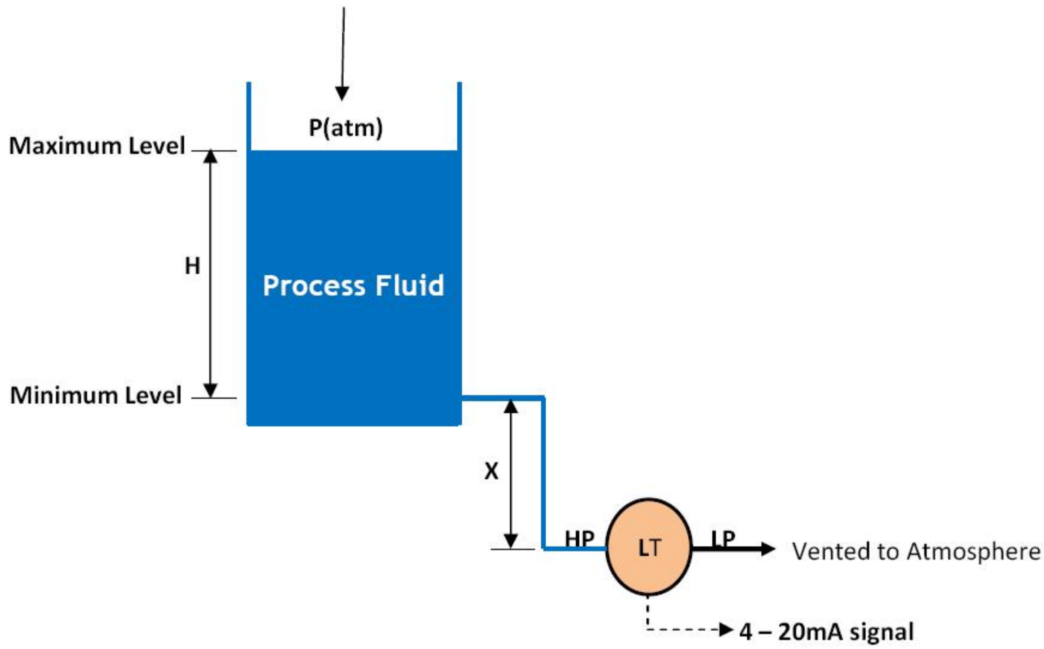
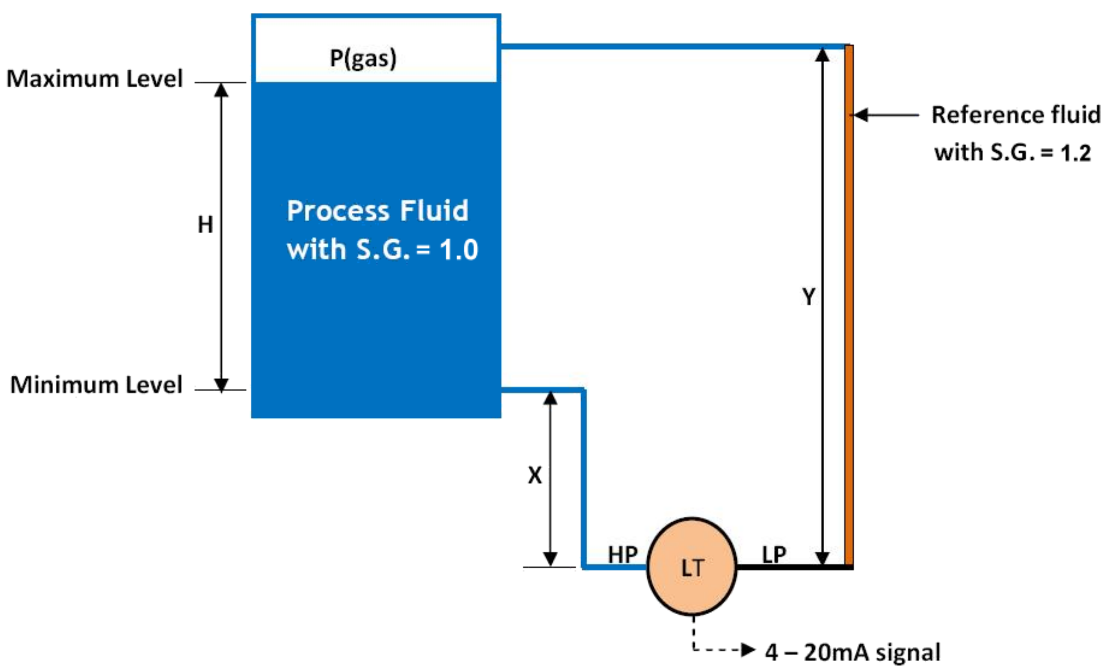
Introduction to Level Measurement

Using Differential Pressure Transmitters





Revision 1.3

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, CCST III is

Introduction to Differential Pressure Transmitter Measurement

When measuring the pressure in a pipe or the level in an open to atmosphere tank, all that is needed is a "Gauge Pressure" transmitter. The gauge pressure transmitter has only one (1) pressure inlet.

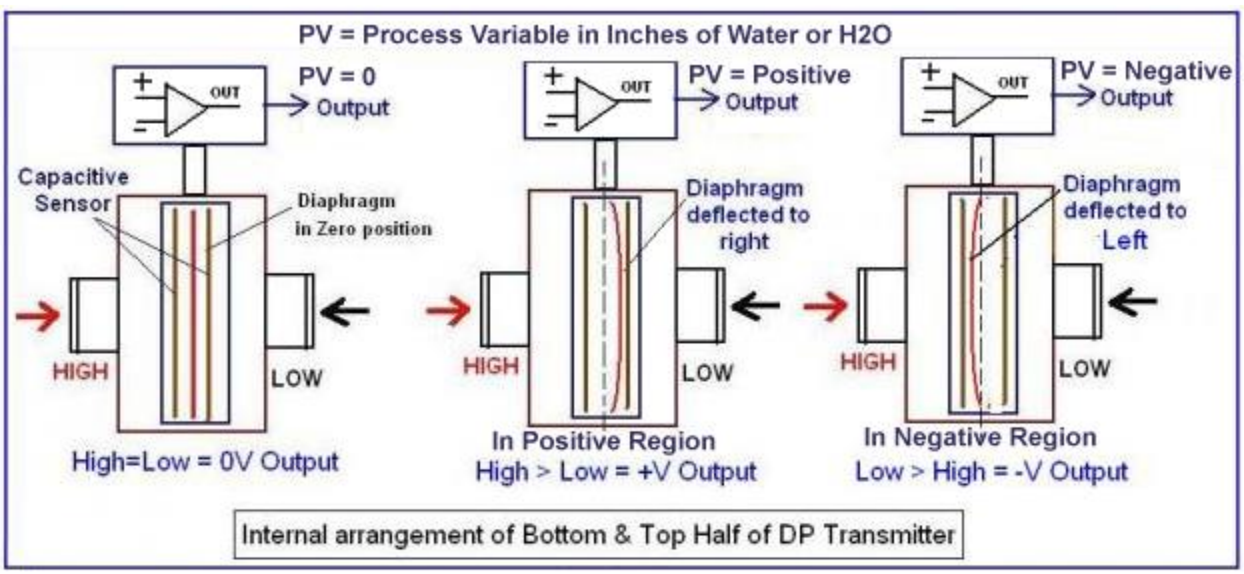
When measuring flow in a pipe or a level in a closed pressurized tank or a tank below grade, we need a DP "Differential Pressure" transmitter. The DP transmitter has a "High" pressure side and "Low" pressure side. Positive pressure is applied to both of the transmitter sides, high side(HP) and low side (LP).

If positive pressure is applied to the low-pressure side (LP) only, it will cause the transmitter communicator to display the a "Negative Sign" in front of the PV (process variable) and it is understood the PV is a negative measurement. When positive pressure is applied to the high-pressure side (HP) only, no sign is displayed in front of the PV (process variable) and it is understood the PV is a positive measurement.

The low side of the DP transmitter is known as the "Negative Region" and the high side of the transmitter is known as the "Positive Region".

