

Density Measurement

Technology: Pressure

INTRODUCTION

Pressure and differential pressure transmitters are often used to measure the density of a fluid. Both types of transmitters measure level based on the principle that pressure (P) is proportional to the level (L) of the liquid multiplied by its specific gravity (S):

$$P = LS$$

Since specific gravity is the ratio of a fluid's density to the density of water, any change in density will result in a change in pressure. For example, if the height of the fluid is 100 inches and the specific gravity changes from 0.9 to 1.3, the pressure reading changes correspondingly from 90 to 130 inH₂O. Since the density of water is 63.4 pounds per cubic foot, the density of a material with a specific gravity of 0.9 is 57.1 lb/ft³, and the density of a material with a specific gravity of 1.3 is 82.4 lb/ft³. Thus, the density of a material can be determined using a variation of the basic level measurement.

The following information describes how to measure the density of a material for constant and varying level applications, using basic level measurements.

CONSTANT LEVEL APPLICATIONS

Open Tank (vented) Options

In open tank applications, level can be measured with either gauge or differential pressure (DP) transmitters, using the assumption that $P = LS$. If specific gravity needs to be measured, then the equation can be modified to $S = L/P$. For this to work, the level must stay constant so that any pressure changes reflect the specific gravity change. This works well in a tank where there is no change in level, such as when it is desirable to measure a density change as a way of monitoring a reaction, or as the fluid's temperature changes.

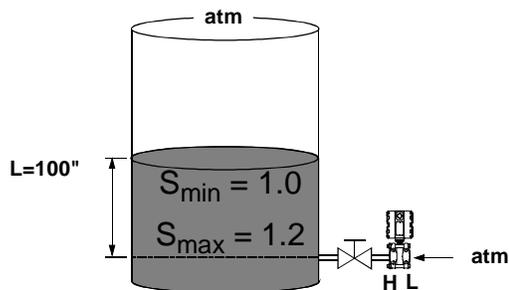


FIGURE 1. Open tank (vented), constant level

Calibration for an open tank (vented) as shown in Figure 1 is:

$$\begin{aligned} 4 \text{ mA} &= LS_{\min} \\ &= 100 \times 1.0 \\ &= 100 \text{ inH}_2\text{O} \end{aligned}$$

$$\begin{aligned} 20 \text{ mA} &= LS_{\max} \\ &= 100 \times 1.2 \\ &= 120 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 100 to 120 inH₂O

In Figure 1, the span is the difference between the specific gravities of the fluid, multiplied by the height. Therefore, in order to get a large enough span to measure, the height must be large. With this arrangement though, the 4 mA setpoint is not 0 inH₂O of pressure, but the height times the smaller specific gravity. While this calibration is possible for transmitters with wide rangeability, it can sometimes be difficult to calibrate a small span when the lower calibrated value is not near zero, or when a sufficiently large difference cannot be obtained.

In such cases, a reference column of an equivalent pressure as the measured fluid height, times the smaller specific gravity could be installed on the low pressure side of the transmitter (Figure 2). The reference column must contain a fluid with a constant specific gravity.

Density Measurement

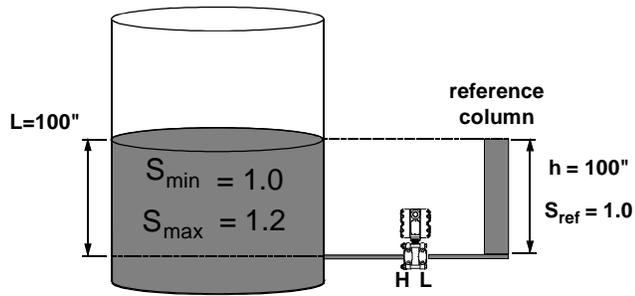


FIGURE 2. Open tank, with reference column, constant level

Calibration for an open tank with a reference column is:

$$\begin{aligned} 4 \text{ mA} &= LS_{\min} - hS_{\text{ref}} \\ &= (100 \times 1) - (100 \times 1.0) \\ &= 0 \text{ inH}_2\text{O} \end{aligned}$$

$$\begin{aligned} 20 \text{ mA} &= LS_{\max} - hS_{\text{ref}} \\ &= (100 \times 1.2) - (100 \times 1.0) \\ &= 20 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 0 to 20 inH₂O

Closed Tanks (pressurized or vacuum), Dry Leg

In closed tanks, the pressure transmitter must compensate for the pressure of the vessel above the liquid surface (Figure 3).

