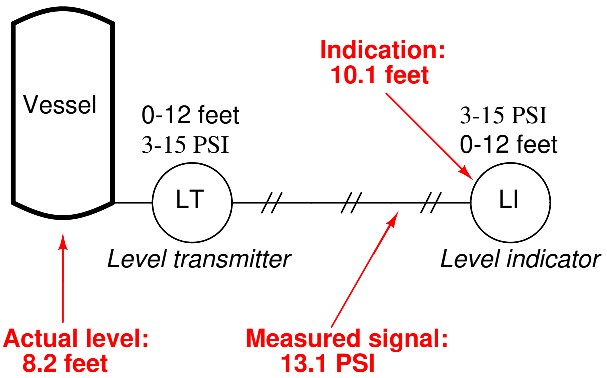
Oppgavesett nivåmåling

Oppgave 1

A level indicator is registering a liquid level that is falsely high. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 8.2 feet, but the level indicator (LI) registers 10.1 feet. The calibrated range of the 3-15 PSI pneumatic transmitter is 0 feet to 12 feet. You measure the pneumatic pressure signal with a test gauge and find that it is 13.1 PSI. Which instrument is at fault in this system? How do you know?

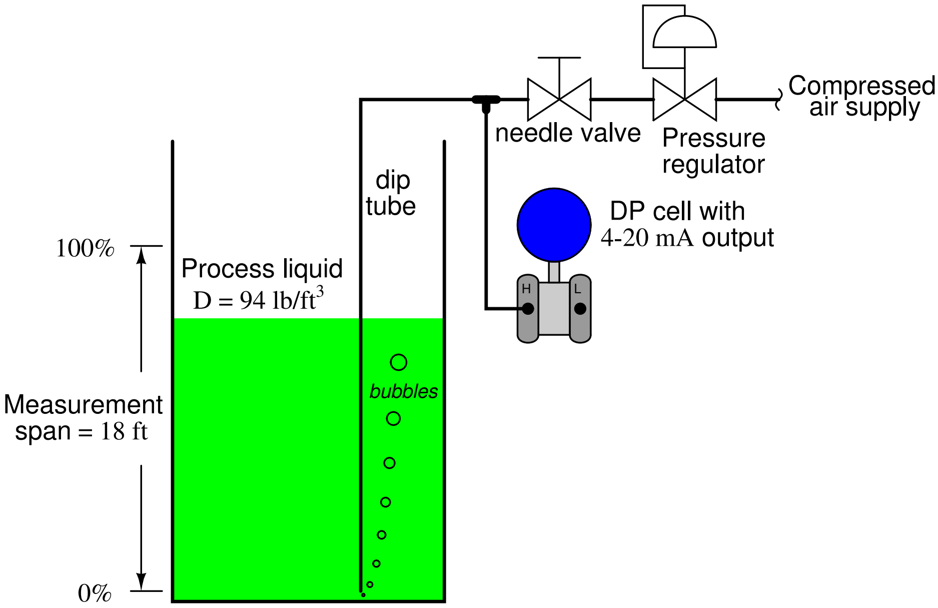


Furthermore, identify whether the fault is a *zero shift*, a *span shift*, a problem with *linearity*, *hysteresis*, or whether it is impossible to determine from the information we have.

file i02961

Oppgave 2

A liquid storage vessel holding a very corrosive liquid has its level measured by a *bubbler* system, whereby a transmitter measures the backpressure of air inside a "dip tube" inserted into the vessel:



Explain how this level measurement system works, and how it protects the DP cell from the corrosive effects of the process liquid.

Also, complete a calibration table for the differential pressure transmitter in this level measurement scenario, with a calibration tolerance of ± 0.5%. Assume that the lower range-value of the process (0% level) is exactly the same height as the bottom of the dip tube:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

file i00249

Oppgave 3

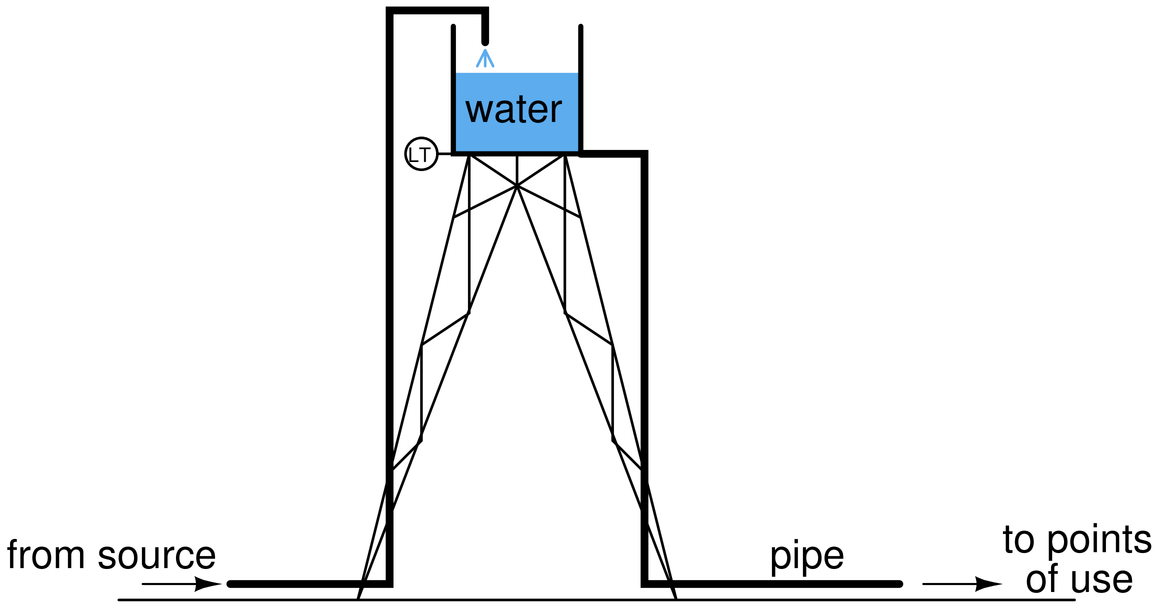
A digital level transmitter has a calibrated input range of 20 to 170 inches of liquid level, and a 10-bit output (0 to 1023 "count" range). Complete the following table of values for this transmitter, assuming perfect calibration (no error):

Input level (inches)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
	11		
	28		
	55		
	73		
	92		

file i03827

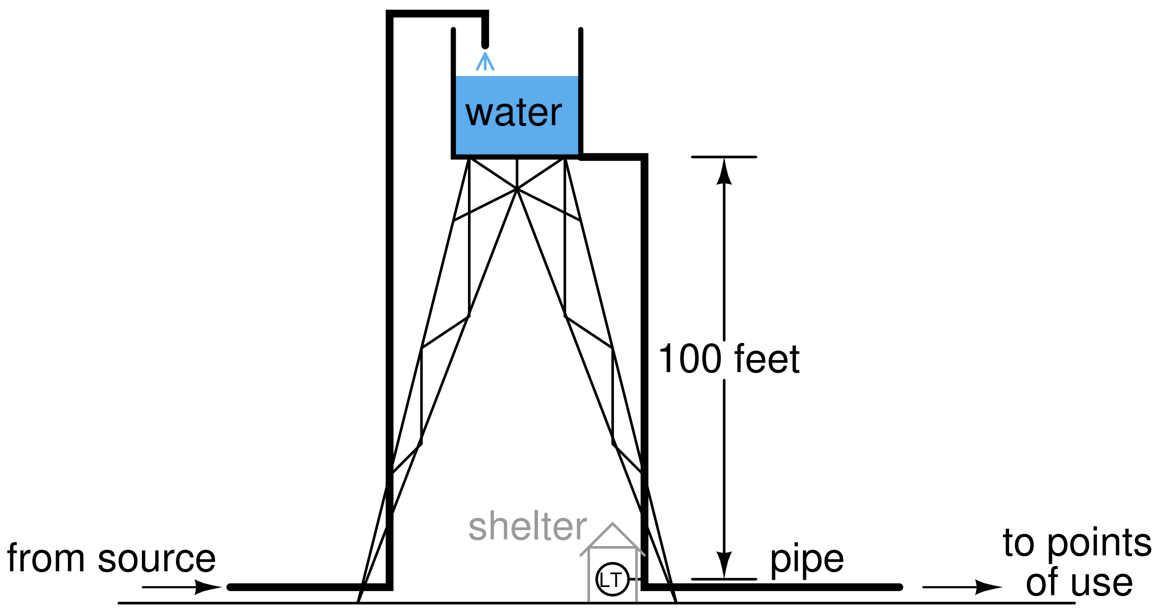
Oppgave 4

A water storage vessel is elevated by a tower structure, to provide a natural source of water pressure to all points of use below:



A pressure-sensing level transmitter is presently located at the base of the vessel, at the top of the tower structure, to measure water level inside the vessel. It has a calibrated range of 0 to 10 feet (0 to 120 inches W.C.). Unfortunately, the water inside the transmitter sometimes freezes in the winter months, preventing operation of the level measurement system. The water inside the storage vessel and the large pipes never freezes, because there is enough circulation as a result of water usage to raise the temperature and prevent ice crystals from forming.

It is decided to move the transmitter to ground level, at the base of the tower, so that it may be located inside a small, heated shelter where it will never freeze. By connecting the transmitter directly to the large water pipe carrying water from the vessel to the points of use, the hydrostatic pressure will still be measurable at this point:

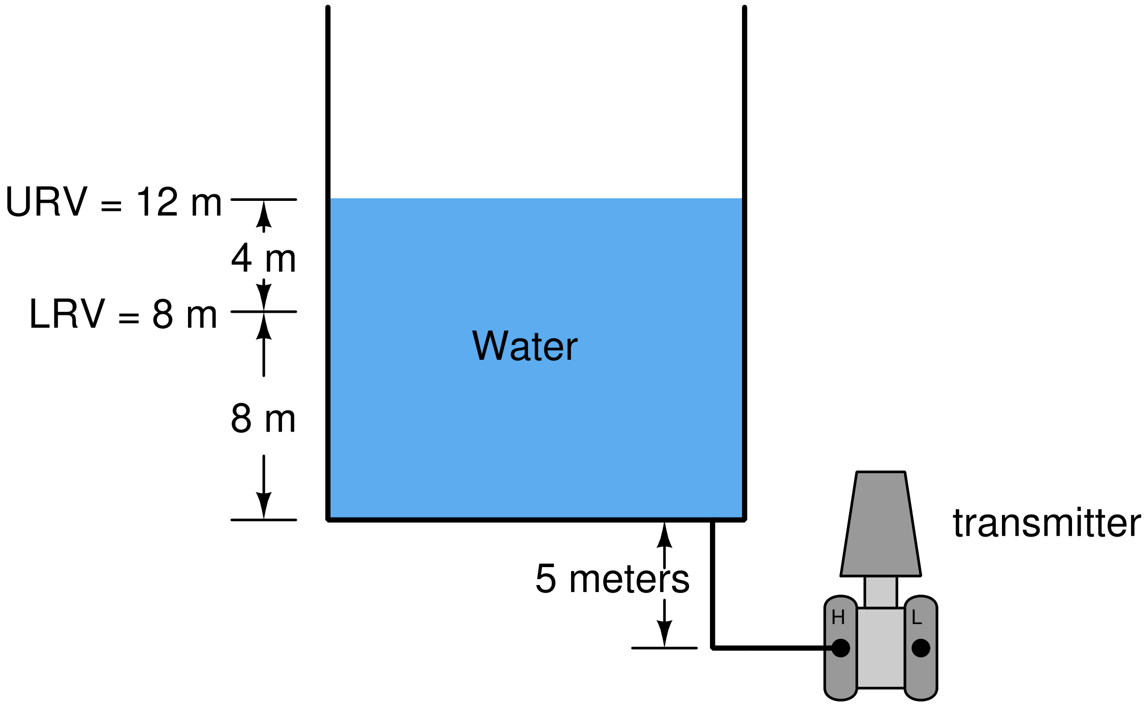


Calculate the new calibration points (lower and upper range-values) for the transmitter in its new location. Also calculate the water level in the vessel when the transmitter output is 13.7 mA, and the amount of hydrostatic pressure at that point in units of PSI.

Finally, identify whether the transmitter move resulted in a shift of its *zero*, a shift in its *span*, or both.
file i00253

Oppgave 5

The following storage vessel holds water. The hydrostatic-pressure level transmitter is located 5 meters below the bottom of the vessel, and the desired level measurement range is 8 meters to 12 meters:



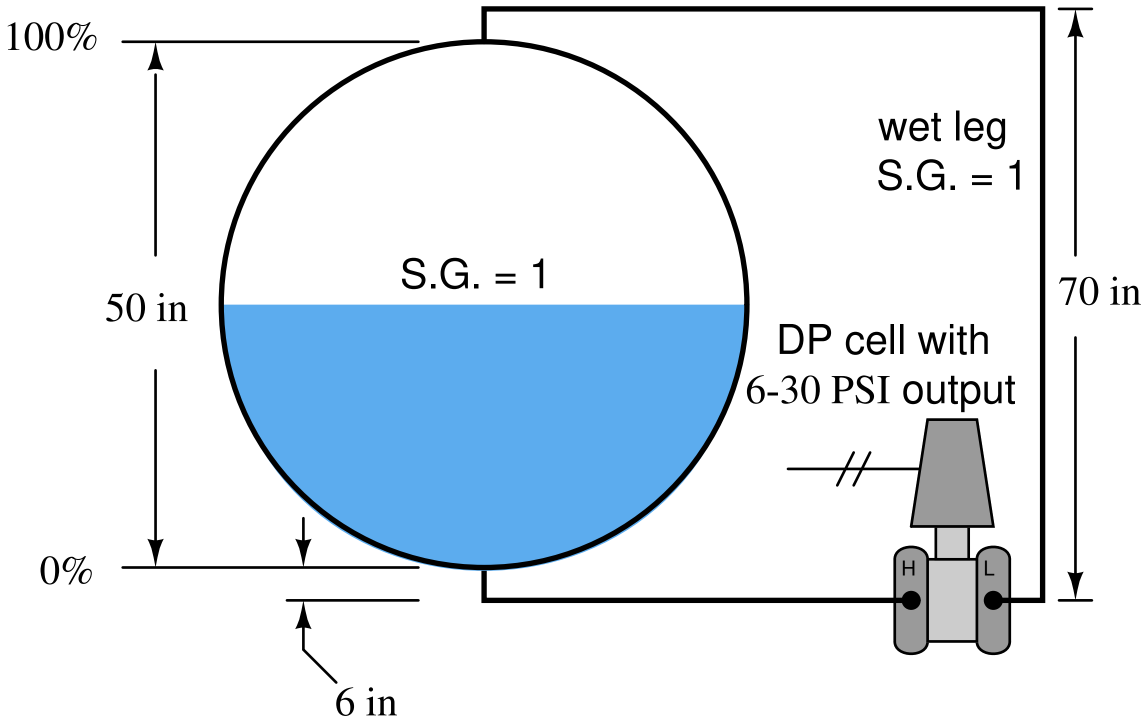
Assuming a pneumatic transmitter with an output range of 4 mA to 20 mA, and a calibration accuracy of +/- 1% of span, complete the following calibration table for the transmitter:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

file i00257

Oppgave 6

Determine a basic 5-point (0%, 25%, 50%, 75%, and 100%) calibration table for the level transmitter in this scenario. Assume a calibration tolerance of +/- 0.5%:

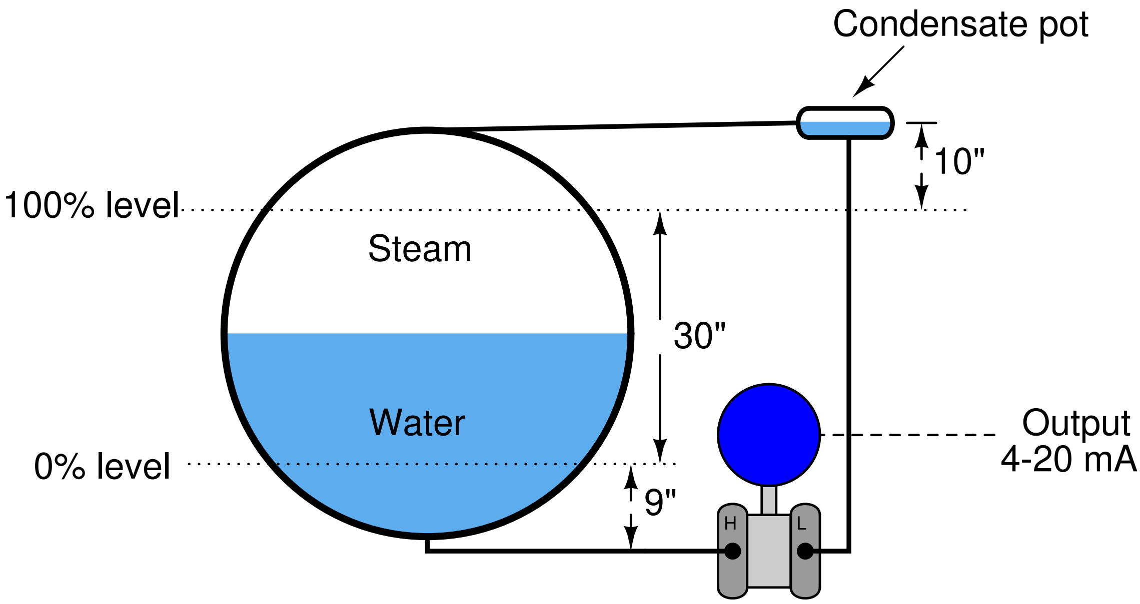


Process level (in)	Percent of span (%)	Differential pressure ("W.C.)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
	0				
	25				
	50				
	75				
	100				

file i00322

Oppgave 7

Calculate the differential pressure sensed by the level transmitter at three different water levels in this boiler steam-drum level measurement system: 0%, 50%, and 100%.



Assume a density for (hot) boiler drum water of 36 lb/ft^3, a density for steam in the drum of 7 lb/ft^3, and a density for (warm) water in the "wet leg" of 61.8 lb/ft^3. If the pressure at the "low" (L) side of the transmitter is greater than the pressure at the "high" (H) side, be sure to express the differential pressure quantity as a negative number.

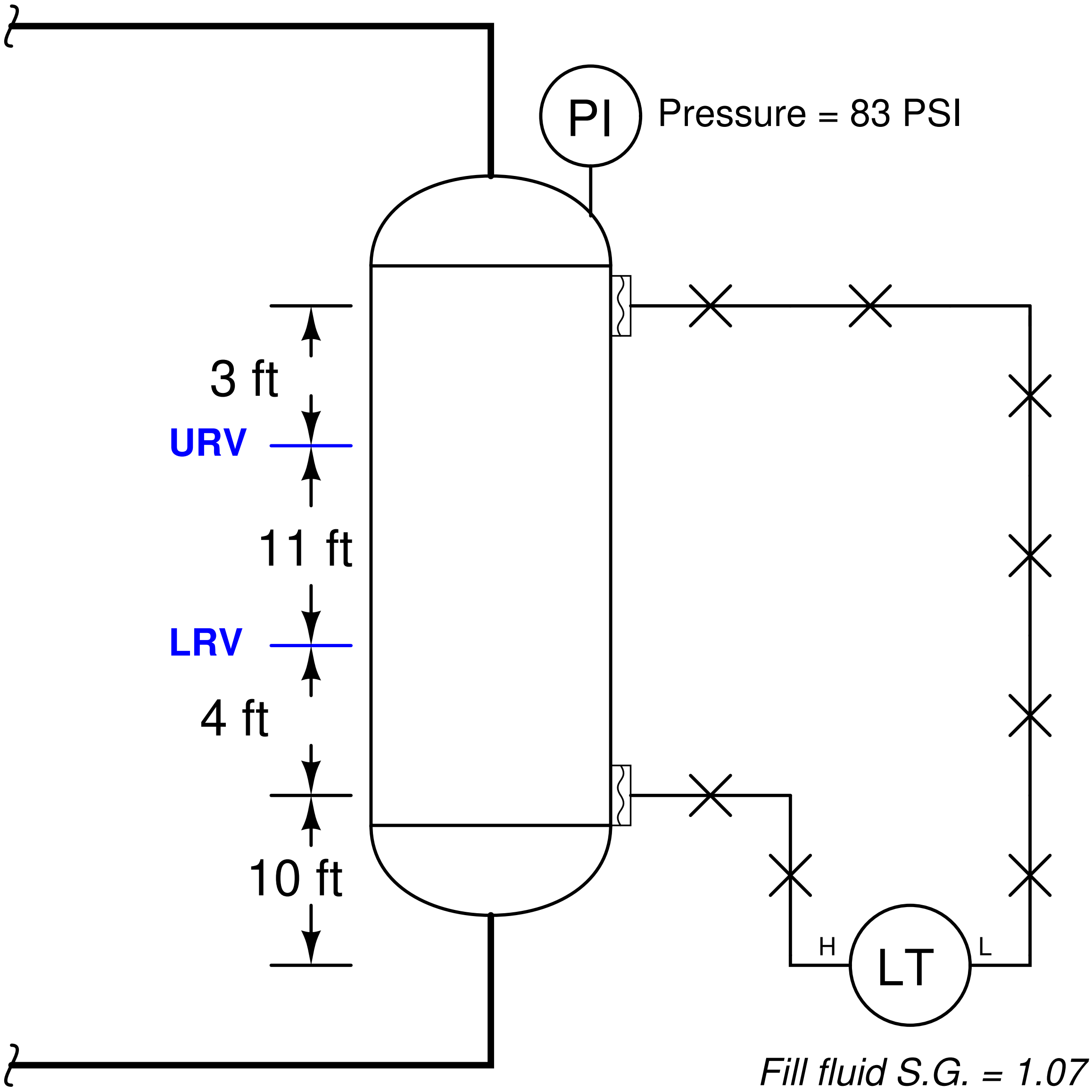
Credit will be given for correctly calculating each of the differential pressures:

- **(6 points)** Transmitter ΔP at 0% water level = ________ "W.C.
- **(6 points)** Transmitter ΔP at 50% water level = ________ "W.C.
- **(6 points)** Transmitter ΔP at 100% water level = ________ "W.C.

file i00516

Oppgave 8

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 43 pounds per cubic foot at the typical operating temperature of 120 degrees Fahrenheit:



Suggestions for Socratic discussion

- Suppose an instrument technician relocates the DP transmitter to a location that is *lower* than it is right now, from 10 feet below the LRV to 15 feet below the LRV. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose an instrument technician relocates the DP transmitter to a location that is *higher* than it is right now, from 10 feet below the LRV to 2 feet above the LRV. Will the transmitter still accurately register liquid level in the vessel? If not, determine

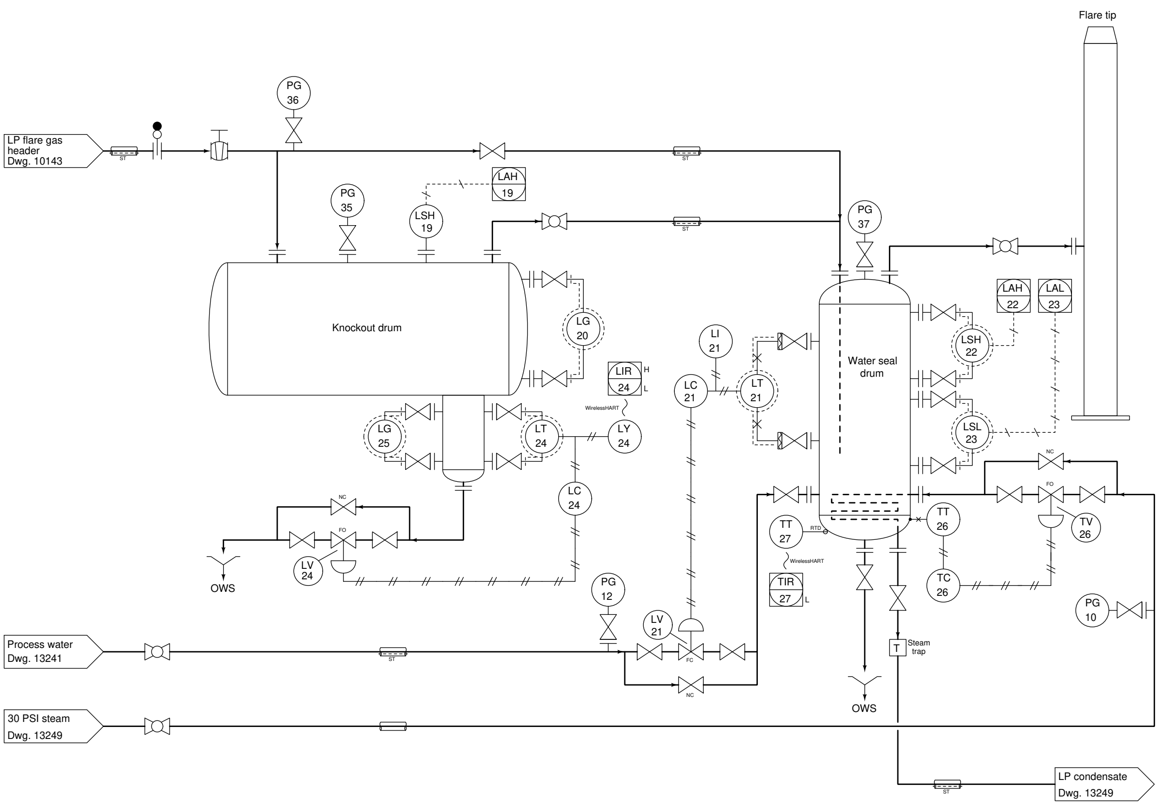
whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).

- Suppose the DP transmitter is replaced with another having a denser fill fluid (1.85 instead of 1.07). Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose some of the fill fluid leaks out of the "low" side capillary tube. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).
- Suppose the ambient temperature dramatically increases, causing the fill fluid to expand inside both capillary tubes. Will the transmitter still accurately register liquid level in the vessel? If not, determine whether the error will be *high* (indicating more liquid than there actually is) or *low* (indicating less liquid than there actually is).

file i04514

Oppgave 9

Determine the LRV and URV settings for the water seal drum lever transmitter (LT-21), assuming the LRV point is at the lower nozzle and the URV point is at the upper nozzle (the two nozzles being 3 feet 8 inches apart from each other), and that the remote seal fill fluid has a specific gravity of 0.934:

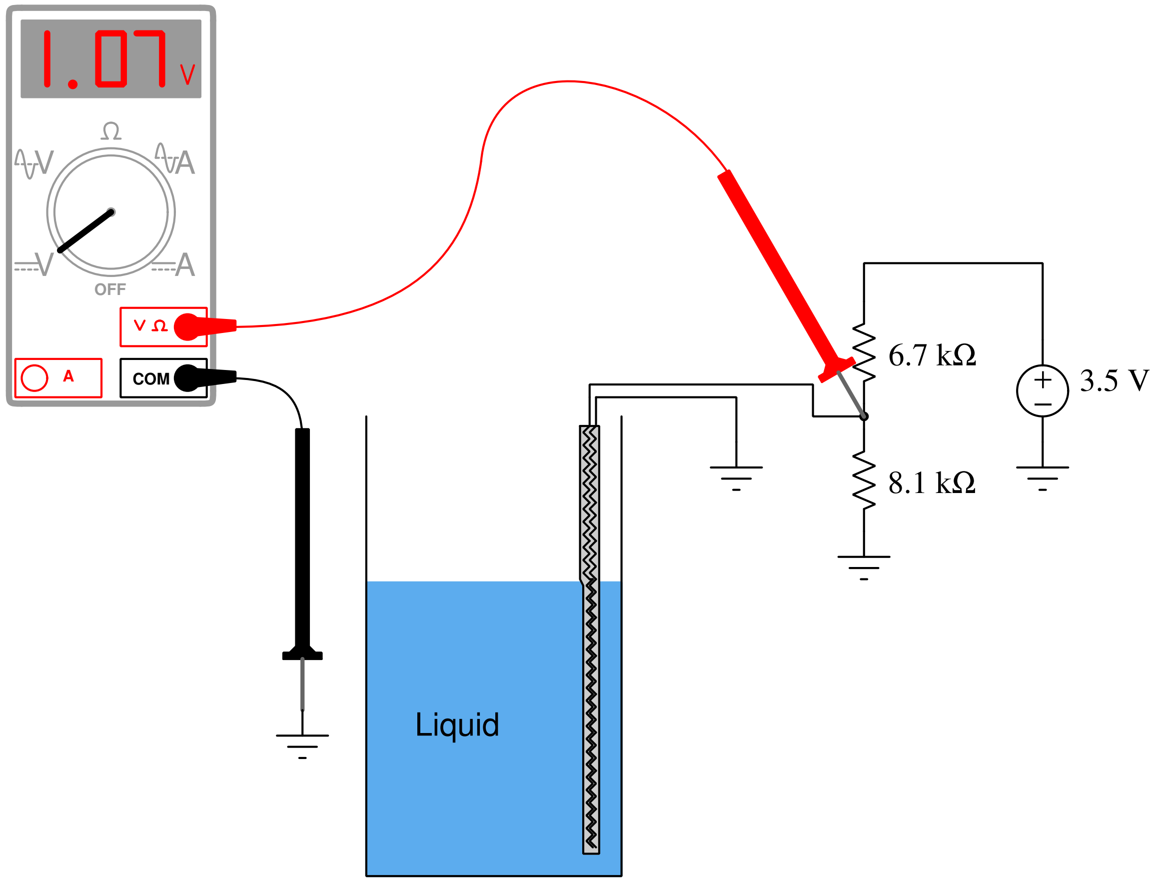


file i02820

Oppgave 10

A **resistive tape** level sensor is a two-wire element immersed in a liquid, which changes resistance as liquid level increases. The principle is the same as placing your rubber-boot-covered foot in a pool of water: the deeper your foot is submerged, the further up your foot and ankle you feel the water's pressure push the rubber boot against your skin. A resistive tape stretches the entire height of the vessel, and contact is made between two resistive wires by the head pressure against the submerged length of the tape. The greater the liquid level, the further the length that the two wires are in contact with each other, resulting in less resistance overall.

Examine the following resistive tape level measurement system and calculate the following, assuming a maximum tape resistance of 10 kΩ (i.e. resistance with zero immersion), a minimum resistance of 2 kΩ (i.e. resistance with total immersion), a linear relationship between tape immersion and tape resistance, and a total tape length of 15 feet:



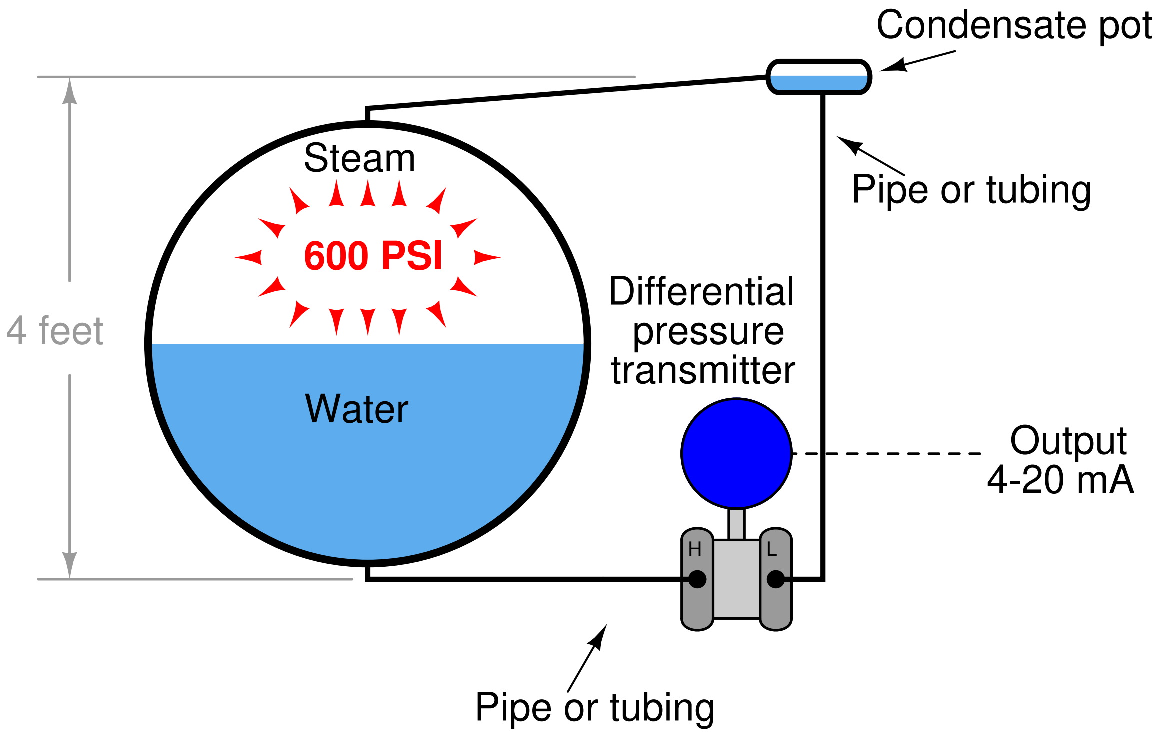
Tape resistance (R_{tape}) = ________

Immersion depth = ________

file i00855

Oppgave 11

The level of water in the steam drum of a boiler typically uses a differential pressure transmitter with a balance line to the top of the drum to equalize static pressure:



Since a 600 PSI steam drum operates at a very high temperature, and the transmitter's balance line connecting to the top of the drum will be much cooler than the drum, steam will invariably condense into water within that line, filling it up until it is completely full of water, making it a *"wet leg"*.

Determine whether or not the static steam pressure of 600 PSI necessitates special calibration of the transmitter.

Describe how the level transmitter must be calibrated differently than if the compensating leg were dry (no condensate), and also explain the purpose of the condensate pot.

file i00307

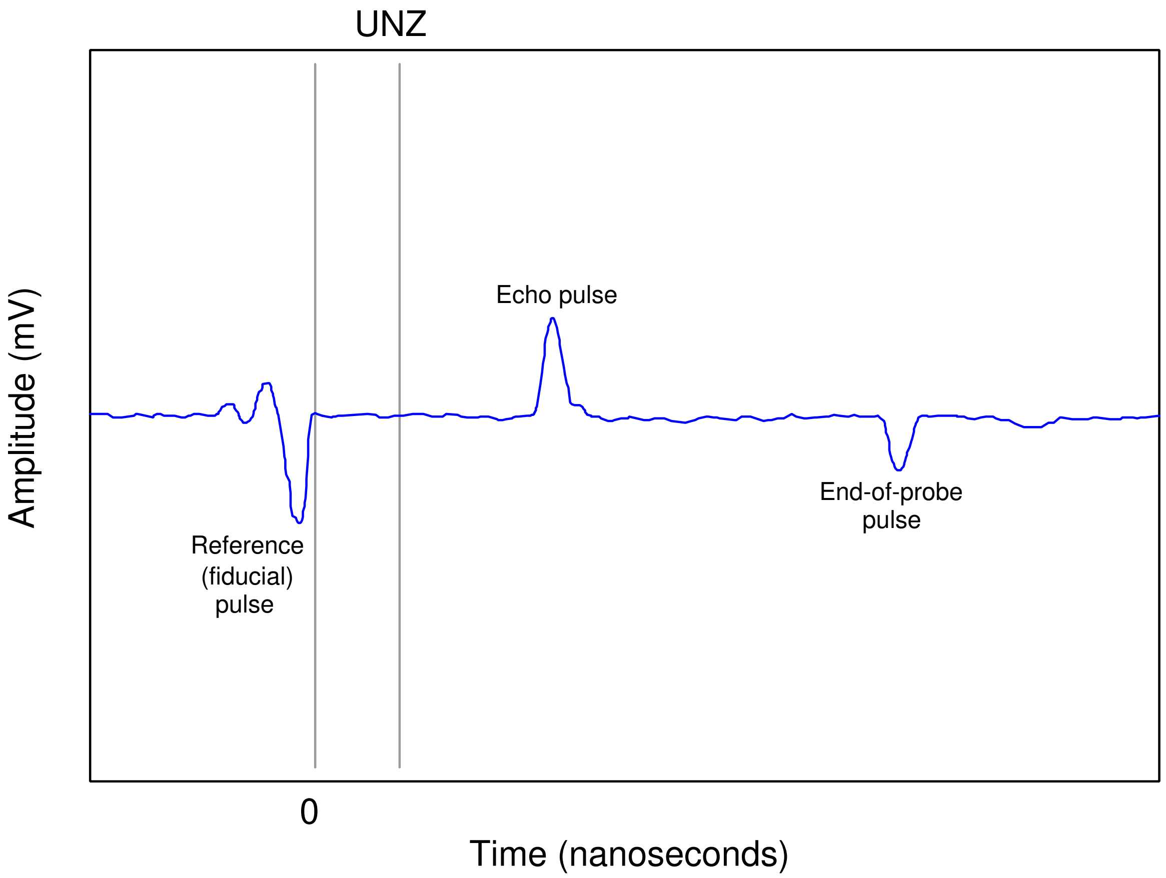
Oppgave 12

A displacer-type density transmitter registers a displacer weight of 6.3 pounds with the cage completely full of sample liquid. The displacer has a dry weight of 14 pounds, a density of 120 lb/ft^3, and is cylindrical in shape. Calculate the density of the liquid in units of pounds per cubic foot.

file i00283

Oppgave 13

The following graph shows the signal strength received by a guided-wave radar (GWR) level instrument over time:



Explain how the graph will change if:

- The liquid level increases
- The dielectric constant (ϵ) of the liquid decreases
- The density of the liquid decreases (assuming constant ϵ)
- A liquid-liquid interface consisting of two liquids with different densities is introduced into the vessel

Also, explain what *UNZ* refers to (the *Upper Null Zone*).

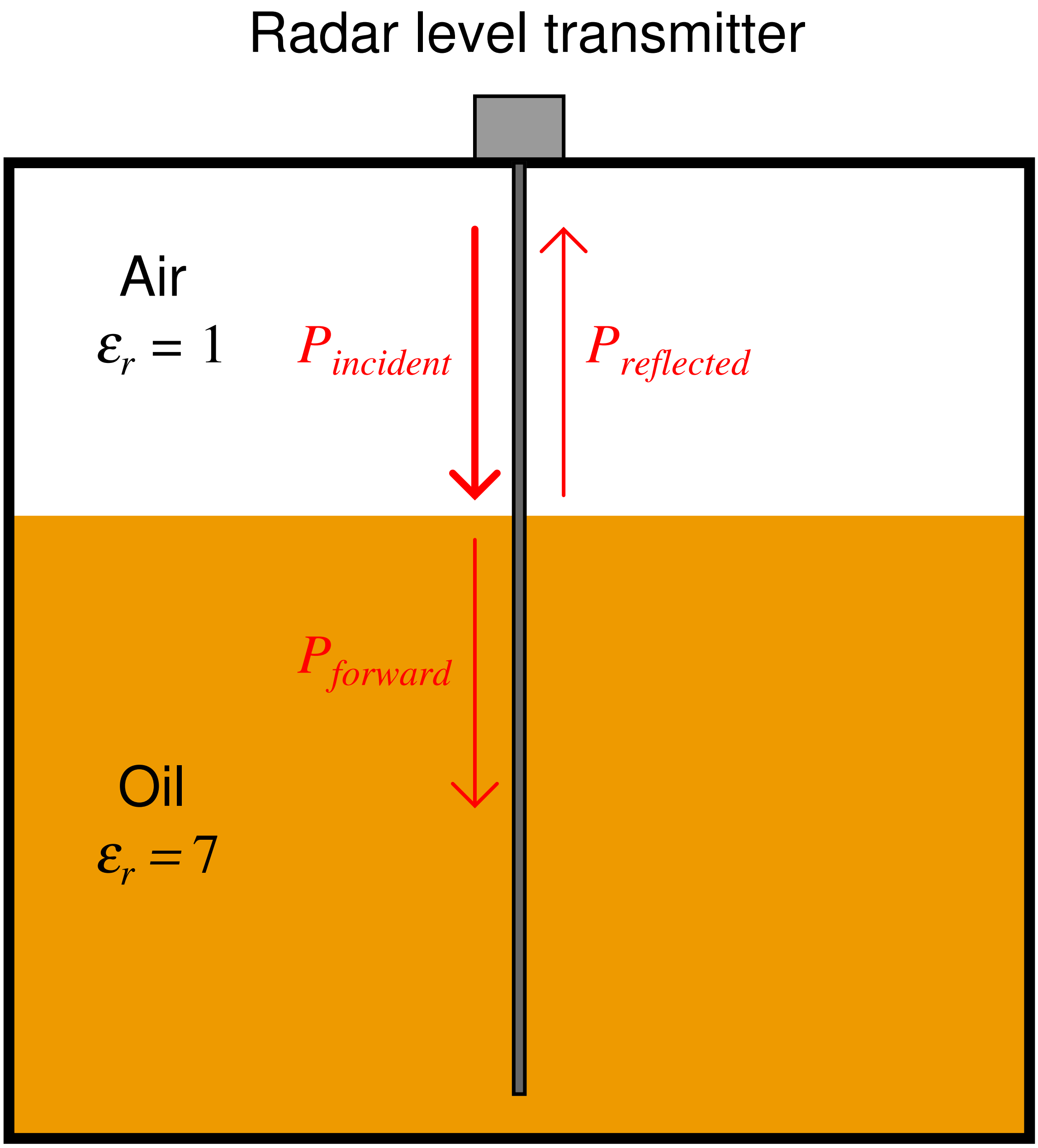
Suggestions for Socratic discussion

- Describe a practical reason for configuring a radar transmitter to have an upper null zone, and how this differs from a radar instrument's *transition zones*.
- Explain why the timing of *both* the echo pulse and the end-of-probe pulse will shift as liquid level changes in this system.

file i00289

Oppgave 14

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:



Also, calculate the ullage for this vessel in units of feet, given a reflected pulse ("echo") time of 17.0 nanoseconds. Assume a speed of light in vacuum to be 3×10^8 meters per second. For all your answers, be sure to show your work!