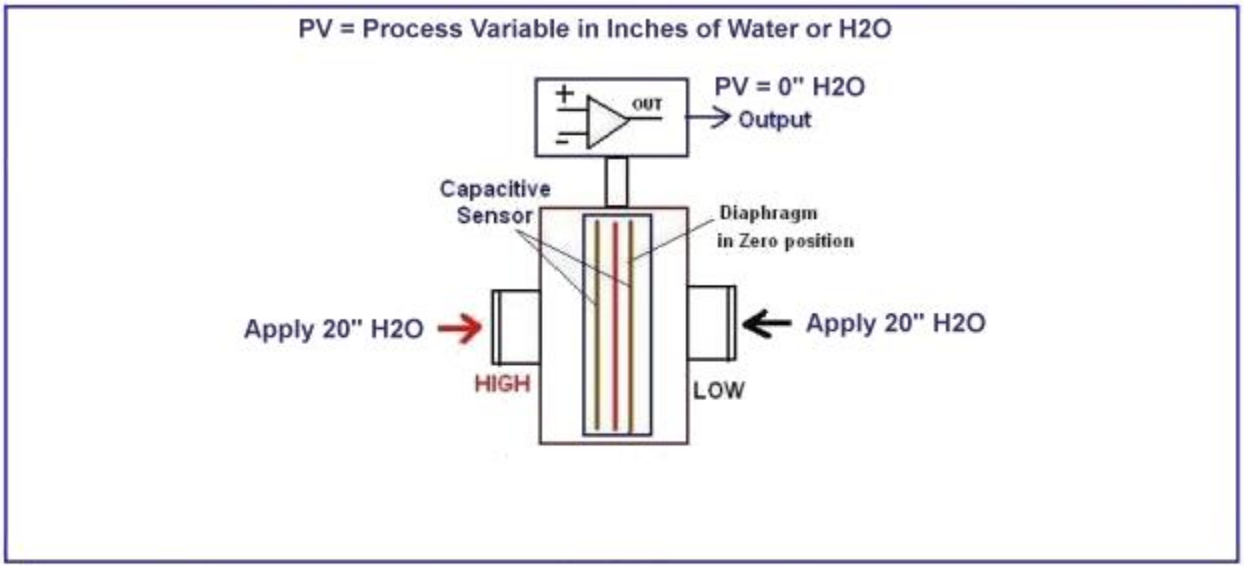
When the transmitter diaphragm is defected with positive pressure applied to high side, it makes the PV signal go positive. The area of the diaphragm cell which the diaphragm deflects to, is called the positive region. The PV will show positive, even if there is a smaller amount of positive pressure being applied to the low side of the transmitter at the same time. (High side pressure is greater than the low side pressure).

When the transmitter diaphragm is defected with positive pressure applied to low side, it makes the PV signal go negative. The area of the diaphragm cell which the diaphragm deflects to, is called the negative region. The PV will show negative, even if there is a smaller amount of positive pressure being applied to the high side of the transmitter at the same time. (Low side pressure is greater than the high side pressure).

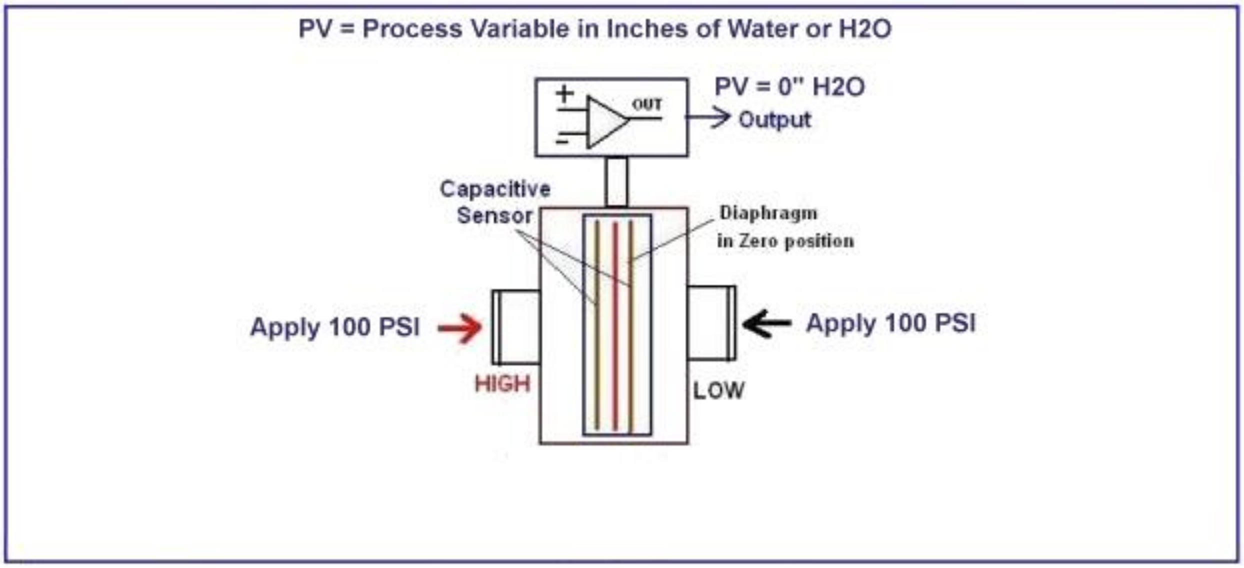


Remember that the DP Transmitter is a "difference of pressure" transmitter. The High-Pressure Side (HP), minus the Low-Pressure Side (LP). ***HP – LP = DP (differential pressure) or PV (process variable).***