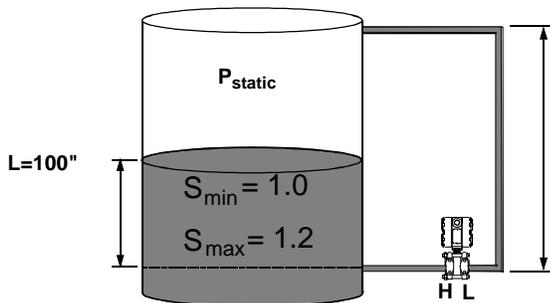


FIGURE 3. Closed tank, dry leg, constant level

$$HP = HS_p + P_{\text{static}}$$

$$LP = P_{\text{static}}$$

$$DP = HP - LP = HS_p$$

Where:

HP = high pressure side

LP = low pressure side

DP = differential pressure

Calibration for a closed tank with a dry leg is:

$$\begin{aligned} 4 \text{ mA} &= HS_{\min} \\ &= 100 \times 1.0 \\ &= 100 \text{ inH}_2\text{O} \end{aligned}$$

$$\begin{aligned} 20 \text{ mA} &= HS_{\max} \\ &= 100 \times 1.2 \\ &= 120 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 100 to 120 inH₂O

Closed Tanks (pressurized or vacuum), Wet Leg or Remote Seal Assembly

In applications where the condensation tends to occur in the dry leg, use a wet leg system or remote seal assembly instead (Figure 4).

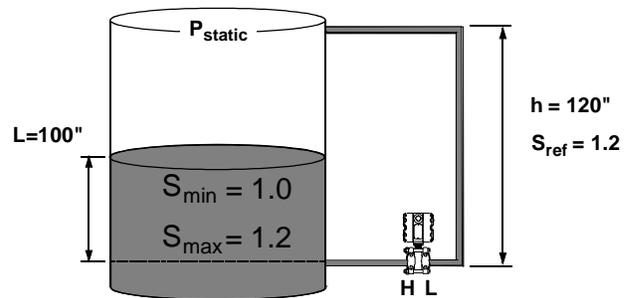


FIGURE 4. Closed tank, wet leg or remote seal assembly, constant level

The expected pressure is determined by:

$$HP = LS + P_{\text{static}}$$

$$LP = P_{\text{static}} + hS_{\text{ref}}$$

$$DP = HP - LP = LS + P_{\text{static}} - (P_{\text{static}} + hS_{\text{ref}})$$

$$DP = LS - hS_{\text{ref}}$$

Thus, calibration for a closed tank with a wet leg or remote seal assembly is:

$$\begin{aligned} 4 \text{ mA} &= LS_{\min} - hS_{\text{ref}} \\ &= (100 \times 1.0) - (120 \times 1.2) \\ &= -44 \text{ inH}_2\text{O} \end{aligned}$$

$$\begin{aligned} 20 \text{ mA} &= LS_{\max} - hS_{\text{ref}} \\ &= (100 \times 1.2) - (120 \times 1.2) \\ &= -24 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: -44 to -24 inH₂O

VARYING LEVEL APPLICATIONS

Use of One Transmitter

Often the density of a fluid must be determined in a vessel where the level is changing and a reference column is impractical. In this case, a differential pressure (DP) measurement can be made. In this situation, the measured height is the distance between the high and low pressure taps. The upper tap must be covered by the process fluid at all times. The connection between the upper tap and the transmitter can be either a wet leg or a remote seal and capillary (Figure 5). In either case, the calibration must account for the reference height contributed by the wet leg or the capillary. This is done by subtracting the reference height times the S_{ref} value from the process (between taps) height, times the process specific gravity.

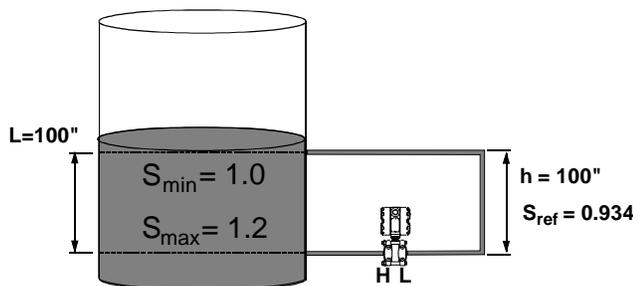


FIGURE 5. Closed tank, wet leg or remote seal and capillary, varying level, transmitter horizontal to tap

The calibration when the specific gravity is changing from 1.0 to 1.2 is:

$$\begin{aligned} 4 \text{ mA} &= LS_{\min} - hS_{\text{ref}} \\ &= 100 \times 1.0 - 100 \times 0.934 \\ &= 6.6 \text{ inH}_2\text{O} \end{aligned}$$

$$\begin{aligned} 20 \text{ mA} &= LS_{\max} - hS_{\text{ref}} \\ &= (100 \times 1.2) - (100 \times 0.934) \\ &= 120 - 93.4 \\ &= 26.6 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 6.6 to 26.6 inH₂O

In order to get the most representative process sample, and to have a reasonably large span, the taps must be placed as far apart as possible and kept submerged. If the level should go below the upper tap, then the transmitter will cease to measure density. If a level measurement is also desired, a second DP transmitter calibrated appropriately for level, would also be needed.

Use of Two Transmitters

Density can also be measured with two transmitters. With this arrangement, the output of the bottom transmitter can be used to provide both a level and, with a second transmitter, a density measurement (Figure 6).