$P_{reflected}$ = ________ %

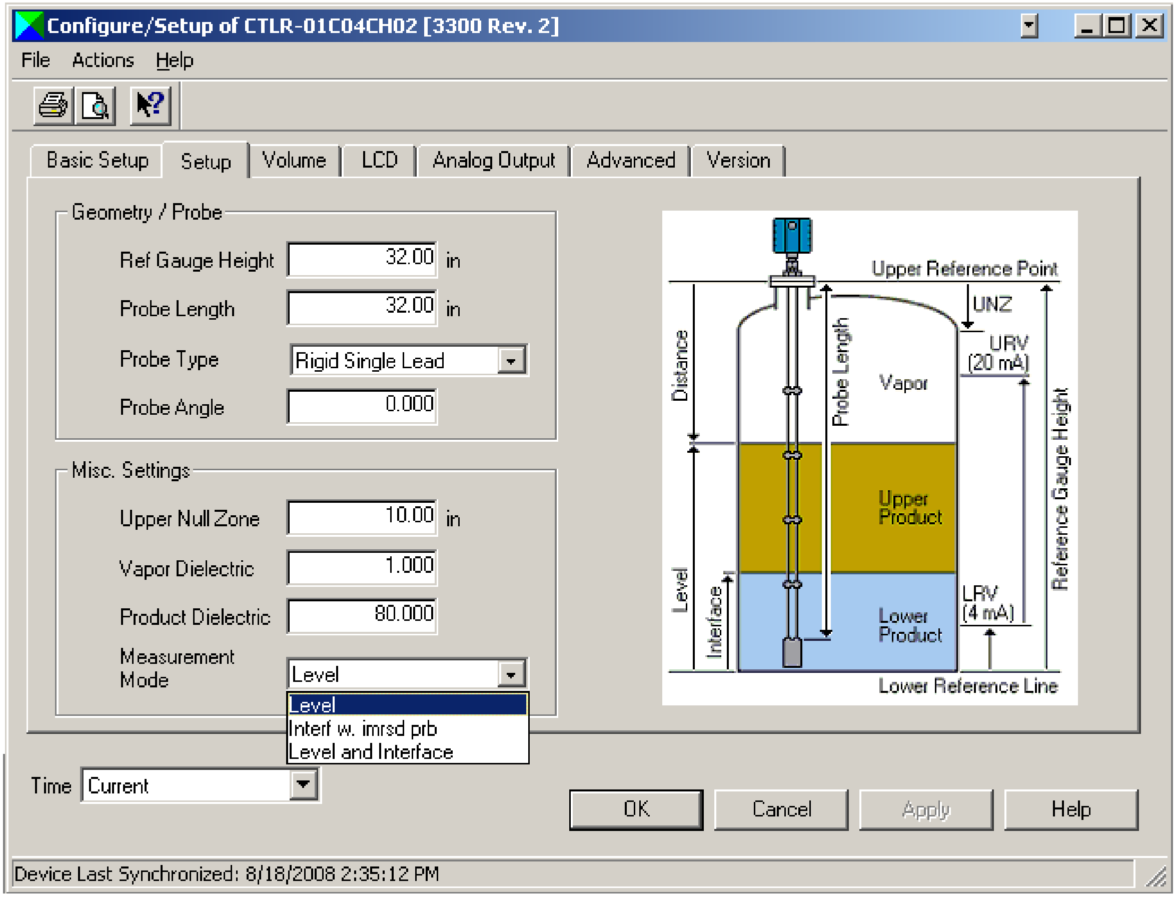
$P_{forward} =$ ________ %

Ullage = ________ ft

file i00034

Oppgave 15

Examine the different configuration parameter fields for a guided-wave radar transmitter shown in this screenshot (taken on a personal computer running Emerson AMS software, interrogating a Rosemount model 3300 level transmitter), and explain the importance of each one:



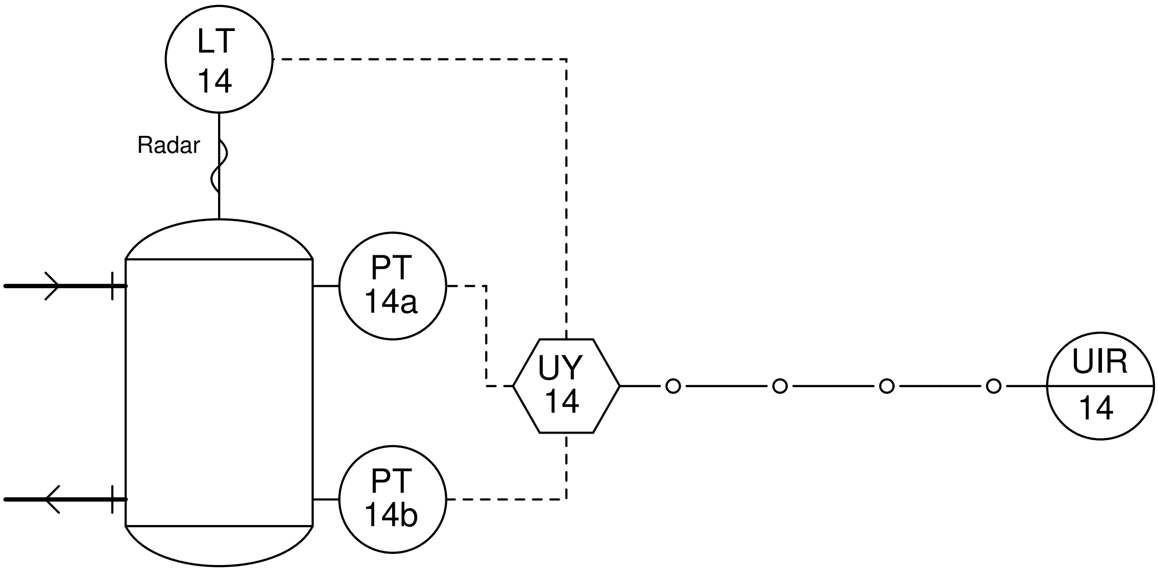
Suggestions for Socratic discussion

- Do you think it is realistic to set the span of a GWR transmitter equal to its probe length? Why or why not?
- What does the selection "Interf w. imrsd prb" mean, especially in comparison with the other measurement mode options?
- What significance does the "Probe Angle" setting have?

file i00292

Oppgave 16

This P&ID shows how two pressure transmitters may be linked with a radar level transmitter to provide data necessary to calculate not only liquid level, but also liquid density and total liquid mass stored in the vessel:

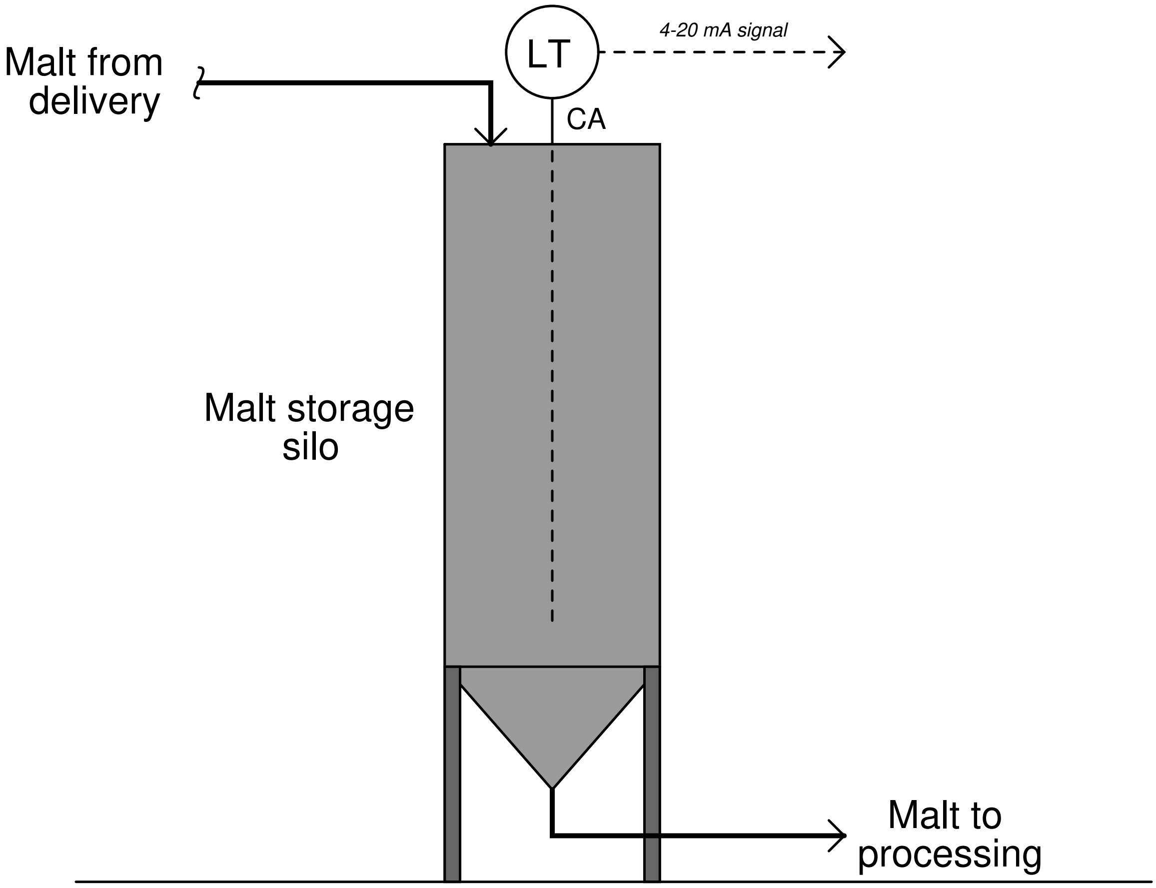


This is sometimes referred to as a *hybrid* level measurement system. Explain what the word "hybrid" means in this context, and how these three transmitters accomplish the measurement objectives of liquid level, density, and total mass. Also, explain what all the symbols mean in the P&ID.

file i00295

Oppgave 17

Suppose a brewery decides to install a capacitive level probe to measure the height of malt (partially germinated barley grains) in a storage silo:



Unfortunately, the capacitive level instrument fails to yield reliable measurements of malt height, due to variations in the malt's moisture content from delivery to delivery. Wet malt has a greater bulk permittivity than dry malt, causing the level transmitter to register differently with the same actual height of malt inside the silo.

The operations manager approaches you for a solution to this problem. What do you recommend?

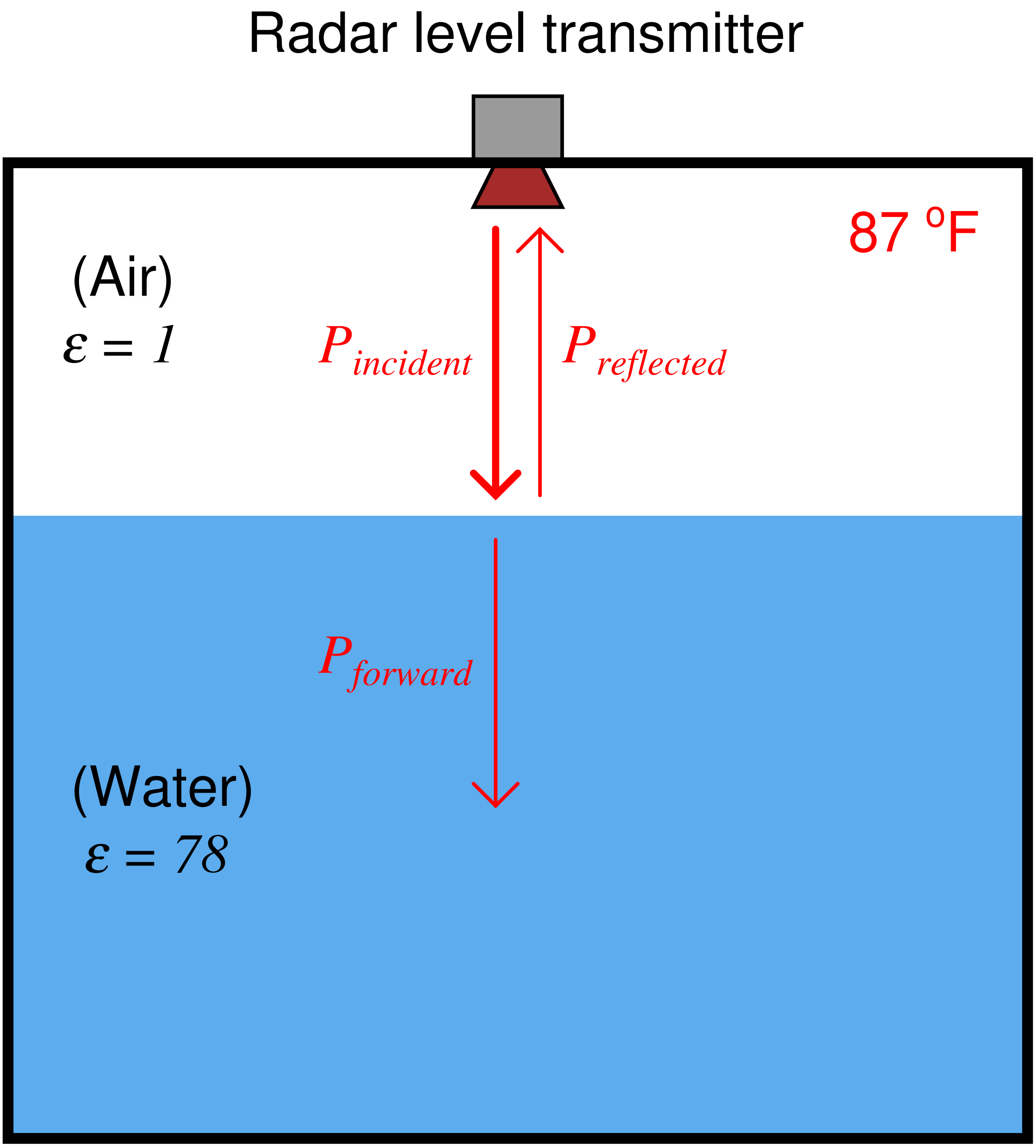
Suggestions for Socratic discussion

- When the malt is wetter but the actual malt level has not changed, will the LT register a greater level or a lesser level? Explain why.
- Are there any ways to make a capacitive instrument do a better job in this application?
- For any alternative technologies you recommend, identify ways in which each one might also suffer problems when trying to measure the height of malted barley gains inside the silo.

file i00318

Oppgave 18

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:



Also, calculate the ullage for this vessel in both units of meters and units of feet/inches, given a reflected pulse ("echo") time of 11.176 nanoseconds. Note: the propagation velocity of radio waves in air is approximately 3×10^8 meters per second, the same as the speed of light in a vacuum.

Suggestions for Socratic discussion

- An effective problem-solving technique to apply to the calculation of ullage is to *simplify the problem* and solve that simplified problem. In this case, an easy way to "simplify the problem" is to change the numerical values for echo time and speed of light until the solution for ullage becomes obvious even without using a calculator. Then the formula we must use to calculate *any* time/speed/ullage echo problem will be apparent. Apply the "simplify the problem" technique to this ullage calculation.

- Would you say this is an example of good signal reflection, or poor signal reflection? In general terms, what condition(s) make for strong reflected signals for a radar-based level instrument?

file i04216

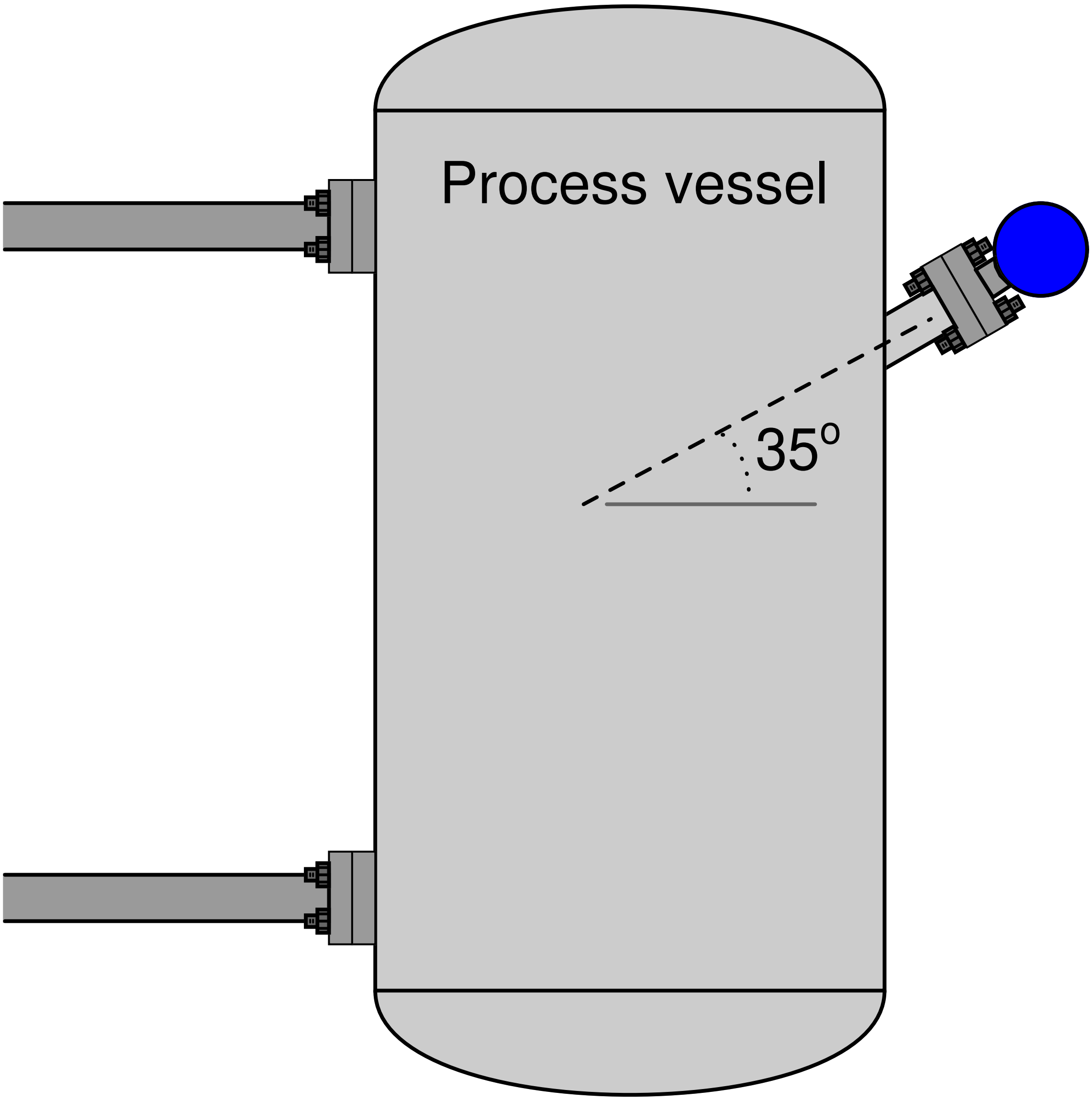
Oppgave 19

Suppose an instrument salesperson comes to your shop and tells you his company's radar level transmitter product is superior to all hydrostatic and displacer level transmitters because those instruments' accuracy depends on a fixed process liquid density, whereas radar transmitters do not. Thus, he tells you, his radar transmitters will give accurate level measurements even when process pressures and temperatures change.
What do you think of this claim? Is the salesperson's claim true, or not? Explain.

If a magnetostrictive level transmitter salesperson made a comparable claim – that the accuracy of a magnetostrictive instrument would not be affected by changes in process liquid density – would you believe it?
file i03626

Oppgave 20

A guided-wave radar transmitter is installed in this process vessel through a nozzle welded to the vessel at a 35^o angle from horizontal:



This transmitter's rigid probe happens to be precisely 8 feet 0 inches long, and has transition zones 20 inches in length (each). Calculate the *vertical* level-measurement span this transmitter will provide as installed.

file i03744

Oppgave 21

Read selected portions of the "Rosemount 5300 Series high performance guided wave radar" manual (part 00809-0100-4530, Revision AA, June 2007), and answer the following questions:

Pages 3-8 and 3-9 list guidelines for installing guided-wave radar instruments in liquid and in solid services. Identify some of these guidelines and explain the rationale for them.

Pages 7-3 through 7-10 discuss the use of Rosemount's "Radar Master" configuration software to analyze the transmitter's "Echo Curve." After reading this section, explain how "threshold" values are used to identify the meaning of echo pulses. Also, explain how the "Amplitude Threshold Curve" may be used to ignore false echos resulting from disturbing objects in the process vessel (e.g. ladders, baffle plates, etc.).

Guided-wave radar transmitters are capable of measuring liquid-liquid interfaces in addition to simple liquid levels. Thus, a GWR transmitter may be considered a *multivariable* device. This presents a challenge: how to communicate multiple measurement variables over a single 4-20 mA signal wire pair. A solution presented on pages 2-6, 5-44, and 5-45 of this manual shows the use of a device called a *HART Tri-Loop* to extract three 4-20 mA signals from the transmitter, each signal representing a different process variable. Explain how this is possible, based on what you know of HART.

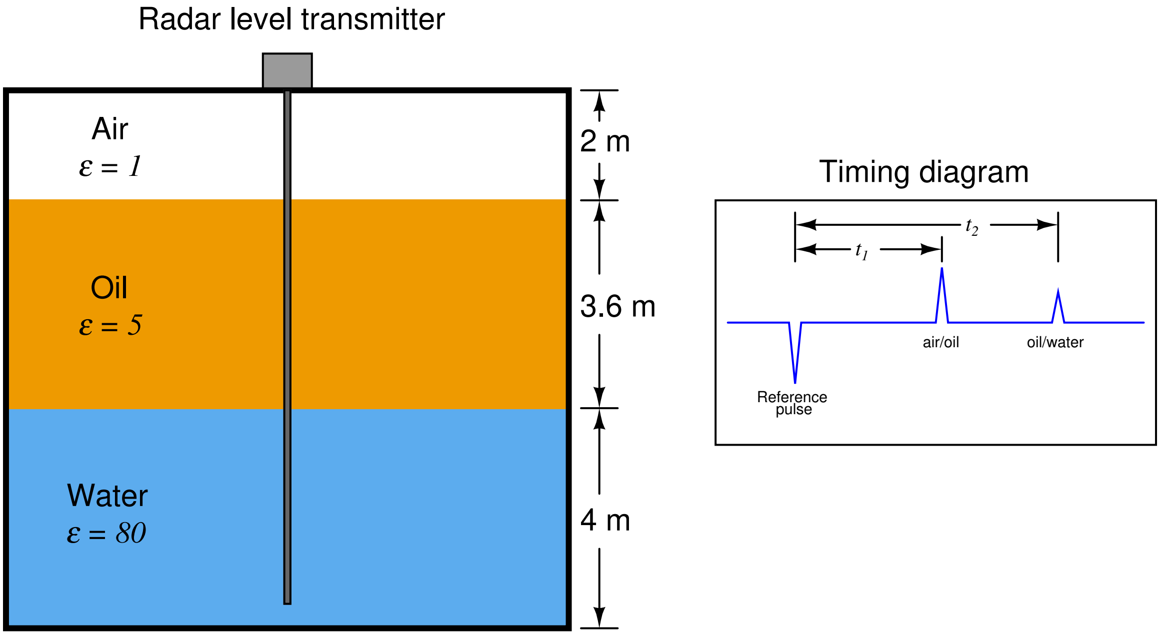
Suggestions for Socratic discussion

- Identify an echo curve shown in the manual where the detection threshold is set incorrectly, and identify whether the threshold value needs to be increased or decreased.
- Explain how the Amplitude Threshold Curve (ATC) may be used to set thresholds in way that is more sophisticated, in order to avoid falsely interpreting interfering objects as liquid levels.
- Explain how "Probe End Projection" may be used to determine product level even in cases where there is insufficient echo generated at the top of the product to measure reliably.
- Will the apparent probe end position rise or fall as the level of material in a vessel increases?
- In order to use a Tri-Loop device with a HART transmitter, the transmitter must be configured for *burst mode*. What do you suppose "burst mode" means for a HART transmitter?
- Identify some of the process and instrument variables which may be communicated using a Tri-Loop device, other than process level of course.

file i00928

Oppgave 22

Calculate the echo times for both the total level (air/oil interface) and oil/water interface in this radar level measurement application:

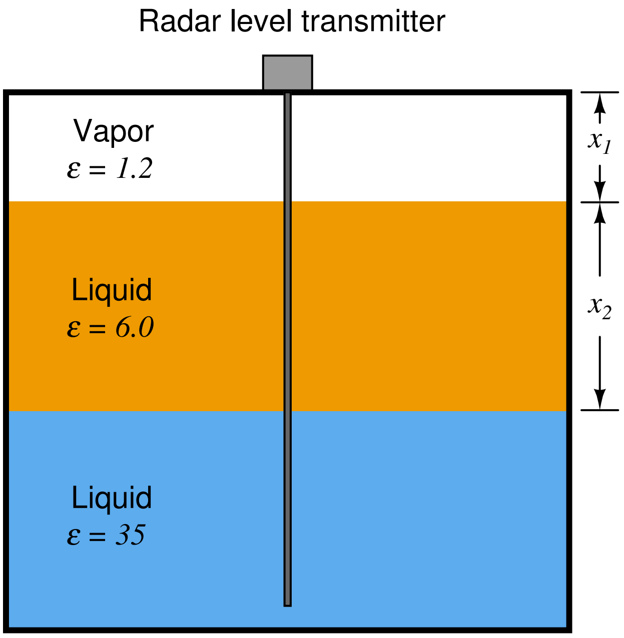


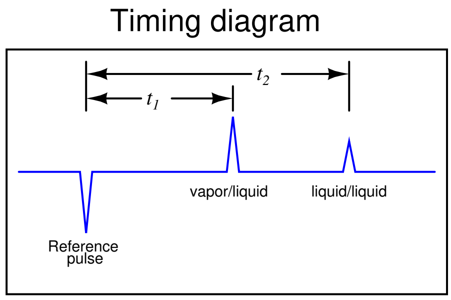
Also, calculate the power reflection factors for both interfaces (air/oil and oil/water).

file i04218

Oppgave 23

Calculate the two distances (x_1 and x_2) in this radar level measurement application given echo times of 9.7 ns and 85.3 ns, respectively:





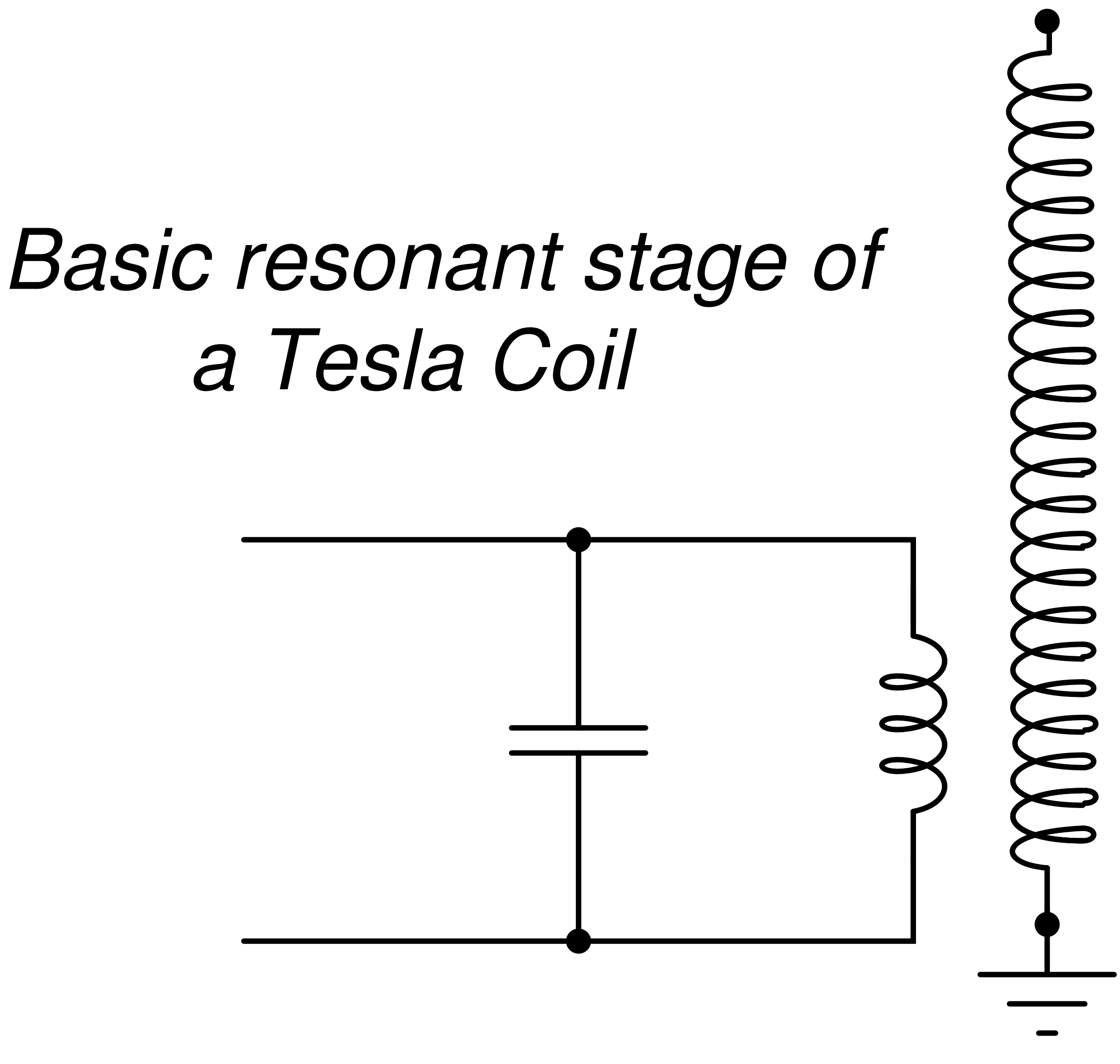
$t_1 = 9.7$ ns

$t_2 = 85.3$ ns

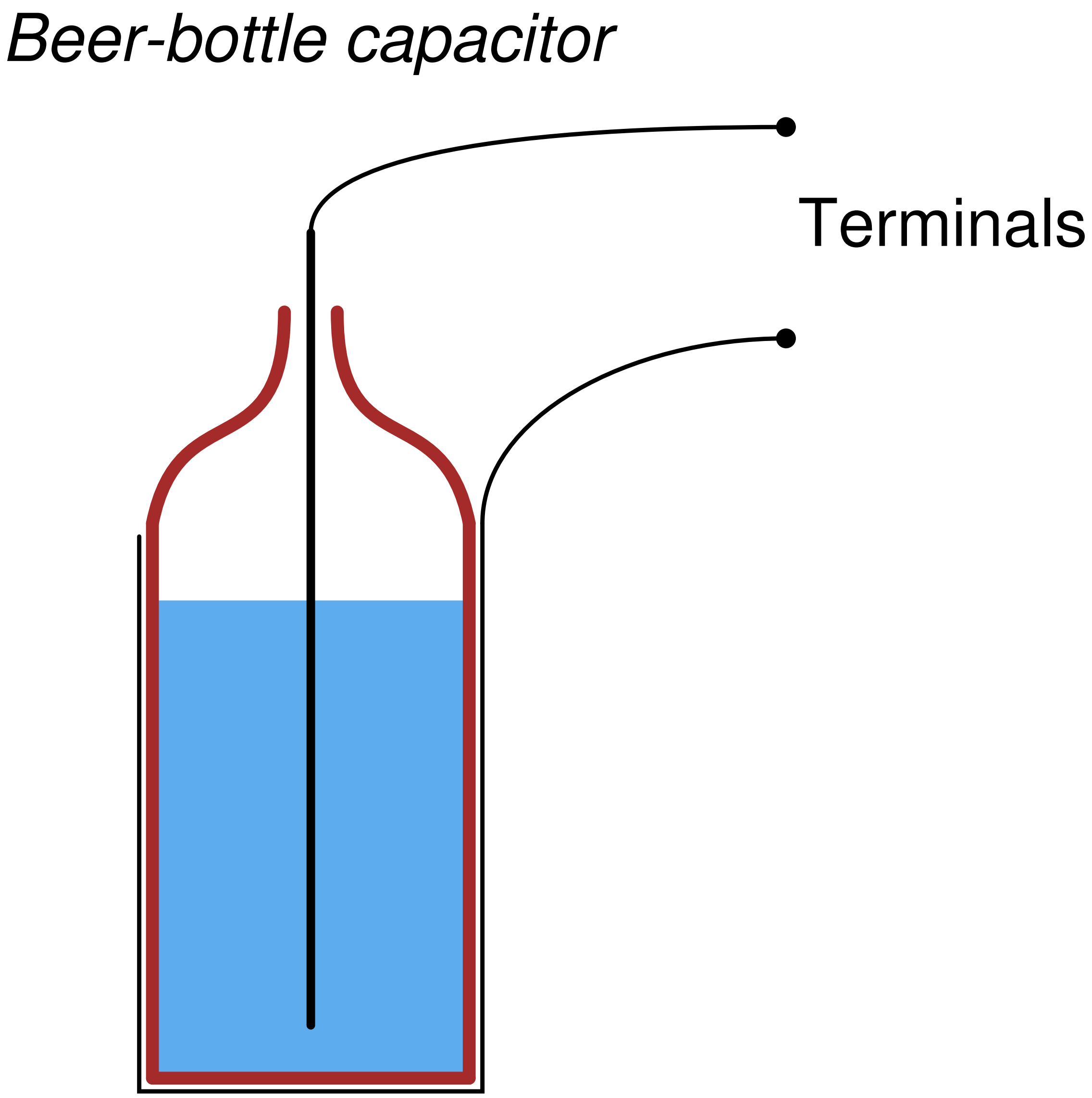
file i04219

Oppgave 24

Hobbyists building their own Tesla Coils often need to fabricate their own high-voltage capacitors for building the LC resonant circuit which is the heart of the coil:



One ingenious way to build such capacitors is to use old glass beer or soda bottles filled with salt water, with a metal rod or chain dipped into the water and aluminum foil wrapped tightly around the outside:



To obtain enough capacitance, one must usually group several of these beer-bottle capacitors together in parallel. I mean, what's the point of having beer-bottle capacitors unless you can make a six-pack with them?

As odd as it may seem, this actually has something to do with industrial instrumentation! Identify which parts of the "beer-bottle capacitor" form the conductive plates of the capacitor and which part forms the dielectric. Then identify how capacitance would be affected if we were to change the level of salt water in the beer bottle. Finally, identify how this principle could be applied to the measurement of liquid level inside a vessel.

Suggestions for Socratic discussion

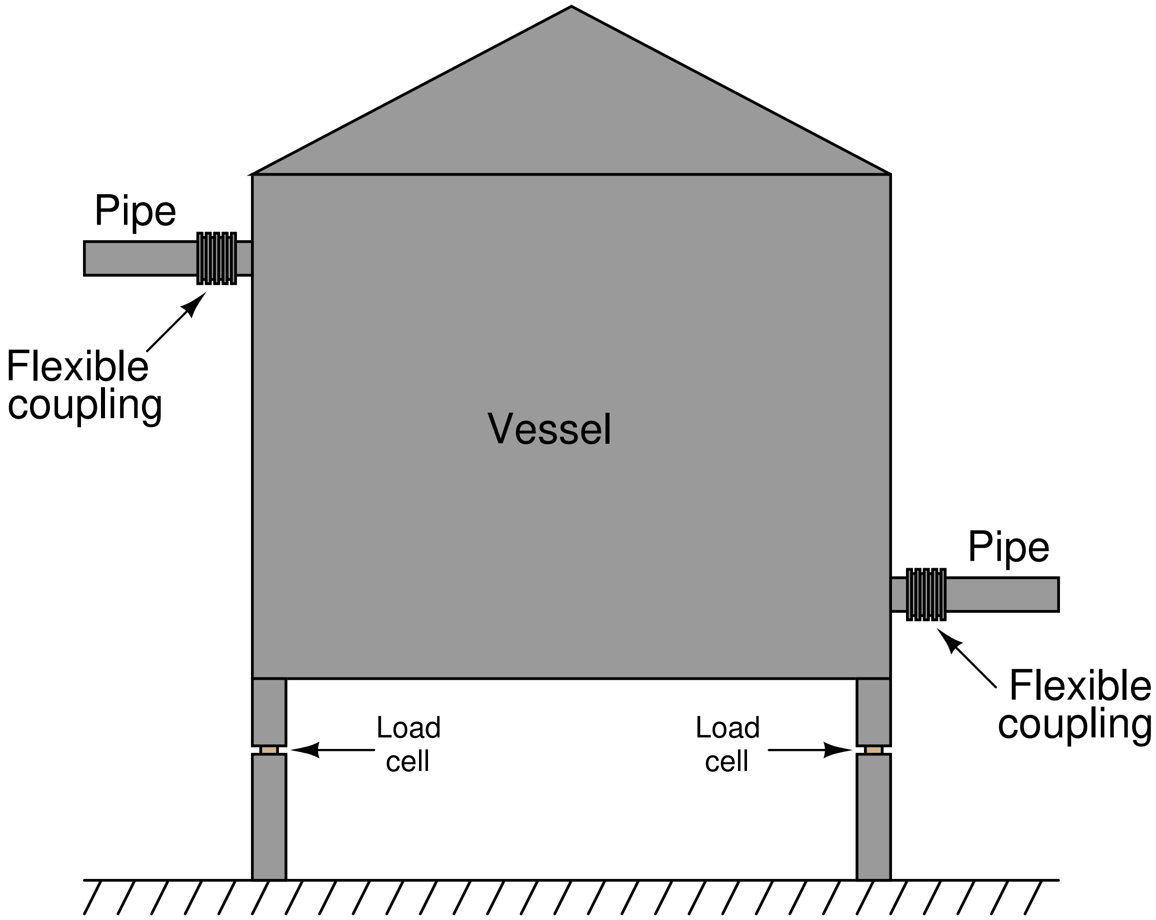
- Why use salt water instead of normal tap water?
- If the bottle were made of thinner glass (all other factors being the same), would the capacitance *increase* or *decrease*?
- If the bottle were taller (all other factors being the same), would the capacitance *increase* or *decrease*?

- If the bottle were wider (all other factors being the same), would the capacitance *increase* or *decrease*?

file i00317

Oppgave 25

When using load cells to measure vessel level, certain precautions must be taken to ensure accurate measurements:



One important precaution to take is installing flexible couplings on all pipes leading into and out of the vessel. Rigid pipes will cause measurement errors – explain why this is.

Supposing this (vertical) cylindrical storage tank is 10 feet in diameter, 8 feet high from the tank bottom to the base of the conical roof (11 feet from the tank bottom to the roof peak), fabricated entirely of mild steel, and weighs 12,933 pounds when empty, calculate the liquid level inside the tank at a measured total weight of 40,854 pounds. Assume a liquid with a density of 60.5 pounds per cubic foot.

Suggestions for Socratic discussion

- Identify some practical applications in industry where weight-based level measurement would be preferable over other technologies.
- One of the factors potentially causing measurement errors in a system such as this *weather*, at last for vessels located outside. Identify some specific weather conditions that could cause problems, and explain how those problems would show up in the vessel's level indication signal.

file i00326

Oppgave 26

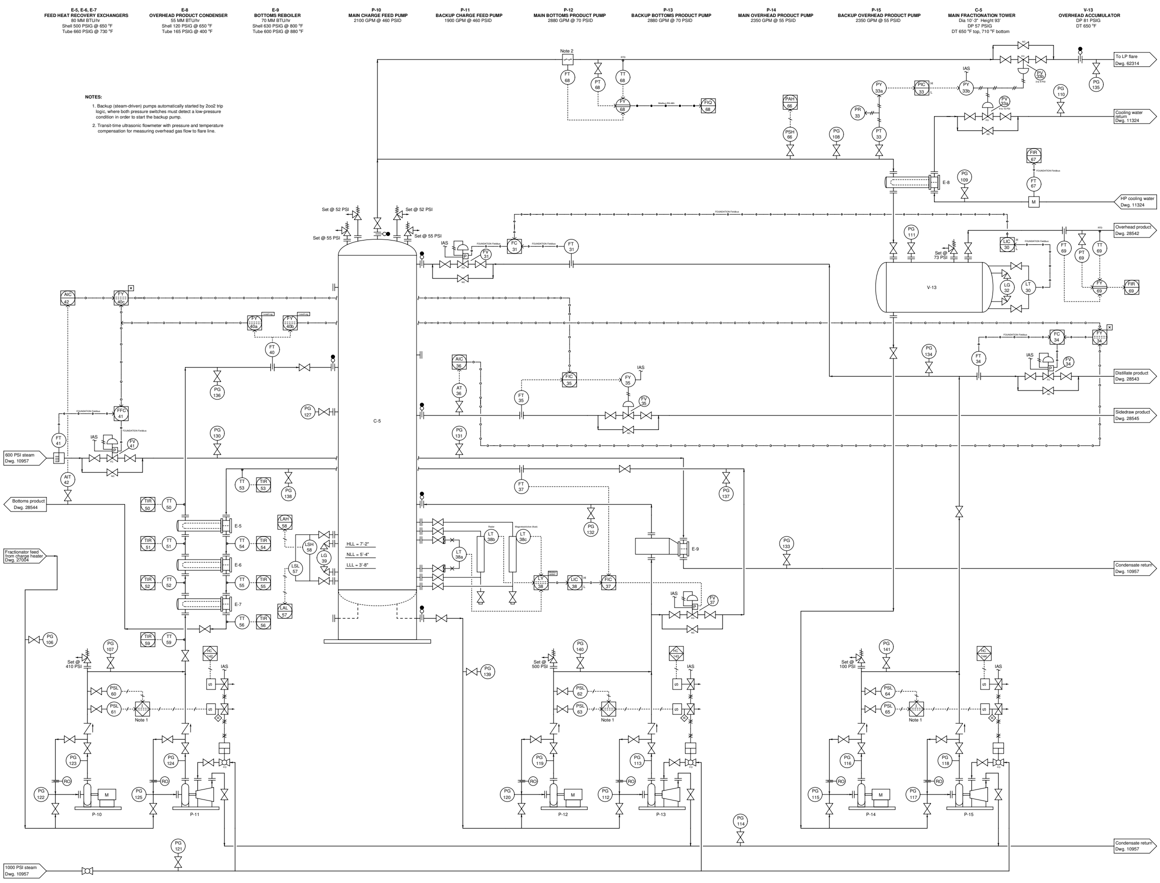
If an ultrasonic level instrument is used to measure the level of nitric acid in a vessel, and the density of that acid increases over time due to increased concentration, how will the instrument respond? Will it register an increased acid level, a decreased acid level, or will its indication remain the same as before? Explain your answer.
file i00802

Oppgave 27

If a tape-and-float level instrument is used to measure the level of alcohol in a vessel, and the density of that alcohol suddenly decreases, how will the instrument respond? Will it register an increased alcohol level, a decreased alcohol level, or will its indication remain the same as before? Explain your answer.
file i00803

Oppgave 28

Three level-sensing instruments measure the same liquid level at the bottom of this fractionation tower (LT-38a, LT-38b, and LT-38c), but their measurements do not agree. An operator calls you to investigate, showing you on the control system display how LT-38a registers 34.8%, LT-38b registers 35.1%, and LT-38c registers 40.4%. According to the P&ID, LT-38a is hydrostatic (sensing pressure through two remote seals), LT-38b is a radar instrument (sensing liquid level by the reflection time of a radar wave inside a cage), and LT-38c is magnetostrictive (sensing the position of a float inside of another cage). The indicating controller (LIC-38) shows a level of 35.1%:



Based on the information you have, identify a condition that could account for the discrepancy in these transmitter indications, and also determine what your first diagnostic step will be.

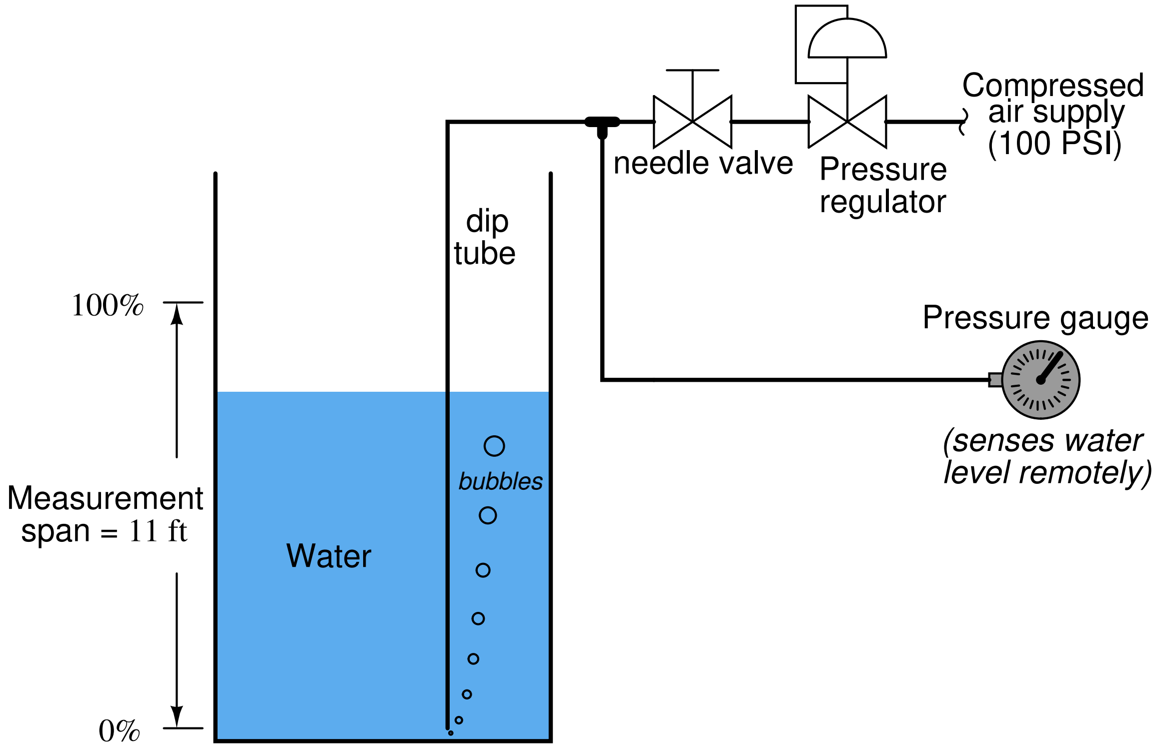
Suggestions for Socratic discussion

- Why do you suppose three different instruments are used to measure the same liquid level in this application?
- Identify the function of LY-38.

file i01200

Oppgave 29

A "bubbler" or "dip tube" system may be used to transfer hydrostatic pressure from within a process vessel to some location outside the vessel, allowing a pressure-sensing instrument such as a gauge or transmitter to sense the liquid level inside the vessel without actually contacting the process liquid:



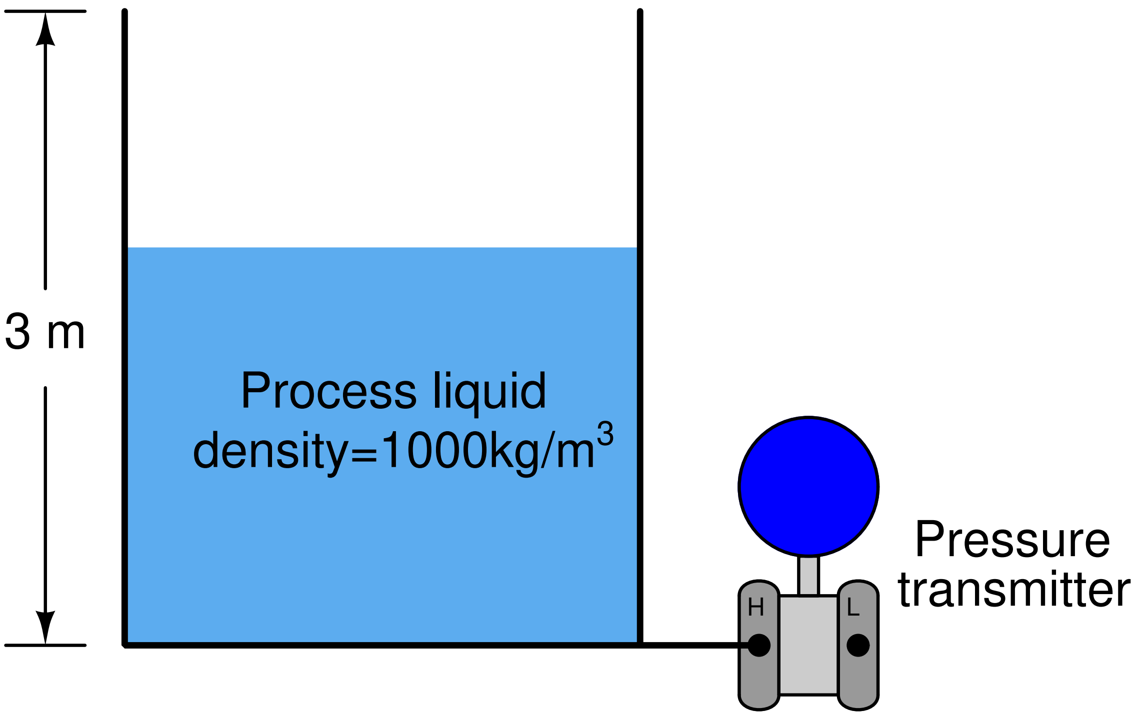
If the flow of purge air to the dip tube is slow, such that individual bubbles come out the end of the tube at a leisurely pace (one or two bubbles per second), the dip tube will function as a sort of "pressure relief" device. At such a low flow rate, the air pressure within the dip tube almost exactly equalizes with the hydrostatic pressure of the liquid at the bottom of the tube. Explain why this is, in your own words.

Also, calculate the amount of pressure seen by the pressure gauge in this bubbler system, given a water height of 8 feet and 10 inches inside the vessel. Assume the pressure regulator is set to 35 PSI.