Examples of Differential Pressure Transmitter and the Process Variable

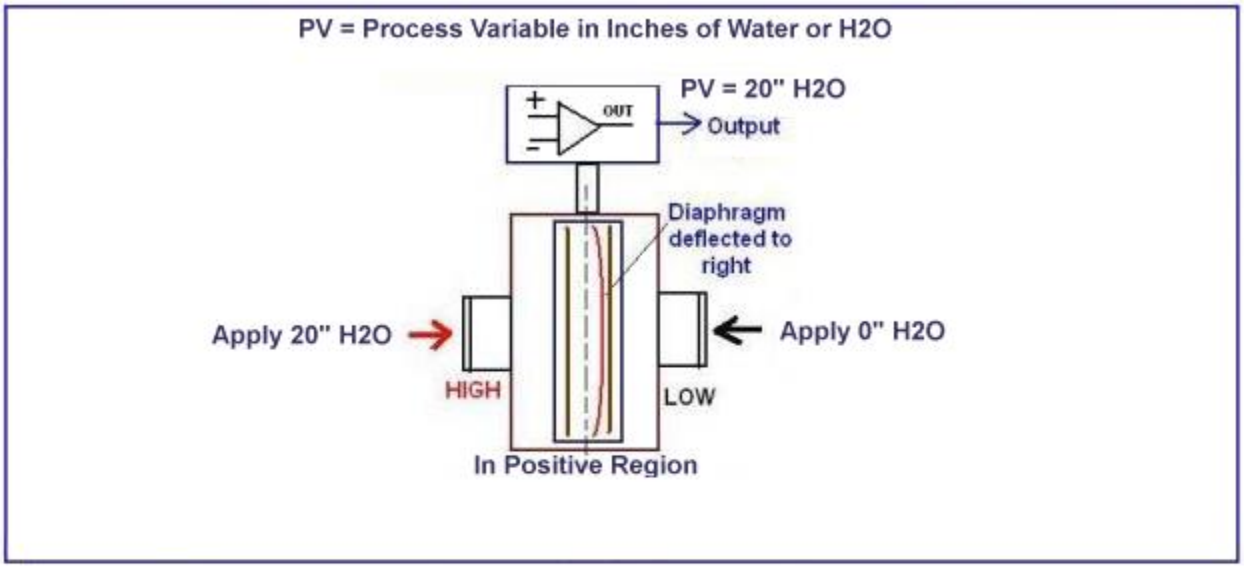


High Side – Low Side = PV
PV or DP = 20” – 20” = 0” H2O

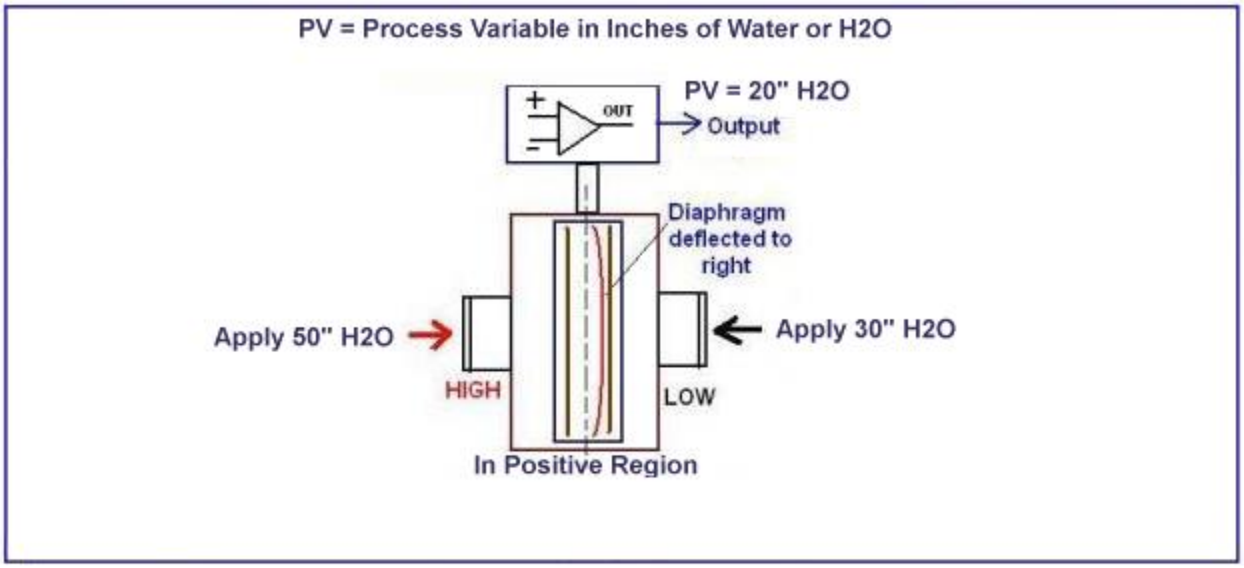


High Side – Low Side = PV
PV or DP = 100 PSI – 100 PSI = 0” H2O

Positive Process Variable

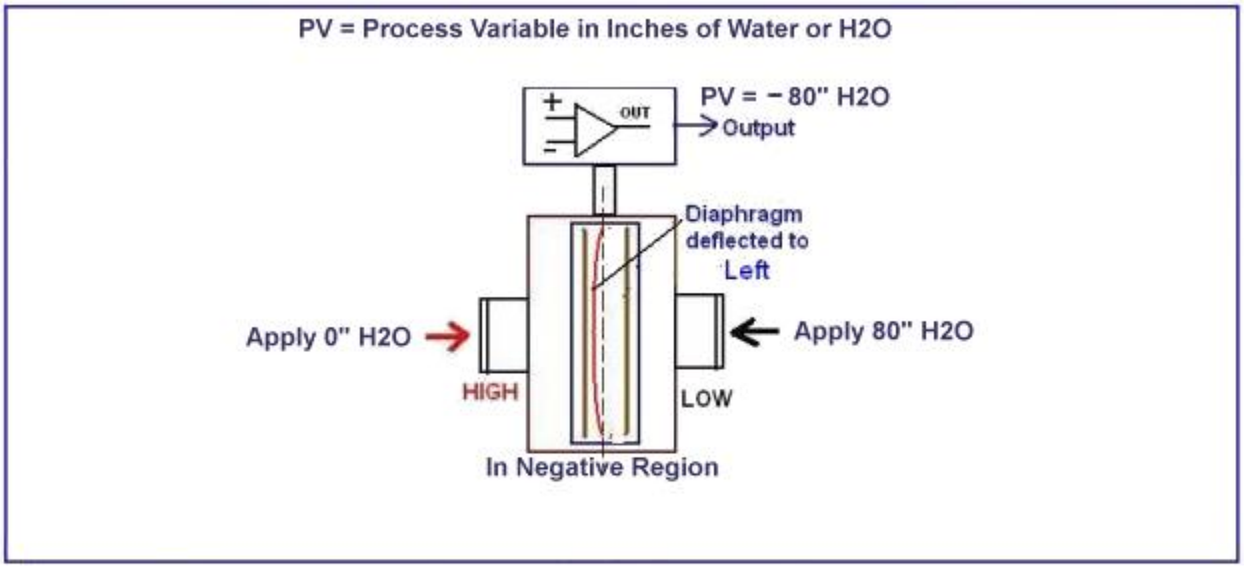


High Side – Low Side = PV
PV or DP = 20” – 0” = 20” H2O

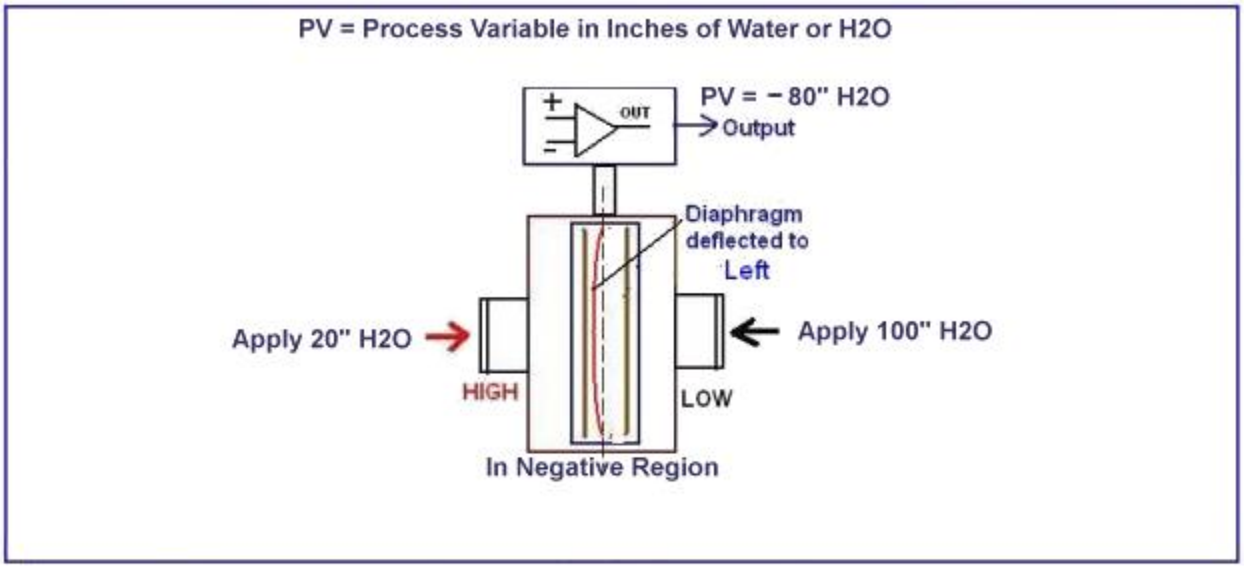


High Side – Low Side = PV
PV or DP = 50” – 30” = 20” H2O

Negative Process Variable



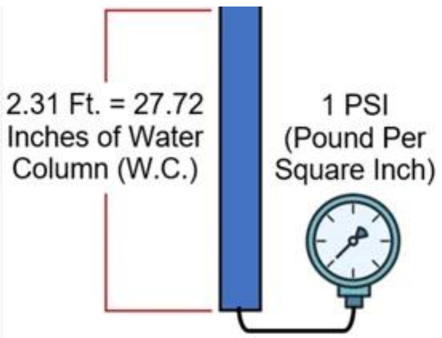
High Side – Low Side = PV
PV or DP = 0” – 80” = -80” H2O



High Side – Low Side = PV
PV or DP = 20” – 100” = -80” H2O

What Are Inches of Water Column or H2O?

An inch of water column (w.c.), is a pressure measurement. An inch of water column is another way to measure a small amount of pressure in PSI (pounds per square inch). One inch of water column is 0.03608 psi. A one-foot water column, on a base of one inch square, generates a pressure of 0.433 psi. And a one-inch square column of water that is 27.72 inches tall generates, a pressure of 1.0 psi at the base.



That is to say that the 27.72 inch column of water weighs one pound, of weight, over the area of one square inch. It is important to understand that pressure in level measurement, is just weight divided by the area on which it is pushing downward. This downward force is in psi (pounds per square inch), but can be measured in inches of water column (w.c. or H2O). Inches of H20 and psi are interchangeable and directly correlate.

It is also important to understand that this 27.72 inch column that is 1 psi, only applies to water at 68 degrees Fahrenheit. Other liquids generate different pressures for the same 27.72 inch column, because the liquids either weight less than water or more than water.

We have to correct for this change in weight of various fluids, by using a factor called the specific gravity of the fluid. Specific gravity (S.G.) is the weight of the fluid or process fluid divided by the weight of water, at 68 degrees Fahrenheit, for the same size volume. Both fluids have to have the same volume!

Water has a s.g. of 1.0; gasoline has a s.g. of approximately 0.79; motor oil has a s.g. of approximately 0.85 and alcohol has a s.g. of approximately 0.78. This shows that all these fluids have a weight that are less than water, for the same volume. For these fluids, we multiply the fluid's height in inches of process fluid (actual height of the fluid) by the s.g. of the process fluid. This gives the equivalent inches of water column (w.c. or H2O) to enter into the calibration data of the pressure transmitter's communicator that is used to program the transmitter.

For a column of gasoline (process fluid) 27.72 inches tall, it will become 21.8988 inches of water column or H2O after we multiply it by the gasoline's specific gravity of 0.79.

$$27.72"(gasoline) \bullet 0.79(s.g.) = 21.8988 \text{ or } 21.9" \text{ H2O}$$

The 27.72 inch column of gasoline weights 1 psi * 0.79 s.g. or 0.79 psi (pounds per square inch). That is the gasoline's weight is 0.79 pounds, instead of 1 pound like water.

The "pressure" transmitter only understands psi or after transmitter configuration, "inches of water column or inches of H2O". We will enter 21.9" H20 into the transmitter to measure a 27.72" column of gasoline and get a 100% output from the transmitter when the column of gasoline actually is 27.72 inches high. If we did not adjust for the gasoline's weight, the column would overflow. If we entered 27.72" H2O into the pressure transmitter for calibration, the column of gasoline would be 35.09" tall, when it generated one psi on the transmitter's measurement diaphragm.

$$27.72"(H2O) \div 0.79(s.g.) = 35.09"(\text{gasoline})$$

We will multiply all fluids (process fluids and reference measurement fluids) by their specific gravity (s.g.) to convert the process fluid or reference fluid height into inches of water column or H2O, (This is weight in psi). The corrected height is the height that will be entered into the pressure transmitter calibration data. The pressure transmitter only understands inches of water column or the psi correlation to inches of water column for the weight of the fluid.

