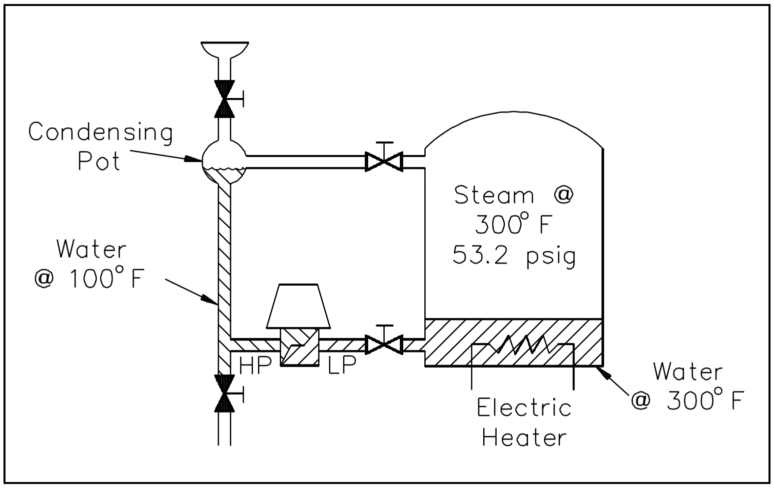

Figure 12 Effects of Fluid Density

A condensing pot at the top of the reference leg is incorporated to condense the steam and maintain the reference leg filled. As previously stated, the effect of the steam vapor pressure is cancelled at the ΔP transmitter due to the fact that this pressure is equally applied to both the low and high pressure sides of the transmitter. The differential pressure to the transmitter is due only to hydrostatic head pressure, as stated in Equation 3-3.

$$\text{Hydrostatic Head Pressure} = \text{Density} \times \text{Height} \qquad (3\text{-}3)$$

Reference Leg Temperature Considerations

When the level to be measured is in a pressurized tank at elevated temperatures, a number of additional consequences must be considered. As the temperature of the fluid in the tank is increased, the density of the fluid decreases. As the fluid's density decreases, the fluid expands, occupying more volume. Even though the density is less, the mass of the fluid in the tank is the same. The problem encountered is that, as the fluid in the tank is heated and cooled, the density of the fluid changes, but the reference leg density remains relatively constant, which causes the indicated level to remain constant. The density of the fluid in the reference leg is dependent upon the ambient temperature of the room in which the tank is located; therefore, it is relatively constant and independent of tank temperature. If the fluid in the tank changes temperature, and therefore density, some means of density compensation must be incorporated in order to have an accurate indication of tank level. This is the problem encountered when measuring pressurizer water level or steam generator water level in pressurized water reactors, and when measuring reactor vessel water level in boiling water reactors.

Pressurizer Level Instruments

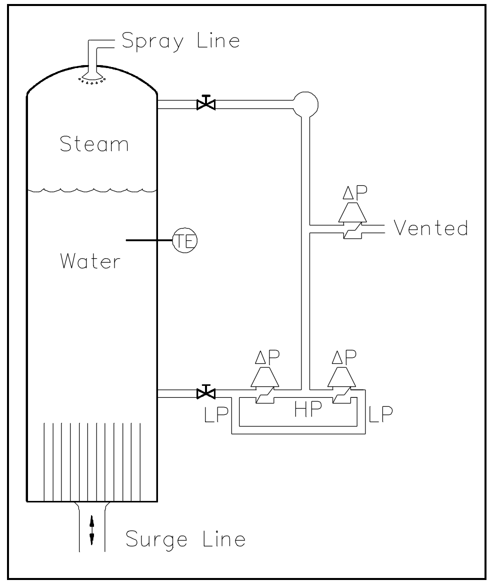

Figure 13 Pressurizer Level System

Figure 13 shows a typical pressurizer level system. Pressurizer temperature is held fairly constant during normal operation. The ΔP detector for level is calibrated with the pressurizer hot, and the effects of density changes do not occur. The pressurizer will not always be hot. It may be cooled down for non-operating maintenance conditions, in which case a second ΔP detector, calibrated for level measurement at low temperatures, replaces the normal ΔP detector. The density has not really been compensated for; it has actually been aligned out of the instrument by calibration.

Density compensation may also be accomplished through electronic circuitry. Some systems compensate for density changes automatically through the design of the level detection circuitry. Other applications compensate for density by manually adjusting inputs to the circuit as the pressurizer cools down and depressurizes, or during heatup and pressurization. Calibration charts are also available to correct indications for changes in reference leg temperature.

Steam Generator Level Instrument

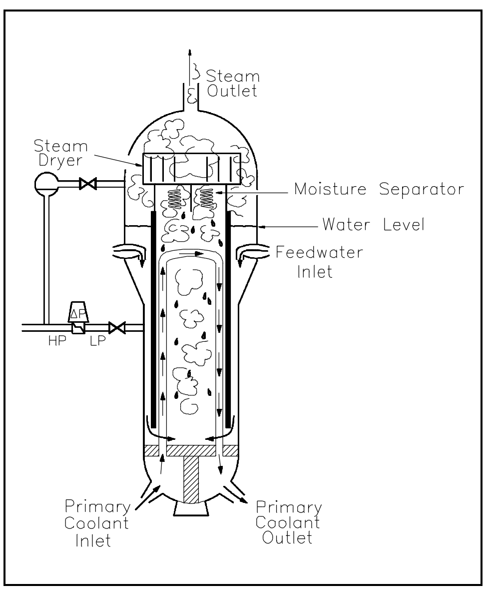

Figure 14 Steam Generator Level System

Figure 14 illustrates a typical steam generator level detection arrangement. The ΔP detector measures actual differential pressure. A separate pressure detector measures the pressure of the saturated steam. Since saturation pressure is proportional to saturation temperature, a pressure signal can be used to correct the differential pressure for density. An electronic circuit uses the pressure signal to compensate for the difference in density between the reference leg water and the steam generator fluid.