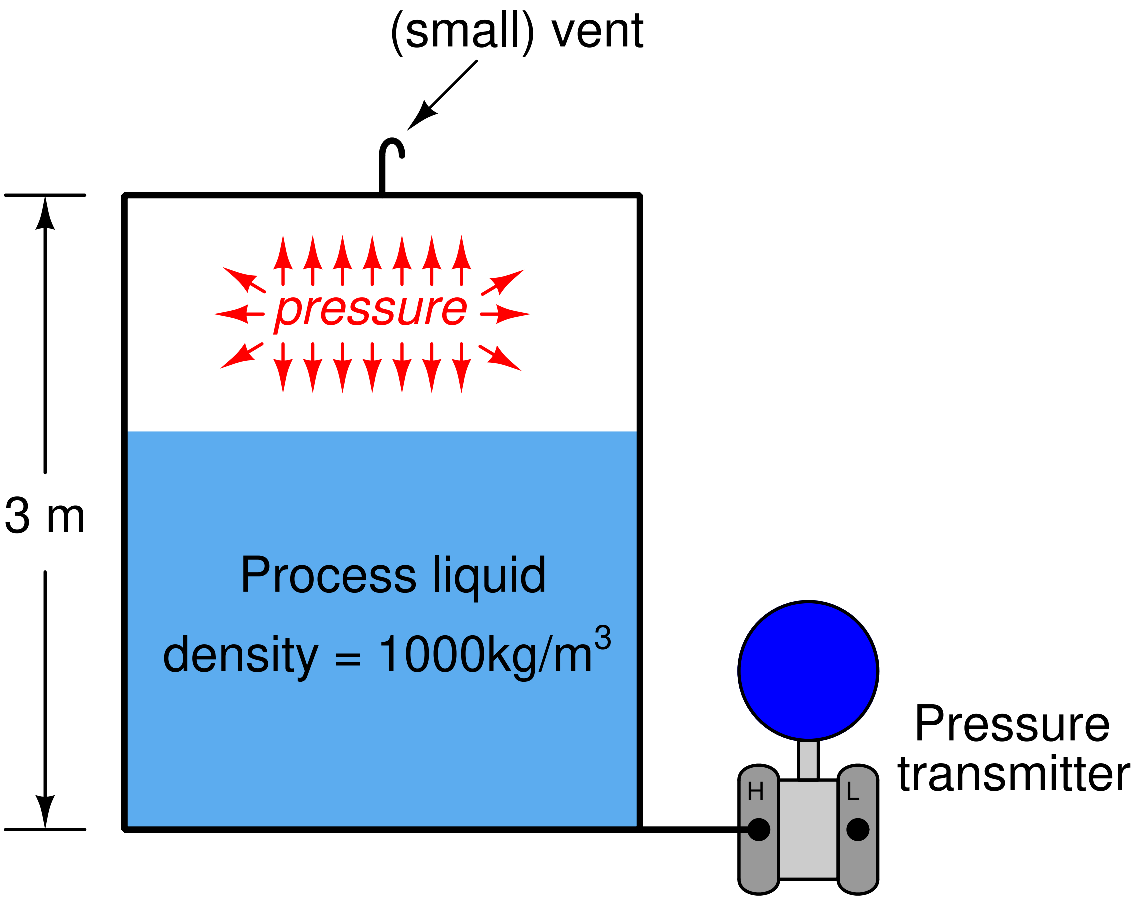
file i02954

Oppgave 30

A vessel holding some process liquid needs to have its level monitored. The range of level in this vessel is 0 to 3 meters, and the process liquid has a densety og 1000 kg/m^3 like water. Someone decides to attach a pressure transmitter to the bottom of the vessel to infer level from hydrostatic pressure like this:



Later, a top is added to this vessel to keep rain from entering in. Unfortunately, though, this process liquid tends to emit vapor which will be trapped by the closed vessel and create a pressure inside of it. A small vent is added to the top of the vessel to permit the vapor to escape, but it is a *small* vent, not big enough to ensure a total absence of vapor pressure buildup at all times:



What problem in level measurement will result from there being an occasional vapor pressure buildup inside this vessel? How may this problem be corrected so that the liquid level will be accurately measured at all times?

file i00248

Oppgave 31

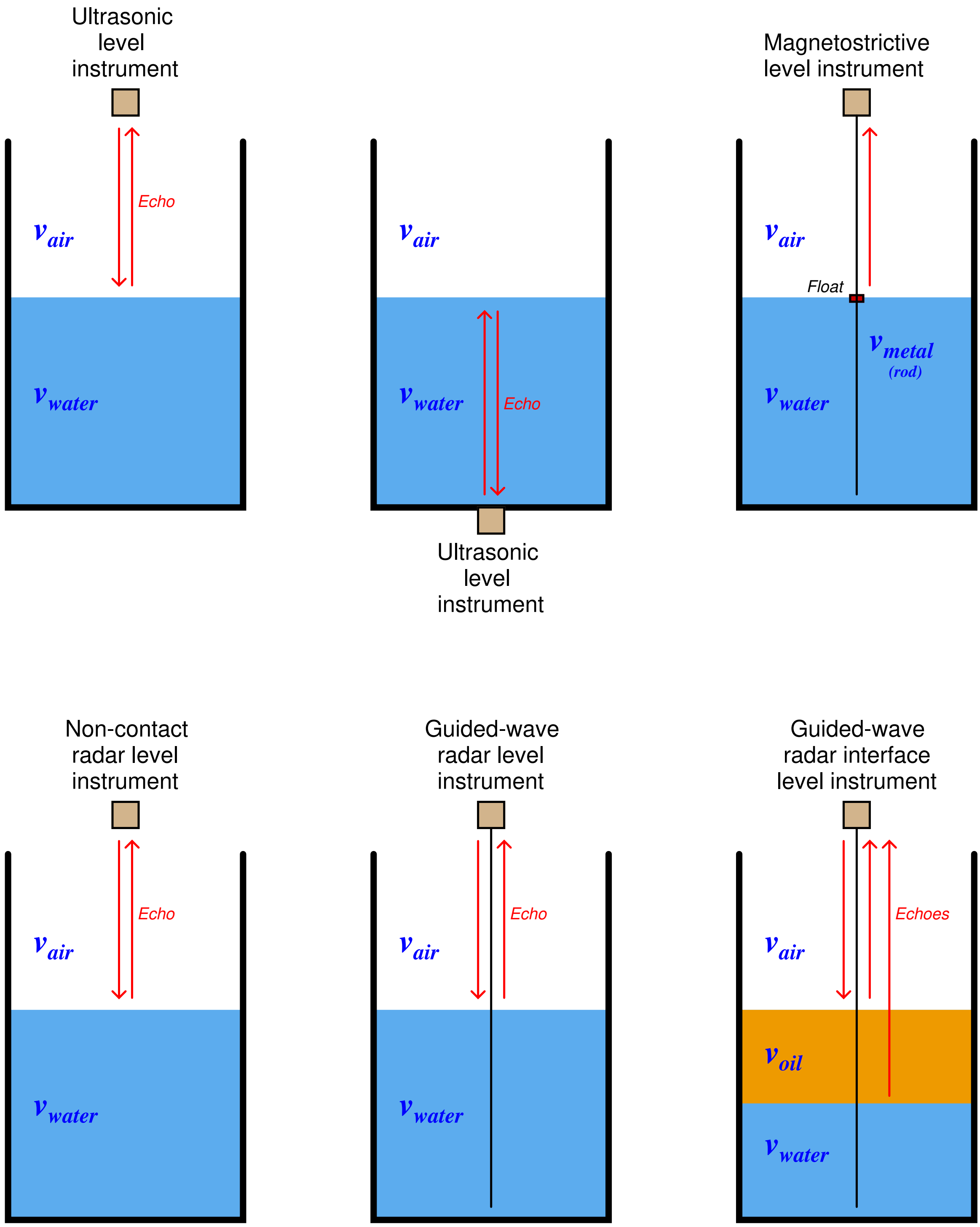
A large vessel containing crude oil has a defective radar-based level transmitter. Until the level transmitter is replaced by one of your co-workers, operators need to periodically check the crude oil level in the vessel. The vessel is vented, but inaccessible to a tape measure, float, or any other manual "sounding" device one might ordinarily use to determine liquid level in a vessel.

Devise a way to provide a simple yet reasonably accurate level measurement indication for operators to use while they wait for the radar-based level transmitter to be replaced.

file i03591

Oppgave 32

Ultrasonic, radar, and magnetostrictive level measuring instruments use the principle of *time-of-flight* to determine the level of a process substance in a vessel. A critical factor for the accuracy of any time-of-flight measurement technology is the velocity of propagation for the wave in question, through the substance(s) that wave must travel. Examine each of these illustrations and then determine which of the velocities of propagation (v) matter and which do not. Be prepared to explain why, in each case!



Next, identify physical variables effecting the velocity of propagation for each of the waves in question.

Suggestions for Socratic discussion

- Which of these level-sensing technologies do you suspect enjoys the greatest immunity from calibration error resulting from changing process conditions?
- In each case, identify factors influencing the *strength* of the received signal.

file i03625

Oppgave 33

Identify characteristics of various level-measurement technologies. *An important tip is to commit to memory the operating principle of each instrument type, and then reason from that basis what each type's characteristics will be*:

Sightglass

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Float

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Hydrostatic (DP with direct contact)

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Hydrostatic bubbler (dip tube)

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Ultrasonic

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Non-contact radar

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Guided-wave radar

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Magnetostrictive

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

Weight (load cells on vessel)

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

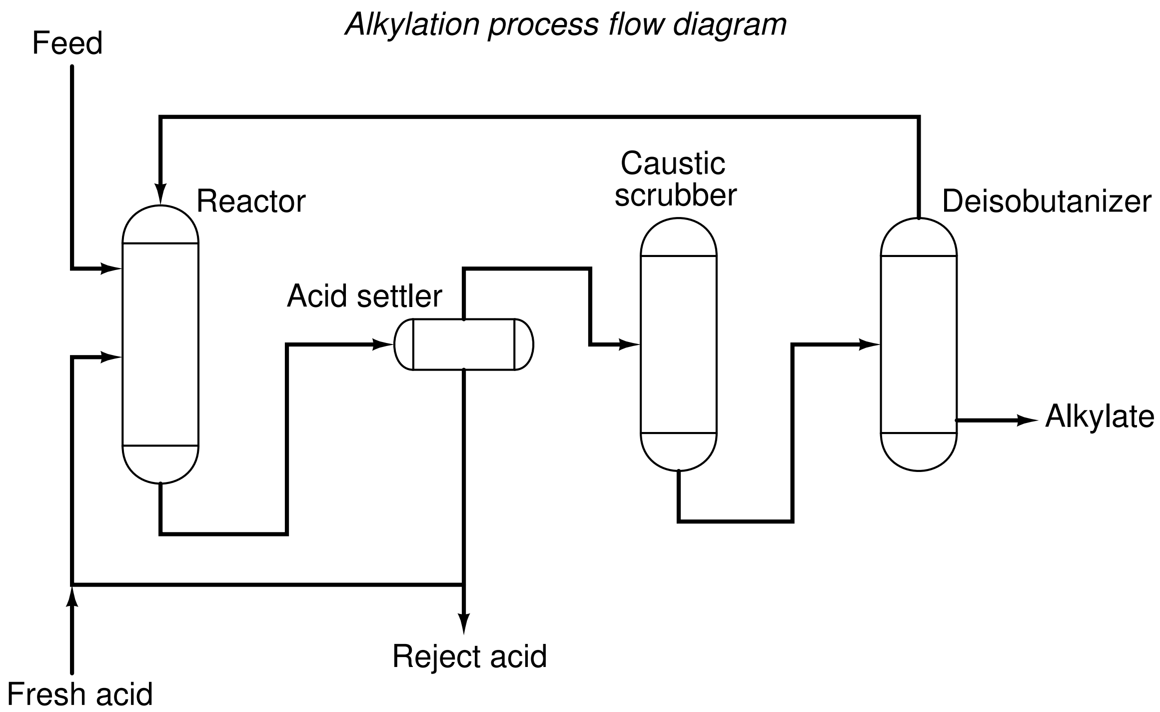
Capacitive

- Can it be used to measure the level of both liquid and solid materials?
- Can it be used to measure liquid-liquid interfaces?
- Does its calibration depend on some fluid property such as density?
- Special advantages:
- Special disadvantages:

file i03037

Oppgave 34

A process used in the oil refining industry to make high-octane gasoline feedstock is called *alkylation*. So-called "alky" units employ a concentrated acid as the catalyst for the alkylation reaction, usually sulfuric acid:



The "acid settler" vessel is a separator, allowing the reaction products and acid catalyst to separate according to their respective densities (concentrated sulfuric acid being denser than any hydrocarbon). The interface level between hydrocarbon liquid and acid must be tightly controlled for the process to work well. It is bad for acid to "carry over" to the caustic scrubber (if the interface rises too high), and it is also bad for hydrocarbon liquids to leave the system through the "reject acid" line (if the interface falls too low).

The major problem here is that the sulfuric acid is highly corrosive, creating a challenge for interface level measurement. Identify a few different level-measurement technologies that might be appropriate for sensing the settler's interface level.

Suggestions for Socratic discussion

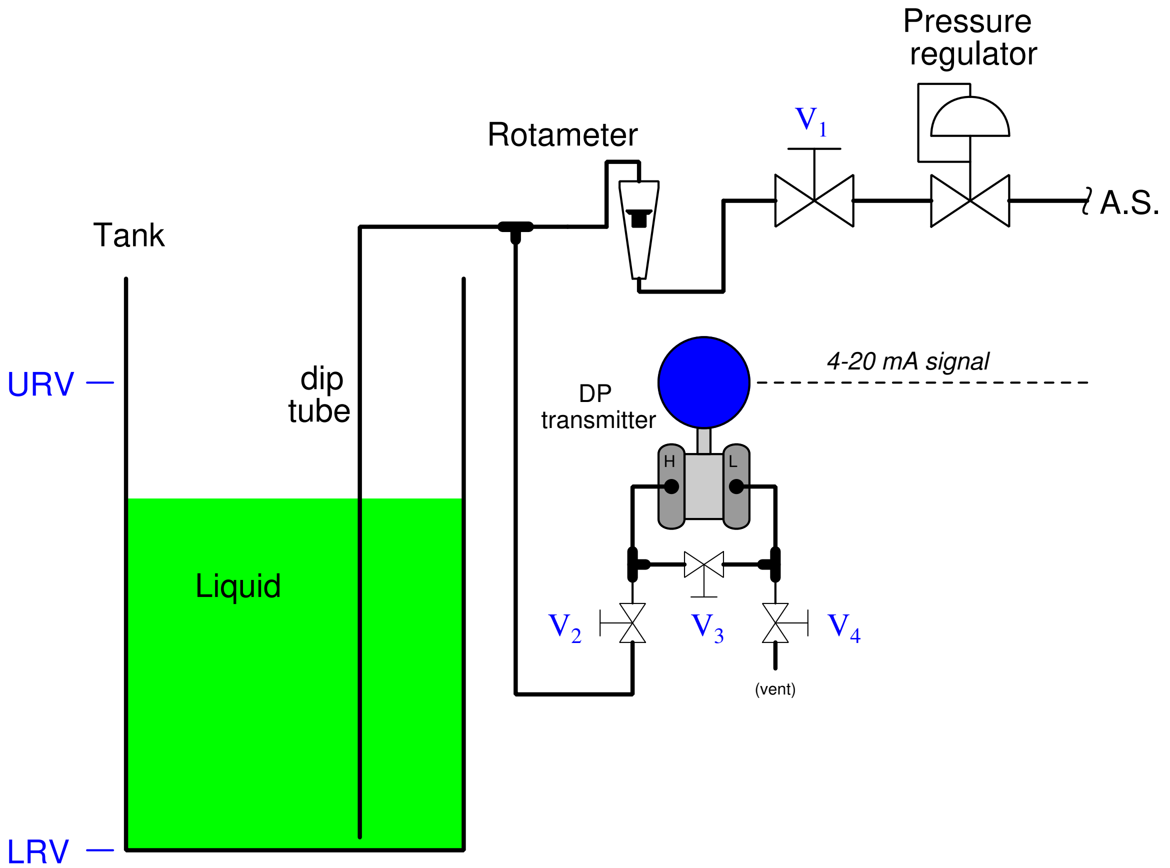
- By contrast, can you think of some level-measurement technologies that would *not* be appropriate for highly corrosive solutions?
- Identify some of the different *flowmeter* technologies appropriate to various process lines shown for this alkylation unit.
- What types of *personal protective equipment* (PPE) do you think an instrument technician might need to wear before working on a instrument contacting this highly concentrated acid?
- How much fresh acid needs to be sent to the reactor, compared to the hydrocarbon feed rate? Explain your answer based on what a *catalyst* does in a chemical reaction.

- Older alkylation units used *hydrofluoric acid* instead of sulfuric acid because HF is a more effective catalyst for the alkylation reaction than H_2SO_4. Unfortunately, while sulfuric acid at this concentration is quite dangerous, hydrofluoric acid is far worse. HF tends to penetrate skin easier than many other acids, and when inside the body it dissolves bones! Explain why the first-aid for topical HF exposure is to apply (or sometimes inject) a calcium gluconate ($C_{12}H_{22}CaO_{14}$) solution.

file i04139

Oppgave 35

The following "bubbler" level measurement system has a problem. It registers zero level at all times, no matter what the actual liquid level is in the tank. Inspecting the rotameter, you see it does register a continuing flow of purge air:



Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

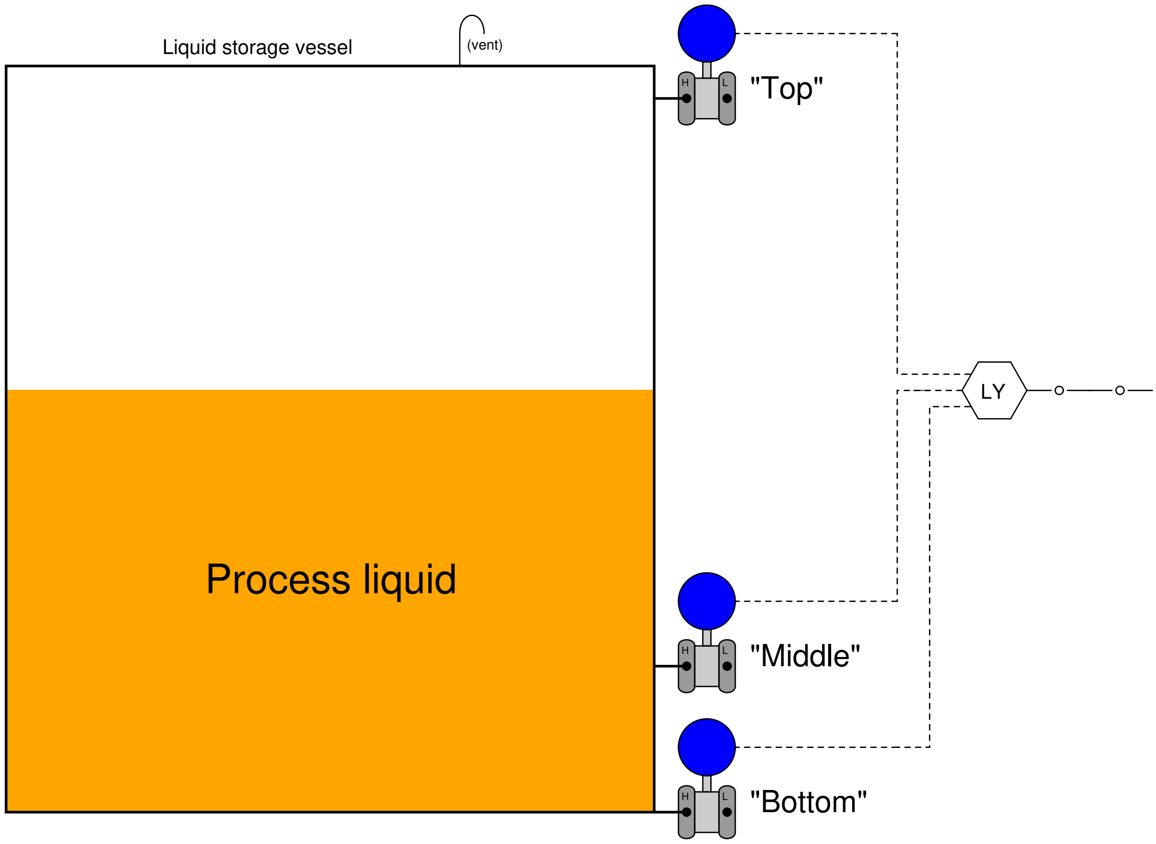
Fault	**Possible**	**Impossible**
Leak in dip tube above liquid level		
Valve V_1 closed		
Valve V_2 closed		
Valve V_3 closed		
Valve V_4 closed		
Regulator mis-adjusted		
Dip tube plugged		
Air supply dead		
Leak in dip tube below liquid surface		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

file i04680

Oppgave 36

A *tank expert* system uses three pressure transmitters to measure level and density of a liquid in a large storage vessel. The three transmitters are labeled "top," "middle," and "bottom," as such:



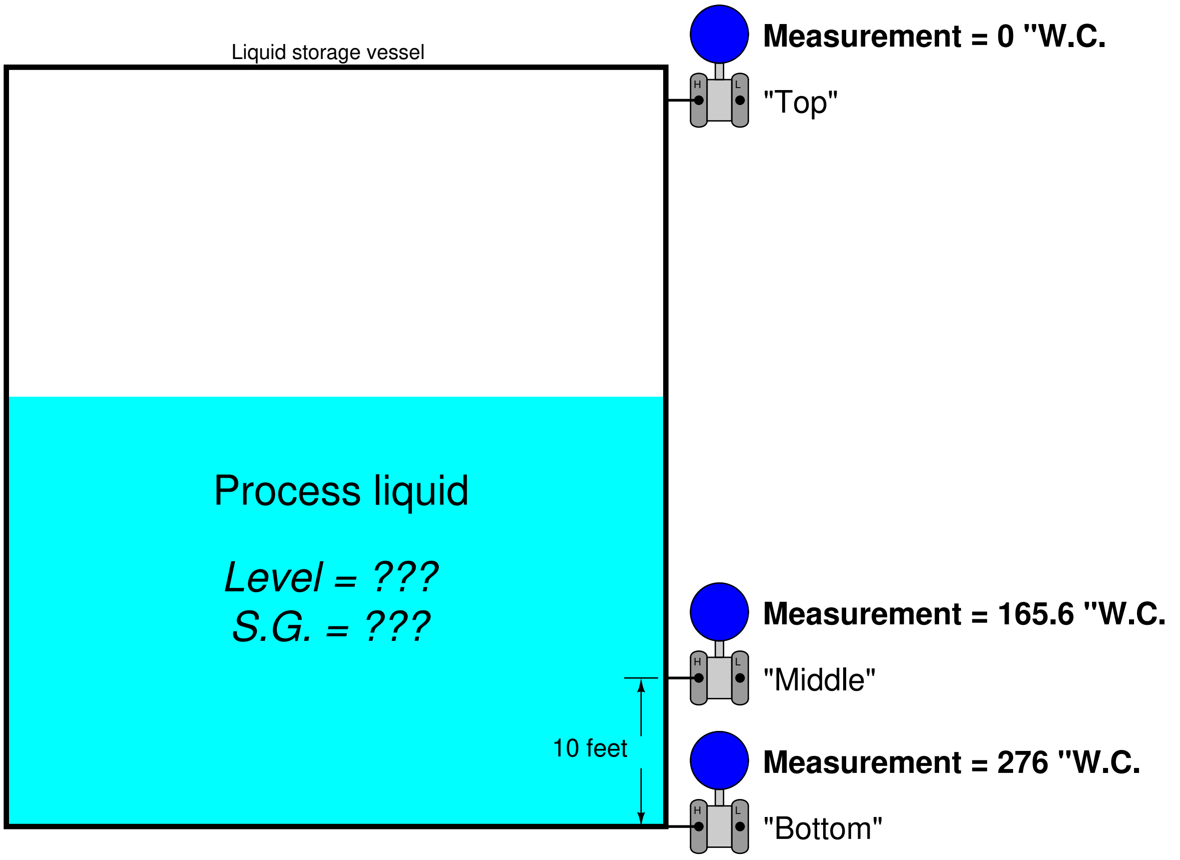
Tank expert systems use a computer (LY in the diagram) to process data gathered from the three pressure transmitters, calculating both liquid density and liquid level. The distance between the "middle" and "bottom" pressure transmitters is known from installation and entered into this computer system as a constant value, to be used in the calculations. An important requirement of a tank expert system is that the liquid level must be above the "middle" pressure transmitter's location if density is to be calculated.

Suppose that a tank expert system has the "middle" transmitter located 10 feet above the bottom of the vessel, the "bottom" transmitter at the very bottom of the vessel, and the "top" transmitter at the very top. Supposing that the vessel is vented at the top (preventing any vapor pressure buildup) and is 40 feet tall, and the liquid level inside is 15 feet with a specific gravity of 0.86, what pressures will the three pressure transmitters report to the computer system under these conditions? In other words, what will be the "raw" data input to the computer system under these conditions?

file i00254

Oppgave 37

A tank expert system gives the following pressure indications from its three transmitters:

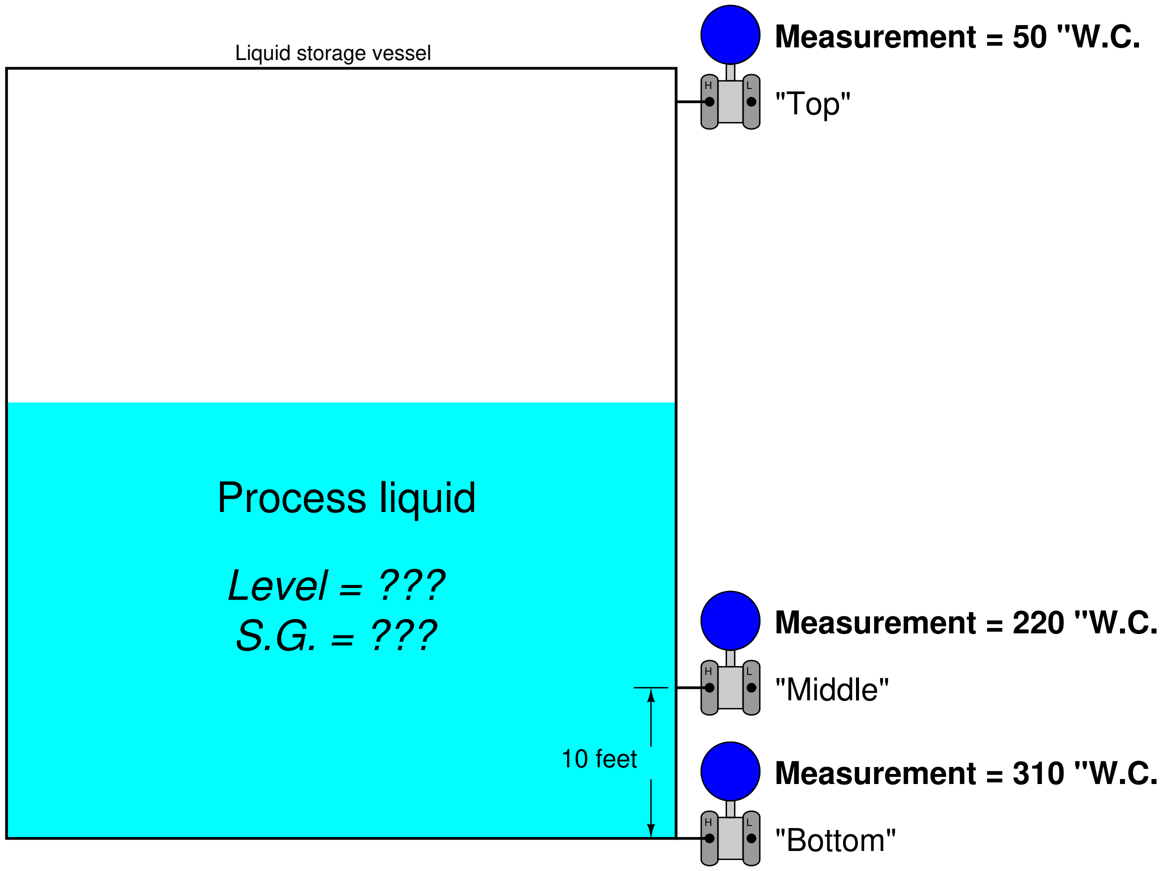


From these pressure measurements, determine the level of liquid in the vessel and its specific gravity. Be sure to explain how you obtained your answers!

file i00255

Oppgave 38

A tank expert system gives the following pressure indications from its three transmitters:

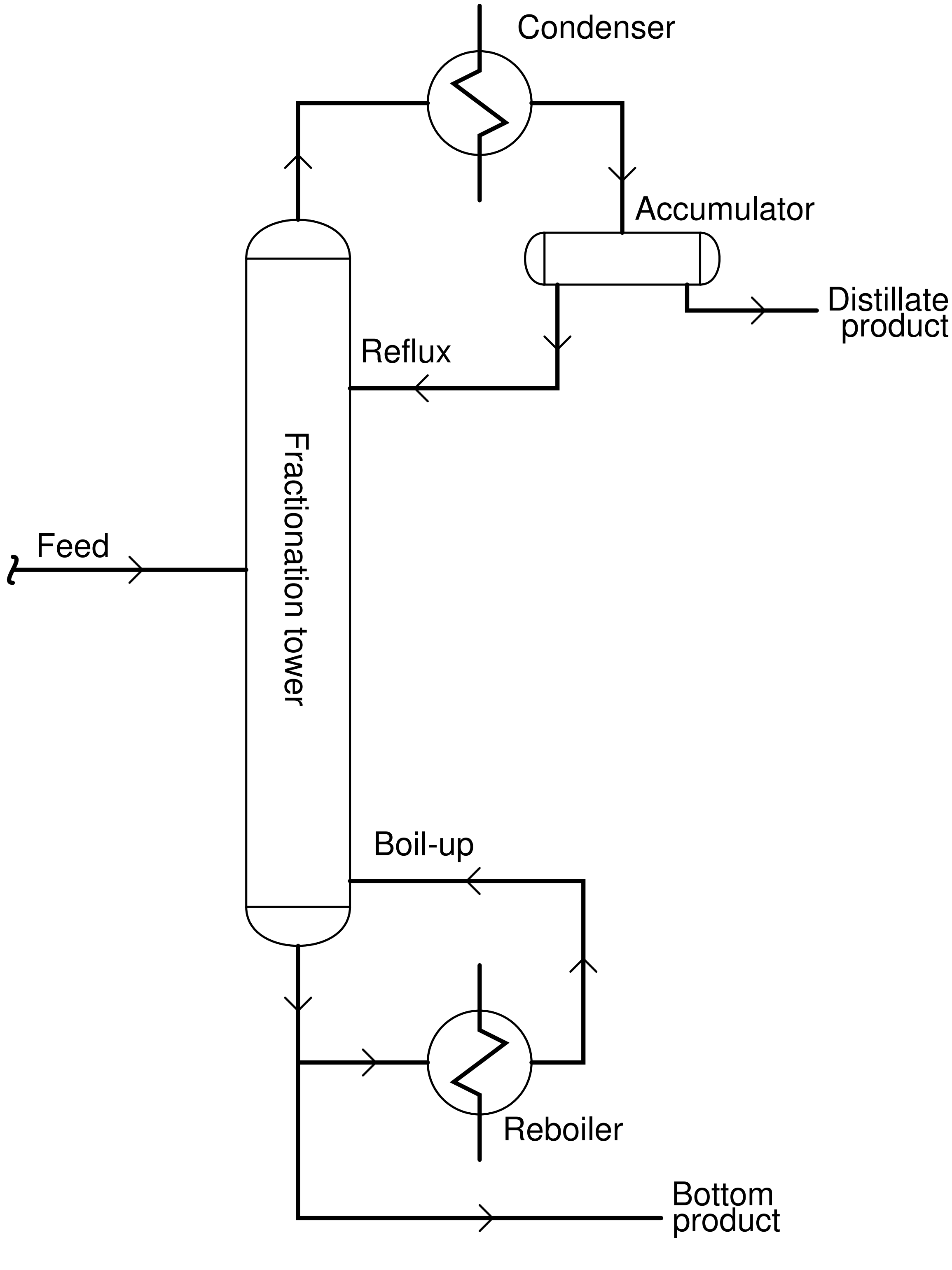


From these pressure measurements, determine the level of liquid in the vessel and its specific gravity. Also, write mathematical equations for calculating both these parameters given the three pressure sensor measurements.

file i00256

Oppgave 39

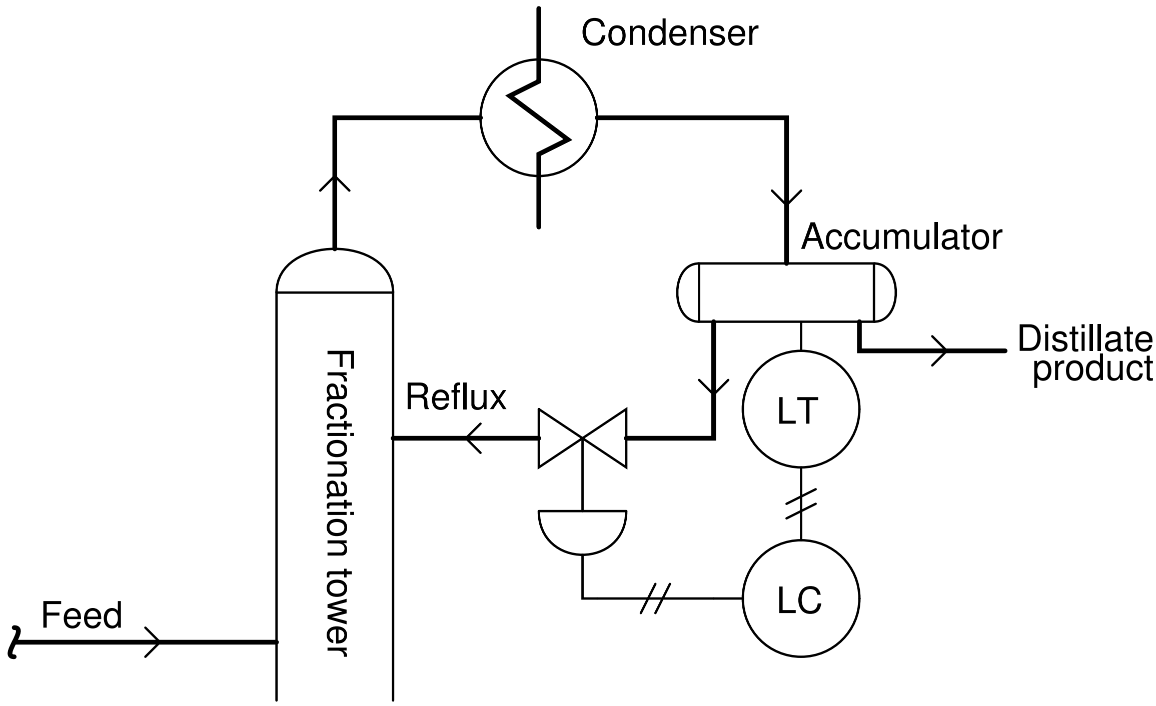
Shown here is a distillation tower, used to separate a liquid mixture of substances into its constituent components. The process of *distillation*, or *fractionation* as it is sometimes called, is very common in heavy process industries, most notably petrochemical processing:



Distillation of this nature works on the principle of different boiling points. The distillation of alcohol (to separate a water/alcohol mix in order to obtain a purer alcohol product) is a well-known application of this technology. In a fractionation tower, the process of boiling and condensation of the mixture's constituent components is repeated endlessly, assuring a high degree of separation between them.

The light vapors extracted from the top of a distillation tower are re-condensed into an "accumulator" vessel and re-introduced into the fractionation process as "reflux." The heavy vapors condensing at the bottom of the tower are re-boiled into vapor form again and re-introduced into the fractionation process as "boil-up." It is necessary for reflux and boil-up to be re-introduced into the tower in order to purify the final products as much as possible. The P&ID shown here is devoid of any instrumentation for the sake of simplicity.

Here, a simple reflux control loop is shown, to control the amount of reflux introduced into the tower from the accumulator:



Suppose the level transmitter in this system fails such that it always outputs a high (21 mA) signal. Determine the effect this fault will have on the accumulator's liquid level.

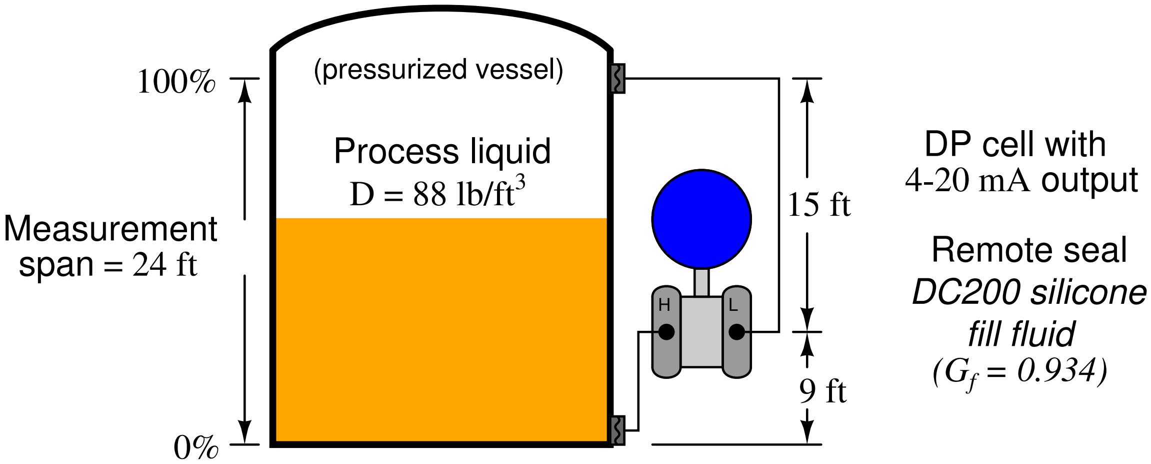
Suggestions for Socratic discussion

- Judging by the symbols used in this P&ID, what type of control system is this on the accumulator level loop (i.e. what type of signaling is used, where are the instruments located, etc.)?
- Identify appropriate level measurement technologies that might be used in this application, since the diagram shown is too vague to reveal specifics.

file i04681

Oppgave 40

An electronic differential pressure transmitter with remote (chemical) seals is used to measure the level of liquid in this pressurized vessel. The specific gravity of fill fluid in both remote seals is 0.934. The range of liquid level measurement is 0 to 24 feet, and the output signal range is 4 to 20 mA. Assume a calibration tolerance of +/- 0.25 percent. Complete the following table of values for this transmitter. Show the equations used to calculate all values given the percentage of span (x):



Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Equations used:

Process level =

Pressure sensed =

Output signal (ideal) =

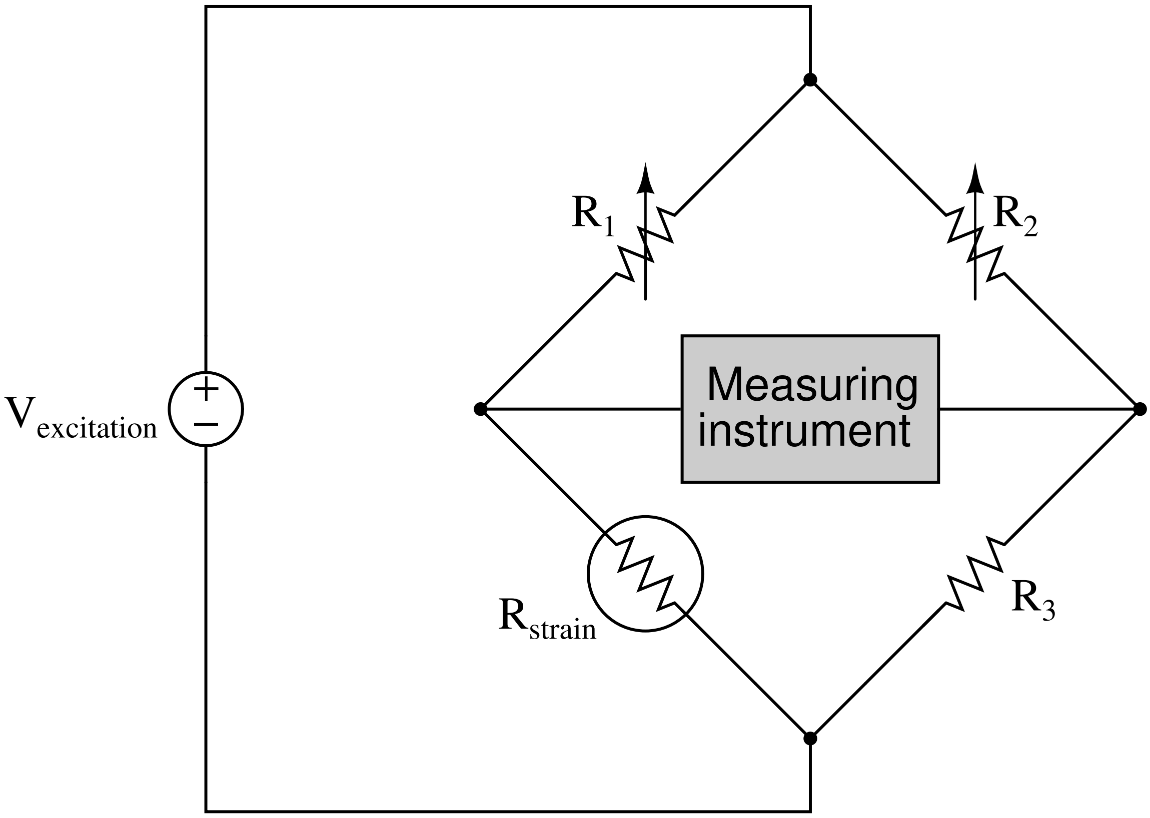
Output signal (min.) =

Output signal (max.) =

file i00033

Oppgave 41

Strain gauges may be used to measure the weight of a process vessel, and therefore infer the level of fluid or solids in that vessel. Strain gauge circuits almost always take the form of a Wheatstone bridge, the bridge circuit producing an output voltage that varies with the amount of strain sensed by the gauge:



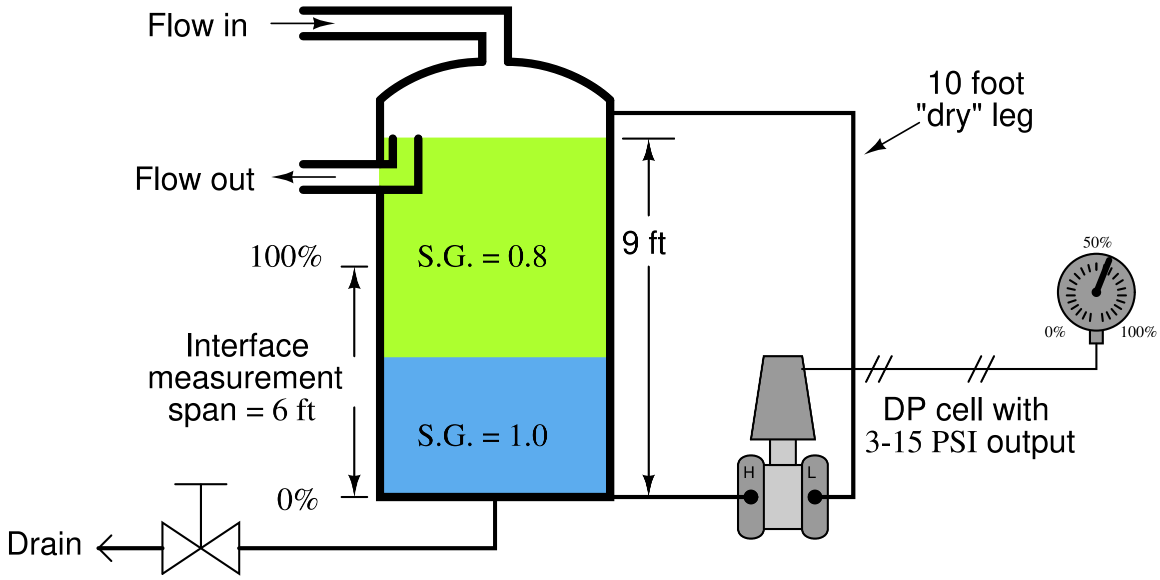
Assume that the bridge is balanced when the vessel is empty (zero level), and that the resistance of the strain gauge increases with increasing vessel weight (increasing level). Identify:

- The polarity of the voltage across all bridge resistors.
- The polarity of the voltage sensed by the measuring instrument as level increases.
- Which variable resistance (R_1 or R_2) adjusts *zero*.
- Which variable resistance (R_1 or R_2) adjusts *span*.
- One electrical fault resulting in a positive over-range (> 100 % level) reading.
- One electrical fault resulting in a negative over-range (< 0 % level) reading.

file i00038

Oppgave 42

In this process, water is separated from an oil stream by gravity. The oil floats to the top of the vessel where it exits, while the water settles to the bottom and is drained off periodically by opening a hand valve. A hydrostatic level transmitter detects the height of the oil/water interface and lets the human operator know when to open up the water drain valve:



Calculate values for the following calibration table, such that the transmitter will register the height of the oil/water interface from 0 to 6 feet off the bottom of the vessel. Note that the oil/air interface is held at a constant 9 feet of level by the position of the overflow tube. Assume a vapor pressure inside the vessel of 2.53 PSI and a transmitter calibration tolerance of +/- 0.25%:

Interface level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Suggestions for Socratic discussion

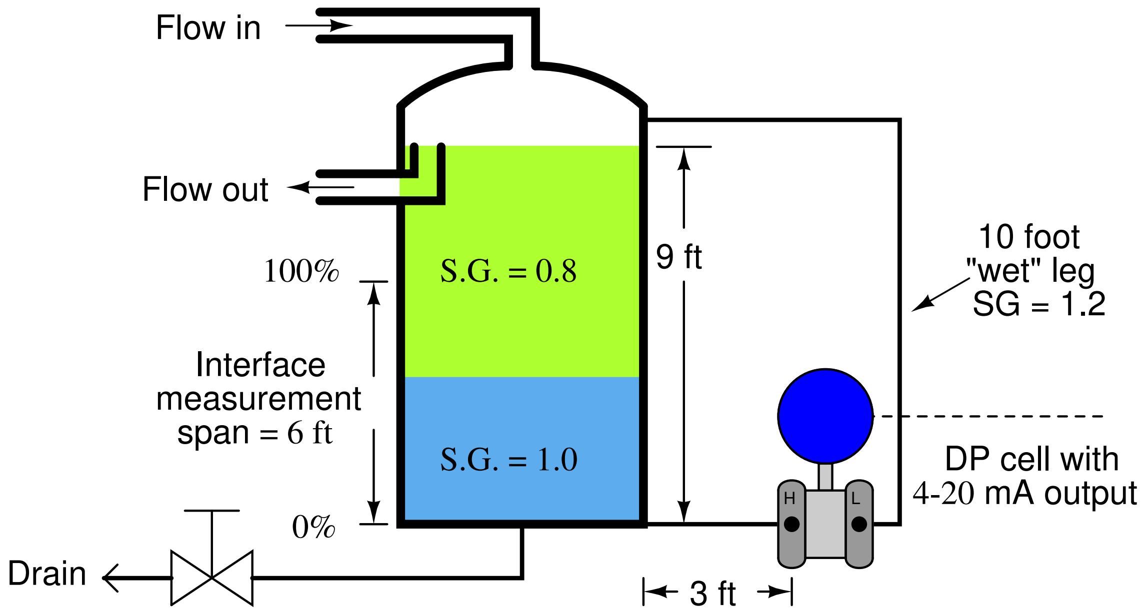
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- How will this level transmitter respond if the gas pressure inside this vessel were to increase?