Example of Using S.G. to Correct Height for Calibrating the Transmitter

If the transmitter was calibrated to 100” H2O and the tank is filled with 100“ of oil (process fluid), then the transmitter will only read 85” H2O, because the oil (process fluid) weights 85% of the weight of water. The 100” actual column of oil only produces 85” of H2O in pressure that pushes on the transmitter’s measurement diaphragm.

If the transmitter was calibrated 100” H2O, the transmitter will never reach 100% output (20mA). The tank will overflow before the level can reach 100” H2O. The oil (process fluid) weights 85% of the weight of water. The oil is lighter than water , so it has to generate a taller column of oil to produce 100” H2O.

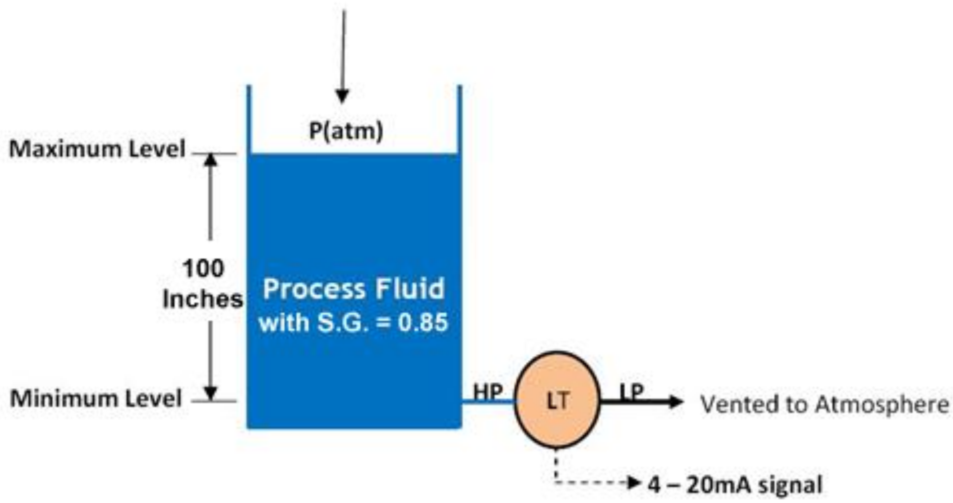
$$\frac{1}{0.85(\text{s.g.})} = 1.17647 \text{ multiplier}$$

So, the column of oil will be:

100” * 1.17647 = 117.647” high, when the oil generates a pressure of 100” H2O. We have to correct for the oil weight:

We correct for the height of the oil by multiplying the weight of the oil in inches, times the specific gravity of the oil.

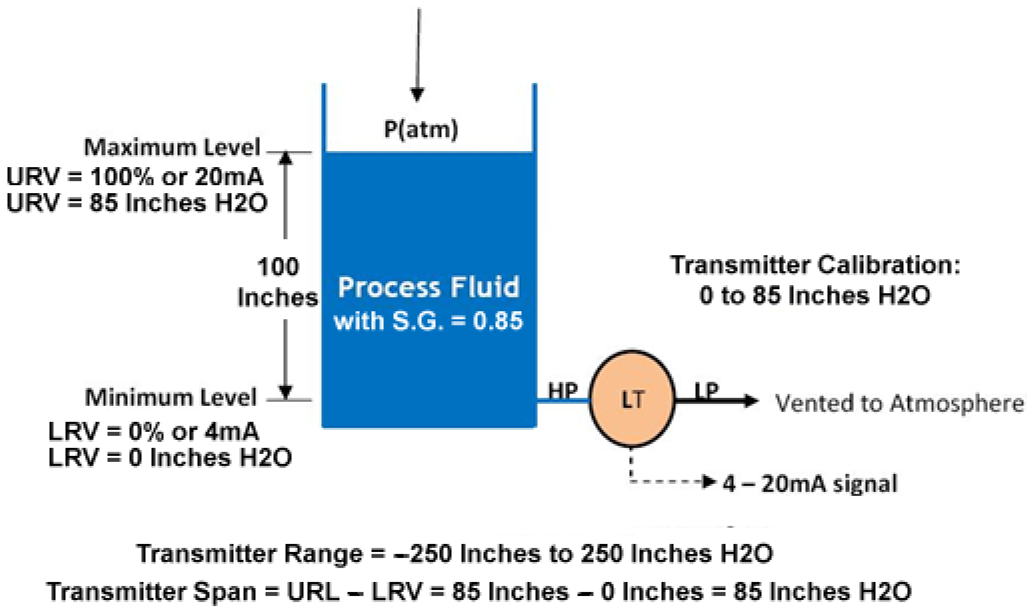
$$100"(oil) \bullet 0.85(s.g.) = 85" \text{ H2O}$$



So, the transmitter must be calibrated to 85” H2O to meet the requirement of 100” actual height of the oil (process fluid). To be at the maximum actual level of 100” and be at 100% of the transmitter output (20 mA), the 85” H20 transmitter measurement calibration value provides the correct configuration in the transmitter for the oil to be 100” high when at 100% transmitter signal output (20mA).

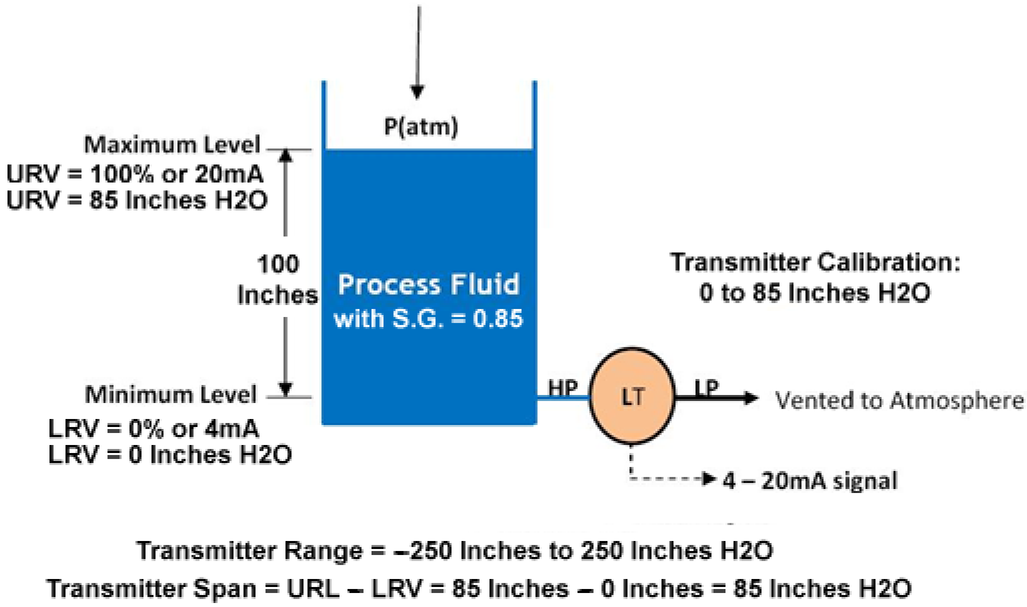
Range, LRV, URV and Span

Range = The smallest process value the instrument will read, to the largest process value the instrument will read.
LRV = Lower Range Value, 0% measured process variable, produces 0% process signal or 4 mA.
URV = Upper Range Value, 100% measured process variable, produces 100% process signal or 20 mA.
Span = The algebraic difference between the URV and the LRV. Span = URV – LRV.
Calibration = LRV to URV (printed on transmitter with factory calibration)



Open to Atmosphere Tank Level Measurement

Example 1



Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

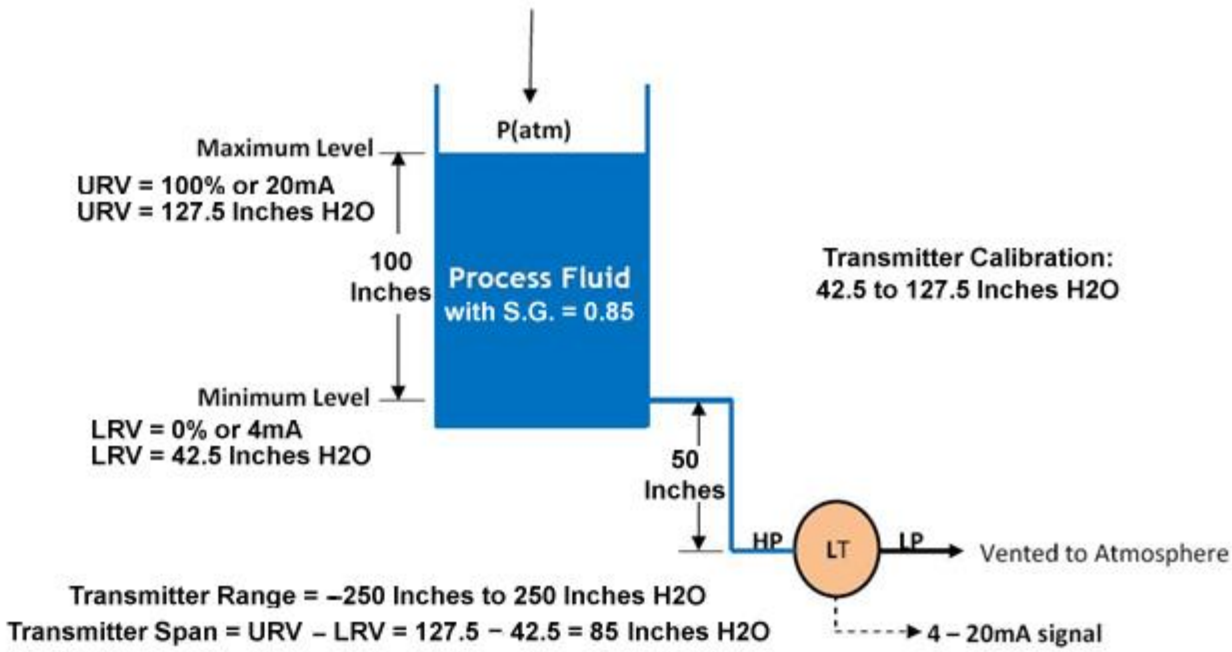
HP Side LP Side
LRV = [0" * 0.85] – [0"] = 0" H2O