As the saturation temperature and pressure increase, the density of the steam generator water will decrease. The ΔP detector should now indicate a higher level, even though the actual ΔP has not changed. The increase in pressure is used to increase the output of the ΔP level detector in proportion to saturation pressure to reflect the change in actual level.

Summary

Density compensation is summarized below.

Density Compensation Summary

- If a vapor with a significant density exists above the liquid, the hydrostatic pressure that it will add may need to be considered if accurate transmitter output is required.

- Density compensation is accomplished by using either:

  - Electronic circuitry
  - Pressure detector input
  - Instrument calibration

LEVEL DETECTION CIRCUITRY

Remote indication provides vital level information to a central location.

EO 1.3 STATE the three reasons for using remote level indicators.

EO 1.4 Given a basic block diagram of a differential pressure detector-type level instrument, STATE the purpose of the following blocks:
a. Differential pressure (D/P) transmitter
b. Amplifier
c. Indication

EO 1.5 State the three environmental concerns which can affect the accuracy and reliability of level detection instrumentation.

Remote Indication

Remote indication is necessary to provide transmittal of vital level information to a central location, such as the control room, where all level information can be coordinated and evaluated. There are three major reasons for utilizing remote level indication:

- Level measurements may be taken at locations far from the main facility
- The level to be controlled may be a long distance from the point of control
- The level being measured may be in an unsafe/radioactive area.

Figure 15 illustrates a block diagram of a typical differential pressure detector. It consists of a differential pressure (D/P) transmitter (transducer), an amplifier, and level indication. The D/P transmitter consists of a diaphragm with the high pressure (H/P) and low pressure (L/P) inputs on opposite sides. As the differential pressure changes, the diaphragm will move. The transducer changes this mechanical motion into an electrical signal. The electrical signal generated by the transducer is then amplified and passed on to the level indicator for level indication at a remote

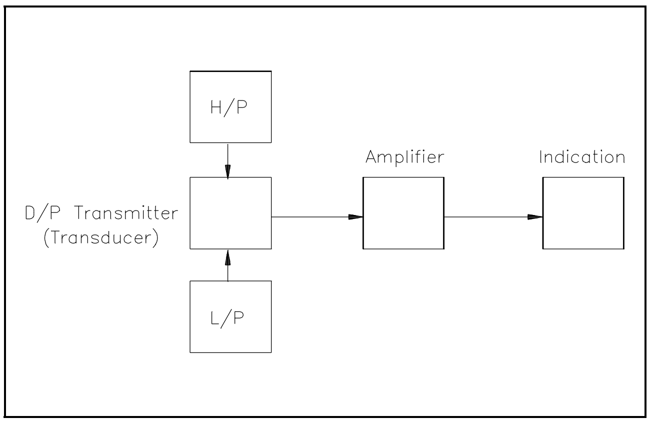

Figure 15 Block Diagram of a Differential Pressure Level Detection Circuit

location. Using relays, this system provides alarms on high and low level. It may also provide control functions such as repositioning a valve and protective features such as tripping a pump.

Environmental Concerns

Density of the fluid whose level is to be measured can have a large effect on level detection instrumentation. It primarily affects level sensing instruments which utilize a wet reference leg. In these instruments, it is possible for the reference leg temperature to be different from the temperature of the fluid whose level is to be measured. An example of this is the level detection instrumentation for a boiler steam drum. The water in the reference leg is at a lower temperature than the water in the steam drum. Therefore, it is more dense, and must be compensated for to ensure the indicated steam drum level is accurately indicated.

Ambient temperature variations will affect the accuracy and reliability of level detection instrumentation. Variations in ambient temperature can directly affect the resistance of components in the instrumentation circuitry, and, therefore, affect the calibration of electric/electronic equipment. The effects of temperature variations are reduced by the design of the circuitry and by maintaining the level detection instrumentation in the proper environment.

The presence of humidity will also affect most electrical equipment, especially electronic equipment. High humidity causes moisture to collect on the equipment. This moisture can cause short circuits, grounds, and corrosion, which, in turn, may damage components. The effects due to humidity are controlled by maintaining the equipment in the proper environment.

Summary

The density of the fluid, ambient temperature changes, and humidity are three factors which can affect the accuracy and reliability of level detection instrumentation. Level detection circuit operation is summarized below.

Circuit Operation Summary

- There are three major reasons for utilizing remote level indication:
  - Level measurements may be taken at locations far from the main facility.
  - The level to be controlled may be a long distance from the point of control.
  - The level being measured may be in an unsafe/radioactive area.
- The basic block diagram of a differential pressure level instrument are:
  - A differential pressure (D/P) transmitter which consists of a diaphragm with the high pressure (H/P) and low pressure (L/P) inputs on opposite sides. As the differential pressure changes, the diaphragm will move. The transducer changes this mechanical motion into an electrical signal.
  - An amplifier amplifies the electrical signal generated by the transducer and sends it to the level indicator.
  - A level indicator displays the level indication at a remote location.

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