- How will this level transmitter respond if the gas pressure inside this vessel were to decrease?
- How will this level transmitter respond if the overflow pipe were to be blocked off, so no light liquid could exit the vessel?
- How will this level transmitter respond if some liquid enters the otherwise "dry" compensating leg?

file i00309

Oppgave 43

Calculate values for the following calibration table, for a transmitter measuring liquid level interface (specific gravities = 0.8 and 1.0), with a calibration tolerance of ± 1% and a 4-20 mA output range. Be sure to specify which port on the ΔP transmitter to apply the calibration pressure:



Interface level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand.**

Suggestions for Socratic discussion

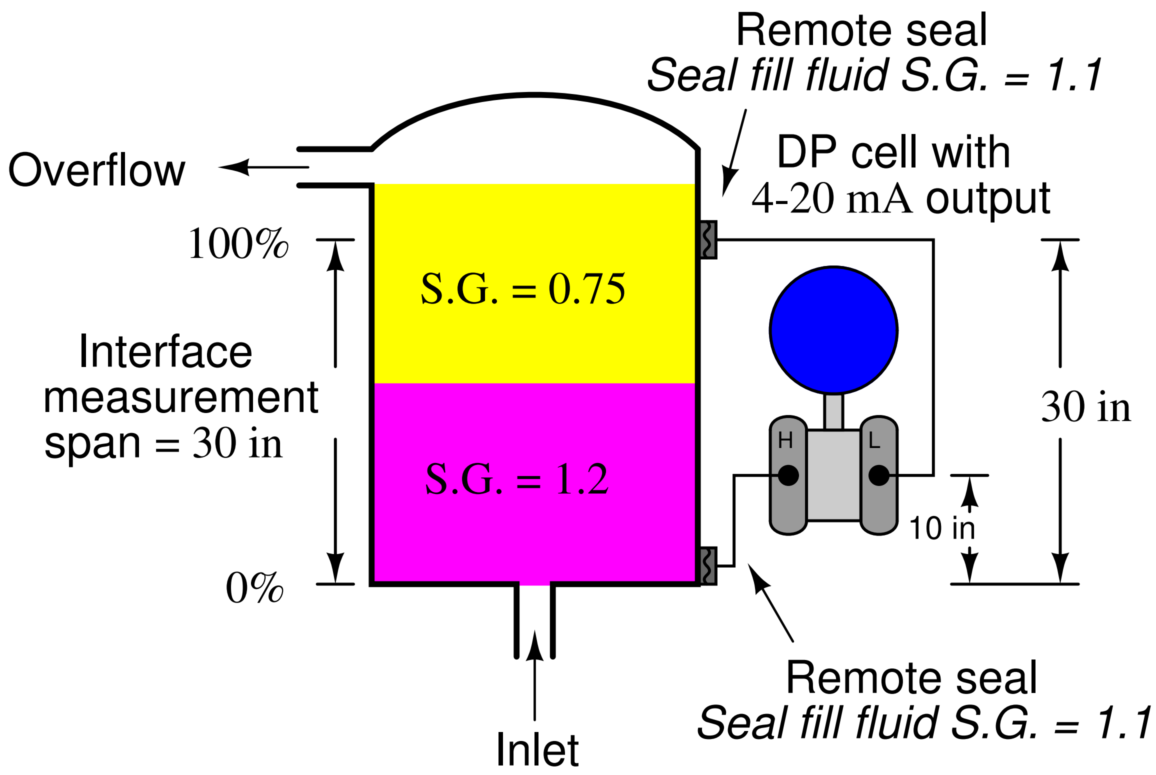
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- How will this level transmitter respond if the gas pressure inside this vessel were to increase?

- How will this level transmitter respond if the gas pressure inside this vessel were to decrease?
- How will this level transmitter respond if the overflow pipe were to be blocked off, so no light liquid could exit the vessel?
- How will this level transmitter respond if the heavier fluid's density were to increase, yet the interface level remain the same?
- How will this level transmitter respond if the lighter fluid's density were to increase, yet the interface level remain the same?

file i00310

Oppgave 44

Calculate values for the following calibration table, for a transmitter measuring liquid level interface (specific gravities = 0.75 and 1.2), with a calibration tolerance of ± 0.1%. Be sure to specify which port on the ΔP transmitter to apply the calibration pressure:



Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand.**

Suggestions for Socratic discussion

- Does the position of the transmitter within the 30 inch span matter? For example, would the calibration be affected if the transmitter were re-located just 5 inches higher, without moving the remote seals? Why or why not?
- Suppose the process vessel were not filled all the way up to the overflow point. How would this change affect the accuracy of the level transmitter? Would it register falsely low, falsely high, or would it still register as it should?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00311

Oppgave 45

A pneumatic level transmitter has a calibrated range of 0 to 5 feet, and its output signal range is 3 to 15 PSI. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (feet)	Percent of span (%)	Output signal (PSI)
3.2		
		4
	50	
2.4		
		11.3
	18	

file i00097

Oppgave 46

An ultrasonic level transmitter has a calibrated range of 40 to 75 inches and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (inches)	Percent of span (%)	Output signal (mA)
47		
		6
	75	
60		
		15.1
	34	

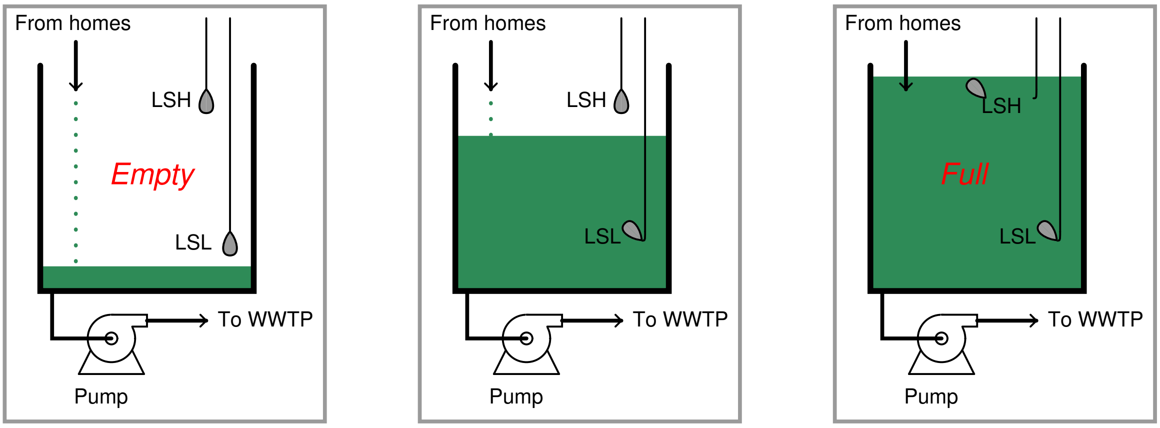
Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

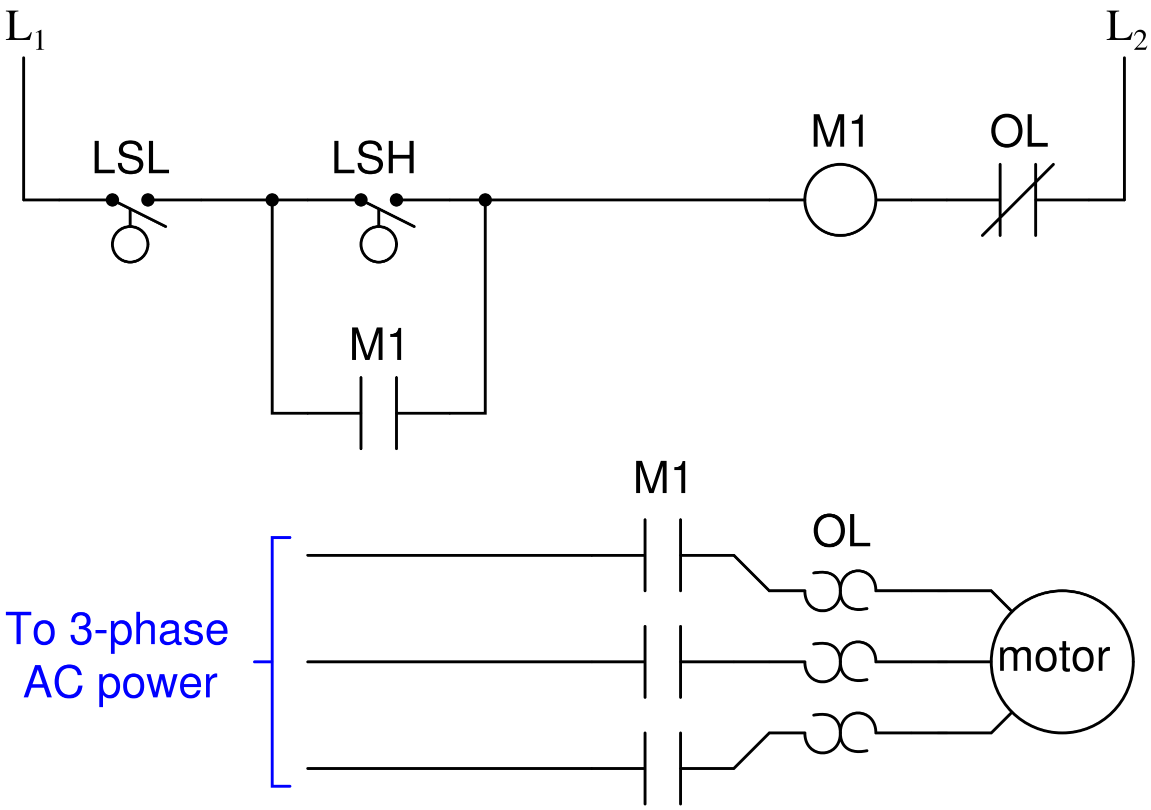
file i00098

Oppgave 47

A form of liquid level switch called a *tilt switch* is often used for detecting sewage level in "lift stations" where sewage collected from homes via gravity is pumped out of the collection sump to the wastewater treatment plant (usually located miles away):



Suppose the pump motor refuses to start even with the sump level above the LSH position:

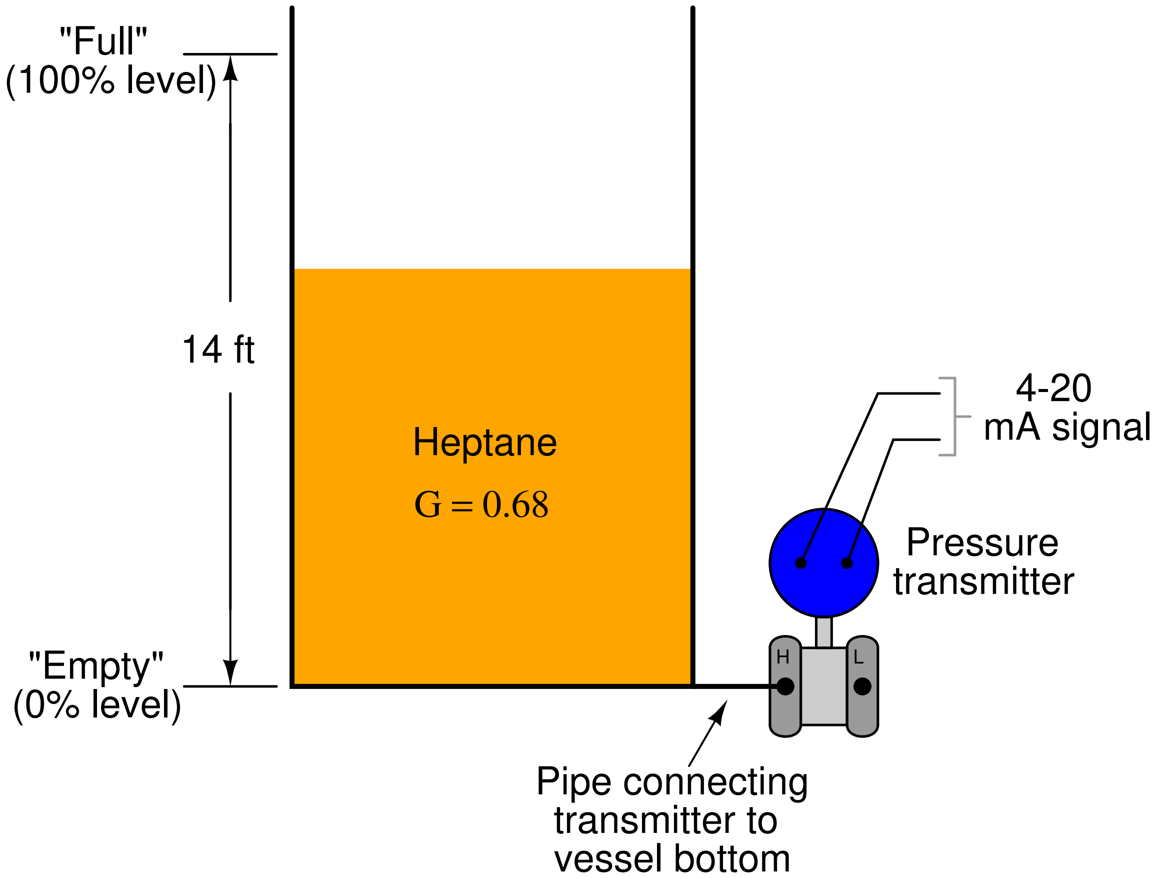


An electrician claims this could be the result of the M1 auxiliary contact (connected in parallel with the LSH) being failed open. Do you agree? Also, identify at least two other possible causes of the pump not starting at a high-level condition.

file i00037

Oppgave 48

The following storage vessel holds liquid heptane, a hydrocarbon with an approximate specific gravity of 0.68. A pressure transmitter located at the bottom infers heptane level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 14 feet) into an output signal of 4 to 20 mA. Please express the transmitter's calibration range in units of inches W.C. (inches of water column).



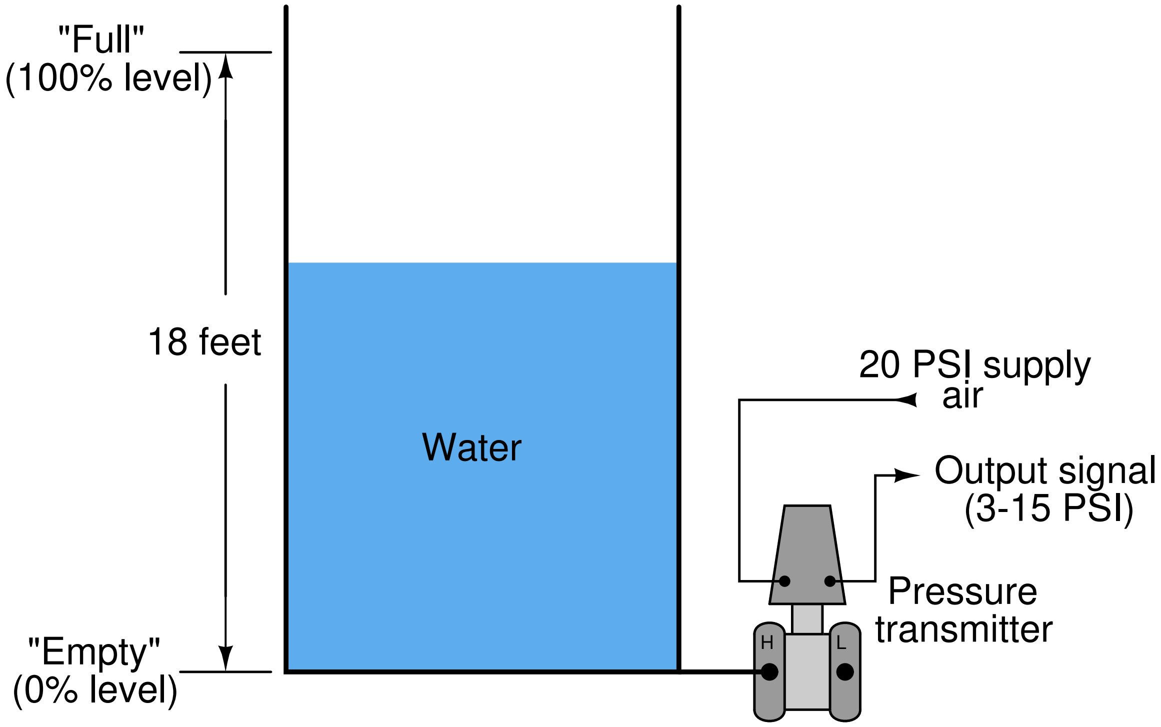
Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (mA) at 8 feet of level
- Heptane level at 5.7 mA signal output

file i00241

Oppgave 49

The following storage vessel holds water. A pneumatic pressure transmitter located at the bottom infers water level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 18 feet) into an output signal of 3 to 15 PSI. Please express the transmitter's calibration range in units of inches W.C. (inches of water column).



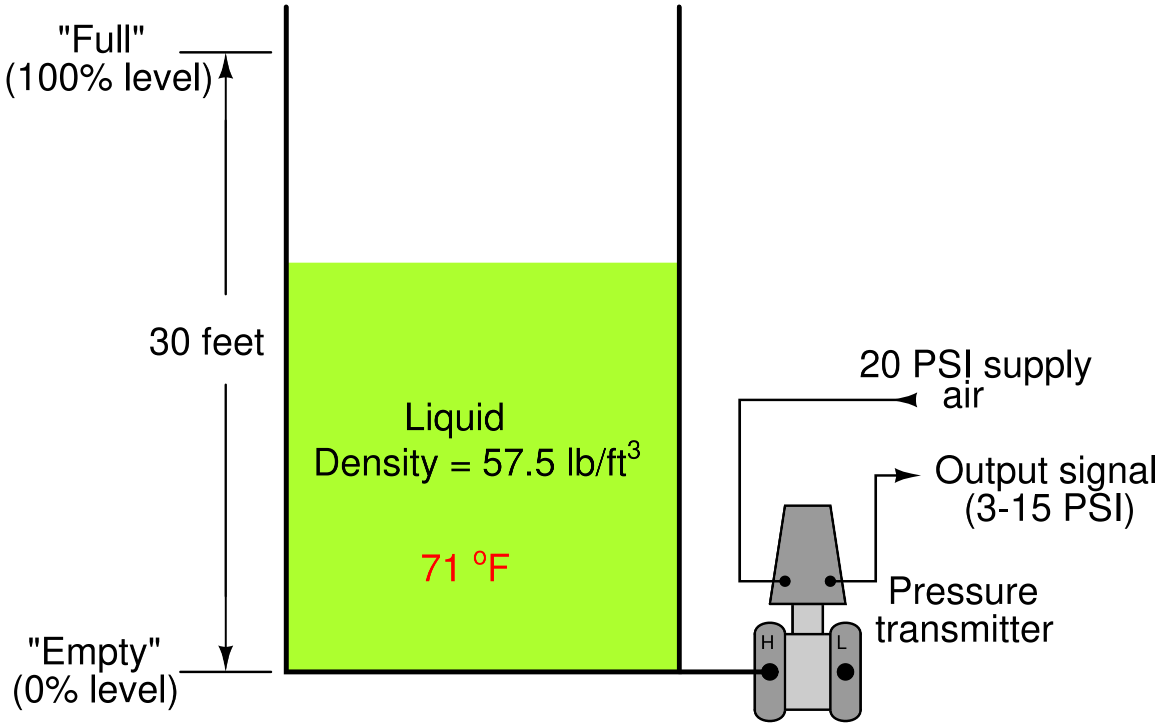
Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (PSI) at 12 feet of level
- Water level at 5.9 PSI signal output

file i00243

Oppgave 50

The following storage vessel holds a liquid with a density of 57.5 lb/ft^3. A pneumatic pressure transmitter located at the bottom infers liquid level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 30 feet) into an output signal of 3 to 15 PSI. Please express the transmitter's calibration range in units of PSI.



Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (PSI) at 19 feet of level
- Liquid level at 12.4 PSI signal output

file i00244

Oppgave 51

A vessel containing a weak acid/water mixture has a calibrated level range of 0 to 10 feet, measured by a pressure transmitter at the bottom. Suppose that the specific gravity of the normal mixture is 1.12 (112% heavier than pure water, giving 1.12 inches of water column pressure for every inch of vertical height), and that the liquid level happens to be at 6 feet.
Now, suppose some pure acid is added to the vessel, increasing the actual liquid level *and* increasing the liquid density at the same time. The new liquid level is 7 feet high and the specific gravity has increased to 1.35. Assuming the transmitter has been calibrated for the original specific gravity of 1.12, what will its output signal correspond to in feet of liquid level? In other words, if this transmitter's output signal were driving a level indicator device for an operator to read, how many feet of level would the indicator device register?

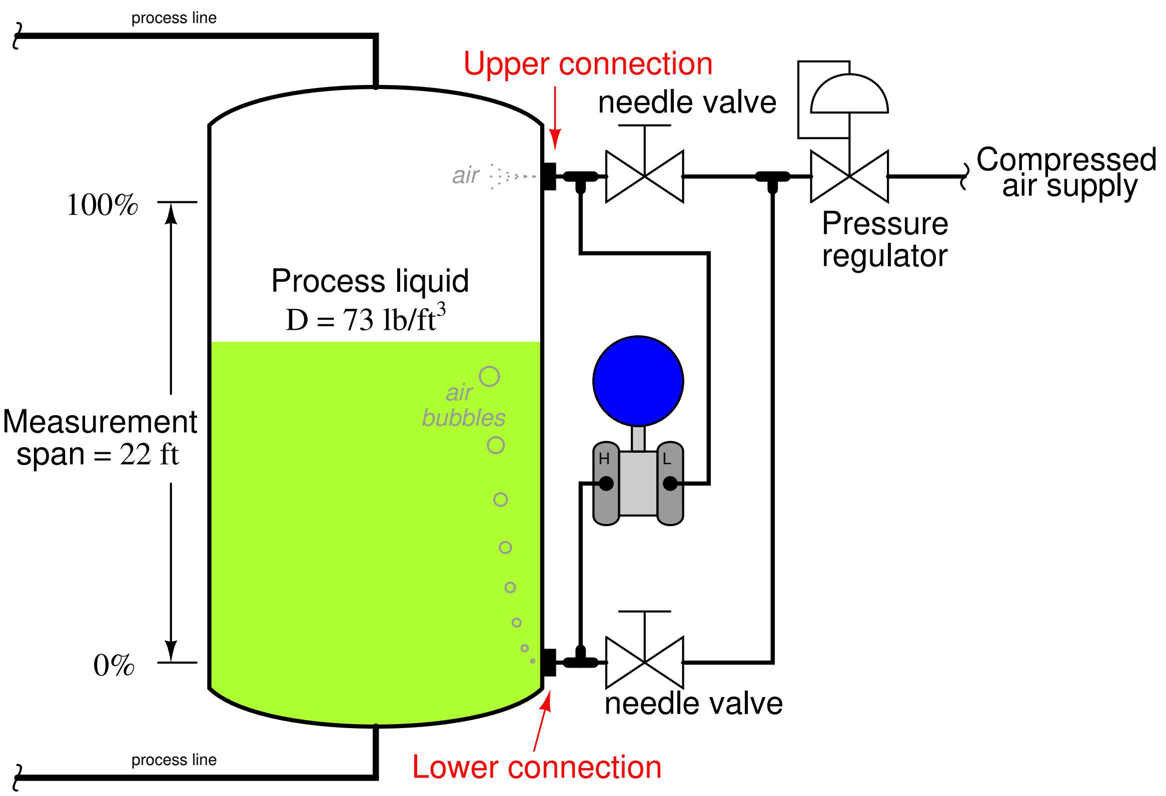
Identify an alternative method for liquid level measurement that would not be affected by changes in liquid density.
file i00245

Oppgave 52

An open vessel contains water at 60^o F. A pressure transmitter located at the bottom of the vessel measures the hydrostatic pressure ("head") generated by the water and outputs a signal corresponding to level. Suppose that the temperature of this vessel were to increase over time to 110^o F due to exposure to very hot outside air (the vessel is located in Death Valley, California during the summer). Knowing that an increase in water temperature will result in a decrease in density, what will happen to the level transmitter's output as the vessel heats up? Will the transmitter output increase, decrease, or stay the same? Why?? Assume that no water enters or exits the vessel during the period of heating from 60^o F to 110^o F.
file i00246

Oppgave 53

Purge systems may be used to detect hydrostatic pressure in a vessel even when there is no dip tube. For example, in this level measurement system, compressed air is used as a purge medium directly into the vessel where the transmitter tubing connects:



First, calculate the appropriate calibration range for the DP transmitter in this application.

Next, explain what would happen to the transmitter's output if the lower connection to the process vessel became plugged by debris (despite the cleaning action of the compressed air flowing through it). Alternatively, what if only the upper connection became plugged?

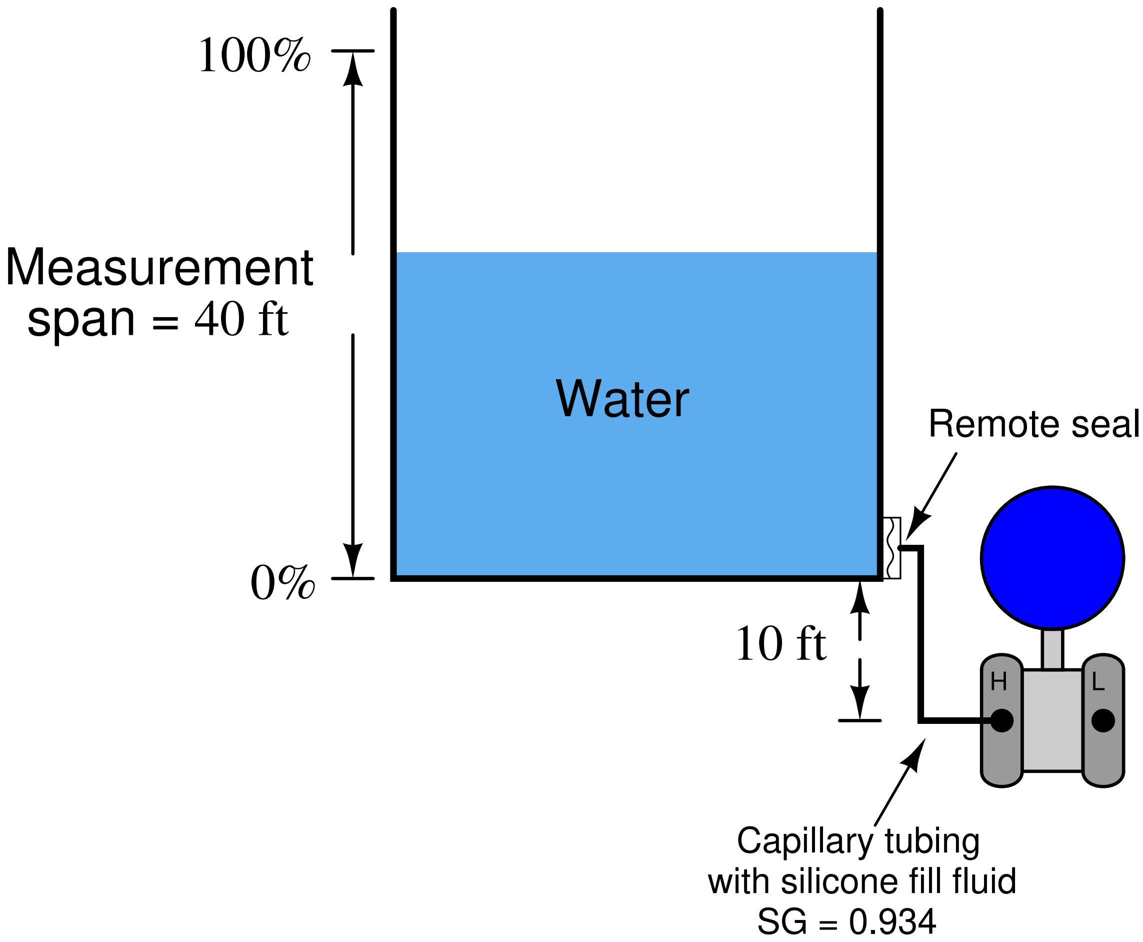
Suggestions for Socratic discussion

- Why would anyone choose to continuously *purge* the nozzles of a hydrostatic level transmitter when they could have easily chosen remote seals (diaphragms)?
- Is air always a safe purge fluid to use? If not, what are some valid alternatives?
- Suppose a slug of process liquid were to find its way into the "H" side impulse line leading up to the DP transmitter. How would this bit of liquid affect the transmitter's accuracy?
- Suppose a slug of process liquid were to find its way into the "L" side impulse line leading down to the DP transmitter. How would this bit of liquid affect the transmitter's accuracy?

file i00250

Oppgave 54

Determine the LRV and URV points for a transmitter measuring water level in this vessel, with the ΔP transmitter located 10 feet beneath the vessel and connected to it with capillary tubing and a remote seal filled with silicone fill fluid (SG = 0.934):



Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand**.

Suggestions for Socratic discussion

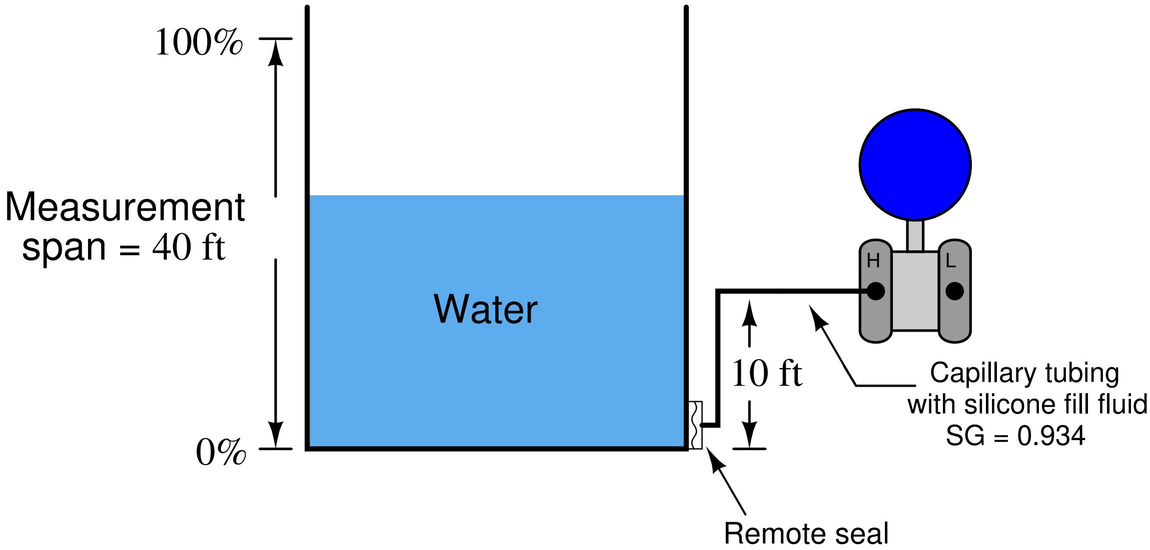
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- When calculating hydrostatic pressures, there are two common methods: one is to use the formula $P = \gamma h$ and another is to translate inches of vertical liquid height directly into PSI using the known relationship between water and PSI (1 PSI = 27.68 inches of water). Demonstrate both methods applied to this problem.

- Identify some realistic situations that would justify the use of a remote seal on a pressure transmitter.
- When using filled impulse lines (un-sealed), it is important to use a fill fluid denser than the fluid inside the process vessel. Is this a requirement when using a remote (sealed) diaphragm?
- Should the "low" side of the DP transmitter be vented or sealed?
- What would happen if a technician inserted a pipe plug into the formerly open "L" port of the transmitter, sealing it off from atmospheric pressure?
- What would happen if the capillary tube developed a leak?
- Explain why this level transmitter does not require a *compensating leg*.

file i00259

Oppgave 55

Determine the LRV and URV points for a transmitter measuring water level in this vessel, with the ΔP transmitter elevated 10 feet above the vessel bottom and connected to it with capillary tubing and a remote seal filled with silicone fill fluid (SG = 0.934):



Also, explain why a remote seal is absolutely necessary in this installation. It would not be a good idea to simply connect the "high" port of the ΔP transmitter to the bottom of the vessel with a length of tubing as is permissible when the transmitter is either level with the bottom of the vessel or suppressed below the vessel's bottom!

Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand**.

Suggestions for Socratic discussion

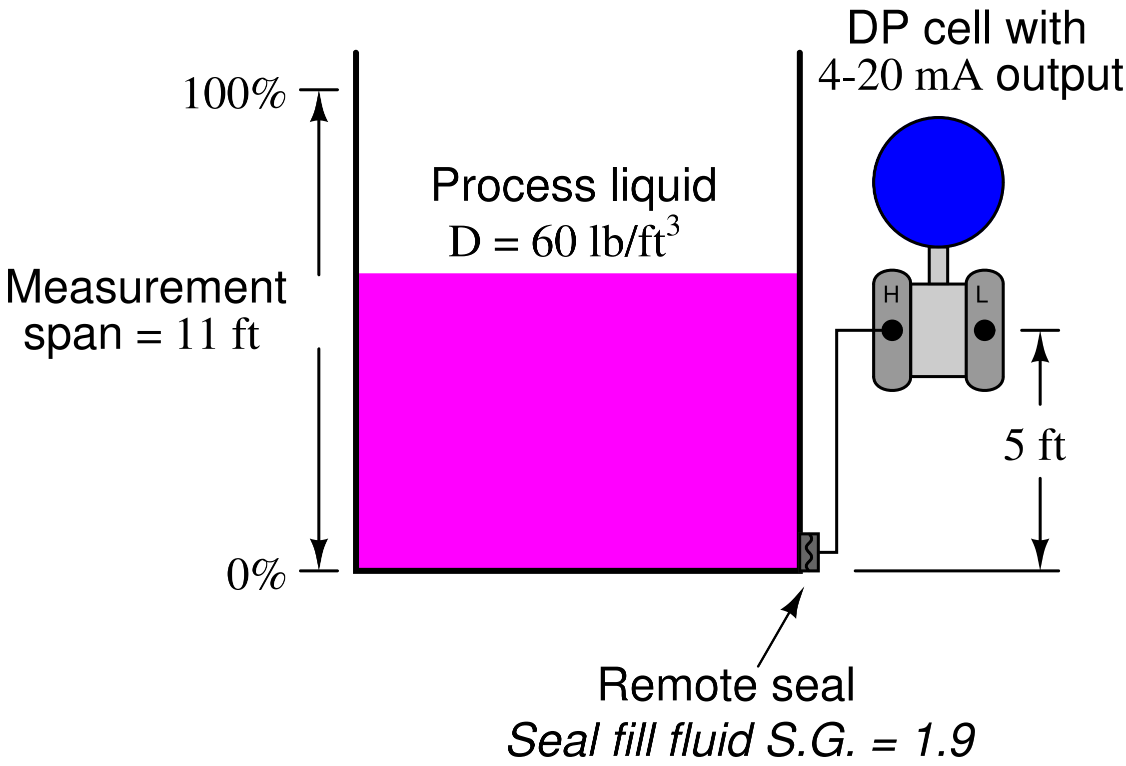
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- When calculating hydrostatic pressures, there are two common methods: one is to use the formula $P = \gamma h$ and another is to translate inches of vertical liquid height directly into PSI using the known relationship between water and PSI (1 PSI = 27.68 inches of water). Demonstrate both methods applied to this problem.
- A good problem-solving technique is to imagine (perform a "thought experiment") the *converse* of a given question. Here, you were asked to explain why a remote seal is necessary. Present a thought experiment where you envision the opposite condition (e.g. the *lack* of a remote seal), and explain how this might help you to answer the initial question.

- Should the "low" side of the DP transmitter be vented or sealed?

file i00260

Oppgave 56

The following storage vessel holds a liquid with a density of 60 lb/ft^3. The ΔP transmitter is located 5 feet above the bottom of the vessel and has a remote seal with capillary tubing whose fill fluid has a specific gravity of 1.9. The desired level measurement range is 0 feet to 11 feet:



Assuming an electronic transmitter with an output range of 4 to 20 mA, and a calibration accuracy of ± 0.2% of span, complete the following calibration table for the transmitter:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

Be sure to show all your mathematical work so that your instructor will be able to check the conceptual validity of your technique(s). A good way to check to see if you're solving the problem correctly is to check that each and every one of your intermediate calculations (i.e. the results you get mid-way during the process to arrive at the final answer) has real physical meaning. **If you truly understand what you are doing, you will be able to identify the correct unit of measurement for every intermediate result and also be able to show where that number applies to the scenario at hand**.

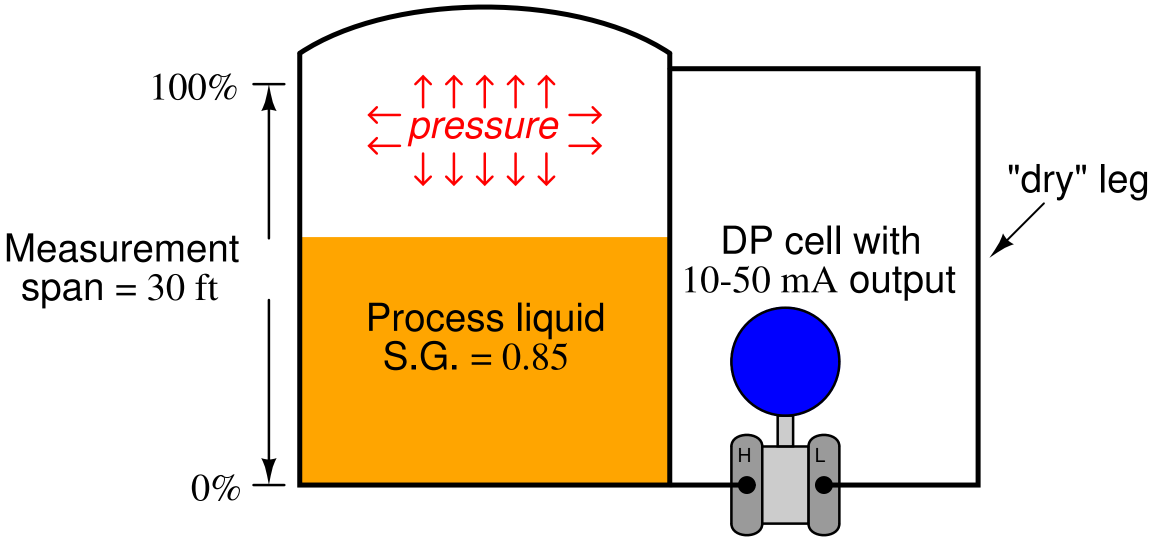
Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- Suppose this vessel were enclosed at the top, and a remote-sealed compensating leg connected from the transmitter's "L" port to the top of the vessel. How would this change the transmitter's necessary calibration? Would it require an adjustment in zero, span, linearity, or some combination of these?
- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the bottom of the vessel.
- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the capillary tube (at the remote seal).
- Given a 100% full vessel, calculate the amount of pressure that would be registered by a pressure gauge connected to the capillary tube (at the transmitter "H" port).

file i00261

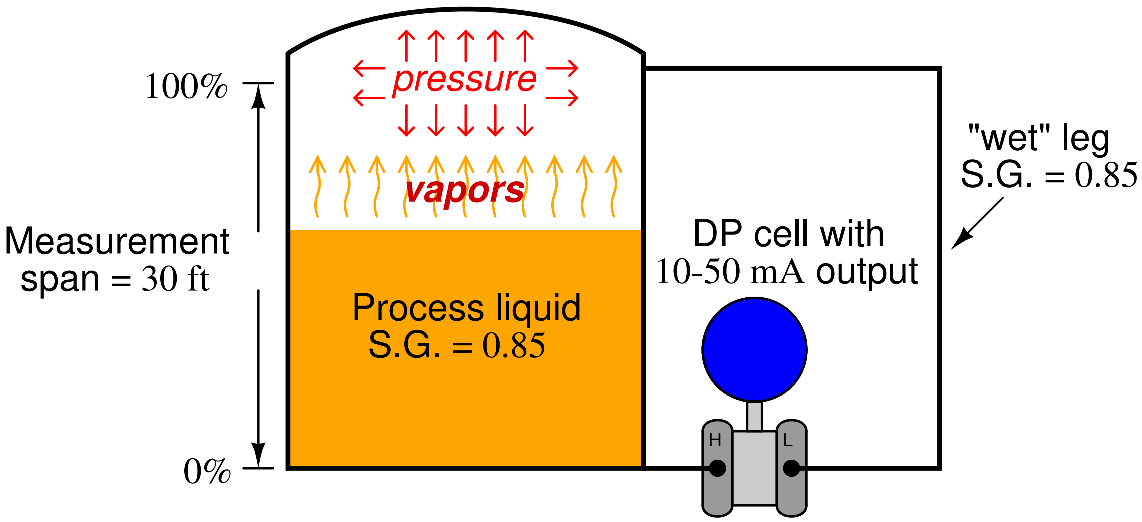
Oppgave 57

Calculate the 0%, 50%, and 100% calibration points for the ΔP transmitter to measure liquid level in this vessel, given a range of 0 to 30 feet and a specific gravity of 0.85. Note that the "low" side of the transmitter connects to the top of the vessel to compensate for vapor pressure inside the vessel. This tube is called a "dry leg" because there is no liquid inside of it:



% of span	ΔP ("H_2O)	Output (mA)
0		
50		
100		

Now suppose the vessel is heated, and the liquid inside the vessel emits condensible vapors. These vapors will condense inside low-side tube leading to the ΔP transmitter which is cooler than the storage vessel, resulting in a "wet leg" instead of a "dry leg." In other words, the transmitter will now "see" a constant column of liquid (SG = 0.85) 30 feet high connected to its "low" process port:



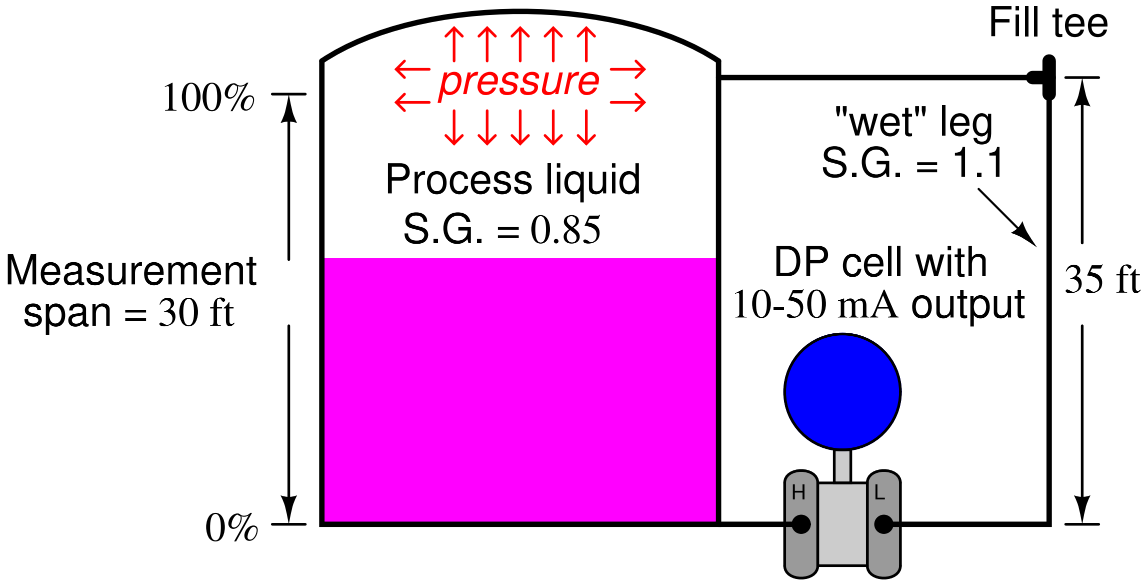
Re-calculate the 0%, 50%, and 100% calibration points for the ΔP transmitter to measure liquid level in this vessel with a wet reference leg instead of a dry reference leg.