HP Side LP Side
URV = [100" * 0.85] – [0"] = 85" H2O

Span = URV – LRV = 85" – 0" = 85" H2O

Calibration = 0" to 85" H2O

Example 2



Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(There is 50" of process fluid above the transmitter when the tank is empty)
HP Side LP Side
LRV = [50" * 0.85] – [0"] = 42.5" H2O

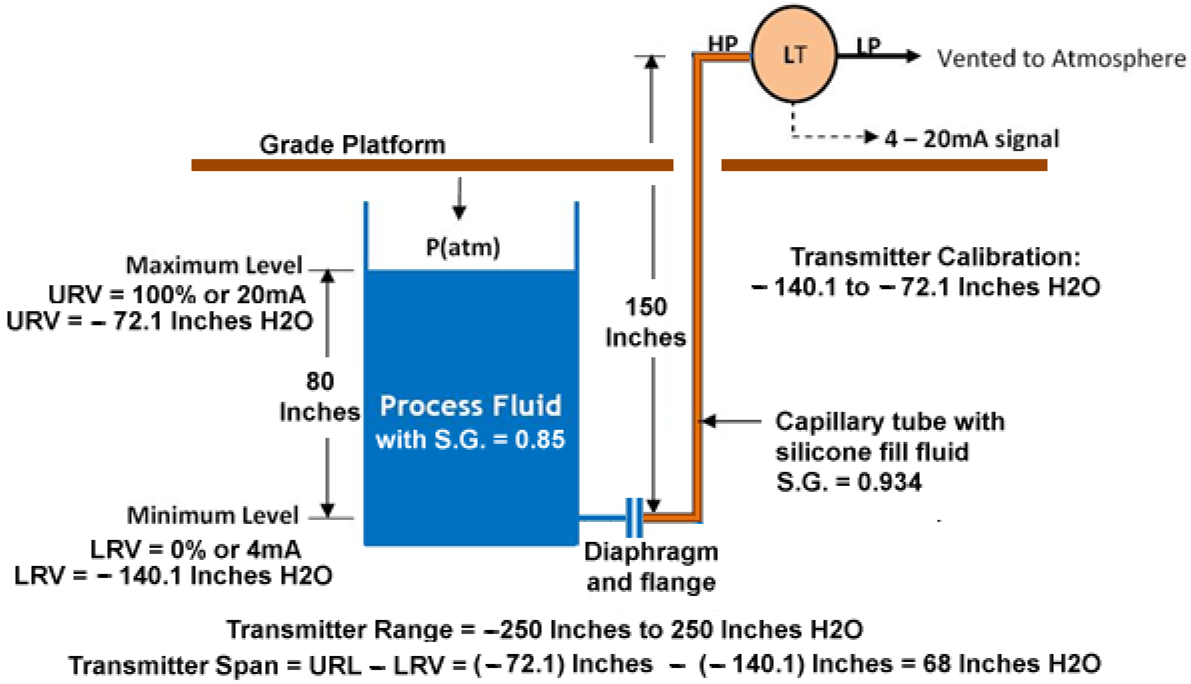
(There is 100" plus 50" of process fluid above the transmitter when the tank is full)
HP Side LP Side
URV = [(100" * 0.85) + (50" * 0.85)] – [0"] = 127.5" H2O

Span = URV – LRV = 127.5" – 42.5" = 85" H2O

Calibration = 42.5" to 127.5" H2O

Open to Atmosphere Tank Level Measurement (Using Diaphragm)

Example (Below Grade)



Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(There is 150” of capillary tube below the transmitter when the tank is empty and it is sucking down on the transmitter)

HP Side LP Side
LRV = [-150” * 0.934] – [0”] = -140.1” H2O

(There is 80” in the tank and it adds to the transmitter when the tank is full)

HP Side LP Side
URV = [(80” * 0.85) + (-150” * 0.934)] – [0”] =
URV = [68 + (-140.1)] – [0”] = -72.1” H2O

Span = URV – LRV = (-72.1”) – (-140.1”) = 68” H2O

Calibration = -140.1” to -72.1” H2O

NOTE:
The capillary tube has a silicone fill fluid (S.G. = 0.934) and it is pulling down or sucking down on the transmitter high side (HP) diaphragm. Therefore, it excerpts a negative pressure on the transmitter high side (HP). Hence the -150” of capillary tubing to the flange diaphragm.

Proof Open to Atmosphere Tank Level Measurement (Using Diaphragm) works

Example (measurement below grade) is at 50% or 40 Inches high

Calculations:

DP or PV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

Precent Process Signal = $\frac{\text{(DP or PV) - LRV}}{\text{SPAN}} = \%$

Actual Tank Level = $\frac{\text{(DP or PV) - LRV}}{\text{SPAN}} \bullet \text{ Maximum Tank Level (80 Inches Process Fluid)}$

HP Side LP Side
LRV = [-150" * 0.934] – [0"] = -140.1" H2O

(There is 40" of oil or process fluid in the tank and it adds to the transmitter when the tank is filling)

HP Side LP Side
URV = [(40" * 0.85) + (-150" * 0.934)] – [0"] =
URV = [34 + (-140.1)] – [0"] = -106.1" H2O

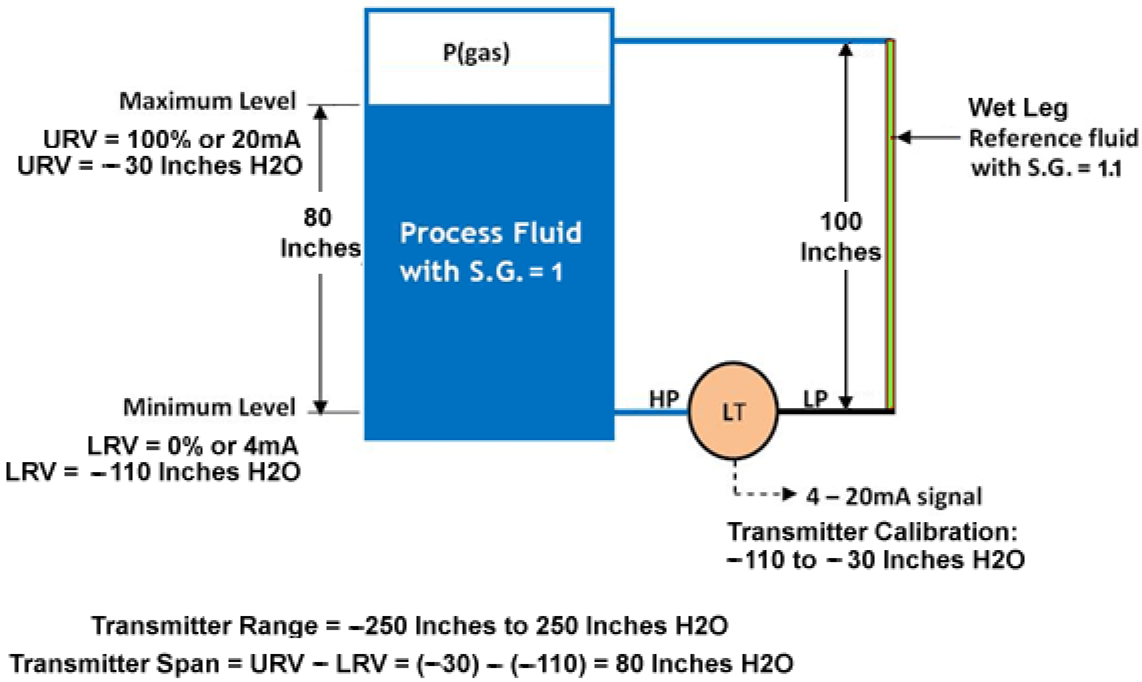
Span = URV – LRV = (-72.1") – (-140.1") = 68" H2O

Actual Tank Level = $\frac{(-106.1) - (-140.1)}{68} = \frac{34''}{68''} = 0.5 \quad \text{Therefore } (0.5 \bullet 80'' = 40'' \text{ Inches of Process Fluid})$

Note:
There are two PV (process variables) with level measurement. The first PV (process variable) is the actual DP (differential pressure) measured by the transmitter and communicator. The second PV is what most people talk about. It is the PV (process variable) in the Computer, DCS or PLC. It is the actual level in the tank (uncompensated).