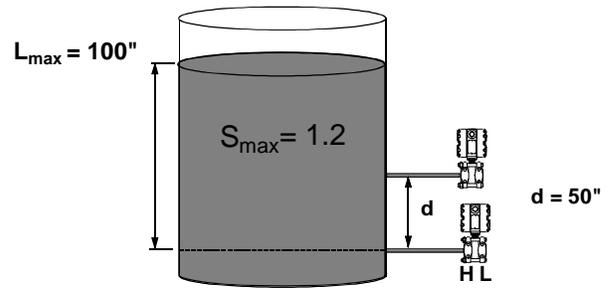


FIGURE 6. Closed tank, transmitters horizontal to taps, and two transmitters

To measure density with two transmitters:

- Calibrate the bottom transmitter to measure from its tap to the maximum level with maximum S.
- Calibrate the top transmitter to measure from its tap to the maximum level with maximum S.
- Determine the specific gravity by:

$$\frac{\text{difference in transmitter readings}}{\text{vertical distance between transmitters (d)}}$$

- Calibrate the bottom transmitter to read:

$$\begin{aligned} 20 \text{ mA} &= L_{\max}S_{\max} \\ &= 100 \times 1.2 \\ &= 120 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 0 to 120 inH₂O Calibrate the top transmitter to read:

$$\begin{aligned} 20 \text{ mA} &= (L_{\max} - d)S_{\max} \\ &= 100 - 50 \times 1.2 \\ &= 60 \text{ inH}_2\text{O} \end{aligned}$$

Calibration: 0 to 60 inH₂O

- Determine the specific gravity by:

$$\frac{\text{bottom transmitter reading} - \text{top transmitter reading}}{\text{distance between transmitters (d)}}$$

For example, when the level is at 80 inches, the top transmitter reads 34.5 inH₂O and the bottom transmitter reads 92 inH₂O. The specific gravity is calculated by:

$$S = \frac{(92 - 34.5)}{50} = 1.15$$

Once the specific gravity is determined, the bottom transmitter reading can be correlated to the appropriate level by using the reading divided by the calculated specific gravity: 92 inH₂O/1.15 = 80".

Density Measurement

This approach works well for open tank applications, using either DP or gauge pressure transmitters. If the tank is closed and sees either a positive or a negative pressure, then compensation must be made for the static pressure. This is most easily done by using DP transmitters at both locations. The use of two gauge pressure transmitters is possible if the static pressure is not high. If gauge units are used, the units must be calibrated to measure both the level change and the static pressure. This can result in a resolution problem.

For the example in Figure 6, if the static pressure is 100 psi and the level is 100 inches, then the calibrated span of the bottom unit is 2890 inH₂O and the calibration of the upper unit is 2830 inH₂O. With the same specific gravity of 1.15, the difference between the units would still be 57.5 inH₂O. However, this difference would be less than 2% of the overall calibration and could easily be lost. The limitations of using two transmitters in a pressurized application would be determined by the overall range needed, the sensitivity of the units, and the amount of density change expected.

Density Measurement

Advantages

- Low cost
- Simple to install
- No additional components required.

Limitations

- Control of level height is critical; either the level must be kept constant or the upper, low pressure tap must be covered.
- Small differences in specific gravity or limitations in height will result in small spans. Transmitter must be sized appropriately.
- Fluids that stratify may cause erroneous readings if only a small portion is measured
- Wet leg must be kept at a constant height and density.
- Condensation of vapors could occur with some dry leg applications; a method of drainage may be required.

APPLICATION CONSIDERATIONS

Process

Some products may stratify in a tank with the heavier material moving towards the bottom and the lighter material towards the top. If this happens, then the location of the taps to the density transmitter is critical. Taps that are farther apart will yield a more representative measurement. A small measurement distance will represent only the part it sees and will provide just a snapshot of the overall density.

Installation

Wet legs need to be filled with a fluid that is heavier than the fluid being measured, in order to avoid fluid mixing. Remote seals are often used to avoid this mixing problem. Since the fluid in the wet legs or the capillary system is also subject to temperature changes, care must be taken to minimize change. Temperature changes of the reference fluid could change its density and reference value, resulting in errors in the measurement.

Transmitter

A transmitter must be chosen that is capable of measuring the needed span at the desired 4 and 20 mA setpoints. Therefore, the minimum span of the transmitter must be less than or equal to the calibrated span and the upper and/or lower range limits must be greater than the span limits.

For instance, in Figure 1, the calibrated span of 100 to 120 inH₂O results in a span of 20 inH₂O. The transmitter needs to have an upper range limit (URL) of at least 120 inH₂O and a minimum span capability of 20 inH₂O. The analog 1151DP4E is not able to support this calibration because it does not meet both requirements. Although its URL is 150 inH₂O, its minimum span capability is 25 inH₂O. The smart 1151DP4S can support this calibration, because, with its increased rangedown, its minimum span capability is 10 inH₂O.

KEY TO NOTATIONS

Notation	Description
L_{max}	maximum level
L_{min}	minimum level
S	specific gravity of process fluid
S_{ref}	specific gravity of reference leg fluid
S_f	specific gravity of fill fluid
L	process level
h	reference level
HP	high pressure
LP	low pressure
DP	differential pressure
d	distance between tap and transmitter
span	maximum level: minimum level
x	specific gravity of process
S_{min}	minimum process specific gravity
S_{max}	maximum process specific gravity
I	interface

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