% of span	ΔP ("H_2O)	Output (mA)
0		
50		
100		

file i00262

Oppgave 58

Calculate the 0%, 50%, and 100% calibration points for the ΔP transmitter to measure liquid level in this vessel, given a range of 0 to 30 feet and a process specific gravity of 0.85. Note the "wet" leg filled with fluid different than the process (SG = 1.1), 35 feet tall:

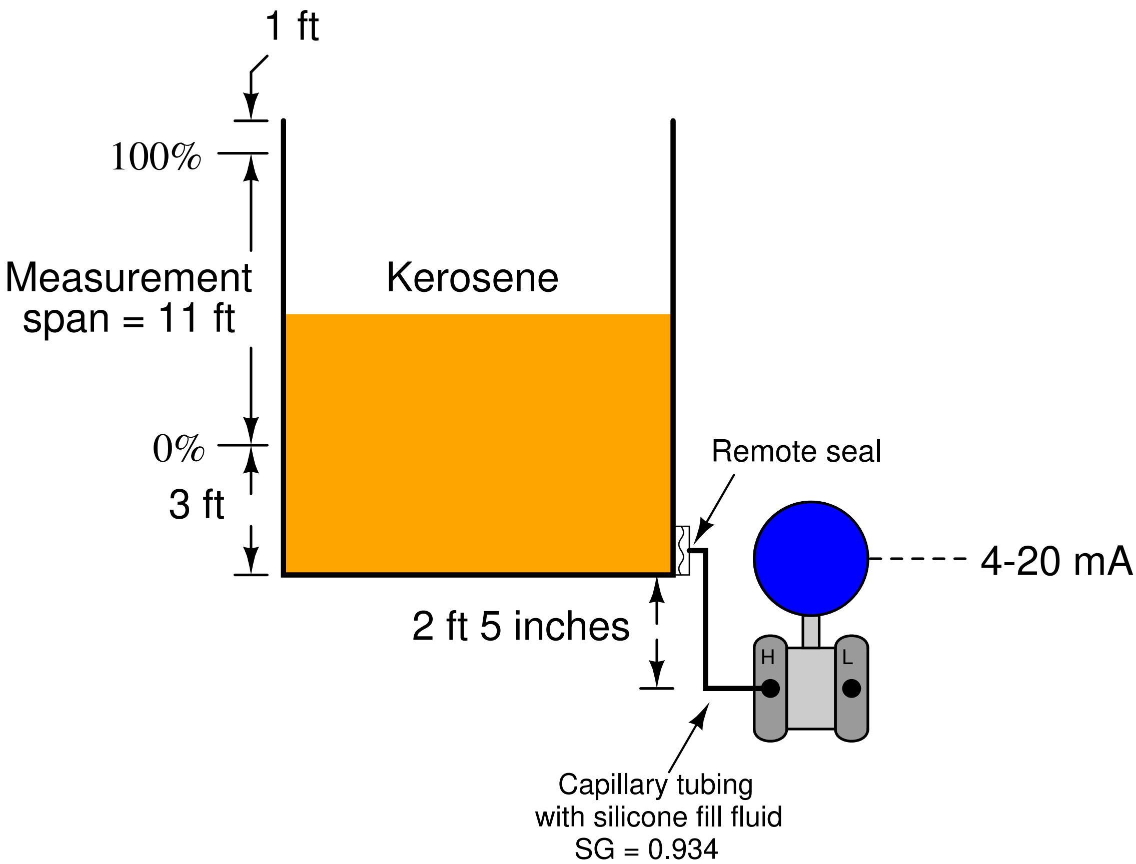


% of span	ΔP ("H_2O)	Output (mA)
0		
50		
100		

file i00263

Oppgave 59

Calculate the proper LRV and URV pressures for the 4-20 mA loop-powered ΔP transmitter in this level measurement scenario:



- LRV = ________ inches water column
- URV = ________ inches water column

Then, calculate the transmitter's output given the following process levels (assuming perfect transmitter calibration):

- Output = ________ mA with the kerosene level 4 feet up from the bottom of the tank (4 feet "fillage")
- Output = ________ mA with the kerosene level 6 feet down from the top of the tank (6 feet "ullage")

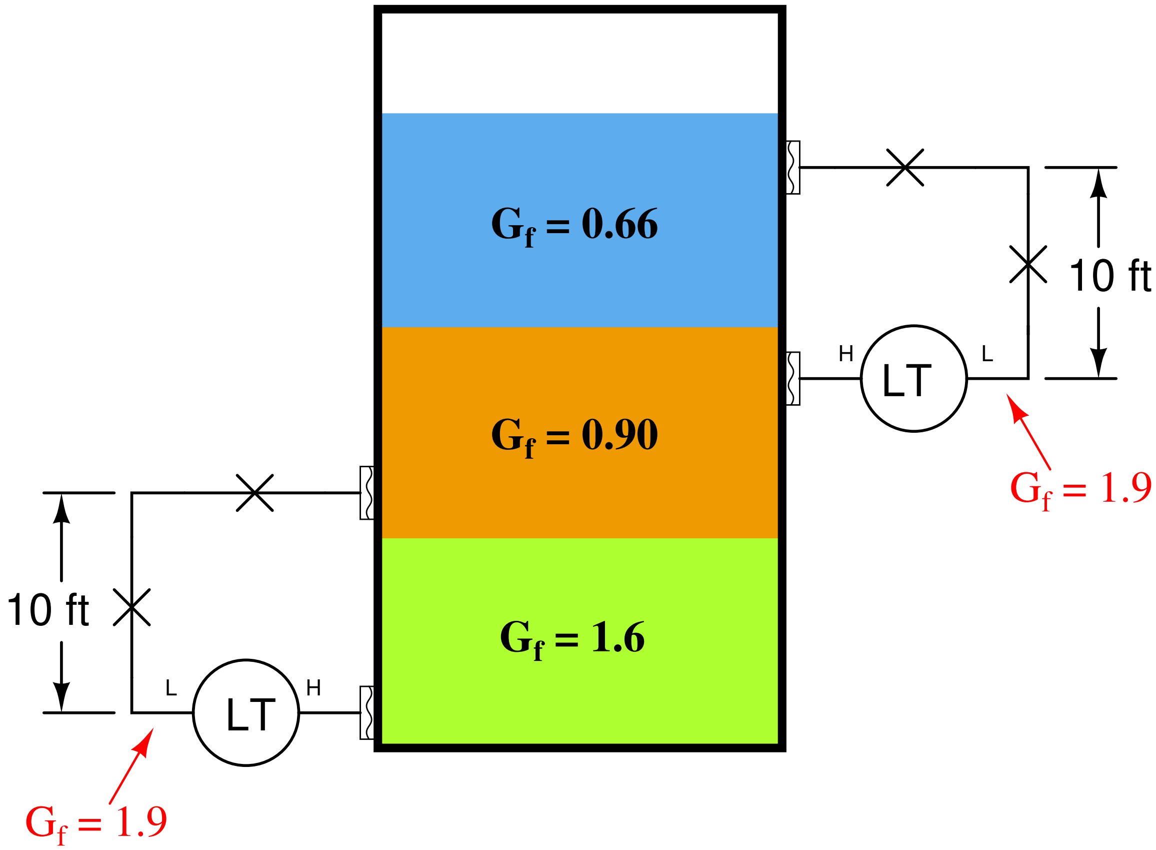
Suggestions for Socratic discussion

- Suppose the DP transmitter with the remote seal failed and had to be replaced. Unfortunately, you don't have another DP transmitter with a remote seal in stock to replace it. Could you use a DP transmitter *without* a remote seal for this application? If so, would its calibration have to be different from the remote-seal transmitter?
- Explain why this installation does not require a *compensating leg*.

file i00520

Oppgave 60

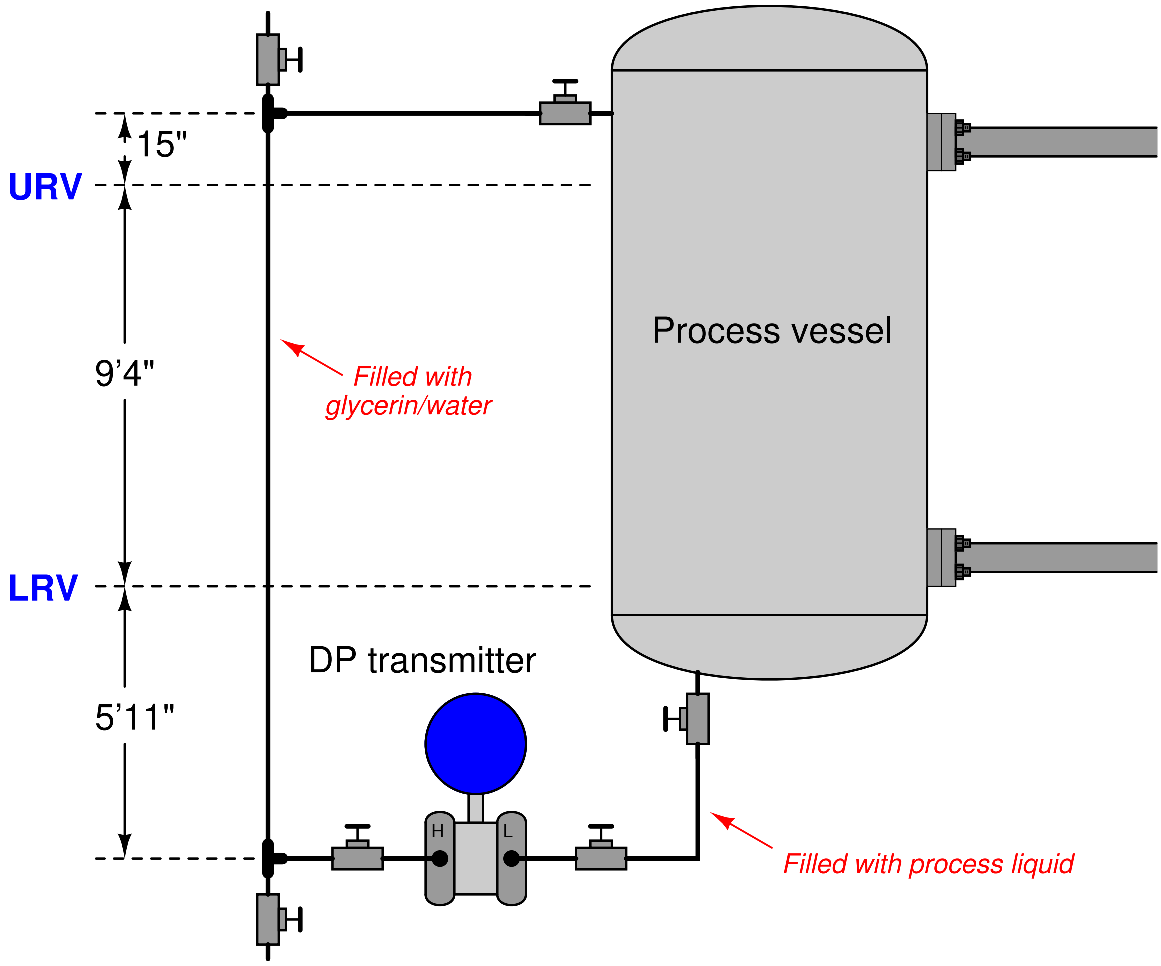
Calculate the appropriate LRV and URV pressures for each of these transmitters to measure two different liquid-liquid interfaces, assuming the span of each transmitter is 10 feet:



Express your answers in units of *inches water column* ("W.C. or "H_2O).
file i03746

Oppgave 61

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 44 pounds per cubic foot at a temperature of 23 degrees Celsius, and that the "wet leg" compensating impulse line is filled with a glycerin/water mix (S.G. = 1.13). Assume a static vessel pressure of 126 PSI:



Express your answers in units of *inches water column* ("W.C. or "H_2O).

Suggestions for Socratic discussion

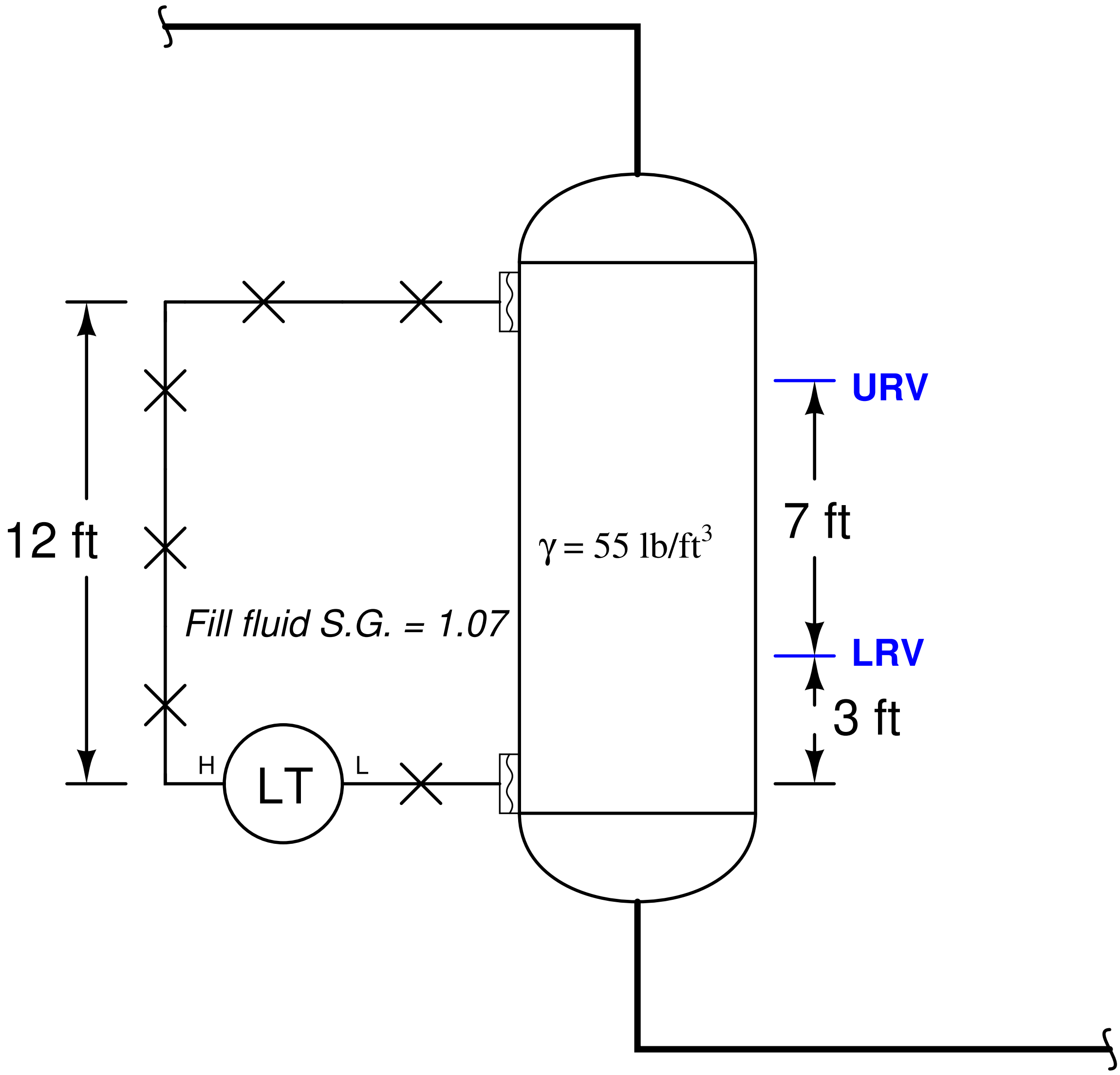
- As liquid level increases in this vessel, will the transmitter's signal increase or decrease (i.e. is this level transmitter *direct* or *reverse* acting?
- If the process liquid heats up and becomes less dense (but the actual level remains the same), will the transmitter's 4-20 mA signal increase, decrease, or remain the same?
- If the wet leg is filled with pure glycerin instead of a glycerin/water mixture (but the process liquid level remains the same), will the transmitter's 4-20 mA signal increase, decrease, or remain the same?
- How would this system respond if someone closed the upper nozzle block valve, isolating the compensating leg impulse line from the process vessel?

- Describe a step-by-step procedure for re-filling the wet leg with glycerin, assuming a pressurized vessel.

file i03747

Oppgave 62

Calculate the appropriate LRV and URV pressures for this hydrostatic level measurement system, assuming the process liquid has a weight density of 55 pounds per cubic foot:



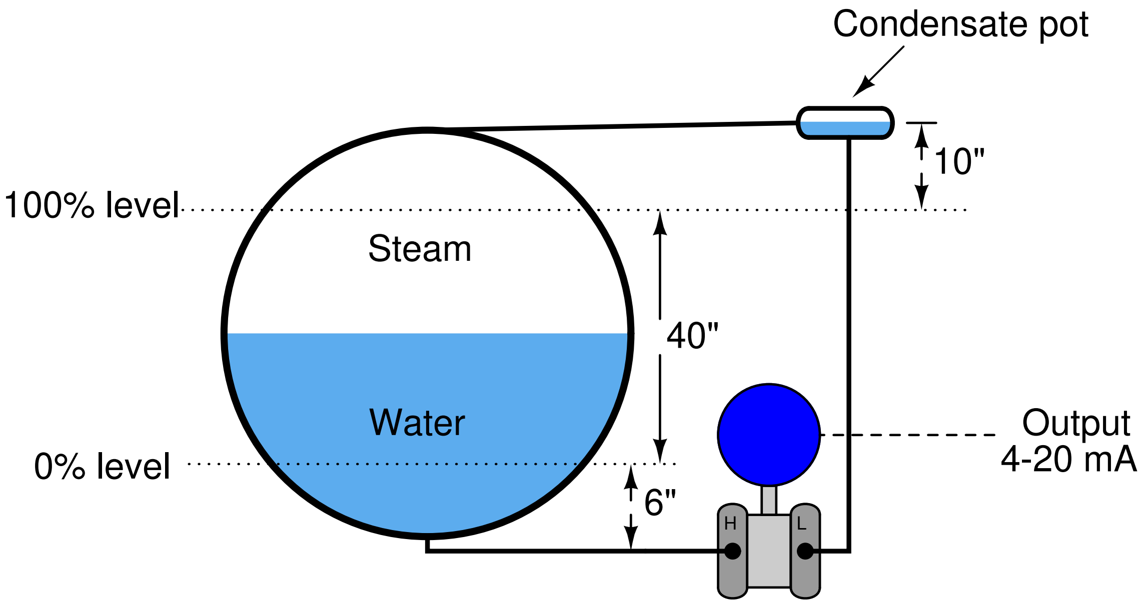
Express your answers in units of *PSI*.

If this transmitter were replaced with another one having the exact same calibration but different fill fluid (S.G. = 0.951 instead of 1.07), how would its level-measurement accuracy be affected?

file i03748

Oppgave 63

Calculate the differential pressure sensed by the level transmitter at three different water levels in this boiler steam-drum level measurement system: 0%, 50%, and 100%.



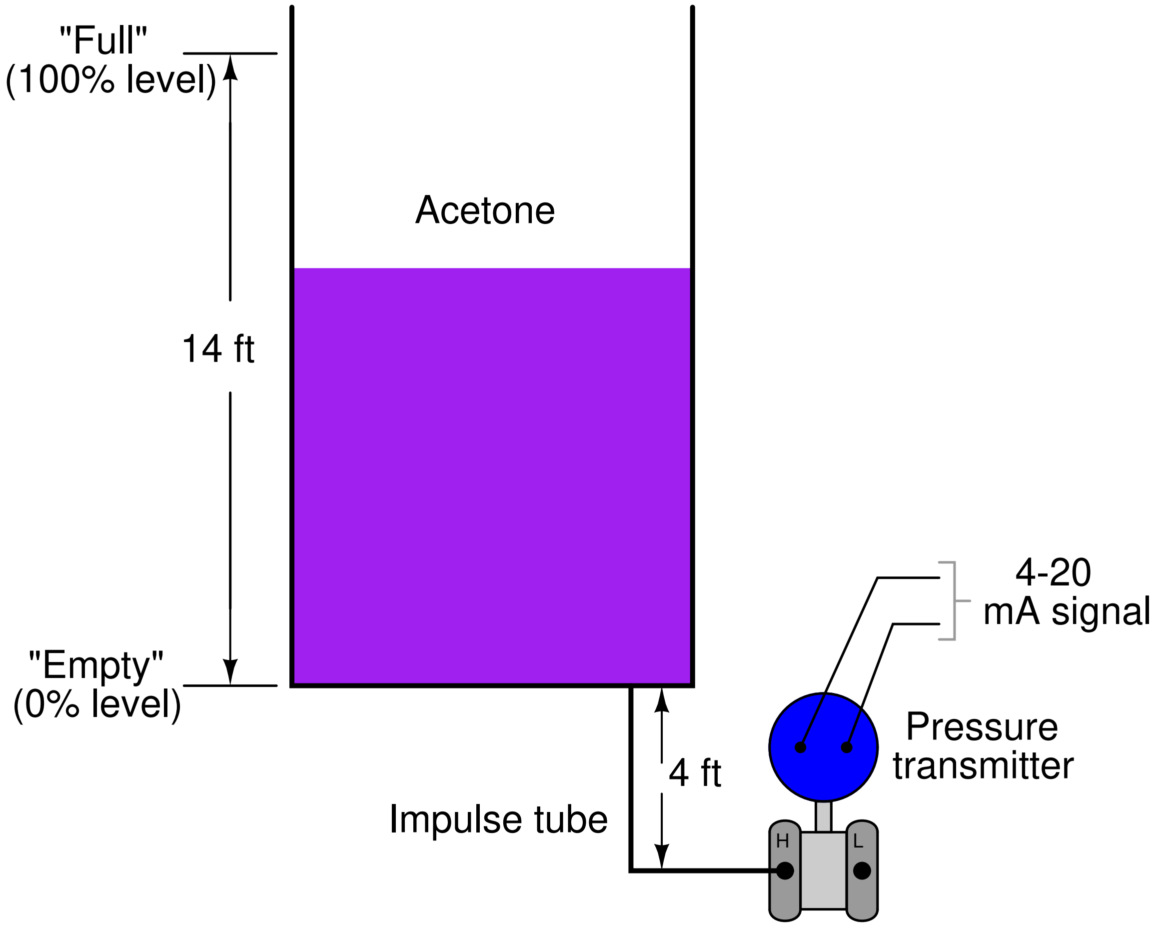
Assume a density for (hot) boiler drum water of 49 lb/ft^3, a density for steam in the drum of 1.3 lb/ft^3, and a density for (warm) water in the "wet leg" of 61 lb/ft^3. If the pressure at the "low" (L) side of the transmitter is greater than the pressure at the "high" (H) side, be sure to express the differential pressure quantity as a negative number.

- Transmitter ΔP at 0% water level = ________ "W.C.
- Transmitter ΔP at 50% water level = ________ "W.C.
- Transmitter ΔP at 100% water level = ________ "W.C.

file i03612

Oppgave 64

The following storage vessel holds acetone, a liquid with a density of 49.4 lb/ft^3. A pressure transmitter located 4 feet below the vessel bottom infers acetone level by hydrostatic pressure (head). Determine the calibration range of this pressure transmitter in order to properly translate the range of vessel level (0 to 14 feet) into an output signal of 4 to 20 mA. Please express the transmitter's calibration range in units of kPa.



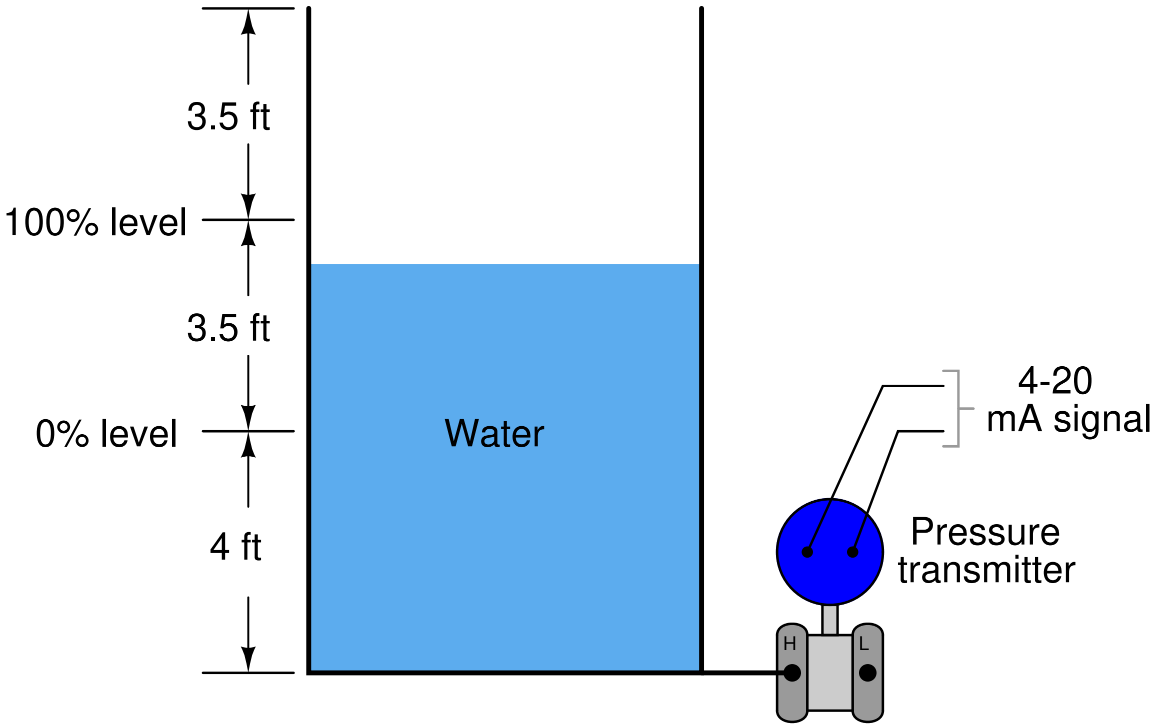
Then, determine the following (assuming the transmitter has been properly calibrated for the application):

- Transmitter output signal (mA) at 5.2 feet of level
- Acetone level at 12.7 mA signal output

file i02962

Oppgave 65

Suppose we wish to measure water level in this vessel, where the LRV and URV points are both between the extreme limits of "empty" and "full":



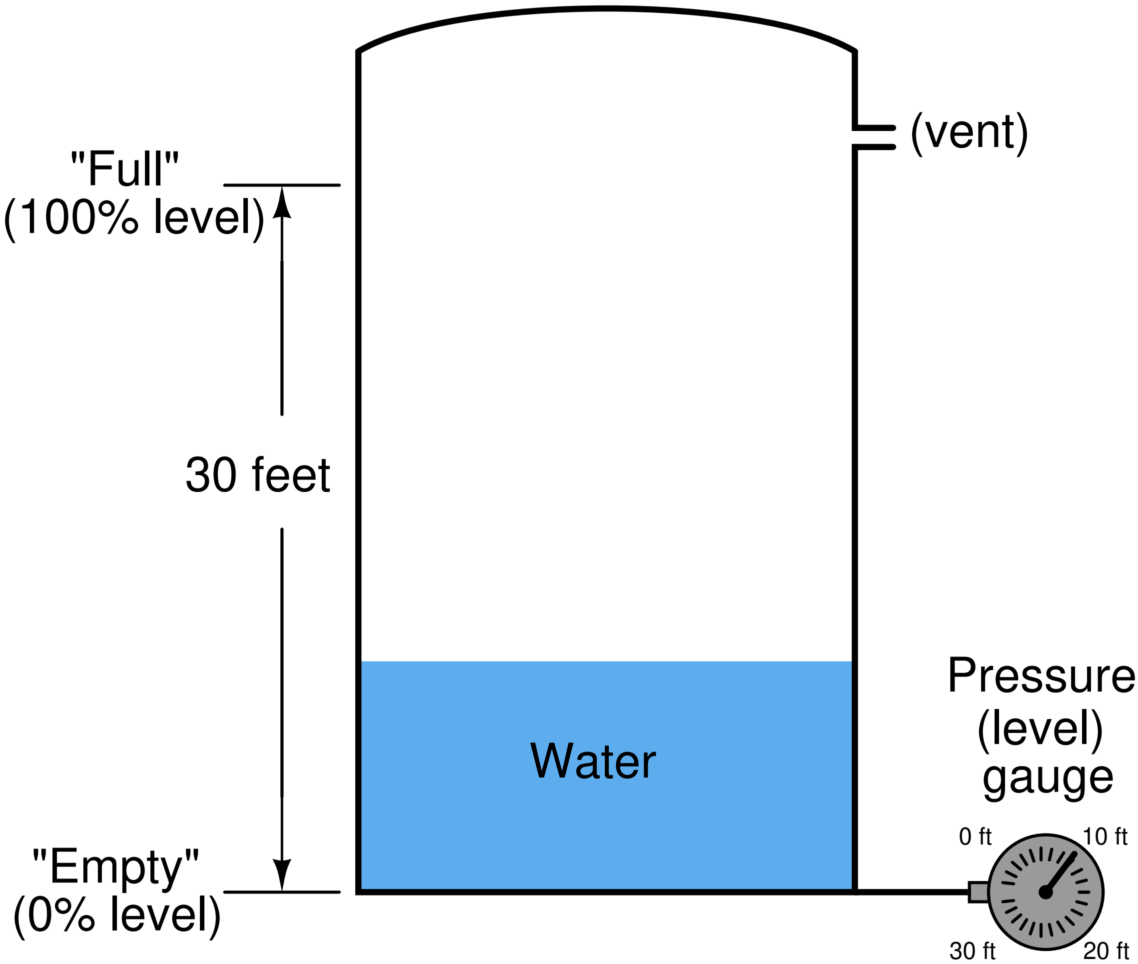
Complete the following calibration table for this level transmitter:

Process level (in)	Percent of span (%)	Hydrostatic pressure (PSI)	Output signal ideal (mA)
	0		
	25		
	50		
	75		
	100		

file i02963

Oppgave 66

A business owns a large storage tank which was used to hold water for fire protection. This tank is equipped with a pressure gauge at the bottom to infer water level. The face of the gauge reads out in feet of water rather than PSI or some other common pressure unit:



The operation of this level-indicating pressure gauge is quite simple: as the water level changes in the tank, the amount of hydrostatic pressure generated at the bottom changes proportionally.

When the local municipality upgrades the size of the water supply line to the company property, there is no longer a need for the fire-water storage tank. Not wanting to abandon the tank, a manager at the company decides to use it for gasoline fuel storage instead.
After emptying the water and re-filling the tank with gasoline, however, they notice a problem with the level-indicating gauge: it no longer reads correctly. With gasoline in the tank instead of water, the gauge's reading no longer correlates with tape-measure readings of liquid level like it used to. Instead, the gauge consistently registers low: there is always more gasoline in the tank than the gauge indicates.
Someone at this company asks you to explain what the problem is, because you have studied instrumentation technology. Describe the nature of the problem in your own words, and propose a solution to this problem that does not involve purchasing any new equipment.

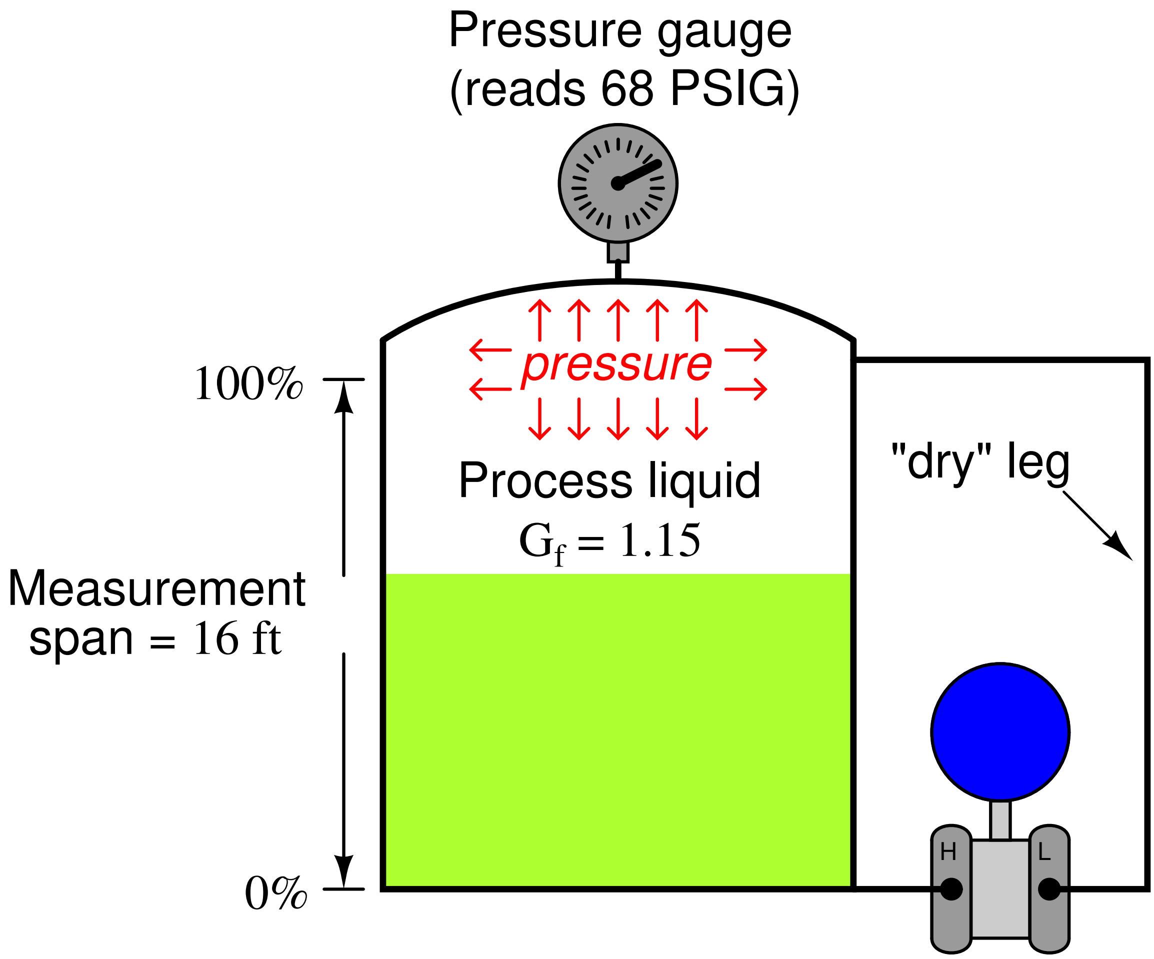
Suggestions for Socratic discussion

- If there is actually 10 feet of gasoline in the tank, how many feet with the water-calibrated gauge read?

file i02949

Oppgave 67

Calculate the amount of pressure applied to each side of the differential pressure transmitter (in units of PSI) when there is 9 feet of liquid level in the process vessel. Note the pressure gauge at the top of the vessel registering the amount of vapor pressure inside:



P_{high} = _________ PSIG P_{low} = _________ PSIG

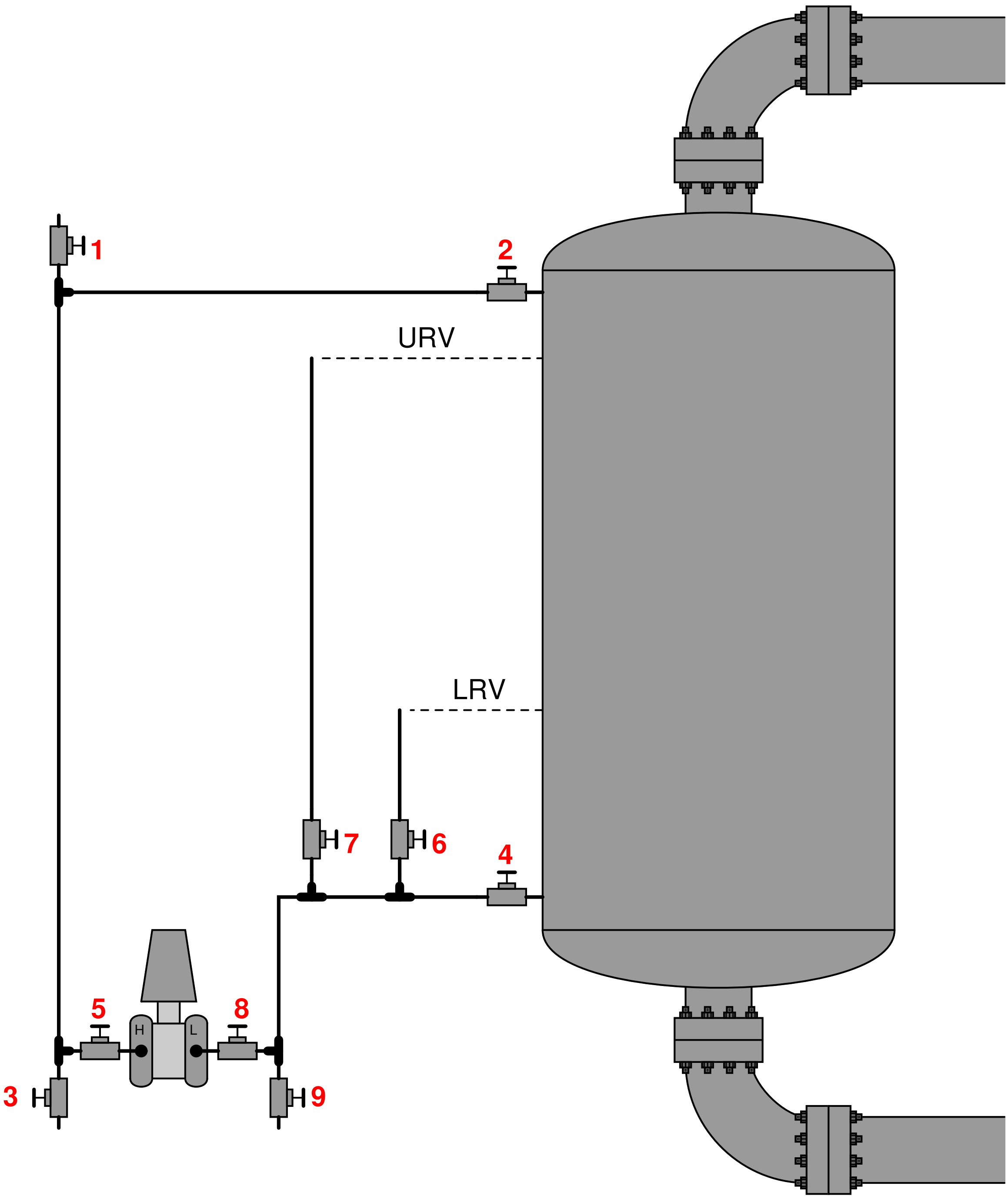
Also, calculate the *differential* pressure seen by the transmitter (in units of PSI):

ΔP = _________ PSID

file i02950

Oppgave 68

This hydrostatic liquid level transmitter system has been equipped with *standpipes* and extra hand valves to enable "wet calibration" of the transmitter:



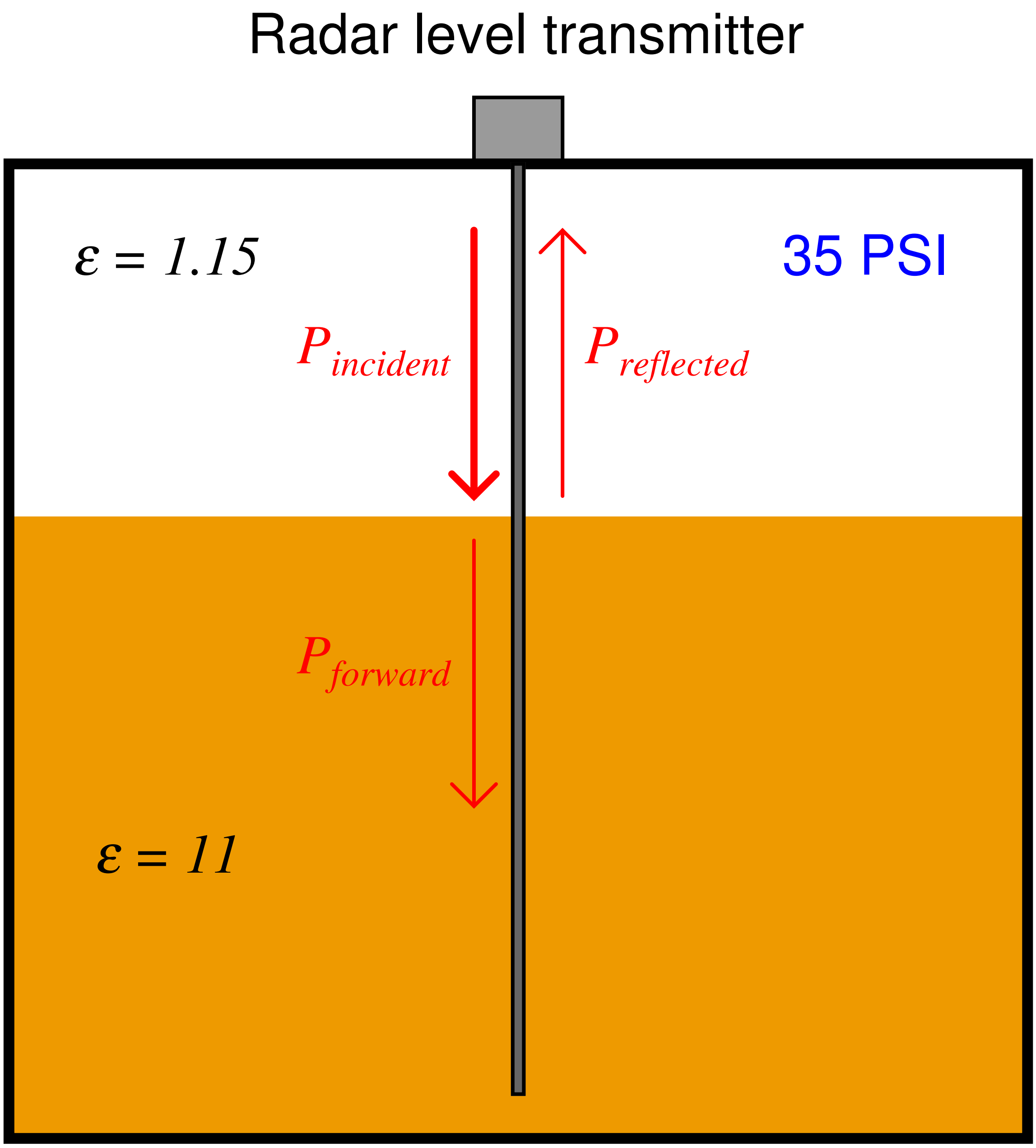
First, identify the proper position (*open* or *shut*) for each hand valve when the transmitter is in regular operation.

Next, specify a procedure to apply an LRV "test pressure" to the transmitter using the valves and standpipe(s).

file i01016

Oppgave 69

Calculate the percentage of incident power reflected back to the transmitter, and the percentage of incident power transmitted (forward) through the liquid in this radar level measurement application:



Also, calculate the ullage and fillage for this vessel, given a reflected pulse ("echo") time of 18.3 nanoseconds and a total vessel height of 30 feet.