Pressurized Closed Tank Level Measurement

Example 1



Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

HP Side LP Side
LRV = [0" * 1.0] – [100" * 1.1] = -110" H2O

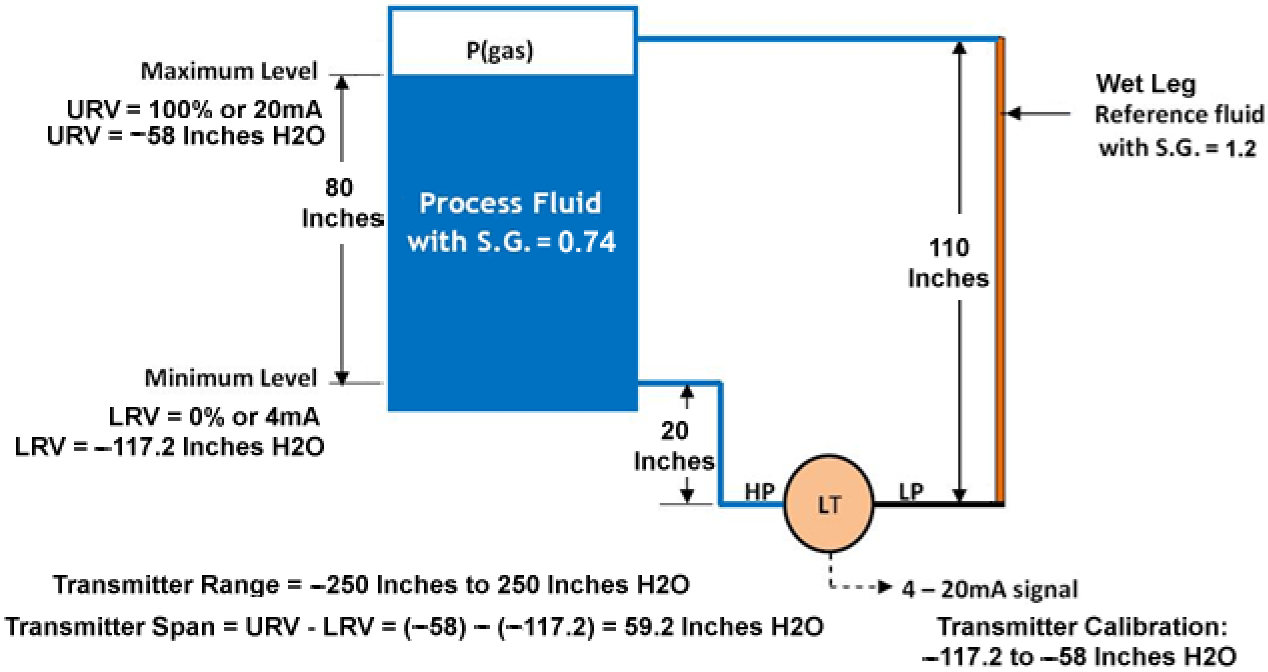
HP Side LP Side
URV = [80" * 1.0] – [100" * 1.1] = -30" H2O

Span = URV – LRV = (-30") – (-110") = 80" H2O

Calibration = -110" to -30" H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP.
100 psi – 100 psi = 0 psi.

Example 2



<u>Calculations:</u>

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(There is 20" of process fluid above the transmitter when the tank is empty)

HP Side LP Side
LRV = [20" * 0.74] – [110" * 1.2] = -117.2" H2O

(There is 80" plus 20" of process fluid above the transmitter when the tank is full)

HP Side LP Side
URV = [(80" * 0.74) + (20" * 0.74)] – [110" * 1.2] =
URV = [100" * 0.74] – [110" * 1.2] = -58" H2O

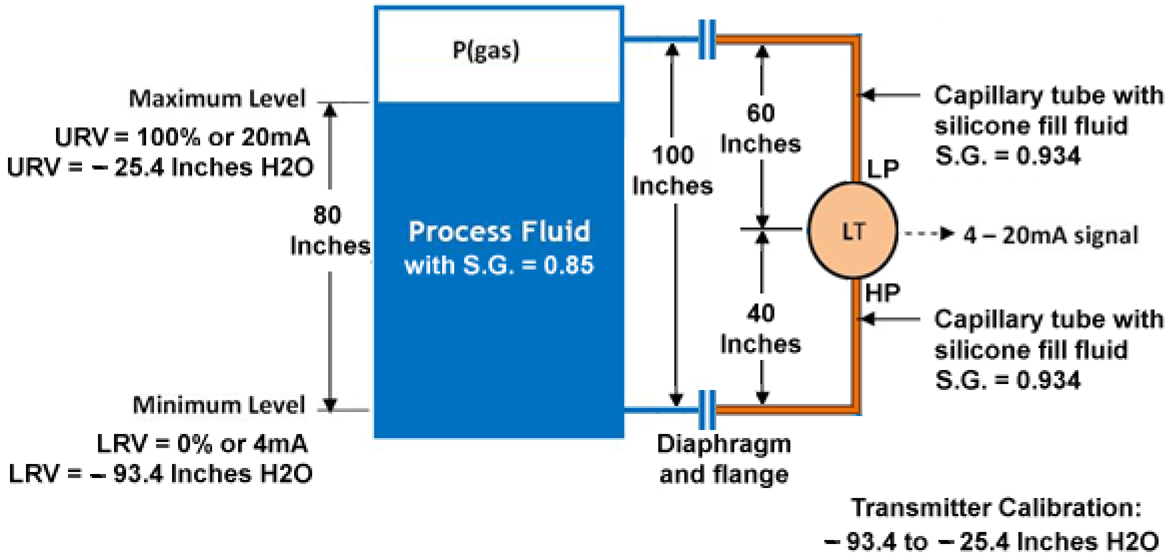
Span = URV – LRV = (-58") – (-117.2") = 59.2" H2O

Calibration = -117.2" to -58" H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP. If there was a nitrogen blanket on the tank of 14" H2O, then:
(14" H2O) – (14" H2O) = 0" H2O.
The tank's gas pressure does not add to the level measurement.

Pressurized Closed Tank Level Measurement (Using Diaphragms)

Example 1 (More Difficult Method)



Transmitter Range = –250 Inches to 250 Inches H2O

Transmitter Span = URV – LRV = (– 25.4) – (– 93.4) = 68 Inches H2O

Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(The capillary tube is pulling down or sucking down on the transmitter high side, hence negative 40")

HP Side LP Side
LRV = [-40" * 0.934] – [60" * 0.934] = -93.4" H2O

(There is 80" of process fluid plus the negative 40" of capillary tubing)

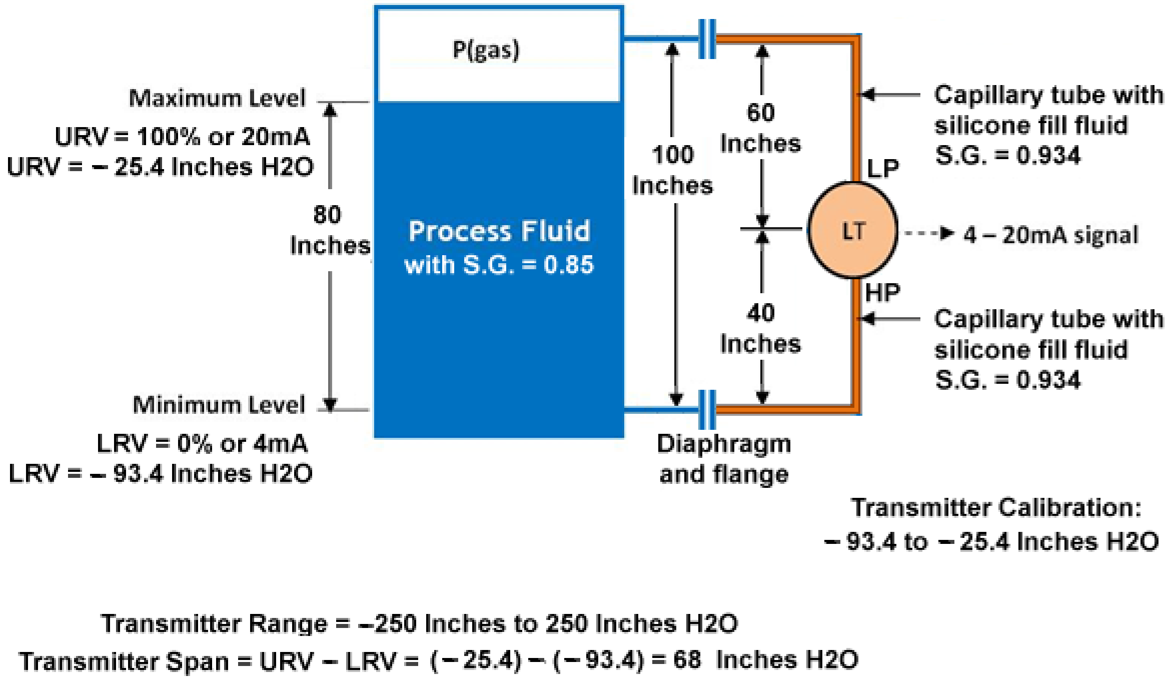
HP Side LP Side
URV = [(80" * 0.85) + (-40" * 0.934)] – [60" * 0.934] = -25.4" H2O

Span = URV – LRV = (-25.4") – (-93.4") = 68" H2O

Calibration = -93.4" to -25.4" H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP.
100 psi – 100 psi = 0 psi.
The tank's gas pressure does not add to the level measurement.

Example 2 (Simple Method)



Calculations:

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(The capillary tube is pulling down or sucking down on the transmitter high side, hence negative 40". Just add this to the low side 60". It will all be 100" in the negative region!)

HP Side LP Side
LRV = [0" * 0.85] – [100" * 0.934] = -93.4" H2O

(There is 80" of process fluid above the flange)

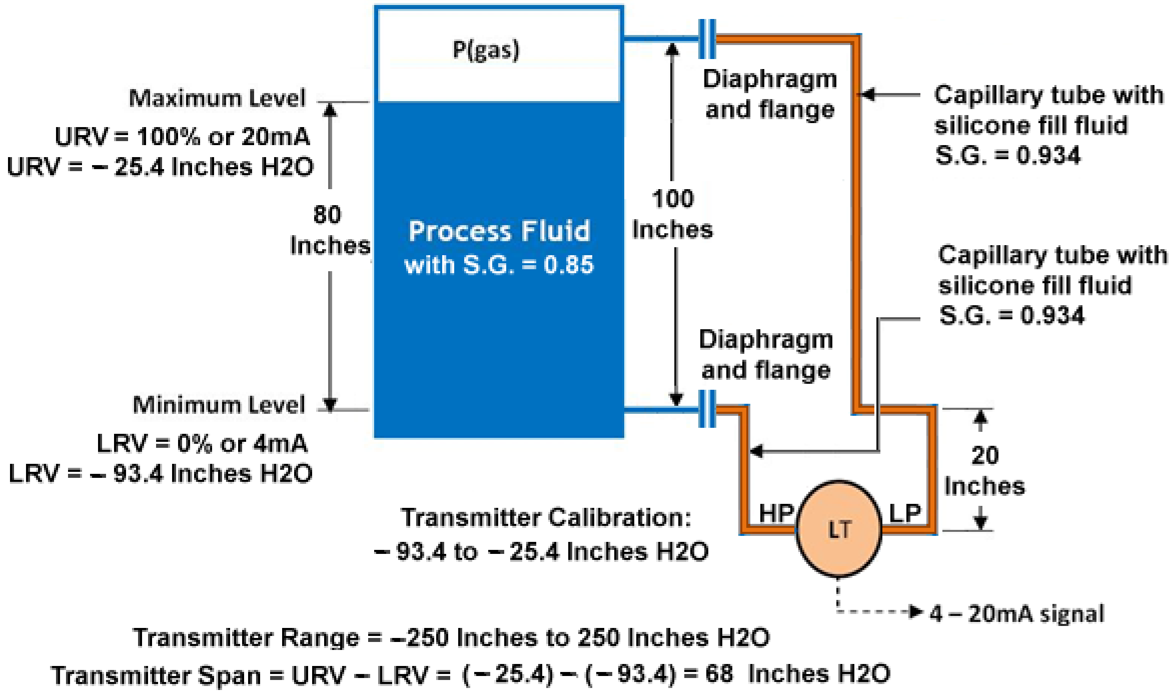
HP Side LP Side
URV = [80" * 0.85] – [100" * 0.934] = -25.4" H2O

Span = URV – LRV = (-25.4") – (-93.4") = 68" H2O

Calibration = -93.4" to -25.4" H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP.
100 psi – 100 psi = 0 psi.
The tank's gas pressure does not add to the level measurement.

Example 3 (Below the Lower Flange – Tubing Cancels Out)



<u>Calculations:</u>

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

(The capillary tube is pulling down or sucking down on the transmitter high side, hence negative 40")
HP Side LP Side
LRV = [-40" * 0.934] – [60" * 0.934] = -93.4" H2O

(There is 80" of process fluid plus the negative 40" of capillary tubing)
HP Side LP Side
URV = [(80" * 0.85) + (-40" * 0.934)] – [60" * 0.934] = -25.4" H2O

Span = URV – LRV = (-25.4") – (-93.4") = 68" H2O

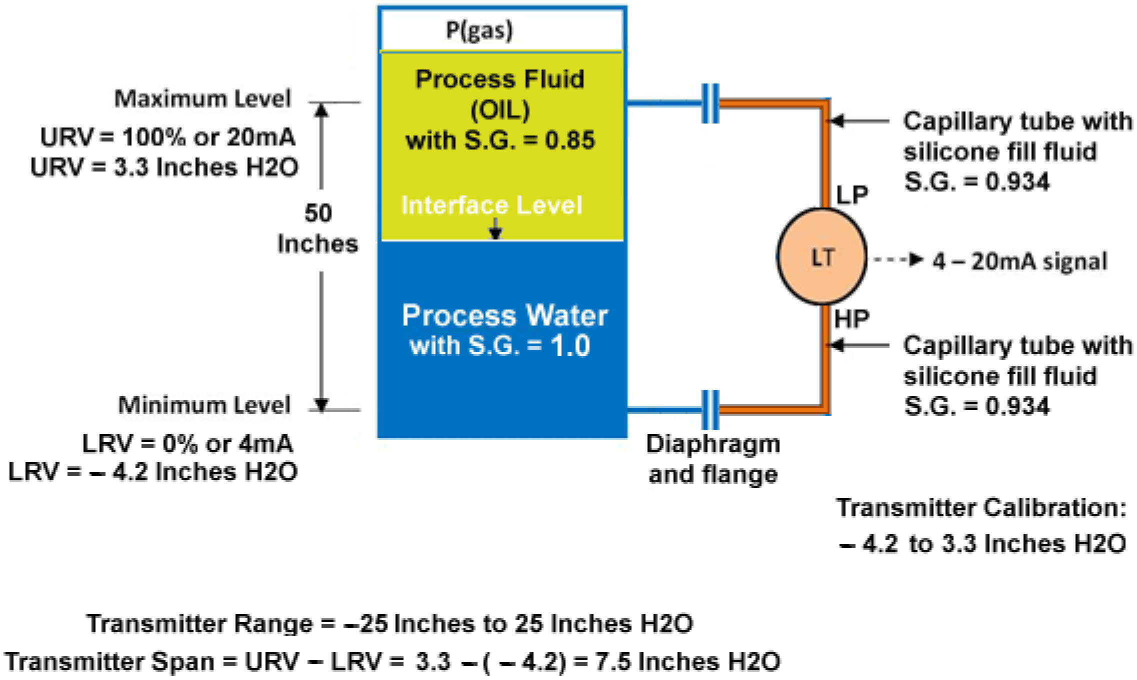
Calibration = -93.4" to -25.4" H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP.
100 psi – 100 psi = 0 psi.
The tank's gas pressure does not add to the level measurement.

The tubing pressure below the lower flange, cancels out.
(20" * 0.934) - (20" * 0.934) = 0" H2O.

Interface Level Measurement (Using Diaphragms)

Example



<u>Calculations:</u>

LRV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]
URV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

The capillary tube is pulling down or sucking down on the transmitter high side at some height. Just add this to the low side height. It will all be 50” in the negative region!

(At first the tank is full of oil only.)
HP Side LP Side
LRV = [50” * 0.85] – [50” * 0.934] = -4.2” H2O

(Then the tank is full of water only up to the max level. The pressure from the oil above the LP flange will cancel out.)
HP Side LP Side
URV = [50” * 1.0] – [50” * 0.934] = 3.3” H2O

Span = URV – LRV = (3.3”) – (-4.2”) = 7.5” H2O

Calibration = -4.2” to 3.3” H2O

Note:
Gas pressure cancels out in the high side (HP) and the low side (LP). DP or PV = HP – LP.
100 psi – 100 psi = 0 psi.
The tank’s gas pressure does not add to the level measurement.

Proof the interface level and calibration of transmitter works

Example 1 - Water (interface level) is at 50% or 25 Inches high

Calculations:

DP or PV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

Precent Process Signal = $\dfrac{\text{(DP or PV) - LRV}}{\text{SPAN}} = \%$

Actual Interface Level = $\dfrac{\text{(DP or PV) - LRV}}{\text{SPAN}} \bullet$ Maximum Interface Level (50 Inches)

(The tank has 25” of water and 25” of oil or process fluid.)