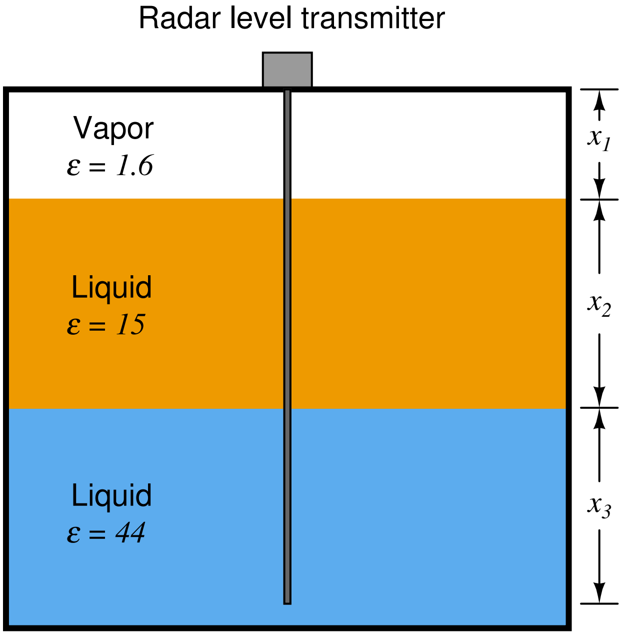
Suggestions for Socratic discussion

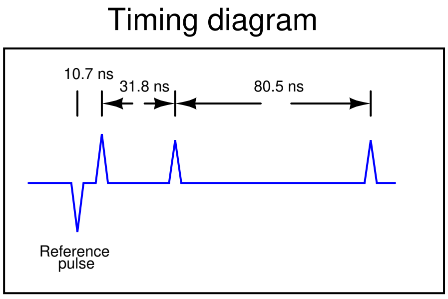
- Suppose the permittivity of the vapor were to increase. How would this affect the calibration of the radar transmitter? Would it result in a zero shift, a span shift, a change in linearity, or some combination of these?
- Identify different process conditions that would result in the permittivity of the vapor significantly changing.

file i04217

Oppgave 70

Calculate the three distances (x_1, x_2, and x_3) in this radar level measurement application given times between echo pulses of 10.7 ns, 31.8 ns, and 80.5 ns, respectively:





$x_1 =$ __________

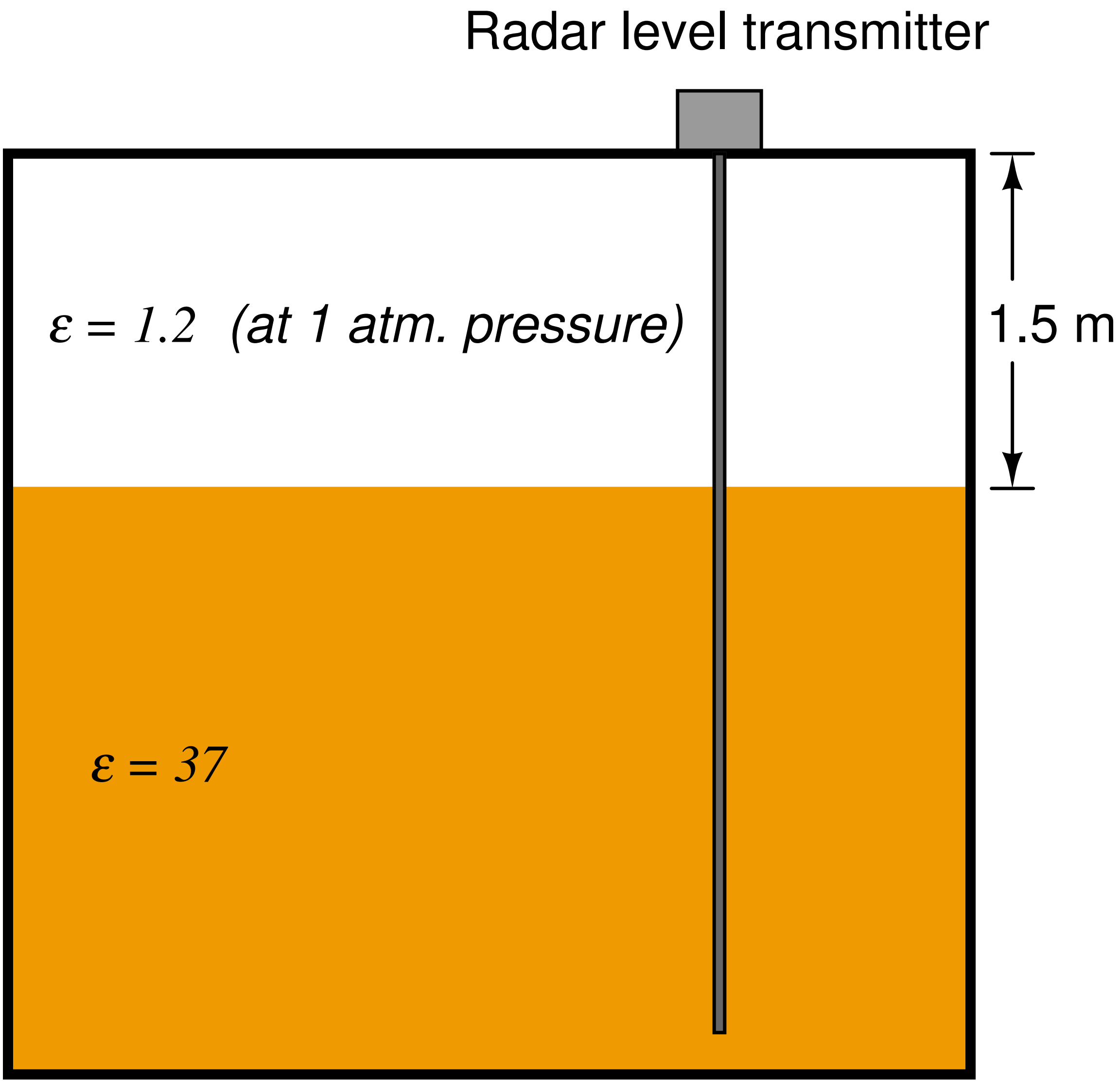
$x_2 =$ __________

$x_3 =$ __________

file i04622

Oppgave 71

Suppose a guided-wave radar transmitter is used to measure the ullage of vessel where the liquid has a relative permittivity of 37 and the vapor has a relative permittivity of 1.2 (at atmospheric pressure and standard temperature):



First, calculate the echo time for an ullage of 1.5 meters (as shown):

$t =$ ________

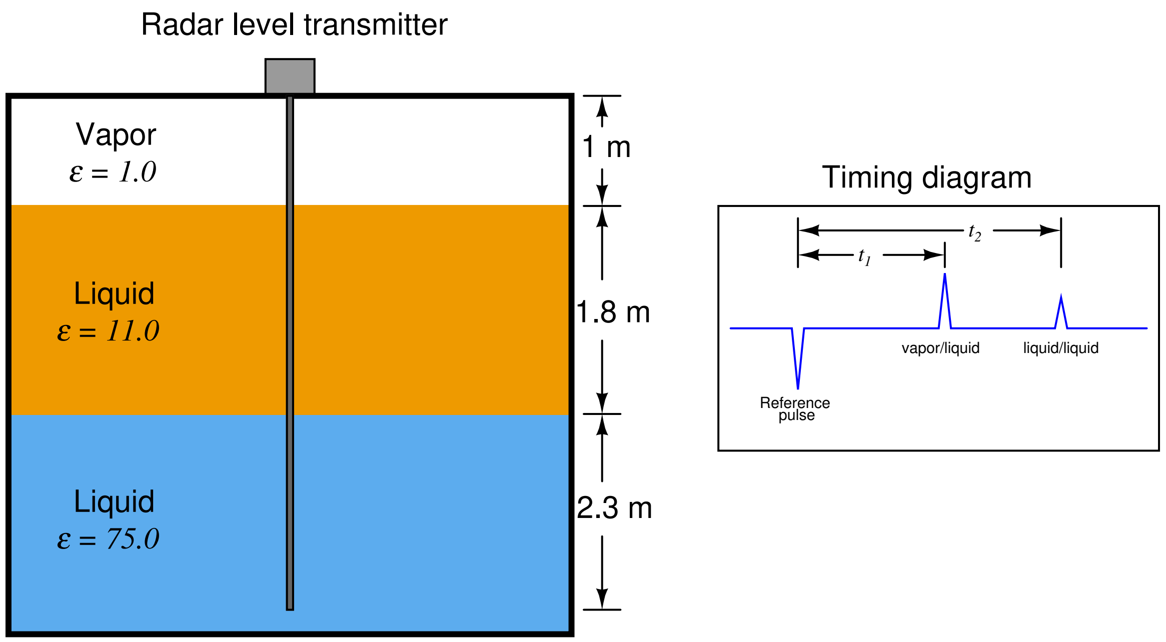
Next, calculate the echo time assuming the pressure of the vapor increases from 1 atmosphere to 3 atmospheres.

$t =$ ________

file i04623

Oppgave 72

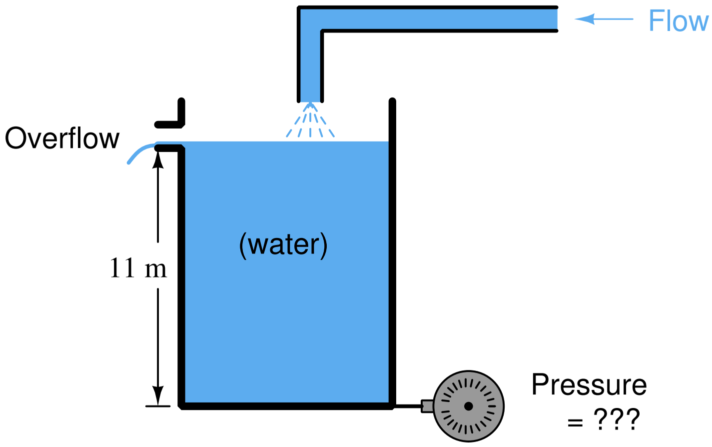
Calculate the two echo times (t_1 and t_2) in this radar level measurement application:



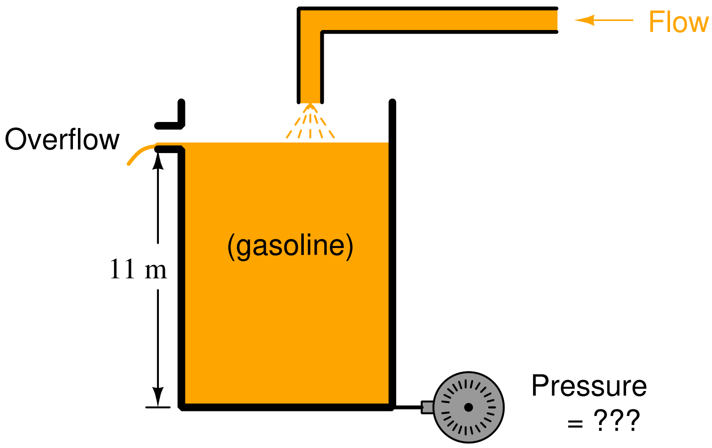
file i04624

Oppgave 73

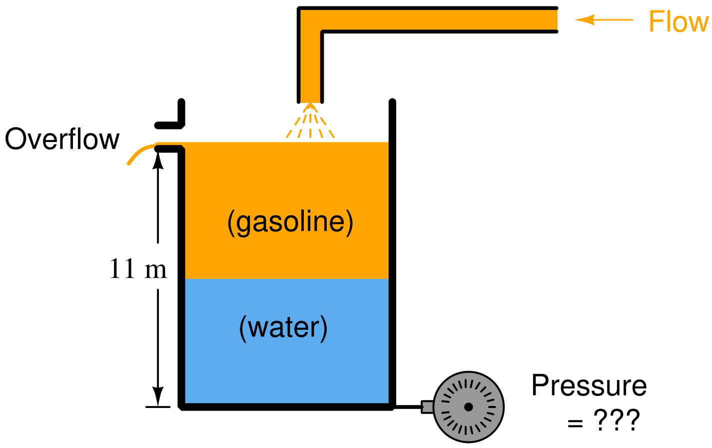
Calculate the hydrostatic pressure generated at the bottom of this vessel (in units of bar) when it is completely filled with water:



Now calculate the hydrostatic pressure at the bottom of this vessel (in units of bar) when it is completely filled with gasoline (density = 672.8 kg/m^3):



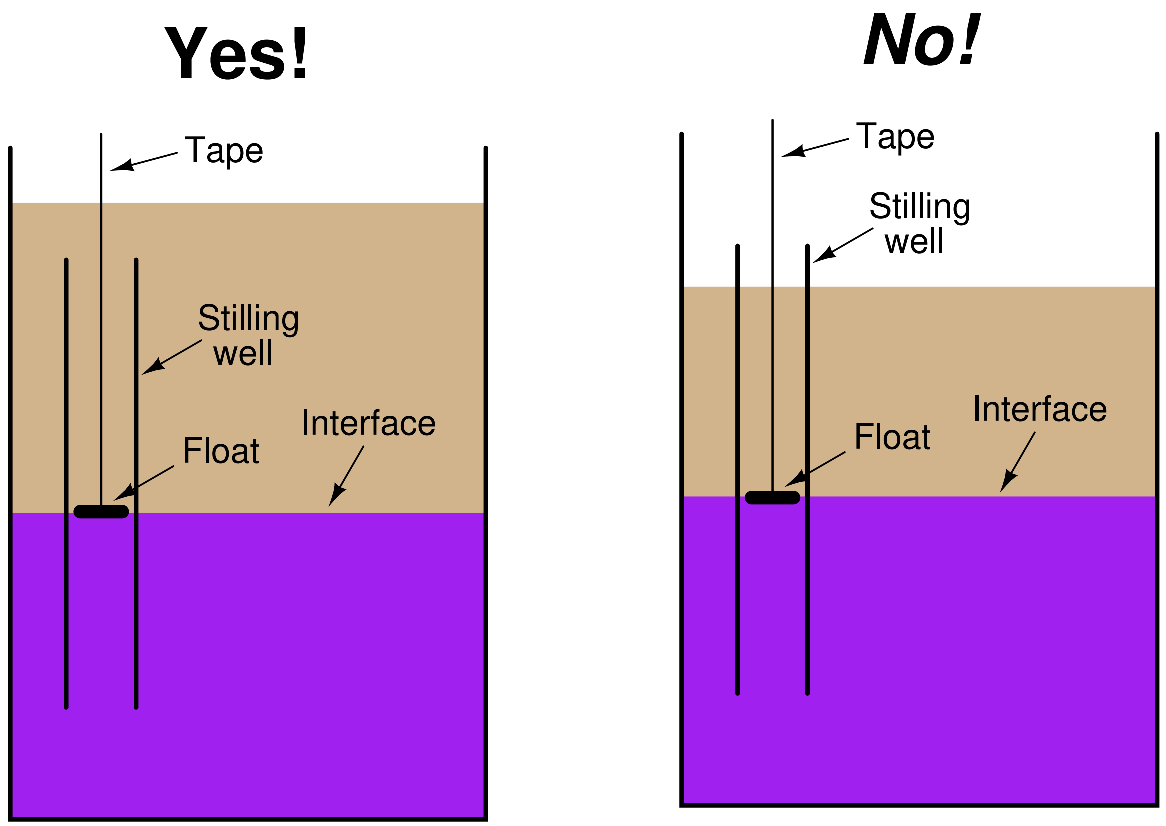
What do you think the pressure will be at the bottom of the vessel if it is exactly half-full of gasoline and half-full of water, with a gasoline-water *interface* at the 5.5 meters mark? Explain your reasoning.



file i00308

Oppgave 74

Stilling wells are very useful accessories to many types of liquid level measurement gauges, including float and ultrasonic. However, if used on a liquid-liquid interface level measurement application, care must be taken to ensure the stilling well is always submerged:

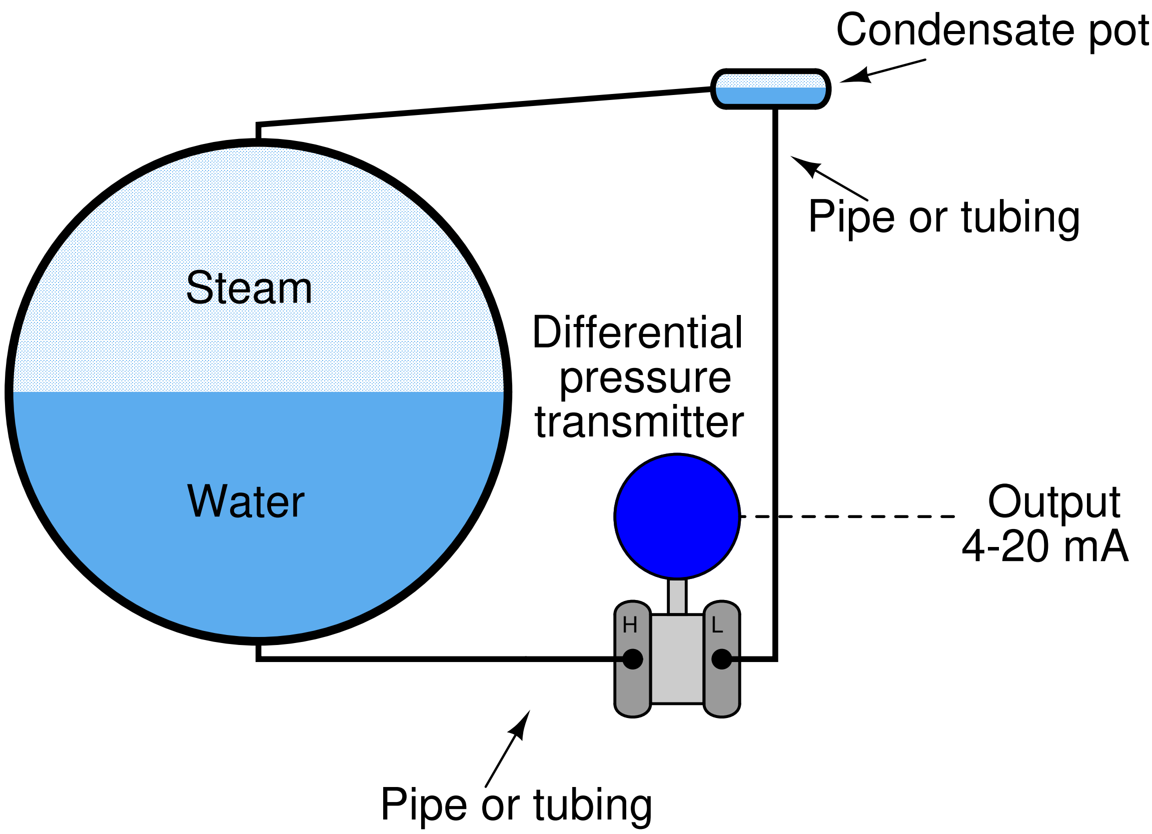


Explain why a stilling well might be used in a liquid level measurement system, and also why it needs to be completely submerged if being used to measure the level of an interface.

file i00315

Oppgave 75

Steam drum water level measurement is actually a form of interface level measurement, because high-pressure steam is significantly denser than air under ambient conditions:

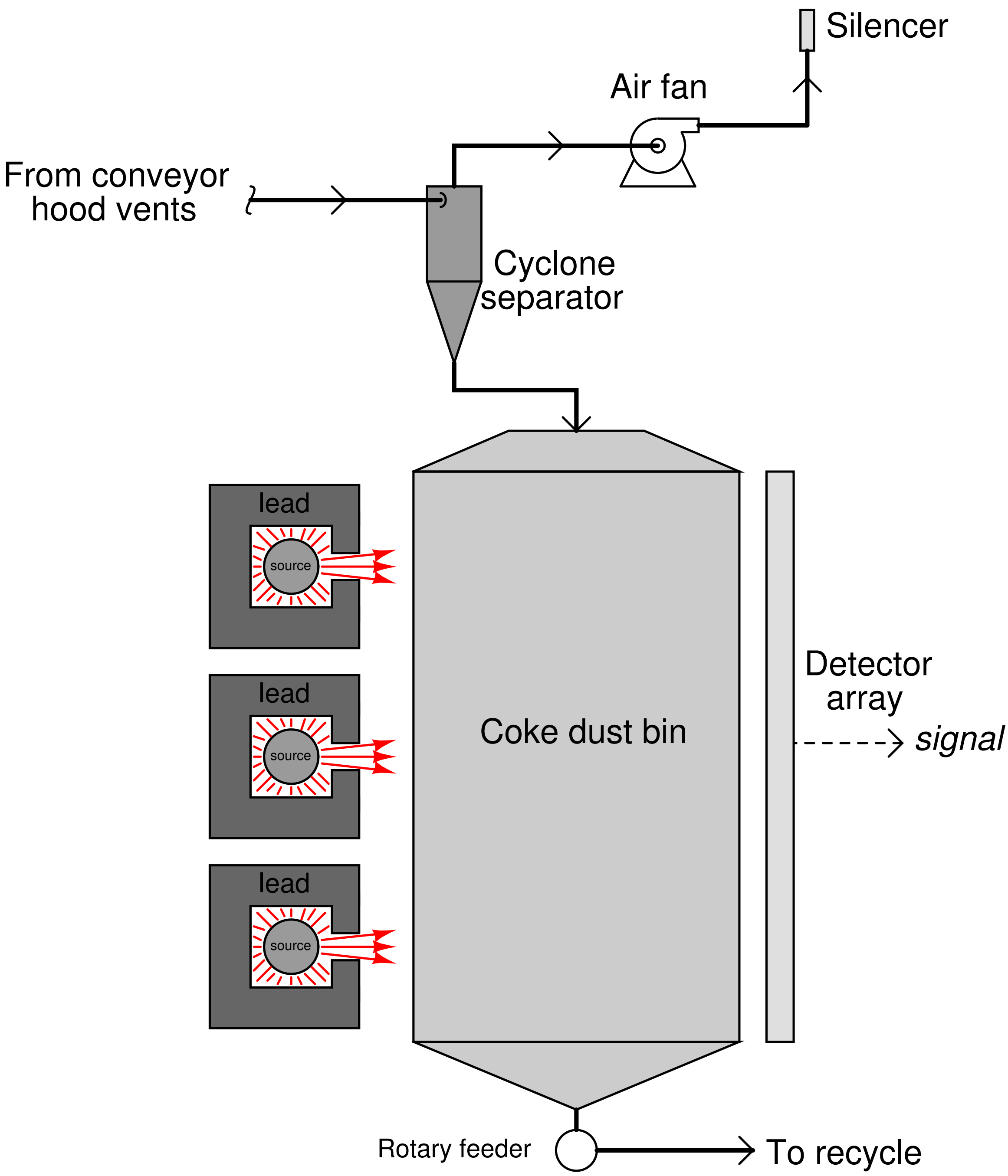


Making this situation even more complex is the fact that the densities of both the water and the steam change as boiler pressure and temperature change. Identify what happens to water density and steam density as both pressure and temperature increase, and explain why.

file i00316

Oppgave 76

A coke *calcining* operation (where petroleum coke is burned to decrease its hydrogen content) uses a large bin to collect coke dust that forms around its hooded conveyor systems. The level of coke dust inside this bin is measured by a gamma-radiation instrument:



Explain how this system uses nuclear radiation to measure coke dust level.

Suggestions for Socratic discussion

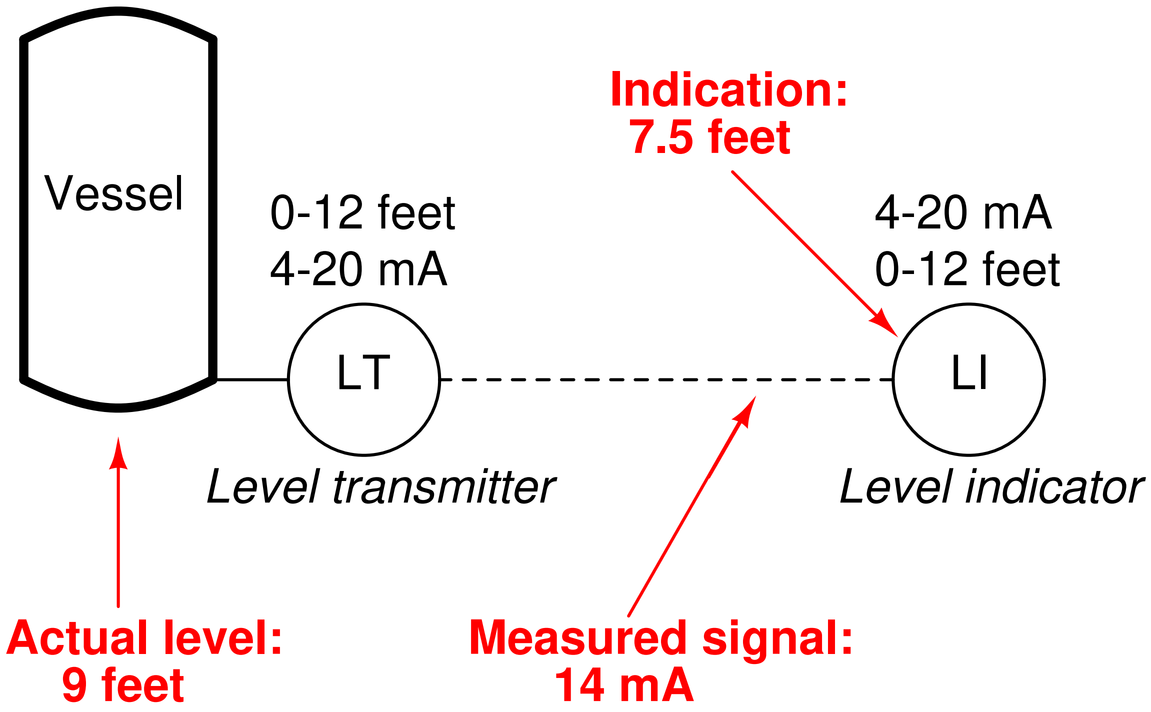
- Why does this system use multiple radioactive sources? Why do you suppose one is not sufficient?

- Suppose some radioactive material accidently entered the storage bin along with coke dust. Would this shift the level instrument's *zero*, the *span*, or both?
- Identify some alternative technologies which we could use to measure the coke dust level.
- What function does a *cyclone separator* perform, based on an analysis of this simple process flow diagram? Note: cyclone separators are commonly used in sawmill operations, to handle wood chips in a moving air stream.

file i00320

Oppgave 77

A level indicator is registering a liquid level that is falsely low. The operator has hand-gauged the storage vessel with a tape measure and determined the actual level to be 9 feet, but the level indicator (LI) registers 7.5 feet. The calibrated range of the 4-20 mA transmitter is 0 feet to 12 feet. You measure the current signal with your multimeter and find that it is 14 mA. Which instrument is at fault in this system? How do you know?



file i00321

Oppgave 78

Draw the symbols for the following types of liquid level indicating instruments, each one mounted to the top of a process vessel:

- Tape and float
- Radar gauge
- Ultrasonic (sound) gauge
- Laser (light) gauge
- Resistive tape
- Capacitive probe
- Nuclear radiation

file i00323

Oppgave 79

Enter this *strapping table* into a computer spreadsheet, then use the spreadsheet program's graphing capabilities to plot the volume-vs.-height relationship for this liquid storage vessel:

Height (ft)	Volume (gallons)
0	0
1	498
2	1165
3	1699
4	2321
5	2910
6	3520
7	4105
8	4743
9	5304
10	5899
11	6522
12	7077
13	7650
14	8285
15	8879

Finally, use the spreadsheet program to generate a *best fit equation* for the strapping table data (plotting a "trendline" and displaying the formula for it). It is recommended to try both a linear function as well as a polynomial function to see which type gives the best fit.

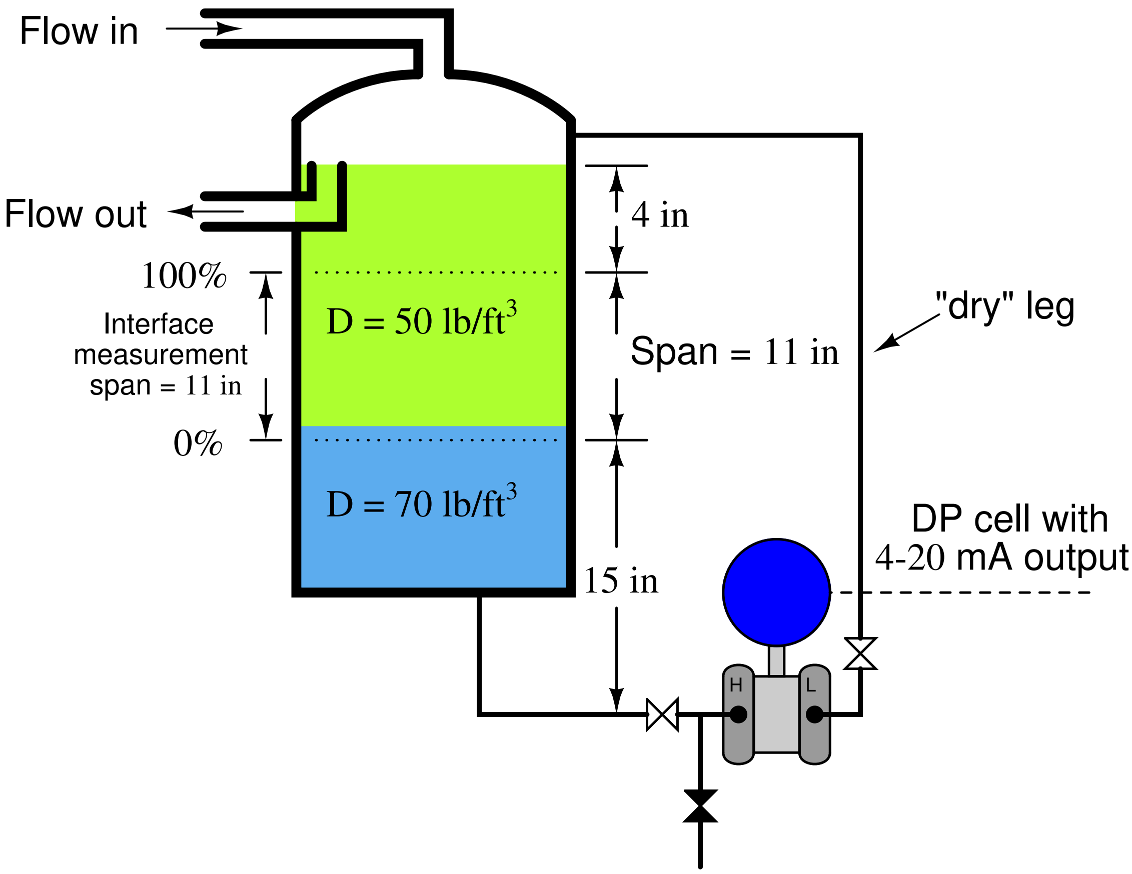
Suggestions for Socratic discussion

- Explain how the "best fit" feature of spreadsheet software might be useful if you need to linearize a level measurement signal in a programmable system such as a PLC.

file i00324

Oppgave 80

Calculate values for the following calibration table, for a transmitter measuring liquid level interface (densities = 50 lb/ft^3 and 70 lb/ft^3), with a calibration tolerance of ± 1% and a 4-20 mA output range:



Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10				
	25				
	50				
	75				
	90				
	100				

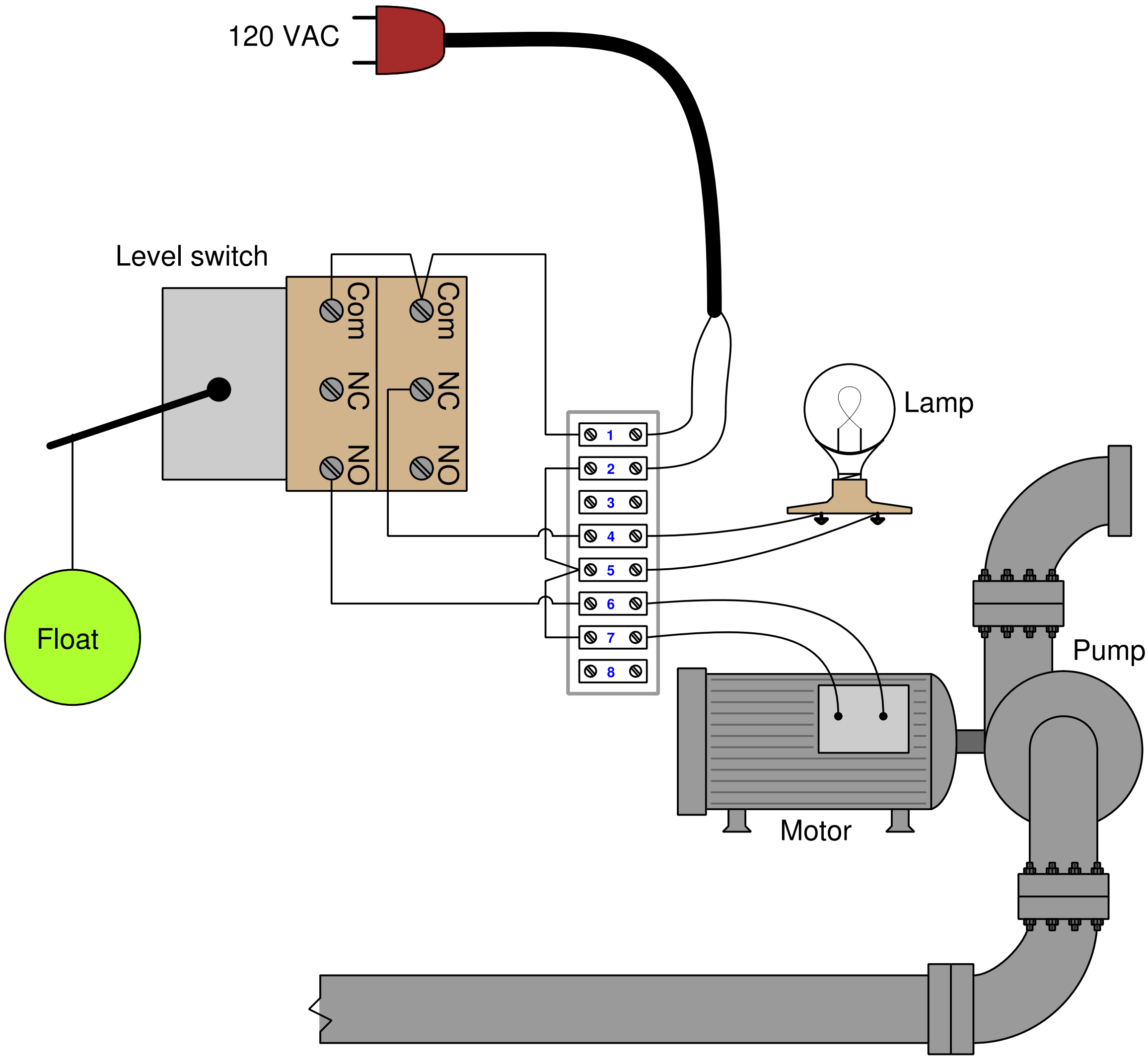
Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

file i00686

Oppgave 81

This pictorial diagram shows how a liquid level switch (with two separate SPDT switch units actuated by a common float mechanism) is wired to control both an electric pump and a lamp:



- Under what liquid level condition will the lamp energize?
- Under what liquid level condition will the pump motor energize?
- Determine what an AC voltmeter would register under the following conditions:
  - Connected between terminals 2 and 6 ; low liquid level
  - Connected between terminals 4 and 7 ; low liquid level
  - Connected between terminals 1 and 6 ; high liquid level
- Supposing the pump motor refused to energize but the lamp still functioned properly (turning on and off when it should), devise a series of diagnostic tests you could implement with an AC voltmeter to locate the fault. For each test, explain what the result of that test *means* for your diagnosis of the problem.

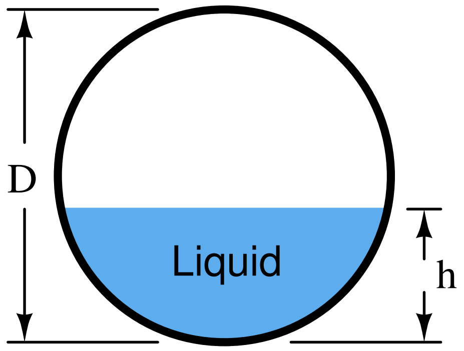
Suggestions for Socratic discussion

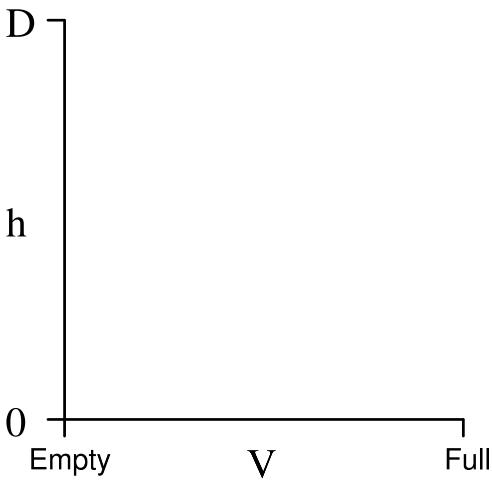
- A problem-solving technique useful for analyzing circuits is to *re-draw the circuit* in a form that is easier to follow than what is shown to you on the given diagram. Discuss and compare different renderings of this circuit, and how these simplified sketches help you with the analysis.

file i02552

Oppgave 82

Qualitatively sketch the height/volume relationship for a spherical vessel, such as the type used to store liquefied butane under pressure:





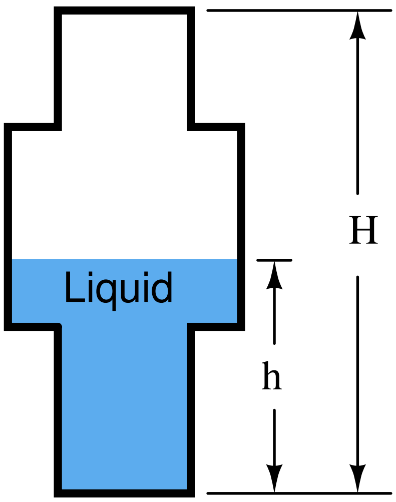
Suggestions for Socratic discussion

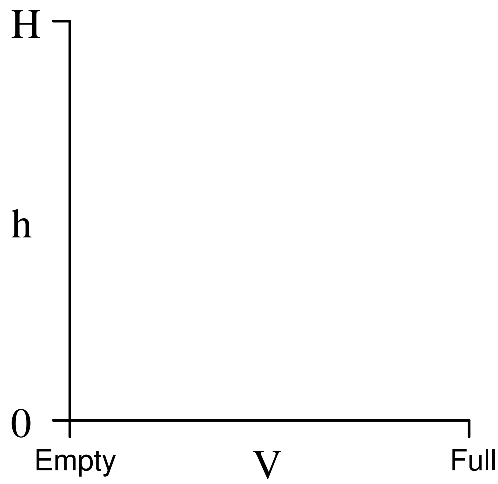
- At which point in the vessel's height is the level transmitter's calibration most critical? In other words, where along the height range will a given height-measurement error translate into the greatest *volume* measurement error?

file i02925

Oppgave 83

Qualitatively sketch the height/volume relationship for a stepped cylindrical vessel:





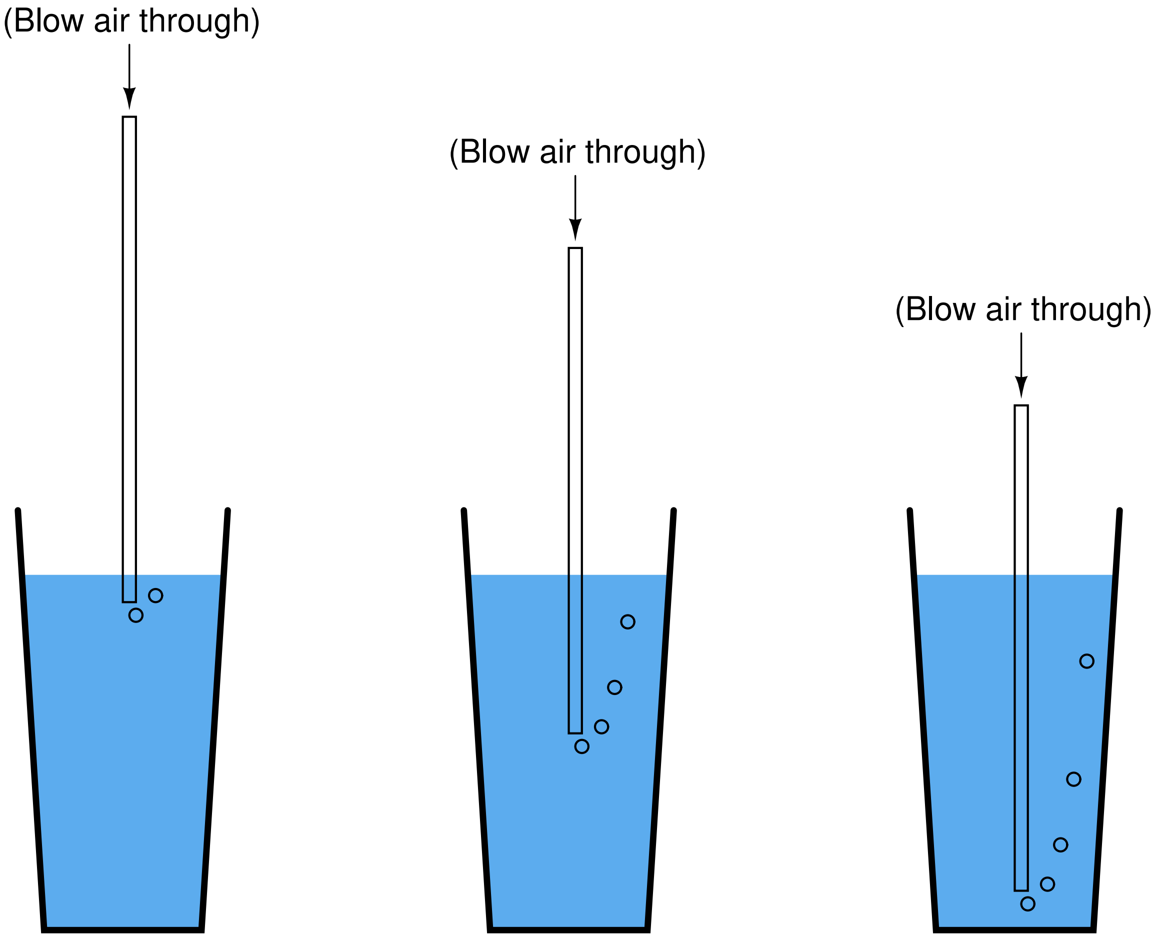
Suggestions for Socratic discussion

- At which point in the vessel's height is the level transmitter's calibration most critical? In other words, where along the height range will a given height-measurement error translate into the greatest *volume* measurement error?

file i02926

Oppgave 84

Fill a tall glass with water, then take a straw and gently blow air through the straw so that bubbles slowly escape from the straw's end. Try this with the straw submerged at different levels within the water:



Note how much pressure it takes to blow bubbles out the end of the tube at these different levels by sensing the air pressure within your mouth as you blow (the tension on your cheeks from the air pressure within).

Explain what causes the required air pressure to vary with straw depth, and elaborate on how this principle might be used to measure the level of liquids in a vessel using compressed air and a "bubble tube."
file i02955

Oppgave 85

Specific gravity is defined as the ratio of densities between a particular fluid and a reference fluid. For liquids, the reference fluid is water; for gases, the reference fluid is air.
For example, the density of olive oil is 57.3 lb/ft^3 and the density of water is 62.4 lb/ft^3. Calculating the ratio of these two densities yields the specific gravity of olive oil: 0.918. That is to say, the density of olive oil is 91.8% that of water.

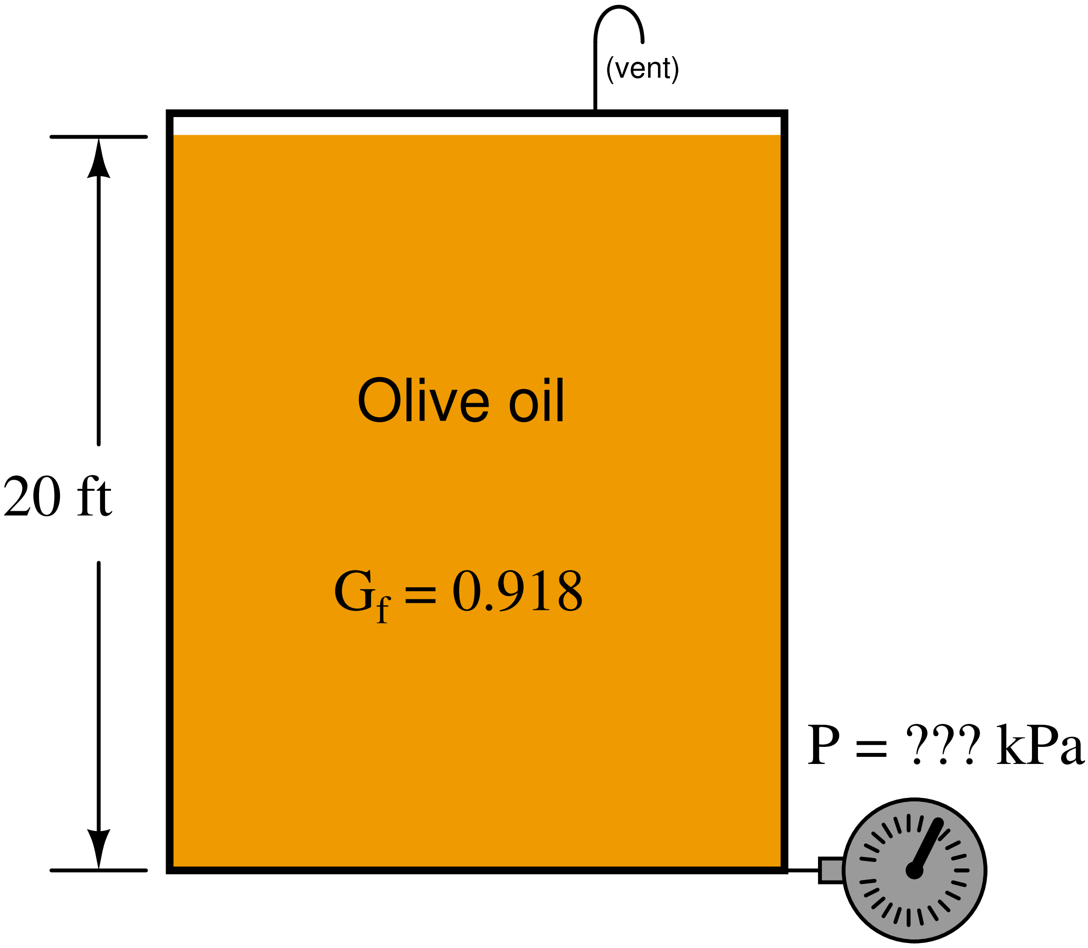
A useful definition of specific gravity when performing hydrostatic pressure calculations for various liquids is the ratio of equivalent water column height to the height of a particular liquid. Using the specific gravity of olive oil (0.918) as an example, we could say that 0.918 units of water column height will generate the same hydrostatic pressure as 1 unit of olive oil height. The unit could be "inches," "centimeters," "millimeters," "cubits," or anything else:

$$0.918 \text{ unit W.C. pressure} = 1 \text{ unit olive oil pressure}$$

We may make a "unity fraction" from this equality, since we are dealing with two physically equal quantities: the amount of hydrostatic pressure generated by two vertical columns of different liquids.

$$\frac{0.918 \text{ unit W.C.}}{1 \text{ unit olive oil}} = \text{ unity}$$

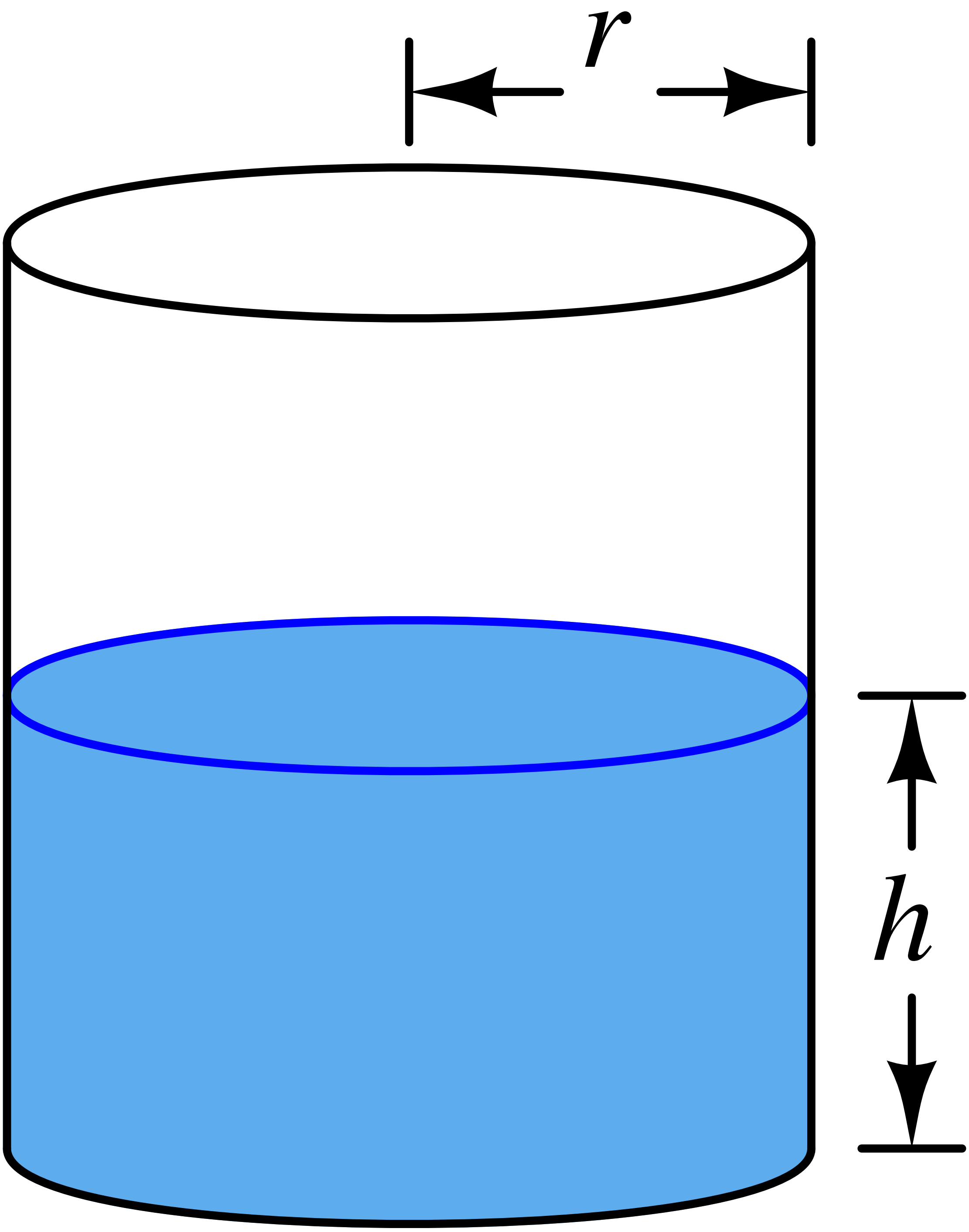
Apply this "unity fraction" to the calculation of hydrostatic pressure at the bottom of a 20 foot tall storage tank filled to the top with olive oil, expressing that pressure in units of kPa. Show how the units cancel in your calculation(s), beginning with feet of olive oil and ending in kilo-Pascals (kPa):



file i02956

Oppgave 86

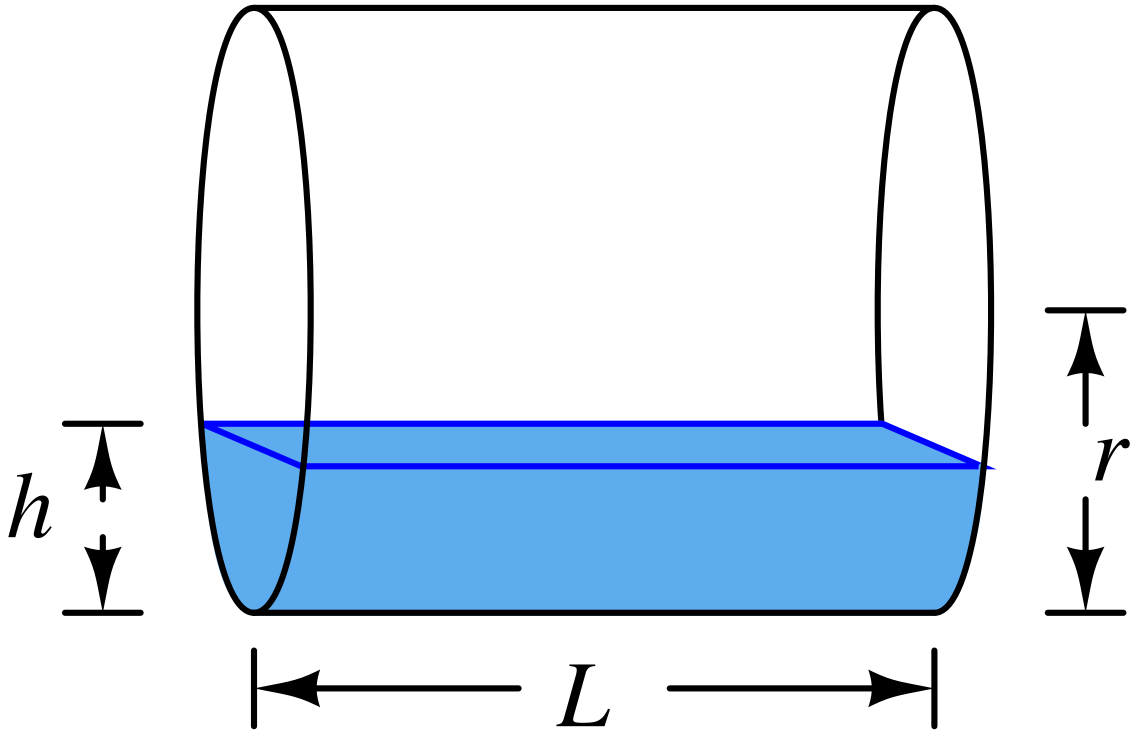
When measuring the volume of liquid stored in a vertical cylinder, the function relating liquid height (h) to stored liquid volume (V) is quite simple:



$$V = \pi r^2 h$$

The term πr^2 defines the cross-sectional area of the cylindrical tank, which when multiplied by the liquid height (h) gives an answer for volume (V) in cubic units.