HP Side LP Side

PV or DP = [(25” * 1.0) + (25” * 0.85)] – [50” * 0.934] =

PV or DP = [25” + 21.25”] – [46.7”] = -0.45” H2O

Actual Interface Level = $\dfrac{(-0.45) - (-4.2)}{7.5} = \dfrac{3.75''}{7.5''} = 0.5$ Therefore ($0.5 \bullet 50'' = 25''$ Inches of Interface Water)

Example 2 - Water (interface level) is at 25% or 12.5 Inches high

Calculations:

DP or PV = [High Side (HP) * S.G.] – [Low Side (LP) * S.G.]

Precent Process Signal = $\dfrac{\text{(DP or PV) - LRV}}{\text{SPAN}} = \%$

Actual Interface Level = $\dfrac{\text{(DP or PV) - LRV}}{\text{SPAN}} \bullet$ Maximum Interface Level (50 Inches)

(The tank has 12.5” of water and 37.5” of oil or process fluid.)

HP Side LP Side

PV or DP = [(12.5” * 1.0) + (37.5” * 0.85)] – [50” * 0.934] =

PV or DP = [12.5” + 31.875”] – [46.7”] = -2.325” H2O

Actual Interface Level = $\dfrac{(-2.325) - (-4.2)}{7.5} = \dfrac{1.8''}{7.5''} = 0.25$ Therefore ($0.25 \bullet 50'' = 12.5''$ Inches of Interface Water)

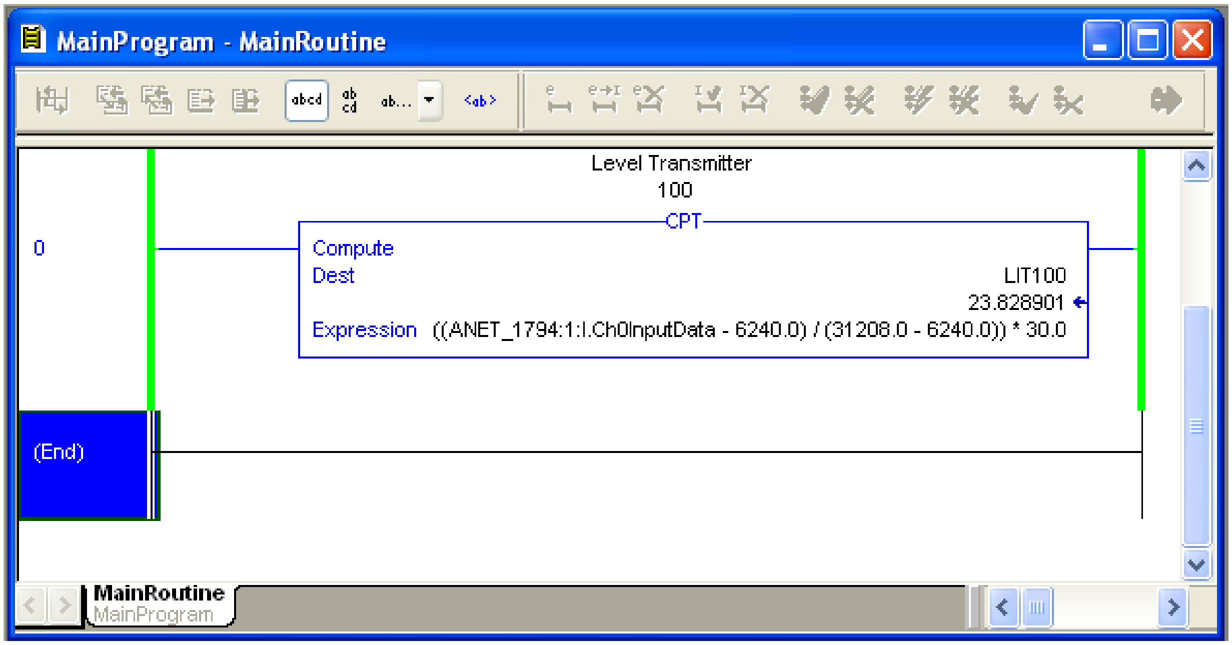
A Simulator with a Rosemount 1151 and Closed Tank 0 to 30 Inches

The tank is adjustable to 30 inches on the HP side. The wet leg is filled with 30 inches of water on the LP Side.

The Transmitter

The Simulated Tank

The Studio 5000/RSLogix 5000 PLC Program in Run Mode



The Transmitter Communicator Display

Notice the PV (process Variable) is -6.218 inH2O.
[(HP * S.G.) - (LP * S.G.)] = DP or PV
[(23.8 * 1.0) – (30.0 * 1.0)] = -6.2 inH20

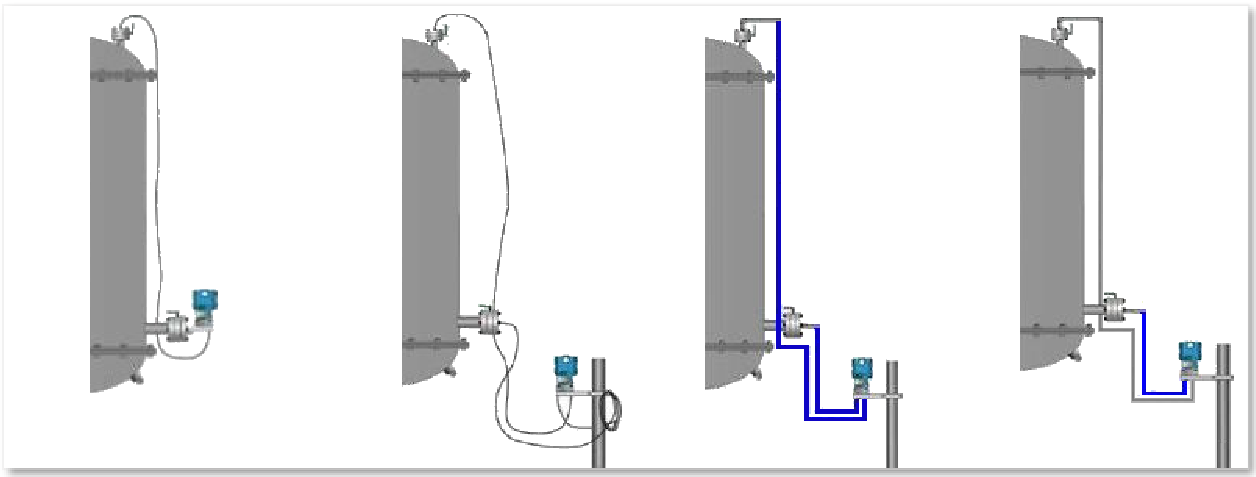
LRV = -30 inH2O
URV = 0 inH2O
AO = 16.683 mA

$$\frac{\text{PV - LRV}}{\text{SPAN}} = \% \qquad \frac{\text{16.683mA - 4mA}}{\text{20mA - 4mA}} = 0.792\% \qquad \frac{\text{(-6.218") - (-30")}}{\text{0" - (-30")}} = 0.792\%$$

Note:
The process variable jumps around a little bit.

Types of Reference Legs on Level Measurement and System Names

TUNED-SYSTEM ***BALANCED SYSTEM*** ***WET LEG*** ***DRY LEG***



A "tuned system" in level measurement, refers to a specific configuration used in differential pressure (DP) level transmitters, where the capillary lines connecting the pressure taps to the transmitter have different lengths, allowing for improved accuracy by compensating for temperature-induced errors through a balancing act between the high-pressure and low-pressure sides of the system. Essentially, it "tunes" the system to minimize the impact of temperature fluctuations on the measurement.

A "balanced system" in level measurement, refers to a differential pressure (DP) transmitter setup where both the high-pressure and low-pressure sides of the transmitter have identical capillary lines (equal lengths and fill fluid) connected to the pressure taps, essentially creating a balanced configuration with minimal impact from temperature fluctuations on the measurement accuracy; it is often used in applications with relatively stable temperature conditions and where precise level readings are needed.

In level measurement, a “wet leg” refers to the reference side of a differential pressure (DP) transmitter, where both sides are filled with a liquid. This compensates for pressure changes at the liquid surface while measuring the level. Vapors cannot condensate into the low-pressure side tube and cause fluctuations in the level reading.

In level measurement, a "dry leg" refers to the reference side of a differential pressure (DP) transmitter, where the connecting pipe is intentionally kept empty. Meaning it has no direct contact with the process liquid, allowing it to compensate for pressure changes at the liquid surface while measuring the level. Essentially, it's a dry pipe used to isolate the pressure measurement from ambient pressure fluctuations.

Capillary Tubes and Diaphragms (Fill Fluid Specific Gravities)

Capillary Fill Fluid	Specific gravity at 25 °C (77 °F)
Silicone 200	0.934
Tri-Therm 300	0.795
Silicone 704	1.07
Silicone 705	1.09
UltraTherm™ 805	1.20
SYLTHERM™ XLT	0.85
Inert (halocarbon)	1.85
Neobee® M-20	0.94
Glycerin and water	1.13
Propylene glycol and water	1.02

Emerson Rosemount™ 3051L Liquid Level Transmitter