Calculating stored liquid volume in a *horizontal* cylinder is not nearly as simple. The effective cross-sectional area of the cylinder varies with liquid height, and this variation is not linearly proportional to height. As a result, the function relating liquid height to stored liquid volume is quite complex:



$$V = L\left[(h-r)\sqrt{2hr-h^2} + r^2 \sin^{-1}\frac{(h-r)}{r} + \frac{\pi r^2}{2}\right]$$

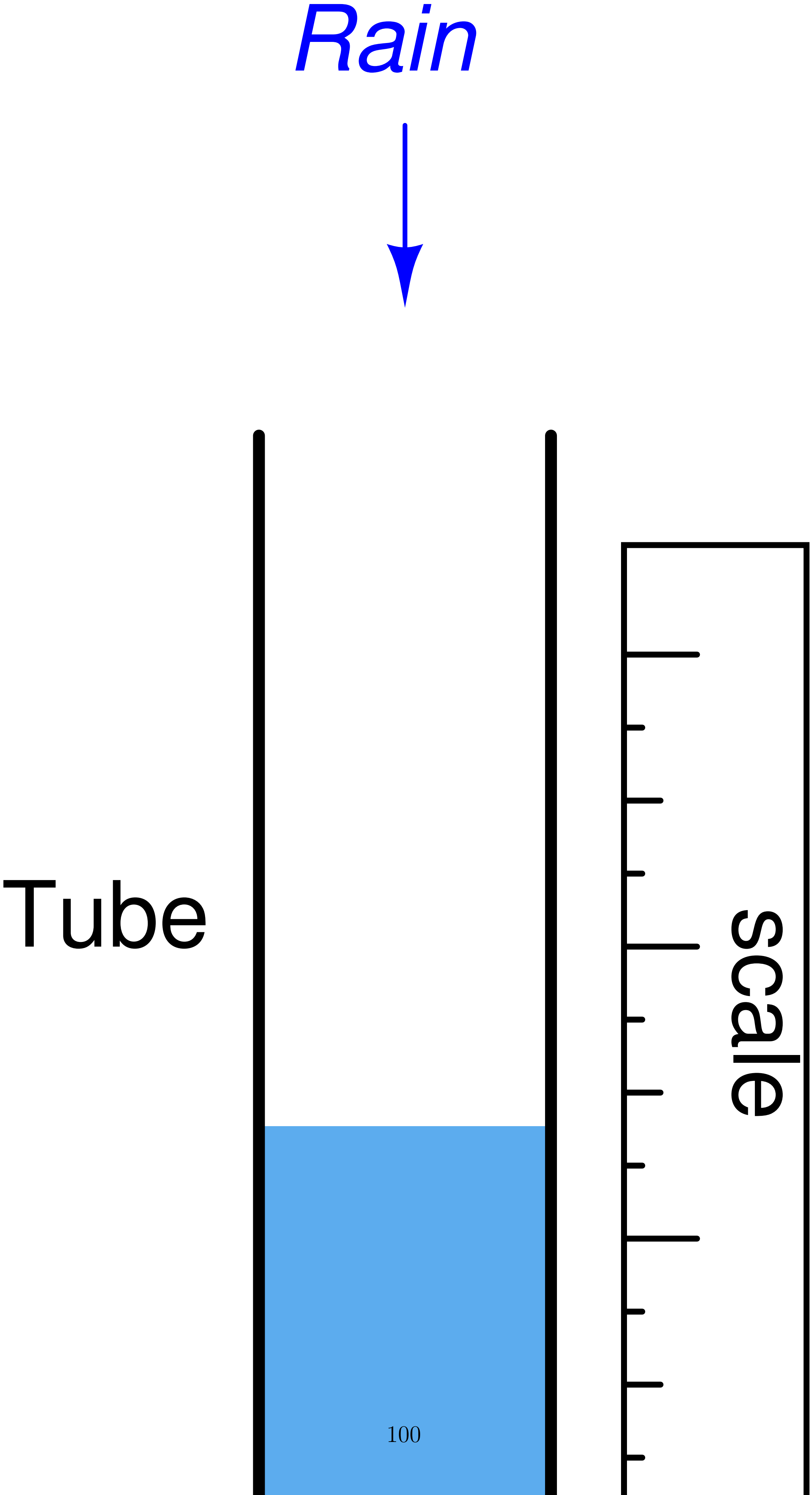
Using this formula, calculate the amount of liquid volume stored in a horizontal cylinder with the following dimensions, assuming a liquid height (h) of 3 feet:

r = 5 feet
L = 25 feet

Express your answer in units of gallons. *Note: the formula shown assumes the use of "radians" as the unit of angle measurement for the arc-sine function rather than "degrees."*
file i02957

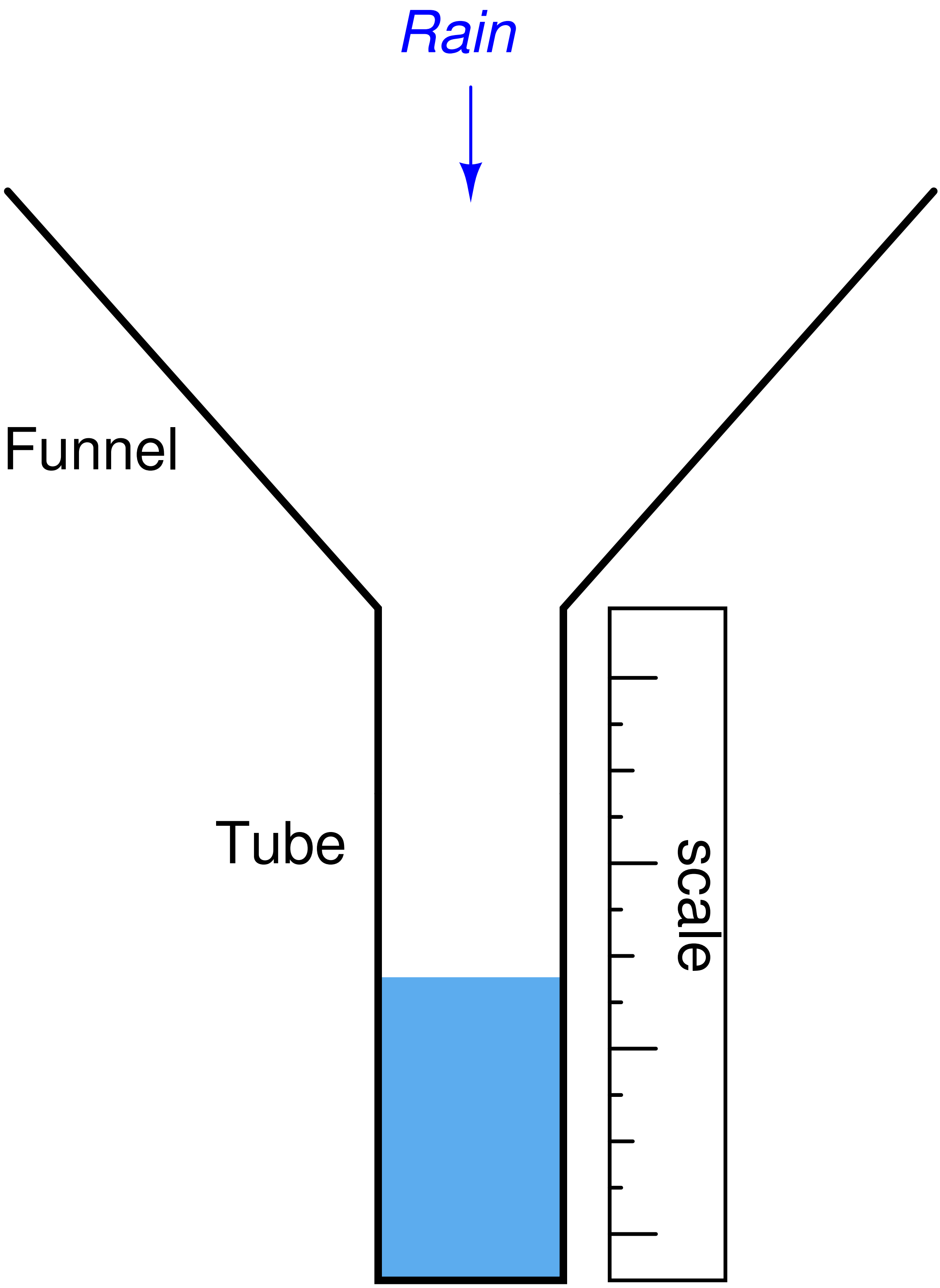
Oppgave 87

A *rain gauge* is nothing more than a vertical tube designed to capture rain water, and indicate the accumulated rainfall on a scale alongside the tube:


Rain
Tube
scale

The diameter of the tube used for the rain gauge is irrelevant. Although a larger tube will of course require more water to fill to the same height, it will also capture proportionally more rain, so any diameter tube measures rainfall just the same.

However, if we equip our rain gauge with a funnel to capture more rain, the measurement will be affected:

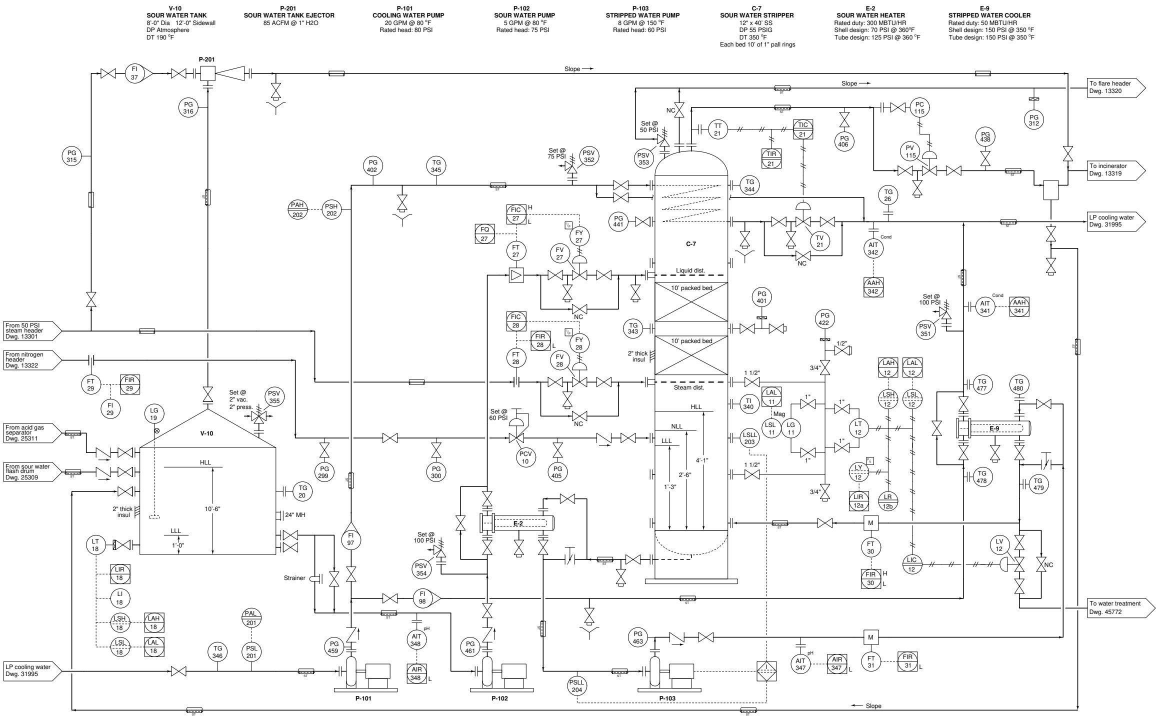


Supposing the diameter of the funnel is 5 inches, and the diameter of the tube is 1 inch, how much rain water level will be indicated by the scale after one-quarter inch of actual rainfall? Does this represent a shift in *zero*, a shift in *span*, or a shift in *both* for the rain gauge compared to its performance without the funnel?

file i02959

Oppgave 88

An operator complains to you, claiming the sour water tank level indication shown by LIR-18 is unreasonably high (something like 6 inches more than it should be). You remove LT-18 and take it to the instrument shop to check its calibration on a bench, and find that it is well within tolerance:



Based on this information, what would be your next step? What sort of problem do you suspect there is – if any – in this system? Also, explained what you could have done differently as your first step, rather than to remove LT-18 from service immediately to check its calibration.

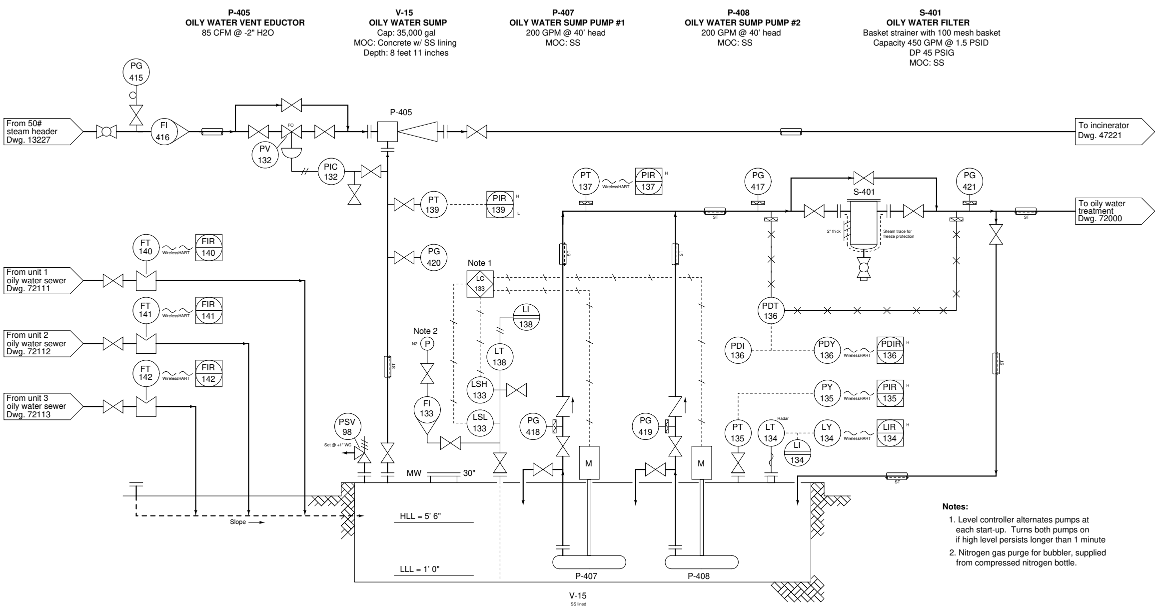
Suggestions for Socratic discussion

- Describe how you would connect the transmitter LT-18 to calibration equipment in the shop to check its calibration, given the type of transmitter that it is.
- Propose a *better* initial step you could have taken besides removing LT-18 for a calibration check in the shop.

file i03527

Oppgave 89

An operator notices that both pumps are running while level indicator LIR-134 shows a very low level in the sump (less than one foot):



The operator summons you to investigate the problem. What do you recommend as your first diagnostic test?

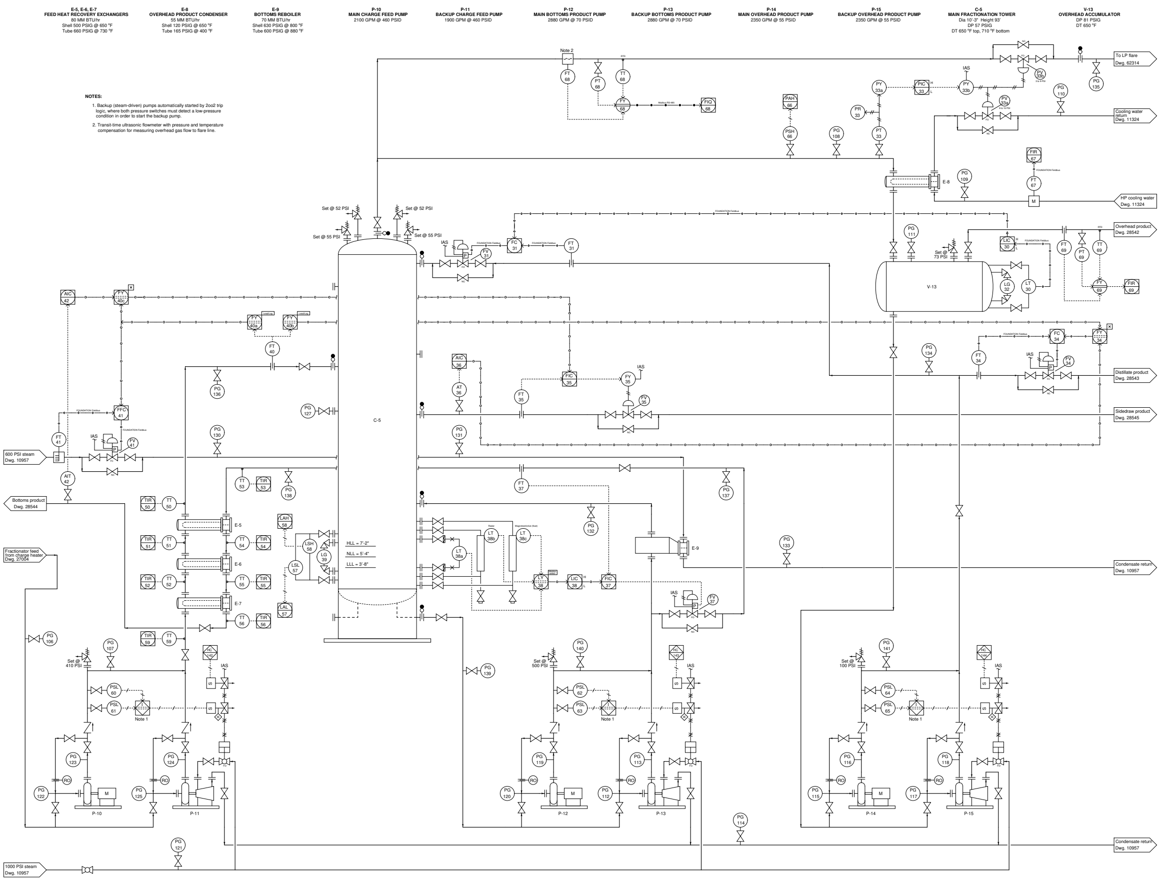
Suggestions for Socratic discussion

- What type of level-measurement technology is being used in this system?

file i03528

Oppgave 90

Suppose the operator of this distillation process calls you to investigate a high-level alarm he is receiving on LAH-58. He doesn't think this should be happening, because LIC-38 registers a liquid level of 5'-1" in the bottom of the tower, which is a bit less than setpoint (5'-4"). Your first test is to measure the current signal from LT-38a, and you find that to be 10.67 mA (LT-38a is ranged 3'-0" to 8'-0"):



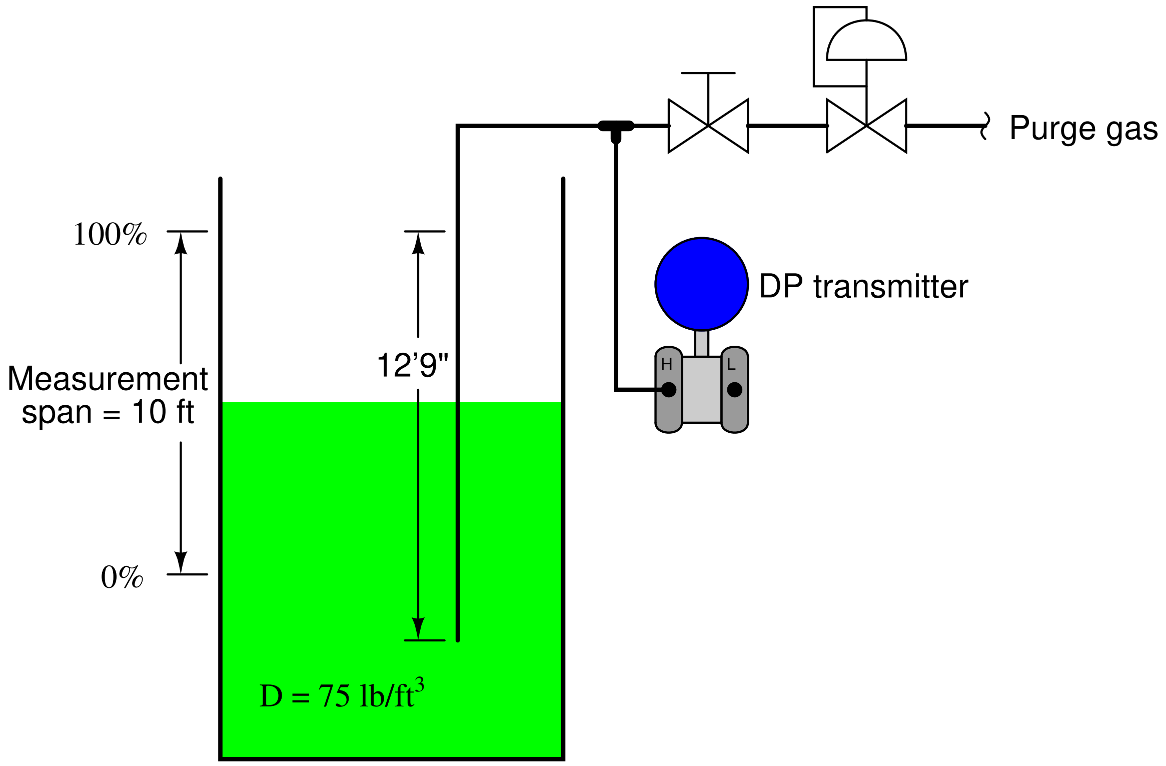
Identify which faults could account for this problem:

Fault	Possible	Impossible
LSH-58 failed		
LAH-58 failed		
LSL-57 failed		
LAL-57 failed		
LT-38a calibration error		
LIC-38 (input) calibration error		
FIC-37 (input) calibration error		

file i03566

Oppgave 91

A liquid storage vessel uses a *bubbler* system to measure its liquid level:



Calculate the LRV and URV range points of the DP transmitter, in units of kPa:

LRV = ________

URV = ________

file i04159

Oppgave 92

An electronic level transmitter has a calibrated range of 0 to 2 feet, and its output signal range is 4 to 20 mA. Complete the following table of values for this transmitter, assuming perfect calibration (no error). Be sure to show your work!

Measured level (feet)	Percent of span (%)	Output signal (mA)
1.6		
		7.1
	40	

file i00032

Oppgave 93

The level of a liquid-to-liquid interface can be difficult to measure. Describe one practical example of a liquid-liquid interface level measurement scenario, and describe in detail at least *two* different level-sensing technologies appropriate for continuously measuring the level of that interface.

file i00036

Oppgave 94

A potable (drinking) water storage tank requires a high-level alarm to warn operations personnel of impending overflow conditions. A high-level switch is on order, but until this switch arrives for installation, you are asked to devise a very simple yet effective high-level indicator device that will function in the interim.

Explain how you would build such a device. Bonus points for devising a method that uses very simple parts (easily found in a maintenance shop).

file i03592

Svar

Svar 1

This is a graded question – no answers or hints given!

Svar 2

Partial answer:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0				
	10				
	25	81.31	8		
	50				12.08
	75				
	90			18.32	
18	100	325.24			

Svar 3

Input level (inches)	Percent of span (%)	Counts (decimal)	Counts (hexadecimal)
36.5	11	112 or 113	070 or 071
62.0	28	286 or 287	11E or 11F
102.5	55	562 or 563	232 or 233
129.5	73	746 or 747	2EA or 2EB
158.0	92	941 or 942	3AD or 3AE

Svar 4

Lower range-values: 100 feet W.C. input (1200 inches W.C.) = 4 mA output
Upper range-values: 110 feet W.C. input (1320 inches W.C.) = 20 mA output

Water level in vessel at 13.7 mA = 6.0625 feet ; applied pressure = 45.98 PSI

Svar 5

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
8	0	156	3	2.88	3.12
8.4	10	160.8	4.2	4.08	4.32
9	25	168	6	5.88	6.12
10	50	180	9	8.88	9.12
11	75	192	12	11.88	12.12
11.6	90	199.2	13.8	13.68	13.92
12	100	204	15	14.88	15.12

Svar 6

Process level (in)	Percent of span (%)	Differential pressure ("W.C.)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
0	0	-64	6	5.88	6.12
12.5	25	-51.5	12	11.88	12.12
25	50	-39	18	17.88	18.12
37.5	75	-26.5	24	23.88	24.12
50	100	-14	30	29.88	30.12

Svar 7

- **(6 points)** Transmitter ΔP at 0% water level = **-38.832** "W.C.
- **(6 points)** Transmitter ΔP at 50% water level = **-31.864** "W.C.
- **(6 points)** Transmitter ΔP at 100% water level = **-24.896** "W.C.

Svar 8

LRV $= -198.1$ inches H_2O URV $= -107.1$ inches H_2O

Svar 9

The elevation for this transmitter (i.e. the total differential pressure applied by the height of fill fluid on both sides) is equal to the total height difference between the remote seal diaphragms multiplied by the specific gravity of the fill fluid:

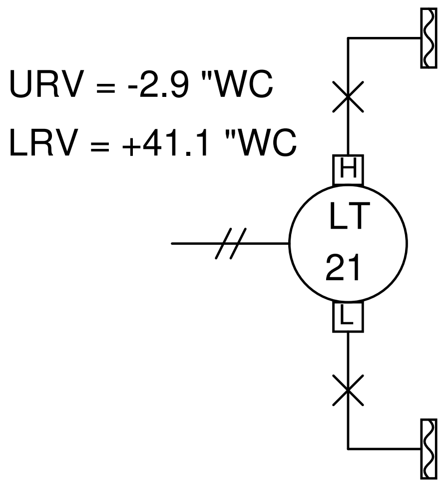
$$P_{elevation} = (44 \text{ in})(0.934) = 41.1 \text{ "WC}$$

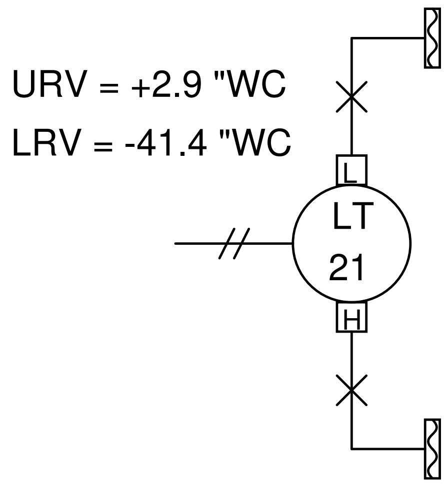
In the LRV condition, this is the only pressure seen by the transmitter. Therefore, 41.1 "WC is the appropriate LRV setting for this transmitter. If we assume that the "H" port of this DP transmitter connects to the lower nozzle, the LRV will be -44.1 "WC. If we assume the "H" port connects to the upper nozzle, the LRV will be $+41.4$ "WC.

In the URV condition, we have the exact same amount of elevation (the fill fluid inside the capillary tubes) but on the lower nozzle we have the hydrostatic pressure of 44 vertical inches of water (i.e. the water inside the seal drum). Thus, in the URV condition the transmitter sees a differential pressure of:

$$P_{differential} = 44\text{" WC} - 41.1 \text{ "WC} = 2.9 \text{ "WC}$$

If we assume the "H" port of this DP transmitter connects to the lower nozzle, the URV will be $+2.9$ "WC. If we assume the "H" port of this DP transmitter connects to the upper nozzle, the URV will be -2.9 "WC.





Svar 10

This is a graded question – no answers or hints given!

Svar 11

The presence of a wet leg will elevate the zero of the transmitter's range by 48" W.C.

Most DP transmitters will suffer *some* calibration error due to high static pressures, but this is typically negligible. Thus, the transmitter need only be calibrated with inches WC air pressure on the calibration bench, nothing special.

It is customary to provide a "condensate pot" at the top of this vertical tube run in order to ensure adequate condensate volume in the wet leg. This helps minimize temporary calibration errors resulting from loss of condensate in the wet leg from drainage during maintenance procedures.

Svar 12

The liquid has a density of 66 pounds per cubic foot.

Svar 13

Svar 14

$P_{reflected}$ = **20.38** %

$P_{forward}$ = **79.62** %

Ullage = **8.366** ft

Svar 15

Svar 16

The use of two pressure transmitters, one at the bottom and one at the top, is reminiscent of a *hydrostatic tank expert* system (using three pressure sensors). If this vessel were vented, we could get away with only using one pressure transmitter along with the radar gauge to calculate liquid level, density, and total mass.

Svar 17

Svar 18

Partial answer:

$P_{reflected} = 63.45\%$

Ullage = 1.676 meters

Svar 19

Caveat emptor! (Latin for "buyer beware")

Radar level transmitters *are* definitely affected by certain properties of the gas or vapor above the liquid surface. I'll let you identify what those properties are!

Svar 20

Vertical measurement span = 2 feet 8 inches

Svar 21

Svar 22

This is a graded question – no answers or hints given!

Svar 23

$x_1 = 1.328$ m

$x_2 = 4.630$ m

Svar 24

Svar 25

Liquid level = 5 feet 10.5 inches from bottom of tank

Svar 26

There will be no change in instrument indication resulting from a density change of the acid. Only the *vapor* density above the liquid affects the speed of sound, which is the primary non-level variable affecting level measurement.

Svar 27

There will be no change in instrument indication resulting from a density change of the alcohol, so long as the liquid remains denser than the float. The buoyancy of the float will be *slightly* affected by the liquid's density, but not much.

Svar 28

One easy diagnostic step would be to change the setpoint of controller LIC-38 (in automatic mode) by 5% or 10%, to see if *all three* transmitters indicate a change in level or only the two in closest agreement.

Svar 29

As compressed air slowly enters the dip tube, it presses the water out the bottom of the tube until the tube is dry. At that point – when all the water is pushed out the end of the tube – the air pressure inside the tube precisely equals the hydrostatic pressure of the water at the bottom of the tube.
If the air pressure exceeds that hydrostatic water pressure by the slightest amount, an air bubble will escape from the tube's end. As soon as this air bubble escapes, the pressure inside the tube drops back down to being precisely equal to the water's hydrostatic pressure. In other words, at low air flow rates the water acts as a sort of pressure relief, preventing the air pressure from significantly exceeding the hydrostatic pressure. In this way, the dip tube replicates the water's hydrostatic pressure in the form of air pressure, which may be sensed by any pressure-measuring instrument connected anywhere along the tube's length.

$P_{gauge} = 3.829$ PSI

Svar 30

Any vapor pressure will be sensed by the transmitter and interpreted as increased liquid level!

Two solutions to this problem:

(1) Use two transmitters (one at top of vessel, one at bottom) and electronically subtract their output signals.

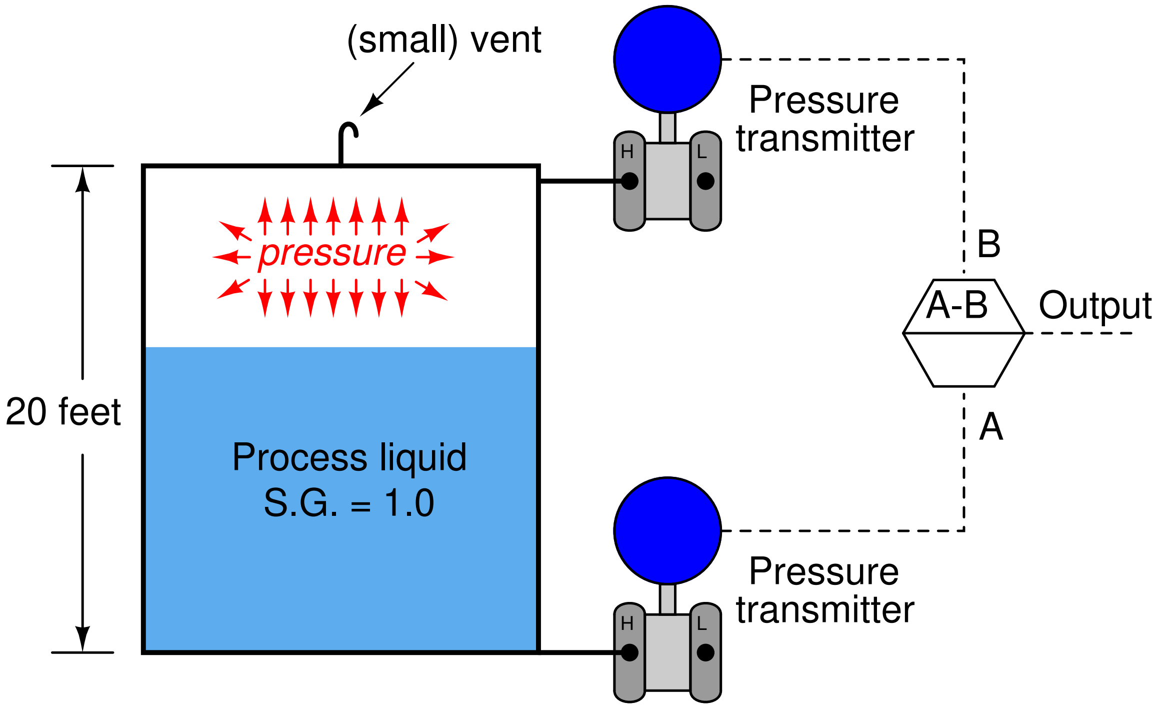
(2) Connect the "Low" side of the one ΔP transmitter to the top of the vessel to naturally compensate for vapor pressure.

Since the transmitter infers level from the amount of pressure sensed at the bottom of the vessel, any vapor pressure buildup inside the vessel will be falsely interpreted as additional liquid level, since the transmitter senses the *sum total* of hydrostatic pressure plus any vapor pressure trapped inside the vessel.

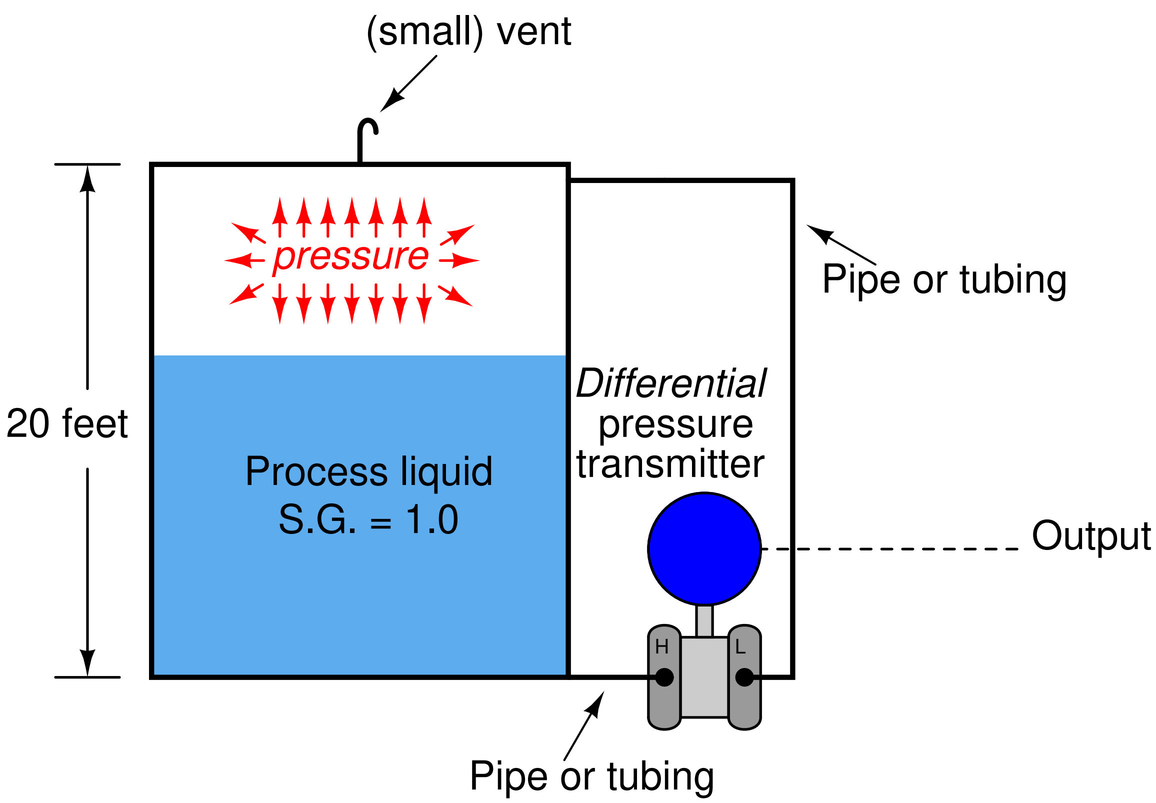
For example, if the process liquid level were at 10 feet (50% of range), the hydrostatic pressure generated by the liquid column would be 120 inches W.C., assuming a specific gravity of 1.0, equal to water. If, however, the vessel contained a vapor pressure equal to 15 inches W.C., this pressure would add with the 120 inches W.C. of pressure generated by liquid head to create 135 inches W.C. of total pressure sensed by the transmitter. As a result, the transmitter would "think" it was detecting a liquid level of 11.25 feet (135 inches high) instead of the true level of 10 feet (120 inches high). Essentially, any vapor pressure in the vessel results in a "zero" shift of the transmitter's indication.

In many applications, the gas pressure inside a vessel far exceeds the hydrostatic pressure generated by the column of liquid inside of it, so this problem can be a very serious one in level measurement. We need to fully understand the nature of the problem and how to solve it in order to successfully measure liquid level in many industrial applications.

The solution to this dilemma is to measure the *difference* in pressure between the top and bottom of the vessel. We could do this by using two pressure transmitters, one at the top and one at the bottom, and detect hydrostatic pressure by subtracting the top transmitter's measurement from the bottom transmitter's measurement. A computer may be used to perform the mathematical subtraction of signals:



Another, more elegant method, incorporates a *differential* pressure transmitter with pipe connections to both ends of the vessel. This solution performs the subtraction mechanically, by directly exposing the transmitter's sensing element to the *difference* of two applied pressures:



Because the differential pressure transmitter solution requires only one sensing instrument rather than two, and results in better accuracy because we are only dealing with

the inaccuracies of a single instrument rather than the compounded inaccuracies of two instruments (three, if you include the subtraction unit), the differential, or "d/p" solution is the one more widely used.
In this particular level measurement application, a differential pressure instrument would have the exact same calibration points (lower and upper range-values) as a "normal" pressure transmitter connected to an open vessel.

Svar 31

Connect a pressure gauge to any accessible port near the bottom of the vessel, and hand-sketch a "level" scale on the gauge face reading in whatever units of measurement the operators find most convenient to use (correlating pressure in PSI to level based on the assumed density of the crude oil).

Svar 32

Partial answer:

- Ultrasonic level, bottom-mounted: v_{water} matters, v_{air} does not
- GWR level: v_{air} matters, v_{water} does not

The velocity of propagation for sound waves varies with the density of the medium and also its bulk modulus. The velocity of propagation for radio waves varies with permittivity. In both cases, changes in density (typically caused by changes in *pressure* and/or *temperature*) affect these factors, thereby affecting the velocity of propagation.

Svar 33

- **Sightglass**
-
- Can it be used to measure the level of both liquid and solid materials? **Liquids only**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, but only if both ports submerged**
-
- Does its calibration depend on some fluid property such as density? **No**
-
- Special advantages: **Simple and inexpensive**
-
- Special disadvantages: **Manual indication only – no output signal**

- **Float**
-
- Can it be used to measure the level of both liquid and solid materials? **Liquids yes, solids only if retracted by automated winch**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, if float density is set properly**
-
- Does its calibration depend on some fluid property such as density? **No**
-
- Special advantages: **Relatively simple and inexpensive**
-
- Special disadvantages: **Requires guides and other apparatus to stabilize in a tall vessel; doesn't work well in turbulent processes**

- **Hydrostatic (DP with direct contact)**
-
- Can it be used to measure the level of both liquid and solid materials? **Liquids only**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, if both ports submerged**
-
- Does its calibration depend on some fluid property such as density? **Yes, density!**
-
- Special advantages: **Fairly simple and reliable**
-
- Special disadvantages: **DP sensor must withstand process fluid corrosion**

- <u>**Hydrostatic bubbler (dip tube)**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Liquids only**
-
- Can it be used to measure liquid-liquid interfaces? **Only if two dip tubes used, with both submerged**
-
- Does its calibration depend on some fluid property such as density? **Yes, density!**
-
- Special advantages: **Dip tube may be made of ceramic or other non-corroding material**
-
- Special disadvantages: **Requires reliable and (possibly) expensive purge fluid**

- <u>**Displacer**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Liquids only**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, if displacer is fully submerged**
-
- Does its calibration depend on some fluid property such as density? **Yes, density!**
-
- Special advantages: **Simple and reliable**
-
- Special disadvantages: **Susceptible to vibration; displacer may become stuck inside of the cage if the process fouls**

- <u>**Ultrasonic**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **No**
-
- Does its calibration depend on some fluid property such as density? **Yes, the speed of sound through the transmission media**
-
- Special advantages: **No contact with process fluid required**
-
- Special disadvantages: **Requires sharp change in density to function (e.g. layers of foam may interfere with measurement); irregular shapes inside of vessel may cause scattering and/or false echoes**

- <u>**Non-contact radar**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **No**
-
- Does its calibration depend on some fluid property such as density? **Yes, the speed of light through the transmission media**
-
- Special advantages: **No contact with process fluid required**
-
- Special disadvantages: **Requires sharp change in permittivity to function (e.g. certain substances such as wood chips may be difficult to detect); irregular shapes inside of vessel may cause scattering and/or false echoes; permittivity of substance(s) above the measured level will affect its accuracy and may change with the density of that substance**

- <u>**Guided-wave radar**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **Yes**
-
- Does its calibration depend on some fluid property such as density? **Yes, the speed of light through the transmission media**
-
- Special advantages: **Waveguide helps ensure a strong echo signal**
-
- Special disadvantages: **Waveguide must withstand corrosion and other stress from the process fluid; requires significant transitions in permittivity to detect surface and interface levels; irregular shapes inside of vessel may cause scattering and/or false echoes; permittivity of substance(s) above the measured level will affect its accuracy and may change with the density of that substance**

- <u>**Magnetostrictive**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **No**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, if float density is set properly**
-
- Does its calibration depend on some fluid property such as density? **No**
-
- Special advantages: **Highly accurate measurement of float position (sub-millimeter resolution capability!)**
-
- Special disadvantages: **Susceptible to fouling of float on waveguide rod**

- <u>**Weight (load cells on vessel)**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **No, unless total height of liquid is fixed (e.g. using an overflow pipe)**
-
- Does its calibration depend on some fluid property such as density? **Yes, if level (height) measurement is desired; No, if mass measurement is desired**
-
- Special advantages: **No contact with process fluid required; yields a linear measurement regardless of vessel geometry**
-
- Special disadvantages: **All mechanical stress must be eliminated from vessel**

- <u>**Capacitive**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, so long as probe is fully submerged**
-
- Does its calibration depend on some fluid property such as density? **Yes, permittivity of the process liquid for the non-conducting style**
-
- Special advantages: **Inexpensive**
-
- Special disadvantages: **Prone to calibration errors due to stray capacitance; irregular shapes inside of vessel may cause nonlinear response**

- <u>**Nuclear**</u>
-
- Can it be used to measure the level of both liquid and solid materials? **Yes**
-
- Can it be used to measure liquid-liquid interfaces? **Yes, if density or other radiation-attenuating/scattering properties are sufficiently different between the two liquids**
-
- Does its calibration depend on some fluid property such as density? **Yes, density!**
-
- Special advantages: **No contact with process fluid required**
-
- Special disadvantages: **Expensive to license and operate; calibration errors may result with fouling of vessel walls**

Svar 34

Svar 35

Svar 36

"Top" pressure = 0 "W.C.
"Middle" pressure = 51.6 "W.C.
"Bottom" pressure = 154.8 "W.C.

Svar 37

The “Top” transmitter’s indication of 0 inches water column tells us that the vessel is vented, or at least there is no vapor pressure buildup in it. This makes the task of determining level and density from the other two pressure measurements that much easier. Determining specific gravity would be the best step to do first, before trying to determine liquid level. Once the liquid’s density is known, its level may be easily calculated from the “Bottom” transmitter’s pressure measurement.

With 10 feet of vertical distance separating the “Bottom” and “Middle” transmitters, there should be 120 inches (10 feet $\times$ 12 inches/foot) of water column pressure *difference* between the two transmitters’ measurements if the liquid in question had a specific gravity equal to 1, like water. In this case, though, there is a pressure difference of only 110.4 inches between the two measurements:

(276 "W.C.) - (165.6 "W.C.) = 110.4 "W.C.

The discrepancy between 120 inches water column and 110.4 inches water column is due to one factor and one factor only: the liquid’s density. We may find the density by dividing the actual pressure difference by the expected pressure difference assuming a density equal to water:

Specific gravity = (110.4 "W.C. / 120 "W.C.) = 0.92

Therefore, the liquid held in this vessel has a specific gravity of 0.92, meaning that its density is 92% that of water. Knowing the liquid density, we calculate the liquid level by re-working the liquid column pressure equation to solve for height:

$$P = hG$$

$$\frac{P}{G} = h$$

Where,
P = hydrostatic pressure in inches water column
h = liquid column height in inches
G = specific gravity of liquid

(276 "W.C.)/(0.92 "W.C. / in) = 300 inches

So, the answer for liquid level is 300 inches, or 25 feet.

Svar 38

The “Top” transmitter’s measurement of 50 inches water column tells us that the vessel is pressurized. This figure will be important to include in our level calculations later.

The difference between “Bottom” and “Middle” pressure transmitter measurements is solely a function of liquid density, since the vertical distance between the two transmitters is fixed and any vapor pressure buildup (50 "W.C., as indicated by the “Top” transmitter) adds equally to *both* transmitters’ indications. In this case, the difference between 310 inches water column and 220 inches water column is 90 inches of water column:

(310 "W.C.) - (220 "W.C.) = 90 "W.C.

If the process liquid were water (S.G. = 1), the pressure difference would be 120 inches of water column, not 90, because the two transmitters are located 10 feet apart from each other. Thus, the density of this liquid is substantially less than that of water:

Specific gravity = (90 "W.C. / 120 "W.C.) = 0.75

To calculate liquid level (height), we must first subtract the measured vapor pressure (50 "W.C.) from the “Bottom” pressure transmitter’s indication, so that we are left with the pressure due to liquid head alone:

hydrostatic pressure = (310 "W.C.) - (50 "W.C.) = 260 "W.C.

Dividing this hydrostatic pressure by the specific gravity yields the liquid column height:

(260 "W.C.)/(0.75 "W.C. / in) = 346.67 inches or 28.89 feet

Equations for calculating specific gravity and liquid level (let x be the distance between the middle and bottom pressure transmitters in units of inches, and all pressures in units of inches water column):

$$\text{Specific Gravity} = \frac{P_{bottom} - P_{middle}}{x}$$

$$\text{Liquid level} = \frac{P_{bottom} - P_{top}}{\text{Specific Gravity}}$$

$$\text{Liquid level} = x\frac{P_{bottom} - P_{top}}{P_{bottom} - P_{middle}}$$

Svar 39

Svar 40

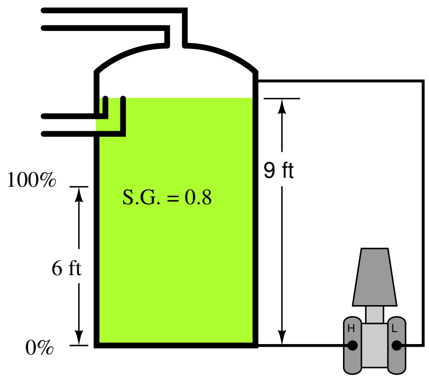
This is a graded question – no answers or hints given!

Svar 41

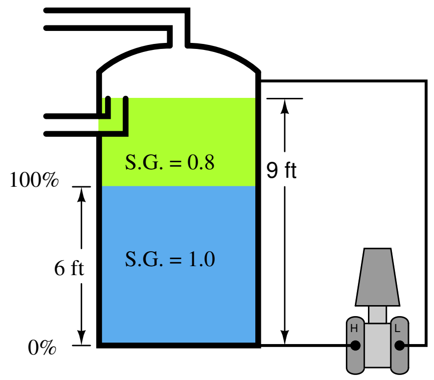
This is a graded question – no answers or hints given!

Svar 42

Here are the two "thought experiment" scenarios pictured to arrive at the LRV and URV pressure values:



P_{LRV} = (9 ft)(12 in/ft)(0.8) = 86.4 "WC



P_{URV} = (6 ft)(12 in/ft)(1.0) + (3 ft)(12 in/ft)(0.8) = 100.8 "WC

Interface level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (PSI)	Output signal min. (PSI)	Output signal max. (PSI)
0	0	86.4	3	2.97	3.03
0.6	10	87.84	4.2	4.17	4.23
1.5	25	90.0	6	5.97	6.03
3	50	93.6	9	8.97	9.03
4.5	75	97.2	12	11.97	12.03
5.4	90	99.36	13.8	13.77	13.83
6	100	100.8	15	14.97	15.03

Svar 43

Partial answer:

Interface level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0				
	10				5.76
	25				
	50		12		
4.5	75				
	90				
	100	43.2 (Low side)		19.84	

Follow-up question: why do you suppose it is a good idea to keep the wet leg filled with a fluid with such a high specific gravity (1.2)? Why not just let it flood with the lighter fluid (SG = 0.8) or even fill it with water (SG = 1.0)?

Svar 44

Partial answer:

Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0	10.5 L			
	10		5.6		
7.5	25				
		3.75 L			
	75			15.984	
	90				18.416
30	100				

Note: the letter "L" following the differential pressure value represents that amount of positive pressure applied to the *low* port of the transmitter.

Svar 45

Measured level (feet)	Percent of span (%)	Output signal (PSI)
3.2	64	10.68
0.4167	8.333	4
2.5	50	9
2.4	48	8.76
3.458	69.17	11.3
0.9	18	5.16

Svar 46

Measured level (inches)	Percent of span (%)	Output signal (mA)
47	20	7.2
44.38	12.5	6
66.25	75	16
60	57.14	13.14
64.28	69.38	15.1
51.9	34	9.44

Svar 47

This is a graded question – no answers or hints given!

Svar 48

Lower range-values (LRV): 0 inches W.C. input = 4 mA output

Upper range-values (URV): 114.24 inches W.C. input = 20 mA output

- Transmitter output signal (mA) at 8 feet of level = 13.14 mA
- Heptane level at 5.7 mA signal output = 1.4875 feet

Svar 49

Lower range-values (LRV): 0 inches W.C. input = 3 PSI output

Upper range-values (URV): 216 inches W.C. input = 15 PSI output

- Transmitter output signal (PSI) at 12 feet of level = 11 PSI
- Water level at 5.9 PSI signal output = 4.35 feet

Svar 50

Lower range-values (LRV): 0 PSI input = 3 PSI output

Upper range-values (URV): 11.98 PSI input = 15 PSI output

- Transmitter output signal (PSI) at 19 feet of level = 10.6 PSI
- Liquid level at 12.4 PSI signal output = 23.5 feet

The 71 ^{o}F liquid temperature is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem. Liquid temperature is relevant for a level instrument only because changes in temperature can cause the liquid density to change as well, thus influencing the proportionality between liquid height and hydrostatic pressure. However, since we are already given the density of the liquid in this situation, the temperature is irrelevant.

Svar 51

If the liquid level in the vessel rises to 7 feet, the transmitter should (ideally) output a final signal corresponding to 7 feet of level. However, since the transmitter in question is a hydrostatic pressure type, and the liquid density has increased as well, it will not register accurately anymore.
The old specific gravity was 1.12, and the new specific gravity is 1.35. The error in span will be the ratio of the new specific gravity to the old, or $1.35/1.12 = 1.2054$. In other words, the new acid/water mixture is 1.2054 times denser than it is supposed to be, according to how the transmitter was calibrated. Thus, the transmitter output will correspond to a liquid level of 7 feet times the error factor of 1.2054, or 8.4375 feet.

A good way to solve this problem is to apply the problem-solving technique of *simplification*. Imagine the two specific gravities being much simpler numbers: 1 and 2 instead of 1.12 and 1.35, respectively. It should be obvious now that a doubling of specific gravity will result in a doubling of level indication (i.e. the transmitter will register twice as much liquid level as there actually is inside the vessel). It should also be obvious that the error factor is 2:1, which is precisely the ratio of new:old specific gravity.

Alternatively, liquid level could be measured with a float, a capacitive sensor, ultrasonic or radar gauge, or some other instrument functioning on the detection of the liquid/vapor interface.

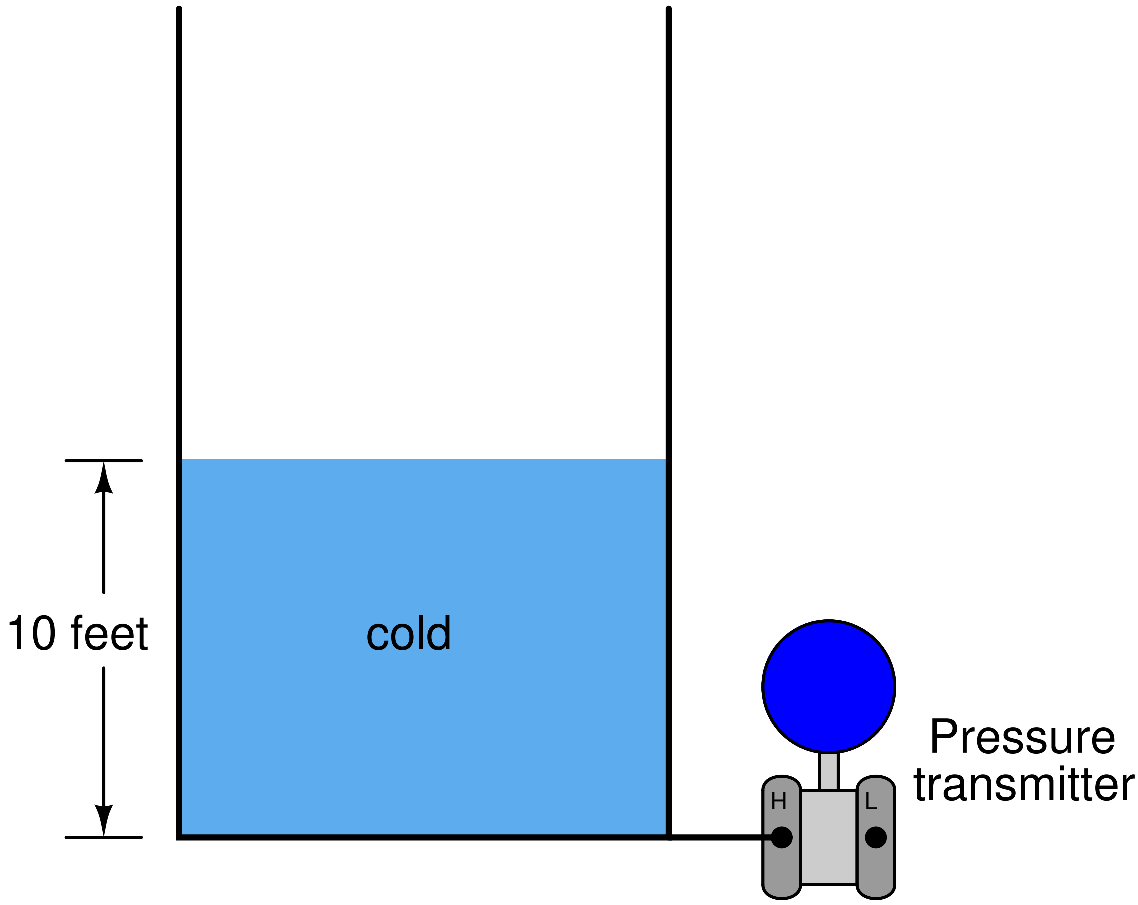
Svar 52

The transmitter output will stay the same.

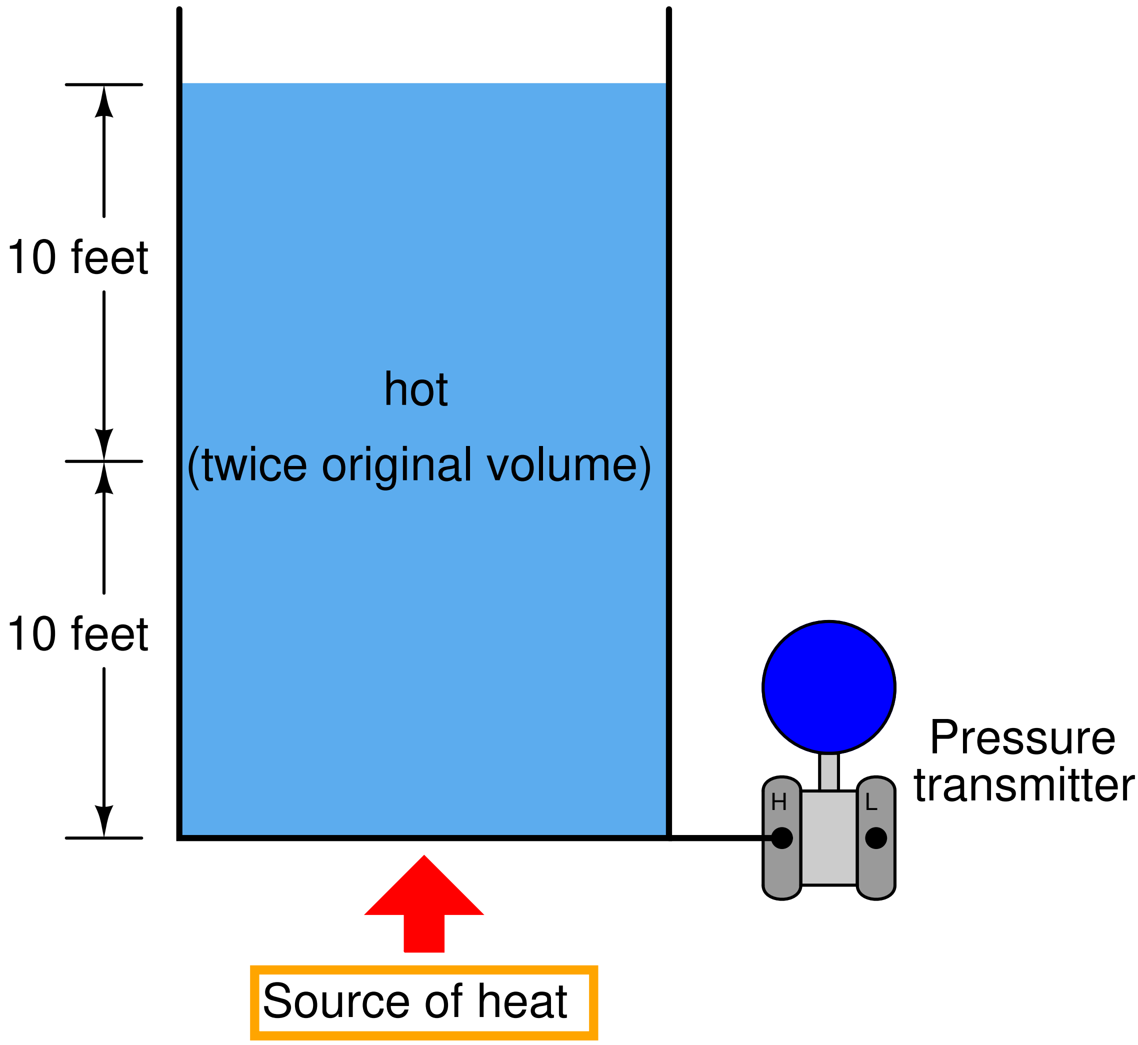
If you thought that the transmitter output would decrease due to the water becoming less dense, I recommend you explore the concept of density a little deeper with the following "thought experiment:"

- Imagine the vessel filled half-way with liquid.
- Imagine that liquid heating up and expanding until it is only *half* as dense as it was at the beginning of the experiment.
- Calculate the new hydrostatic pressure with the expanded, less-dense liquid.

In a way, this is a "trick" question. As any given mass of water heats up, its volume will increase. This is what makes it less dense than before: increased volume with the same mass (weight). Knowing how to calculate hydrostatic pressure from height and specific gravity, you might have approached this problem by assuming the water column height would have stayed the same while its density decreased, resulting in a lesser hydrostatic pressure and decreased transmitter output. However, this answer is incorrect.
If the water volume expands as a result of a temperature increase, the level inside the vessel *must rise*, because it will require a higher vessel level to contain a greater volume of water. The level will rise by the same percentage that the density decreases, resulting in a cancellation of level increase with density decrease. As a result, the hydrostatic pressure at any point in the vessel remains constant.
If you have difficulty picturing this effect, consider an exaggerated example to make things simpler. Suppose that a vessel has been filled to a height of 10 feet with cold liquid:



Now, imagine that same vessel being heated until the liquid expands to exactly *twice* its former volume:



The liquid level must double to accommodate twice the volume in the same vessel, assuming a vessel of constant diameter, and its density will be cut in half (twice the volume with the same mass). Consequently, the two factors of liquid level change and liquid density change cancel each other out to give the exact same hydrostatic pressure as before. In other words, the transmitter will register the same liquid level as it did when the liquid was cold, and will output the exact same signal, even though the actual vessel level is quite a bit more than it was when cold. Pretty tricky, huh?

Svar 53

If the lower process connection were blocked by debris, the transmitter's output signal would increase, quite possibly to a magnitude greater than 100%. Just the opposite would happen if the upper process connection plugged.

Svar 54

Svar 55

Svar 56

Partial answer:

Process level (ft)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
	0				
	10			5.568	
	25	-82.28			
5.5	50				
	75		16		
	90				
	100	$+12.87$			

Svar 57

Dry leg:

% of span	ΔP ("H_2O)	Output (mA)
0	0	10
50	153	30
100	306	50

Wet leg:

% of span	ΔP ("H_2O)	Output (mA)
0	-306	10
50	-153	30
100	0	50

Svar 58

% of span	ΔP ("H_2O)	Output (mA)
0	-462	10
50	-309	30
100	-156	50

Svar 59

Note: a weight density (γ) of 51.2 lb/ft^3 is assumed for kerosene.

- LRV = **56.62** "WC = 2.046 PSI
- URV = **164.9** "WC = 5.959 PSI
- Output = **5.455** mA with the kerosene level 4 feet up from the bottom of the tank (4 feet "fillage")
- Output = **12.73** mA with the kerosene level 6 feet down from the top of the tank (6 feet "ullage")

Svar 60

Upper transmitter: LRV = -148.8 "H_2O URV = -120 "H_2O

Lower transmitter: LRV = -120 "H_2O URV = -36 "H_2O

Svar 61

LRV = +173.7 "H_2O URV = +94.76 "H_2O

The temperature and static pressure values are extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem.

Svar 62

LRV = +4.42 PSI URV = +1.74 PSI

A fill fluid of lesser density would apply less hydrostatic pressure to the "high" side of the transmitter, making the transmitter "think" there was a greater level of process liquid in the vessel. This would be a shift in the level measurement system's *zero* only. This change would neither affect span nor linearity.
Specifically, the zero shift would be equivalent to 1.62 feet of level in the vessel!

Svar 63

This is a graded question – no answers or hints given!

Svar 64

Lower range-values (LRV): 9.461 kPa input = 4 mA output

Upper range-values (URV): 42.57 kPa input = 20 mA output

- Transmitter output signal (mA) at 5.2 feet of level = 9.943 mA
- Acetone level at 12.7 mA signal output = 7.613 feet

Svar 65

Process level (in)	Percent of span (%)	Hydrostatic pressure (PSI)	Output signal ideal (mA)
48	0	1.734	4
58.5	25	2.113	8
69	50	2.493	12
79.5	75	2.872	16
90	100	3.251	20

Svar 66

The problem is that gasoline is less dense than water: for the same liquid height in the tank, gasoline generates less hydrostatic pressure than water. The solution is to re-calibrate the gauge!

Answer to Socratic question: the gauge will register about 6.7 feet of liquid. The density of gasoline varies between 41 and 43 pounds per cubic foot, so the range of possibilities here for gauge reading is 6.57 feet to 6.89 feet.

Svar 67

P_{high} = **72.487** PSIG

P_{low} = **68** PSIG

ΔP = **4.487** PSID

Svar 68

During regular operation:

- Open valves: 2, 4, 5, and 8
- Shut valves: 1, 3, 6, 7, and 9

Procedure to apply an LRV test pressure to the transmitter:

- Shut valves 2 and 4
- Open valves 1 and 6
- Inspect wet-leg liquid level (re-fill if necessary)
- Crack valve 4 open until liquid overflows out of LRV standpipe, then shut
- *The transmitter will now be sensing LRV pressure*

Svar 69

$P_{reflected} = 26.15\%$

$P_{forward} = 73.85\%$

Ullage = 8 feet 4.7 inches

Fillage = 21 feet 7.3 inches

(Note: the velocity of light used in the ullage and fillage calculations is 2.9979×10^8 meters per second)

The 35 PSI gas pressure is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem. Gas pressure is relevant for a radar level instrument only because changes in gas pressure can cause the gas permittivity to change as well, thus influencing the radio wave's propagation velocity. However, since we are already given the permittivity value of the gas in this situation, the pressure is irrelevant.

Svar 70

$x_1 = 1.27$ m

$x_2 = 1.23$ m

$x_3 = 1.82$ m

Svar 71

t (at 1 atm) = 10.96 nanoseconds

t (at 3 atm) = 12.66 nanoseconds

Svar 72

$t_1 = 6.67$ ns

$t_2 = 46.5$ ns

Svar 73

Hydrostatic pressure when completely full of water = 1.065 bar

Hydrostatic pressure when completely full of gasoline = 0.717 bar

Hydrostatic pressure when water-gasoline interface is at the 50% level = 0.891 bar

---

Svar 74

If not completely submerged, the interface level in the well might not match the interface level in the rest of the vessel.

Svar 75

As boiler temperature increases, the water density decreases. For saturated steam conditions (i.e. water and steam in direct contact with each other in the same vessel), pressure and temperature are directly related. So, as temperature in the steam drum increases, pressure must also. This increase in pressure causes the steam to become denser as the steam molecules become packed closer together.

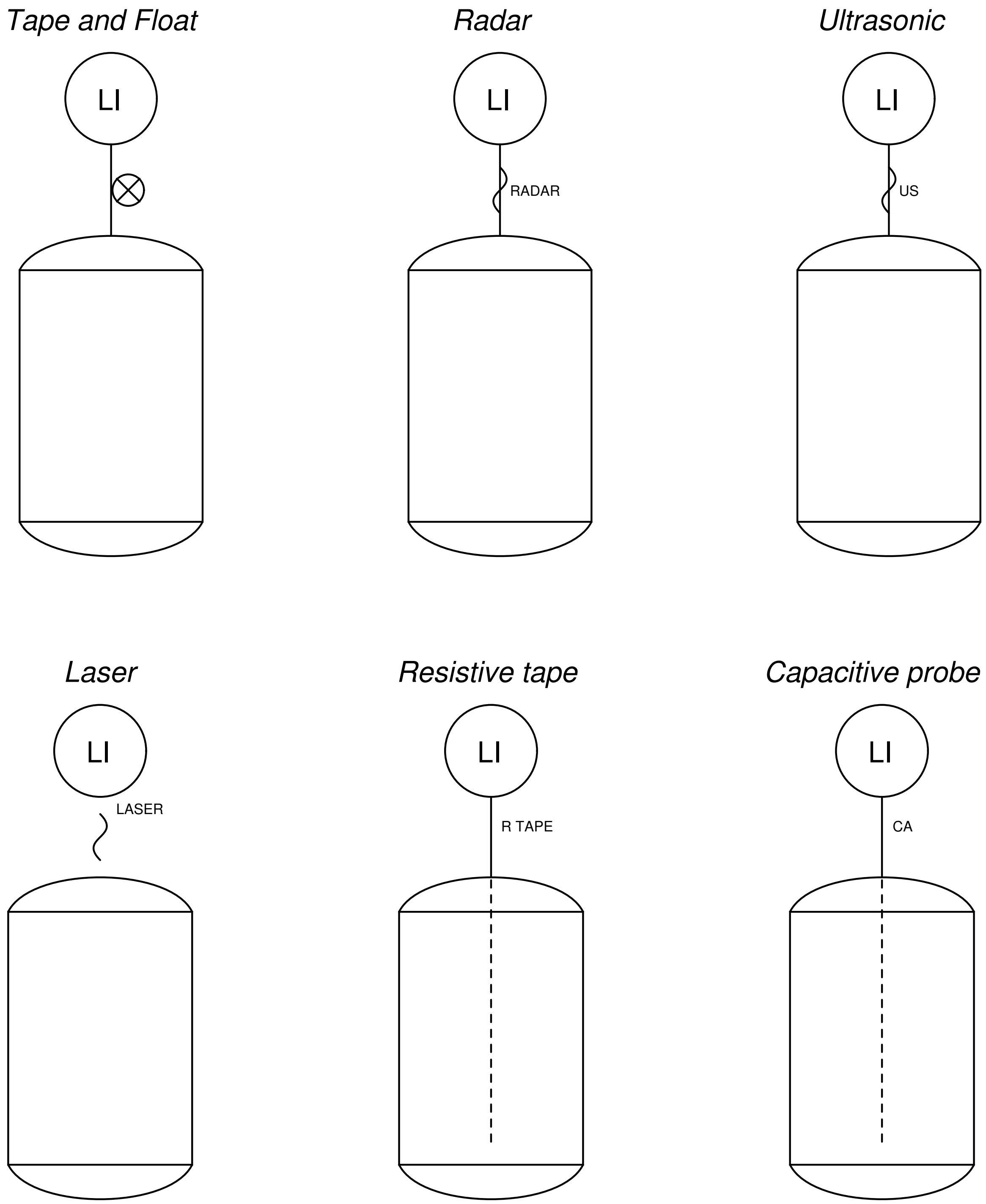
Just to give you an example of how significant these density changes are at high pressure (e.g. power generation boilers), consider the following values:

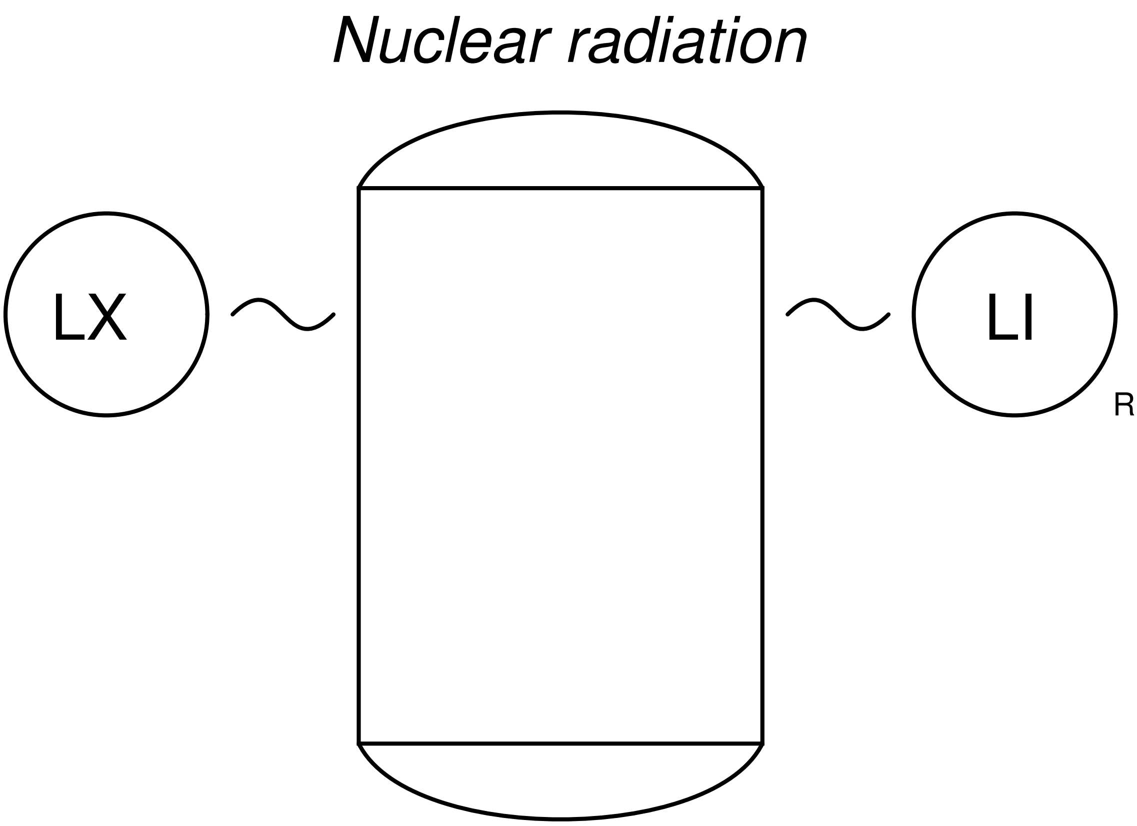
- Boiling (saturated) water density at 2,425 PSIG = 35.49 lb/ft^3
- Saturated steam density at 2,425 PSIG = 7.33 lb/ft^3

Svar 76

Svar 77

The transmitter is at fault, not the indicator.


Tape and Float
LI
Radar
LI
RADAR
Ultrasonic
LI
US
Laser
LI
LASER
Resistive tape
LI
R TAPE
Capacitive probe
LI
CA



Svar 79

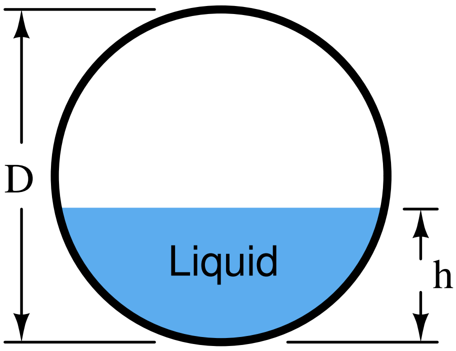
Svar 80

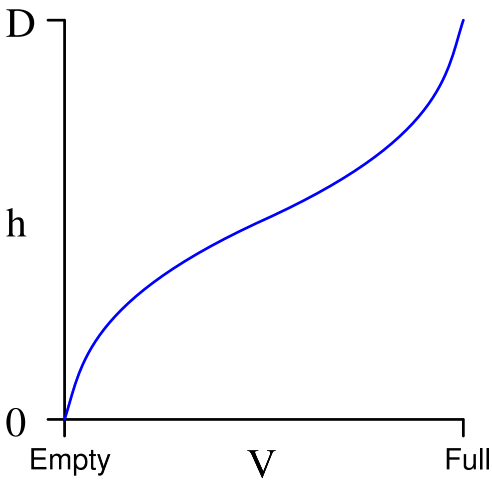
Partial answer:

Interface level (in)	Percent of span (%)	Δ pressure sensed ("W.C)	Output signal ideal (mA)	Output signal min. (mA)	Output signal max. (mA)
0	0	28.83		3.84	
	10		5.6		5.76
2.75	25	29.71		7.84	
	50		12		12.16
	75	31.48		15.84	
9.9	90		18.4		18.56
	100		20	19.84	

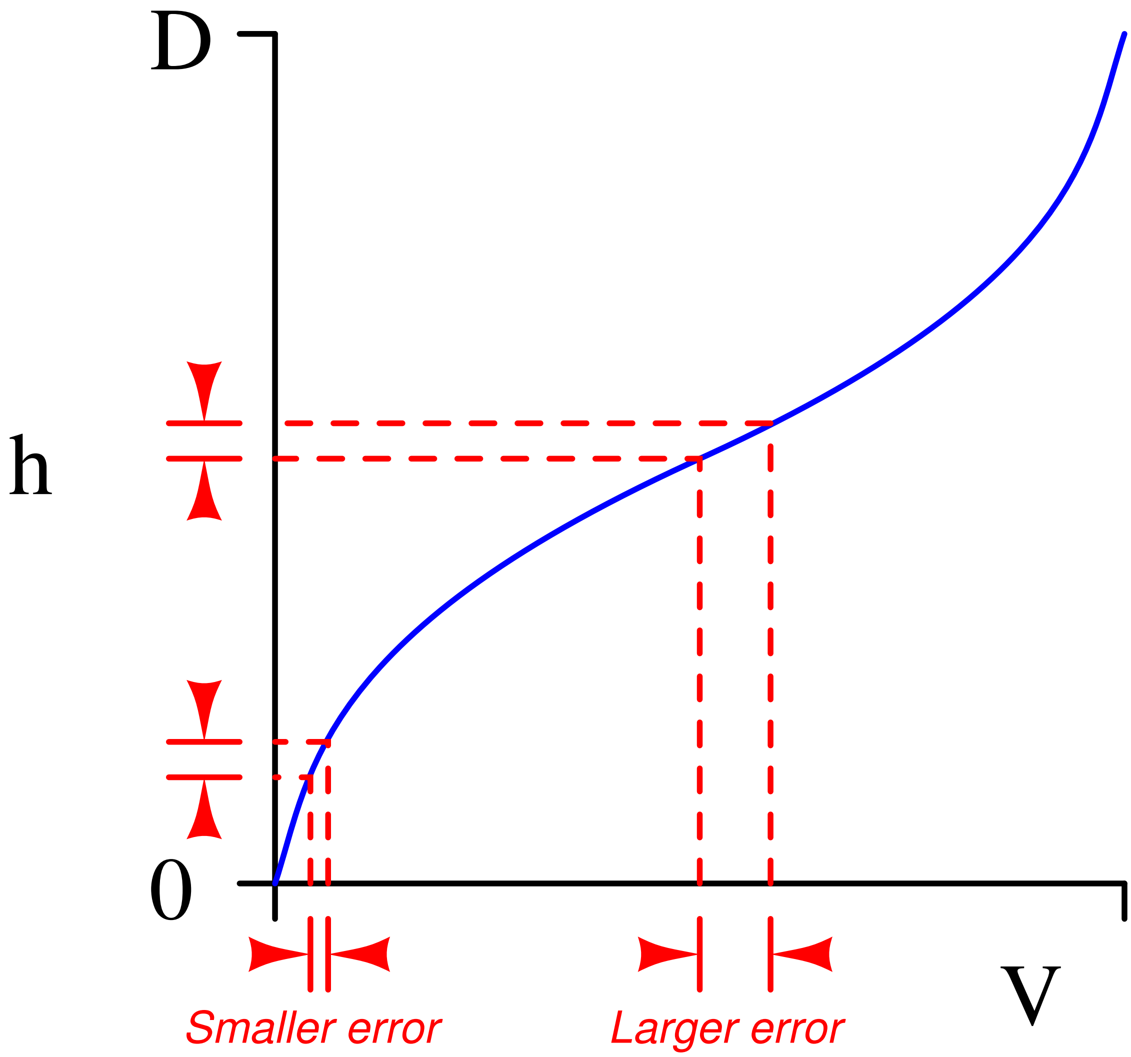
Svar 81

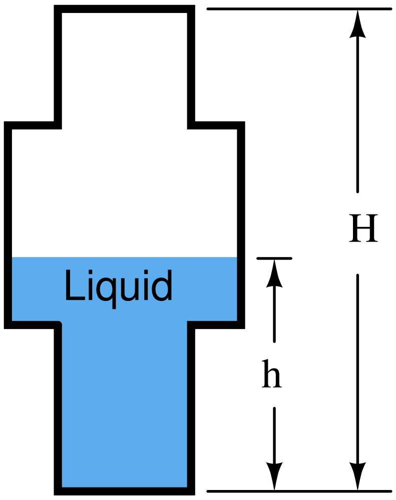
Svar 82

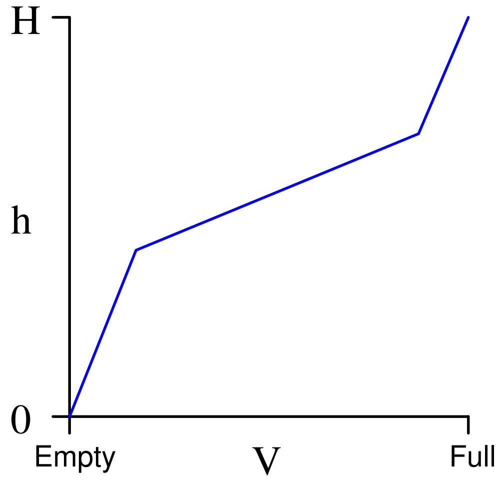




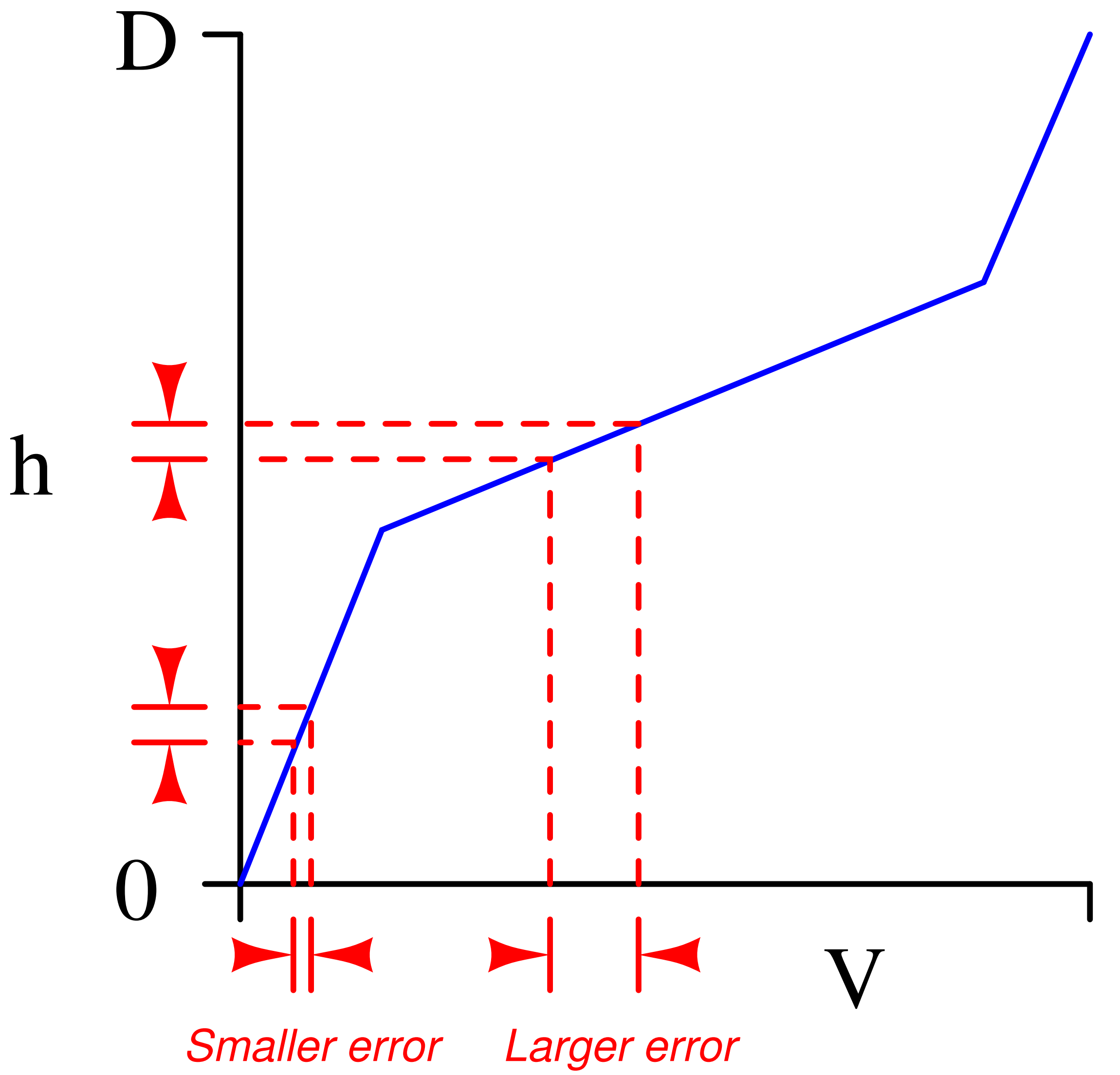
Liquid level instrument calibration is most critical near the center (50% fill) of the vessel.







Liquid level instrument calibration is most critical at the wider span of the vessel.



Svar 84

Svar 85

$$\left(\frac{20 \text{ ft olive oil}}{1}\right)\left(\frac{0.918 \text{ ft W.C.}}{1 \text{ ft olive oil}}\right)\left(\frac{12 \text{ inches}}{1 \text{ ft}}\right)\left(\frac{6.895 \text{ kPa}}{27.6807 \text{ inches W.C.}}\right) = 54.88 \text{ kPa}$$

Svar 86

$V = 495.4 \text{ ft}^3 = 3706$ gallons

Note: if your answer is wildly in error, you might want to check to see that your calculator is set to do trigonometric functions in units of *radians* instead of *degrees*!

Svar 87

Partial answer:

The scale will indicate 6.25 inches of water for one-quarter inch of rainfall.

Svar 88

It is entirely possible that everything is normal in this scenario – no instrument faults and no unusual process conditions!

Svar 89

The first thing you should try to do is verify whether or not there is a real low-level condition in the tank. If so, a danger exists in that the sump pumps may become damaged by running dry, and the pumps should be manually turned off. If not, it's a matter of determining why the level control system "thinks" a high-level condition exists.

Svar 90

Fault	**Possible**	**Impossible**
LSH-58 failed	$\surd$	
LAH-58 failed	$\surd$	
LSL-57 failed		$\surd$
LAL-57 failed		$\surd$
LT-38a calibration error		$\surd$
LIC-38 (input) calibration error		$\surd$
FIC-37 (input) calibration error		$\surd$

It is highly unlikely that LT-38a is at fault because the controller (LIC-38) receives the median-selected signal from *three* different level transmitters. In order for the 10.67 mA signal to be incorrect, at least one of the other two level transmitters (LT-38b or LT-38c) would also have to be experiencing the same calibration error! In other words, this scenario would require coincidental faults, which are highly unlikely.

Svar 91

LRV = 9.87 kPa URV = 45.77 kPa

Svar 92

Measured level (feet)	Percent of span (%)	Output signal (mA)
1.6	80	16.8
0.3875	19.375	7.1
0.8	40	10.4

Svar 93

This is a graded question – no answers or hints given!

Svar 94

Since the process liquid is potable water, it is mildly conductive to electricity. Virtually any high-level alarm circuit built around one or two electrodes located at the high-water level will suffice. Here is a sample idea: