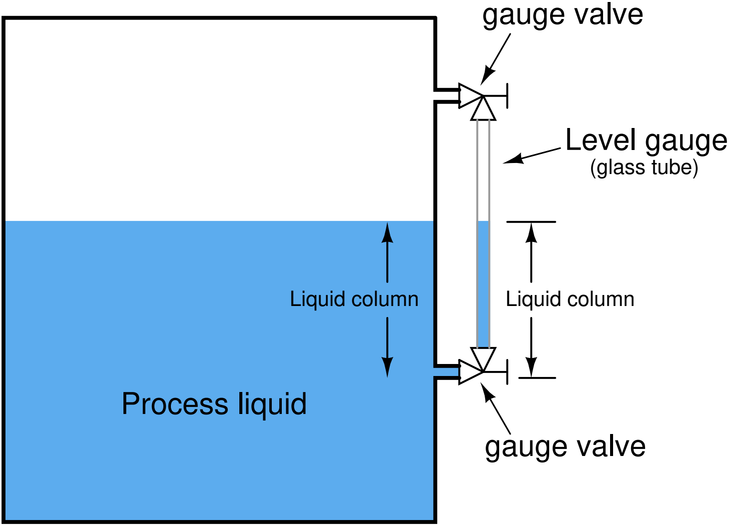
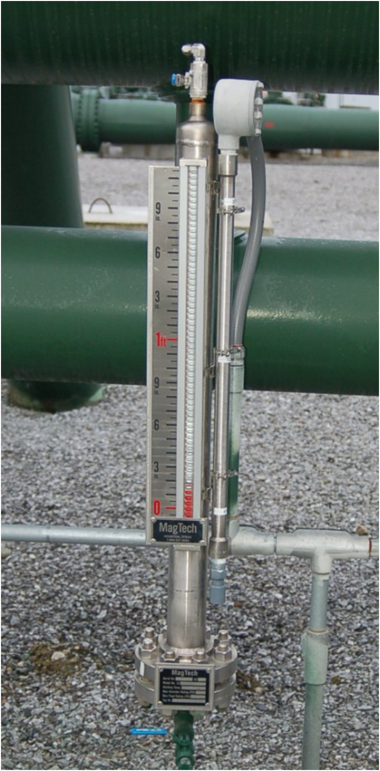
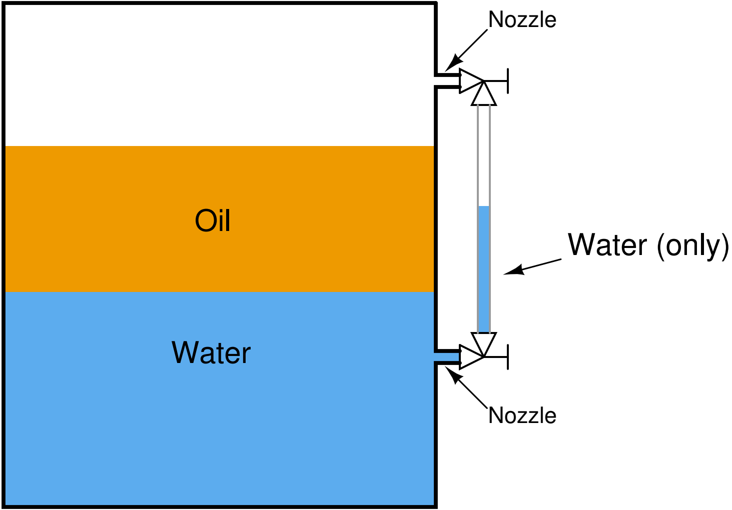
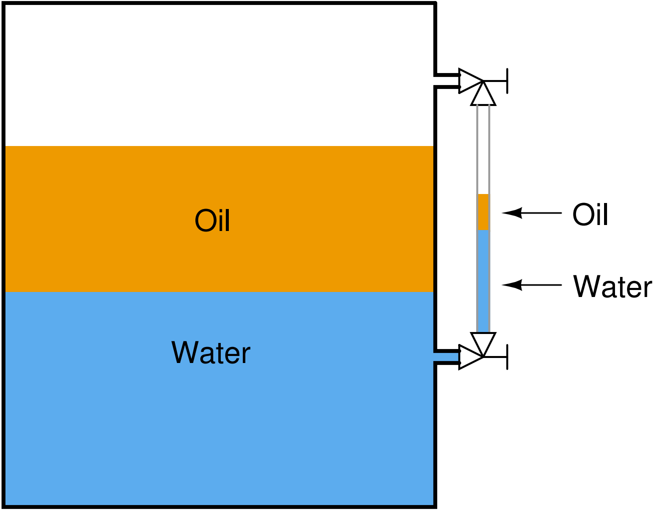
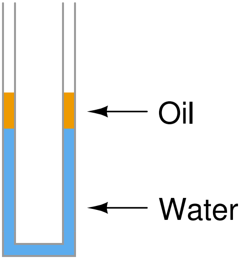
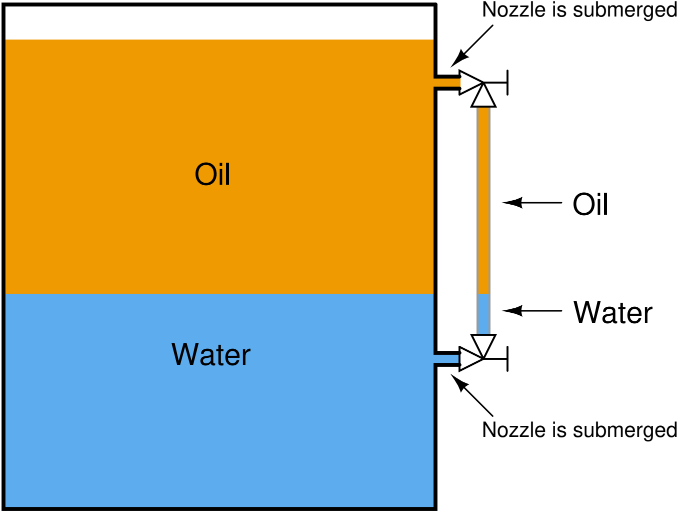

gauge valve
Level gauge
(glass tube)
Liquid column
Liquid column
Process liquid
gauge valve

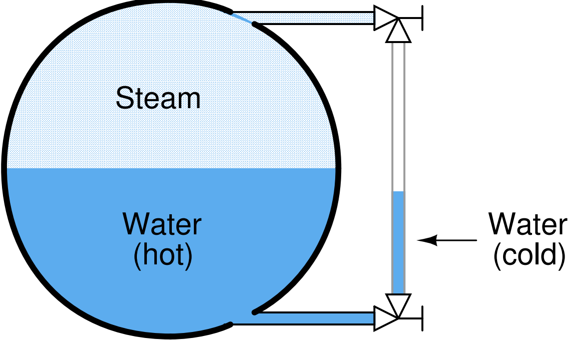

9
6
3
1ft
9
6
3
0
MagTech
MagTech


Nozzle
Oil
Water (only)
Water
Nozzle

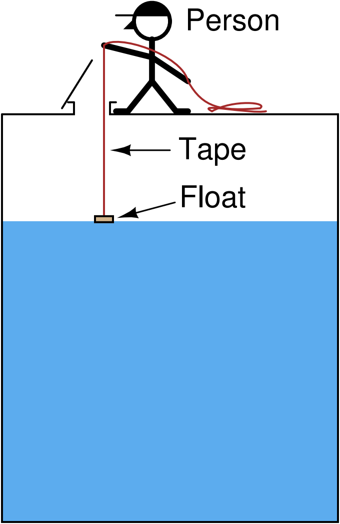

Oil
Water
Oil
Water

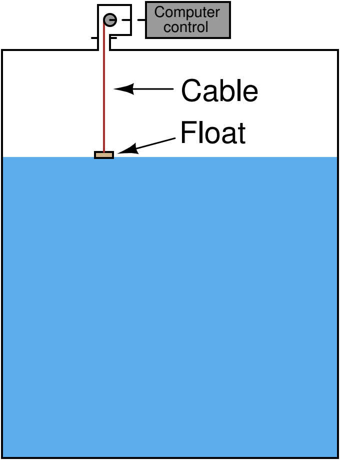

Oil
Water
Oil
Water
Oil
Water

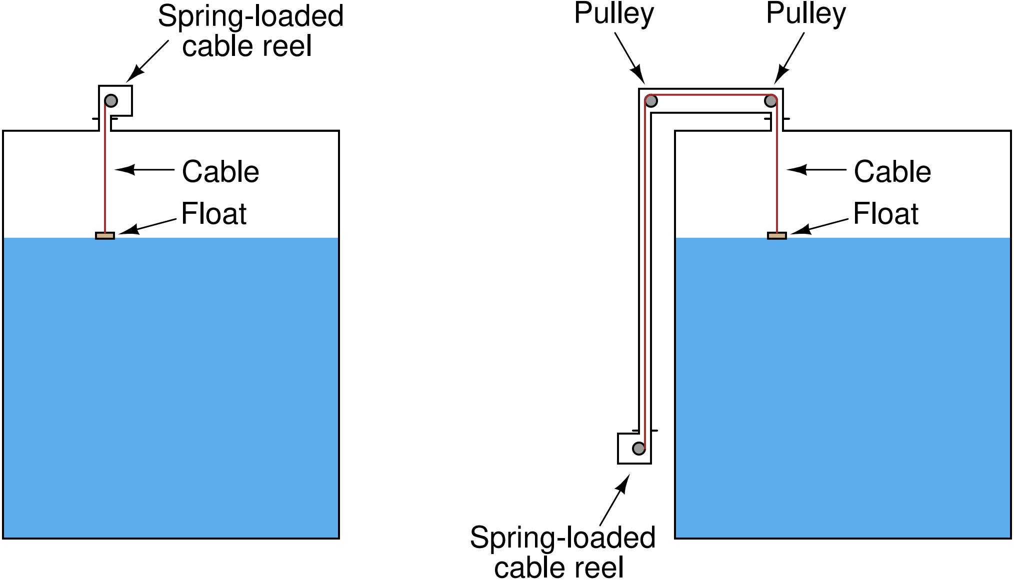

Nozzle is submerged
Oil
Oil
Water
Water
Nozzle is submerged

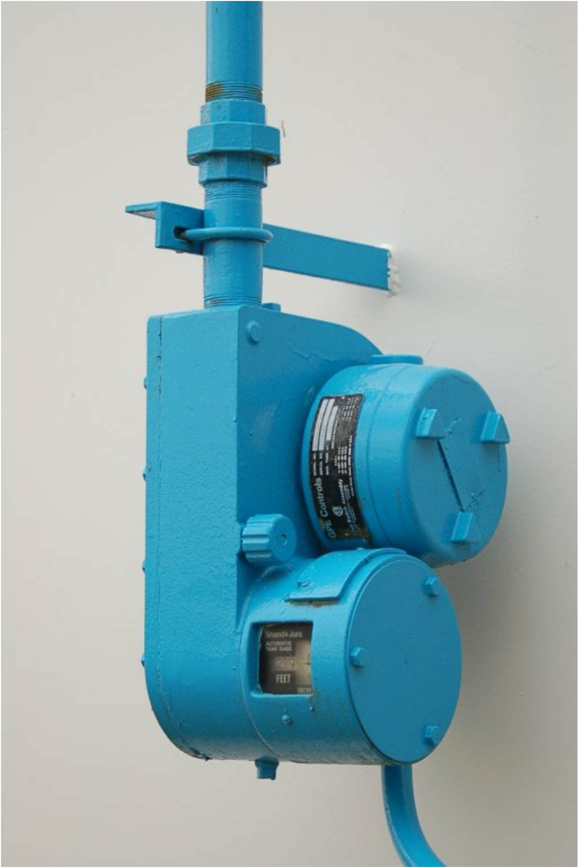

Steam
Water
(hot)
Water
(cold)

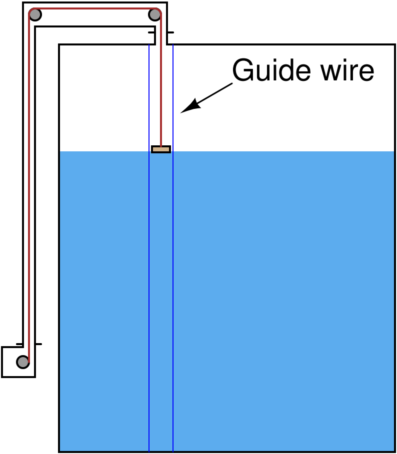
3

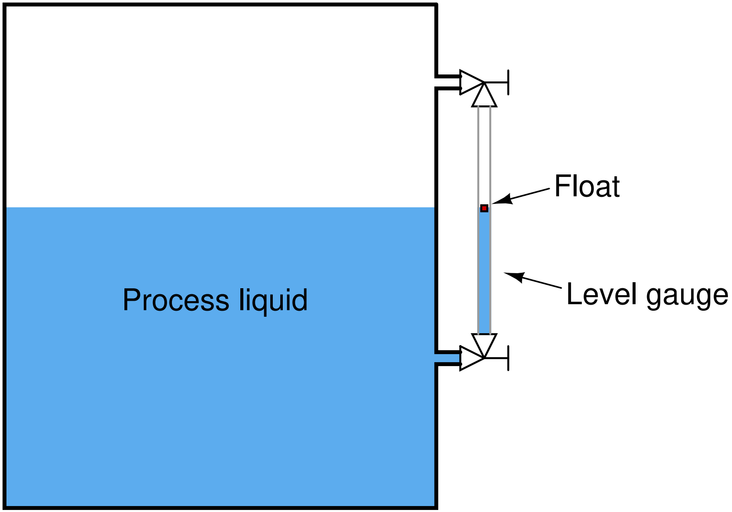

Person
Tape
Float

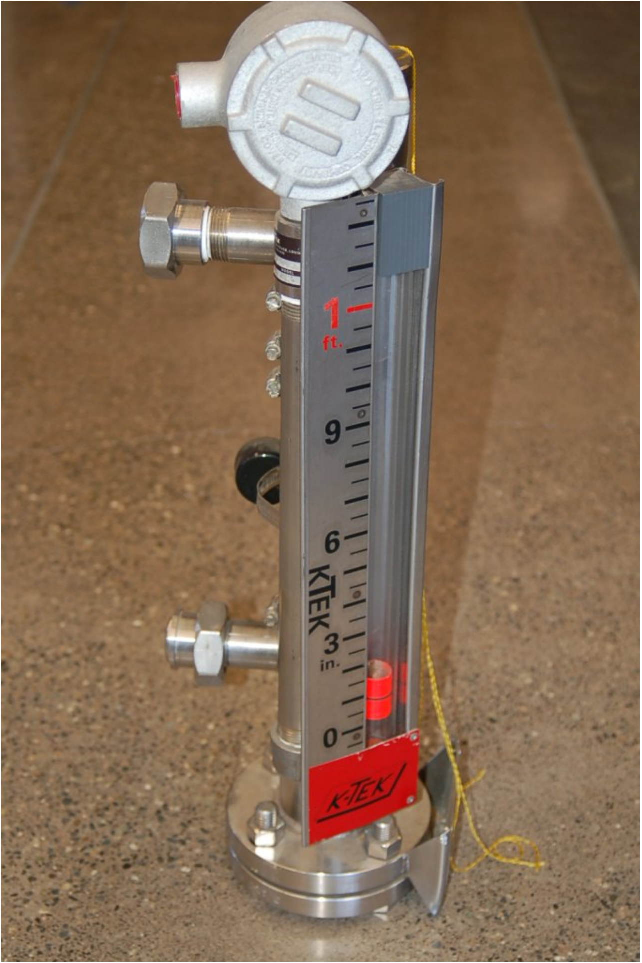

Computer control
Cable
Float


Spring-loaded
cable reel
Cable
Float
Pulley
Pulley
Cable
Float
Spring-loaded
cable reel

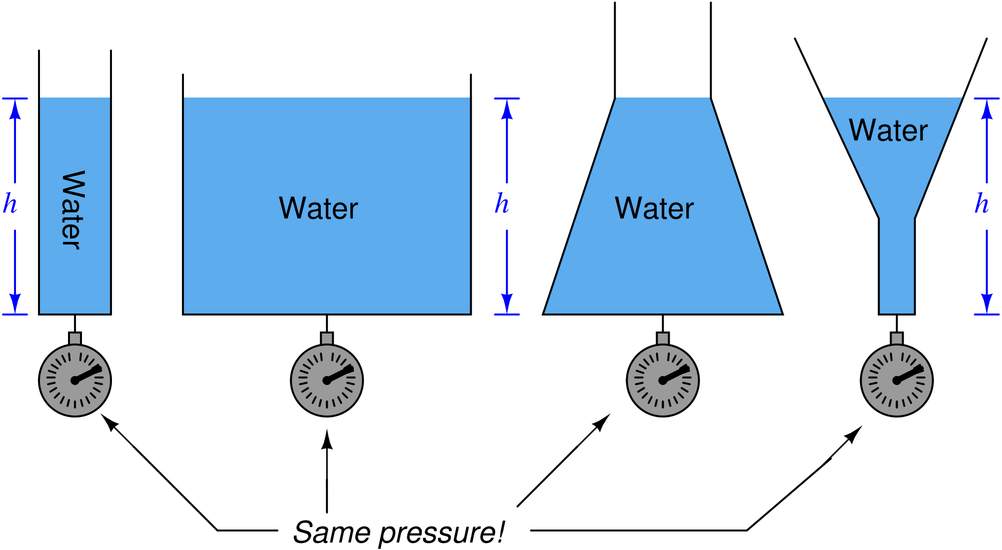

GPE Controls
Shand+Jurs
AUTOMATIC TANK GAGE
FEET


Guide wire


Float
Level gauge
Process liquid


1
ft.
9
6
KTEK
3
in.
0
K-TEK


K-TEK
BATON
ROUGE



Water
Water
Water
Water
h
h
h
Same pressure!

$$P = \rho g h \qquad P = \gamma h$$

P

ρ

g

γ

h

$$P = \gamma h$$

$$P_{oil} = \left(\frac{40 \text{ lb}}{\text{ft}^3}\right)\left(\frac{12 \text{ ft}}{1}\right) = \frac{480 \text{ lb}}{\text{ft}^2}$$

$$P_{oil} = \left(\frac{480\ \mathrm{lb}}{\mathrm{ft}^2}\right)\left(\frac{1^2\ \mathrm{ft}^2}{12^2\ \mathrm{in}^2}\right)$$

$$P_{oil} = \left(\frac{480 \text{ lb}}{\text{ft}^2}\right)\left(\frac{1 \text{ ft}^2}{144 \text{ in}^2}\right)$$

$$P_{oil} = \frac{3.33 \text{ lb}}{\text{in}^2} = 3.33 \text{ PSI}$$

3.33

$$\text{Specific Gravity of oil} = \frac{\gamma_{oil}}{\gamma_{water}}$$

$$\text{Specific Gravity of oil} = \frac{40\ \text{lb/ft}^3}{62.4\ \text{lb/ft}^3}$$

Specific Gravity of oil $= 0.641$

$$P_{oil} = (P_{water})(\text{Specific Gravity})$$

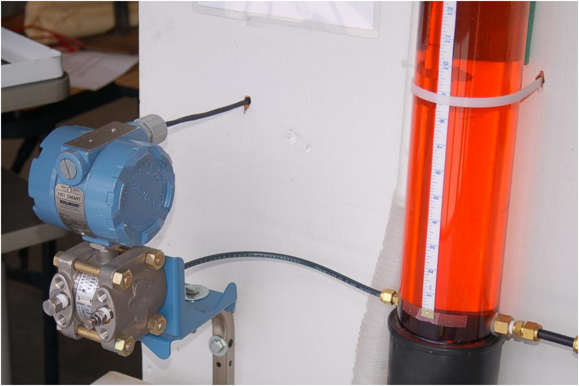
$$P_{oil} = (144\ \text{"W.C.})(0.641)$$

$$P_{oil} = 92.3 \text{ ''W.C.}$$

$$P_{oil} = \left(\frac{92.3 \text{ "W.C.}}{1}\right)\left(\frac{1 \text{ PSI}}{27.68 \text{ "W.C.}}\right)$$

$$P_{oil} = 3.33 \text{ PSI}$$

$$P = \gamma h$$


1151 SMART
ROSEMOUNT

m

$$m = \rho V$$

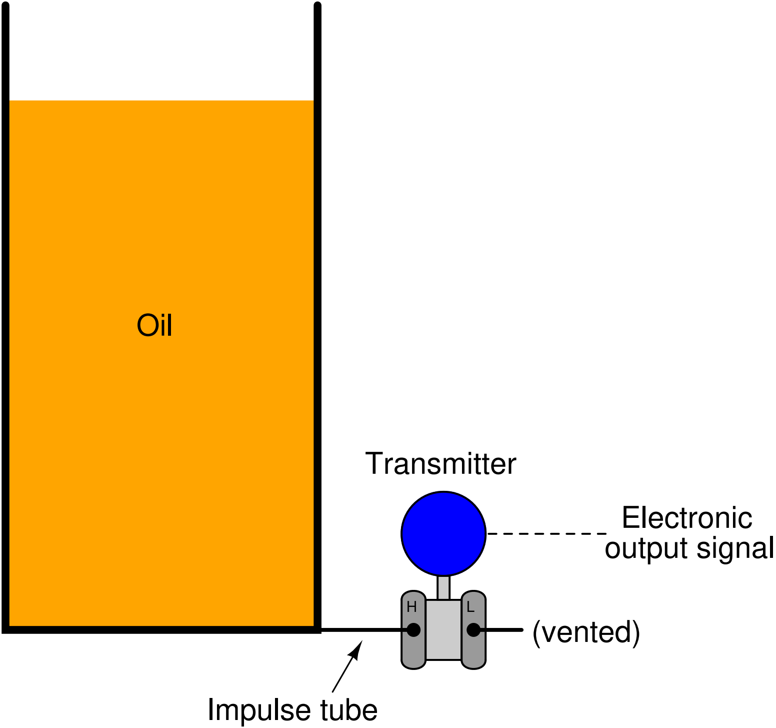
V

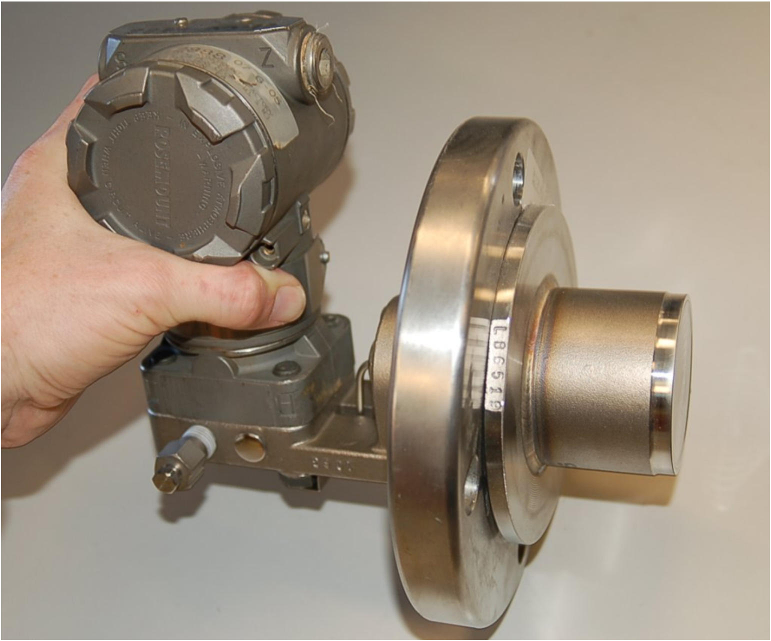
A

$$V = Ah$$

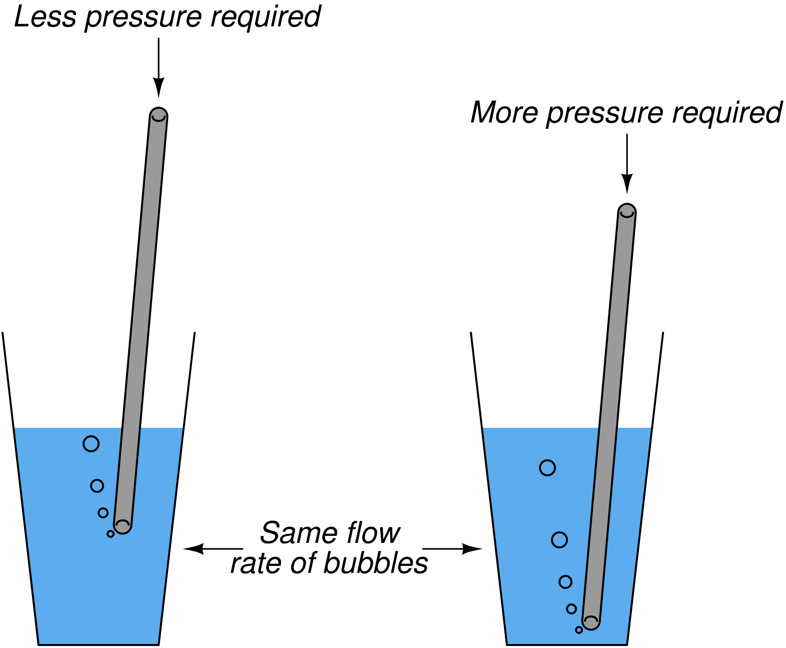
$$P = \rho g h$$

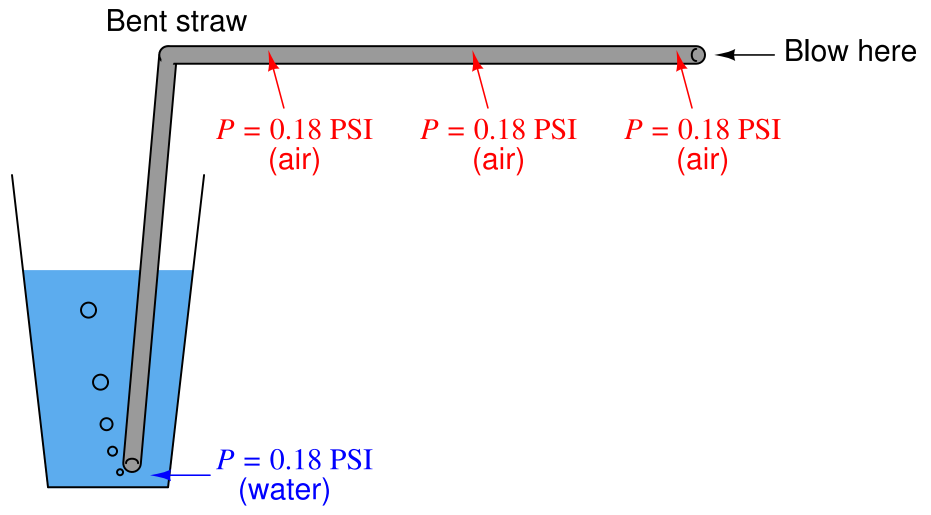
$$m = \frac{AP}{g}$$

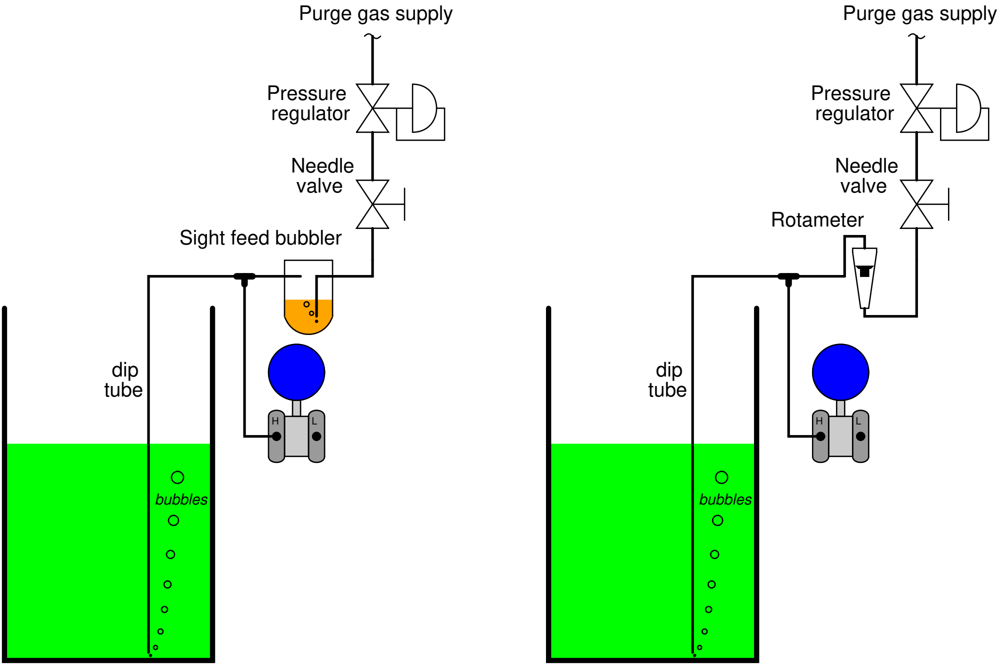

Oil
Transmitter
Electronic output signal
H
L
(vented)
Impulse tube


L86519

Oil level	Percent of range	Hydrostatic pressure	Transmitter output
0 ft	0 %	0 PSI	4 mA
3 ft	25 %	0.833 PSI	8 mA
6 ft	50 %	1.67 PSI	12 mA
9 ft	75 %	2.50 PSI	16 mA
12 ft	100 %	3.33 PSI	20 mA

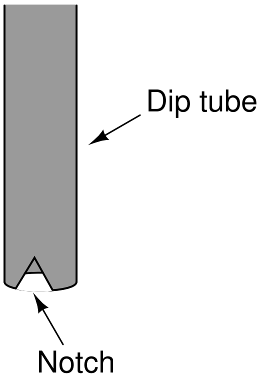

Less pressure required
More pressure required
Same flow
rate of bubbles


Bent straw
Blow here
P = 0.18 PSI
(air)
P = 0.18 PSI
(air)
P = 0.18 PSI
(air)
P = 0.18 PSI
(water)

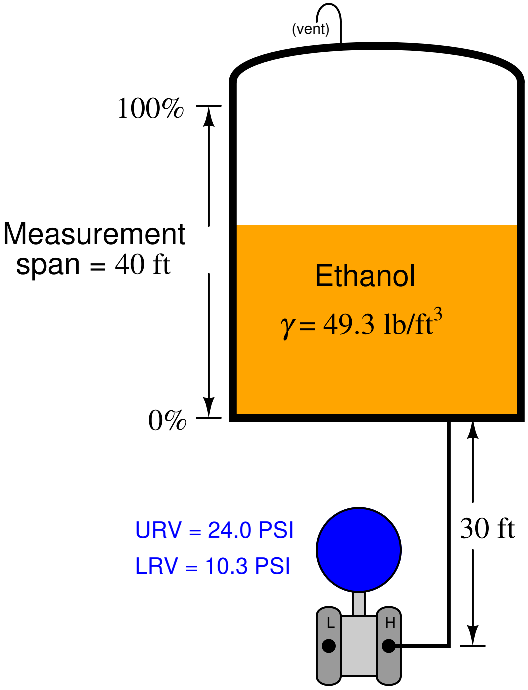


Purge gas supply
Pressure regulator
Needle valve
Sight feed bubbler
dip tube
bubbles
H
L
Purge gas supply
Pressure regulator
Needle valve
Rotameter
dip tube
bubbles
H
L

$$\frac{1}{4}$$

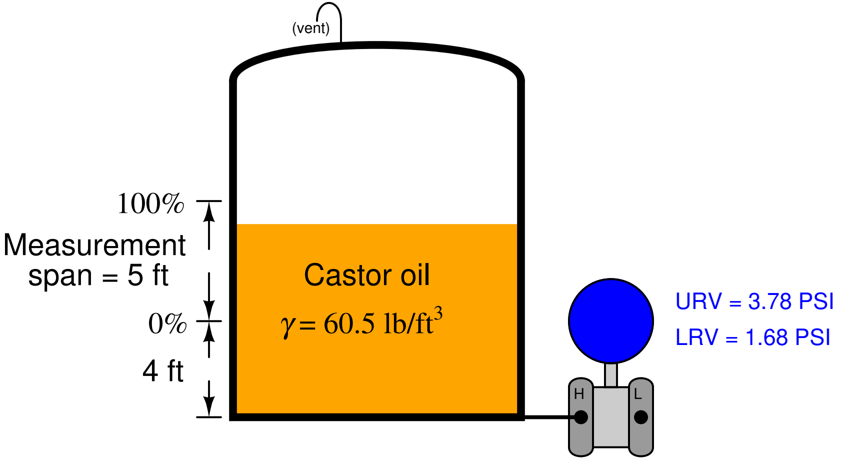

Dip tube
Notch

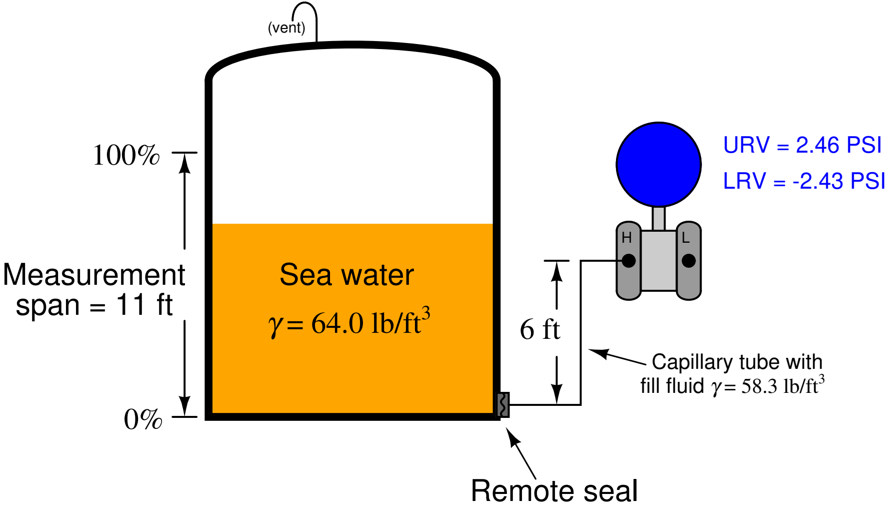

ROSEMOUNT



(vent)
100%
Measurement span = 40 ft
0%
Ethanol
γ = 49.3 lb/ft³
URV = 24.0 PSI
LRV = 10.3 PSI
L
H
30 ft

Ethanol level in tank	**Percent of range**	**Pressure** (inches of water)	**Pressure** (PSI)	**Output** (mA)
0 ft	0 %	284 "W.C.	10.3 PSI	4 mA
20 ft	50 %	474 "W.C.	17.1 PSI	12 mA
40 ft	100 %	663 "W.C.	24.0 PSI	20 mA

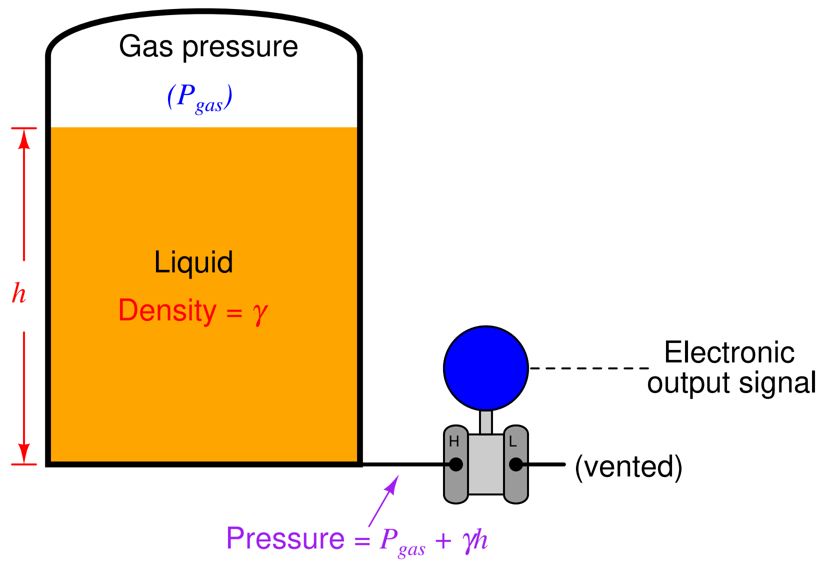

(vent)
100%
Measurement
span = 5 ft
0%
4 ft
Castor oil
$\gamma = 60.5$ lb/ft^3
H
L
URV = 3.78 PSI
LRV = 1.68 PSI



(vent)
100%
0%
Measurement span = 11 ft
Sea water
$\gamma = 64.0$ lb/ft^3
6 ft
H
L
URV = 2.46 PSI
LRV = -2.43 PSI
Capillary tube with fill fluid $\gamma = 58.3$ lb/ft^3
Remote seal

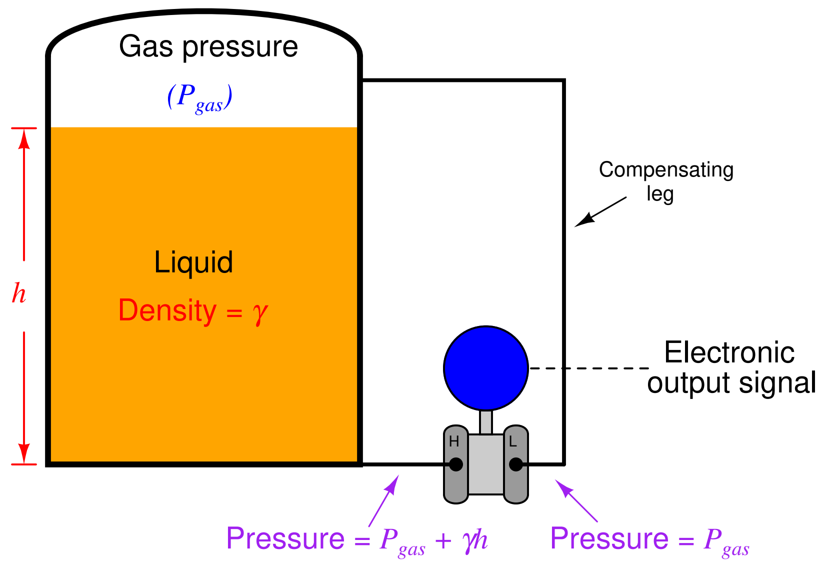
-2.43

-67.2


Gas pressure
(P_{gas})
Liquid
Density = γ
h
Electronic output signal
H
L
(vented)
Pressure = $P_{gas} + \gamma h$

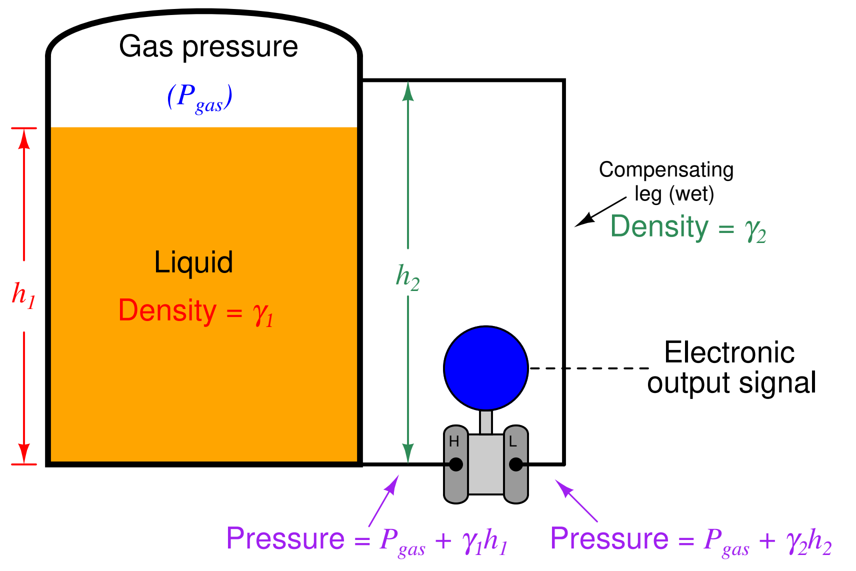
$$P_{gas}$$

$$\gamma h$$



Gas pressure
(P_{gas})
Liquid
Density = γ
h
Compensating leg
Electronic output signal
H
L
Pressure = $P_{gas} + \gamma h$
Pressure = P_{gas}

$$(P_{gas} + \gamma h) - P_{gas} = \gamma h$$

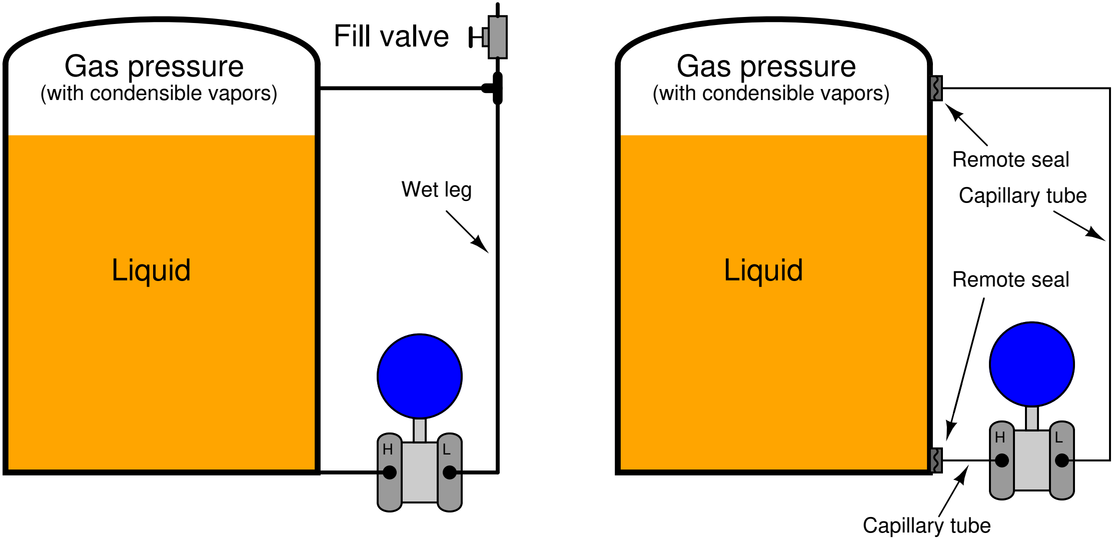


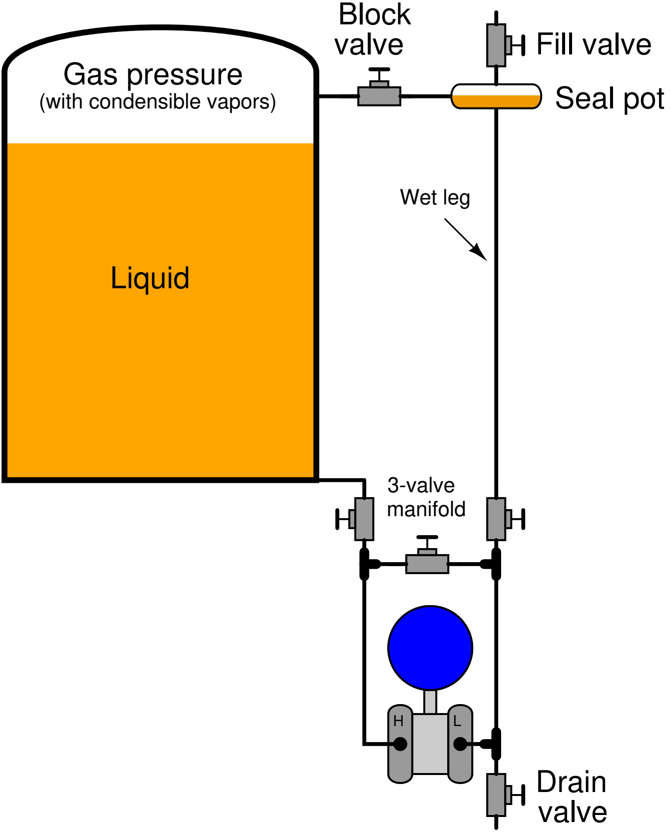
Gas pressure
(P_{gas})
Liquid
Density = γ_1
h_1
h_2
Compensating
leg (wet)
Density = γ_2
H
L
Electronic
output signal
Pressure = $P_{gas} + \gamma_1 h_1$
Pressure = $P_{gas} + \gamma_2 h_2$

$$(P_{gas} + \gamma_1 h_1) - (P_{gas} + \gamma_2 h_2) = \gamma_1 h_1 - \gamma_2 h_2$$

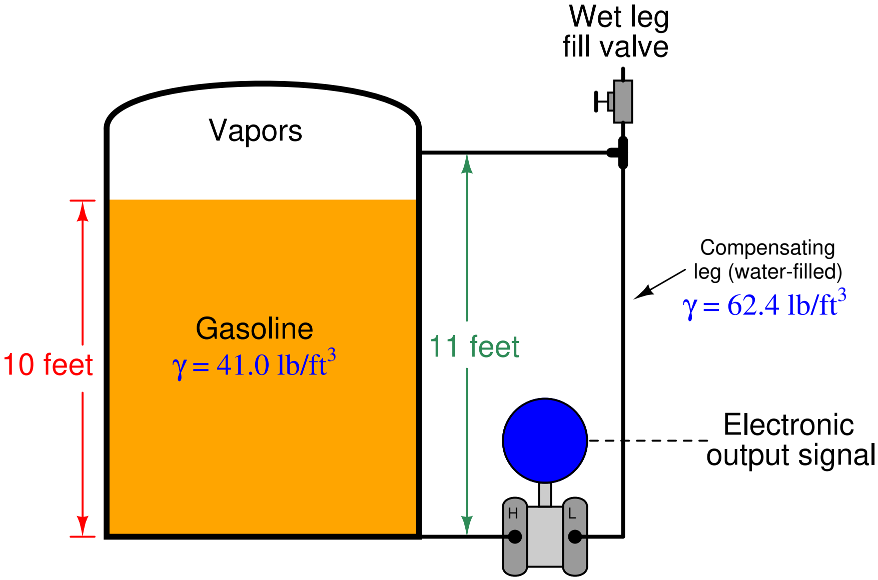
γ_2

$$\text{Differential pressure} = \gamma_1 h_1 - \text{Constant}$$


Fill valve
Gas pressure
(with condensible vapors)
Liquid
Wet leg
H
L
Gas pressure
(with condensible vapors)
Liquid
Remote seal
Capillary tube
Remote seal
H
L
Capillary tube

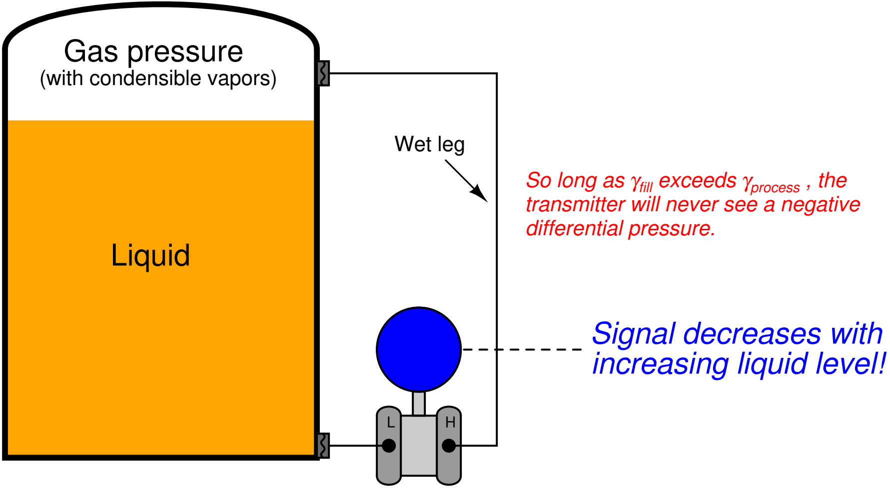


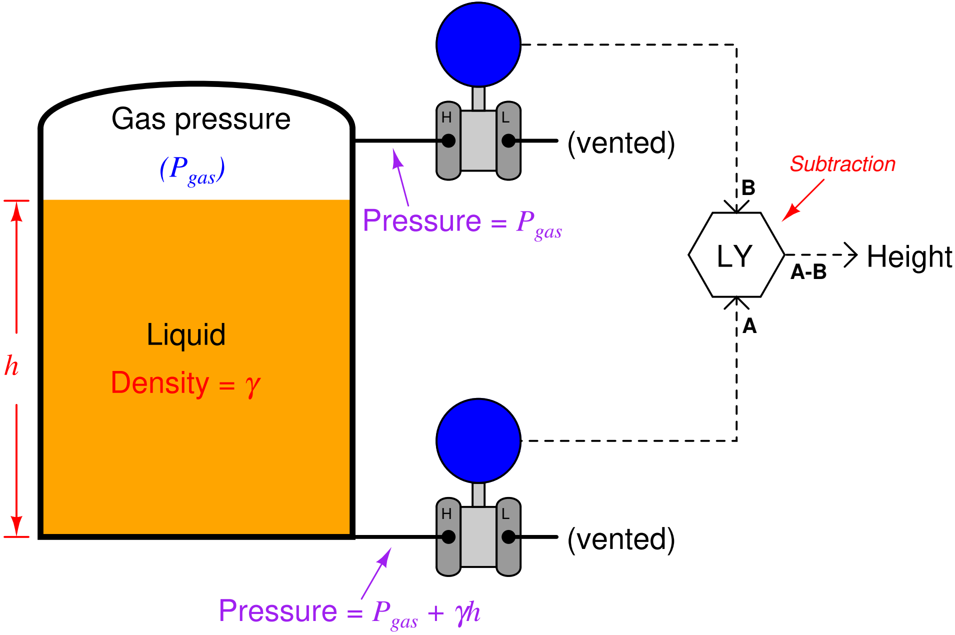
Block valve
Fill valve
Gas pressure
(with condensible vapors)
Seal pot
Wet leg
Liquid
3-valve manifold
H
L
Drain valve


Wet leg
fill valve
Vapors
Compensating
leg (water-filled)
$\gamma = 62.4$ lb/ft^3
Gasoline
$\gamma = 41.0$ lb/ft^3
10 feet
11 feet
Electronic
output signal
H
L

Gasoline level	Percent of range	Differential pressure at transmitter	Transmitter output
0 ft	0 %	−4.77 PSI	4 mA
2.5 ft	25 %	−4.05 PSI	8 mA
5 ft	50 %	−3.34 PSI	12 mA
7.5 ft	75 %	−2.63 PSI	16 mA
10 ft	100 %	−1.92 PSI	20 mA

High side of DP transmitter connected to the compensating impulse leg

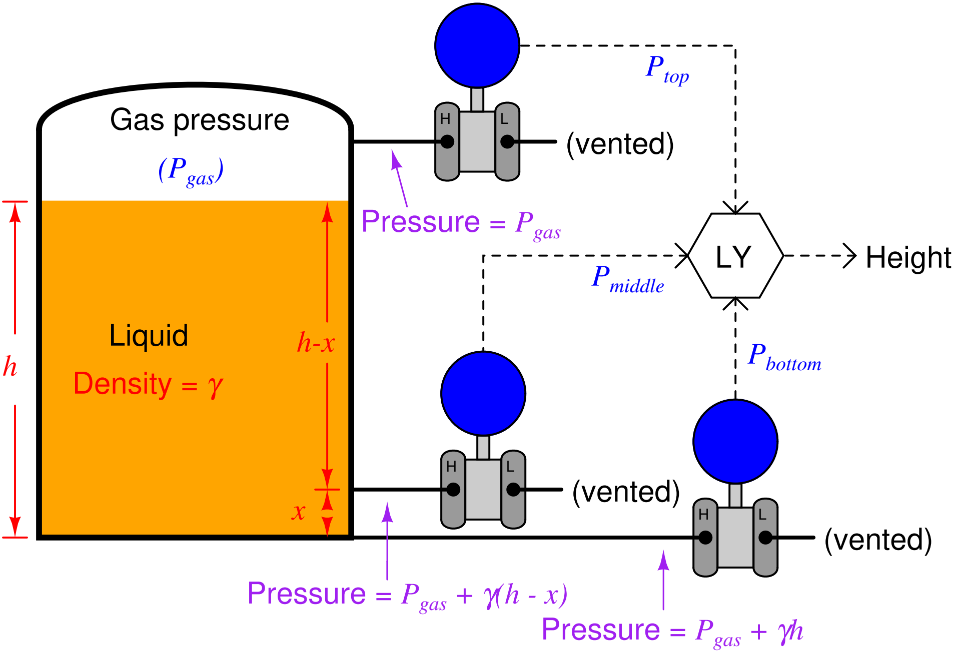




Gas pressure
(P_{gas})
Liquid
Density = γ
h
H
L
(vented)
Pressure = P_{gas}
H
L
(vented)
Pressure = $P_{gas} + \gamma h$
Subtraction
B
LY
A-B
Height
A

x

A "tank expert" system



$$P_{bottom}$$

$$P_{middle}$$

P_{top}

$$P_{bottom} - P_{middle} = (P_{gas} + \gamma h) - [P_{gas} + \gamma(h - x)]$$

$$P_{bottom} - P_{middle} = P_{gas} + \gamma h - P_{gas} - \gamma(h - x)$$

$$P_{bottom} - P_{middle} = P_{gas} + \gamma h - P_{gas} - \gamma h + \gamma x$$

$$P_{bottom} - P_{middle} = \gamma x$$

$$\frac{P_{bottom} - P_{middle}}{x} = \gamma$$

$$P_{bottom} - P_{top} = (P_{gas} + \gamma h) - P_{gas}$$

$$P_{bottom} - P_{top} = \gamma h$$

$$\frac{P_{bottom} - P_{top}}{\gamma} = h$$

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

r

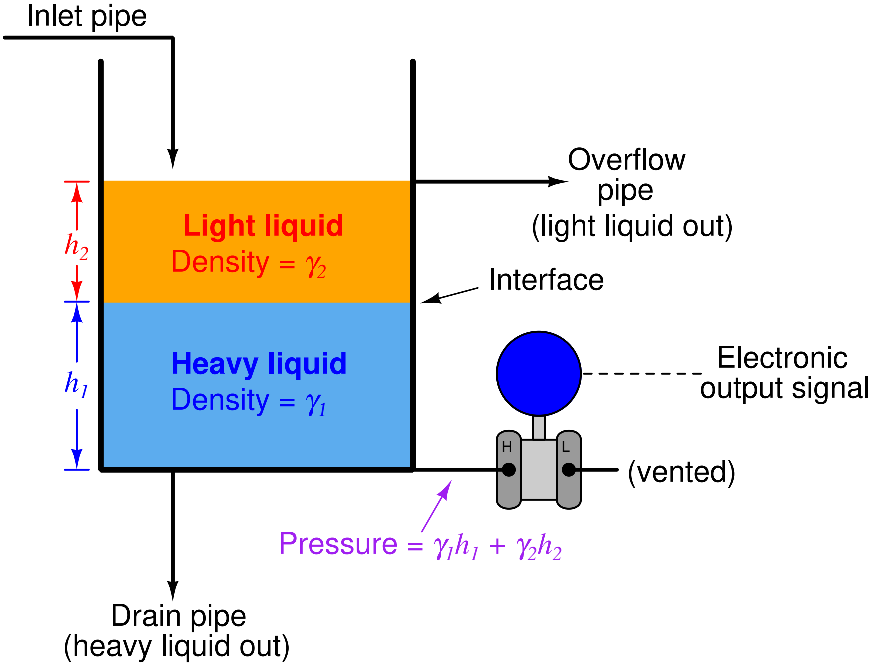
$$\rho g h = \gamma h$$

$$\rho g = \gamma$$

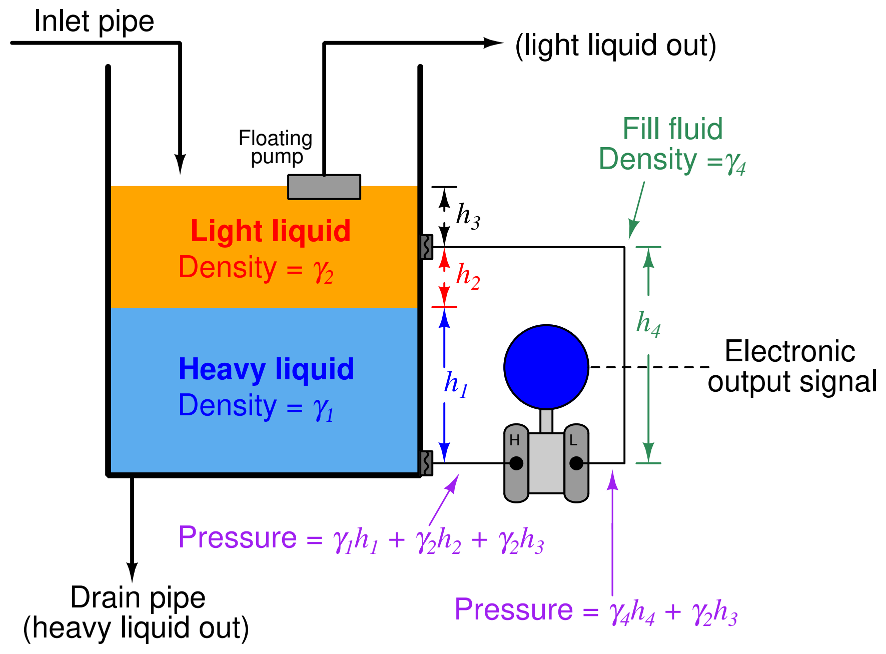
$$\rho = \frac{\gamma}{g}$$

$$m = \rho V$$

$$[\mathrm{kg}] = \left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right] [\mathrm{m}^3]$$



Inlet pipe
Overflow pipe (light liquid out)
Light liquid
Density = γ_2
h_2
Interface
Heavy liquid
Density = γ_1
h_1
Electronic output signal
H
L
(vented)
Pressure = $\gamma_1 h_1 + \gamma_2 h_2$
Drain pipe (heavy liquid out)



Inlet pipe
(light liquid out)
Floating pump
Fill fluid
Density = γ_4
Light liquid
Density = γ_2
h_3
h_2
h_4
Heavy liquid
Density = γ_1
h_1
Electronic output signal
H
L
Pressure = $\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3$
Drain pipe
(heavy liquid out)
Pressure = $\gamma_4 h_4 + \gamma_2 h_3$

$$\gamma_2 h_3$$

$$(\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3) - (\gamma_4 h_4 + \gamma_2 h_3)$$

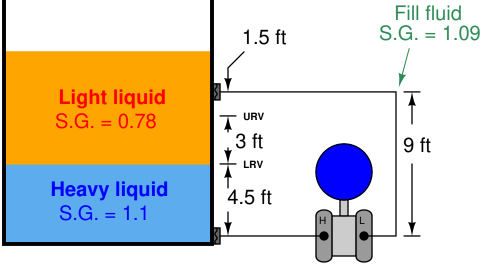
$$\gamma_1 h_1 + \gamma_2 h_2 + \gamma_2 h_3 - \gamma_4 h_4 - \gamma_2 h_3$$

$$\gamma_1 h_1 + \gamma_2 h_2 - \gamma_4 h_4$$

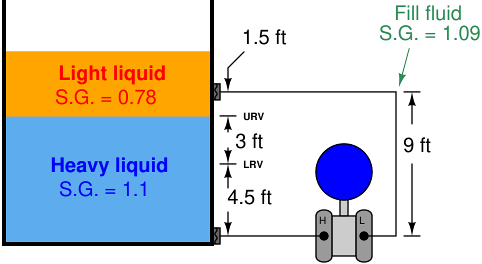
$\gamma_4 h_4$

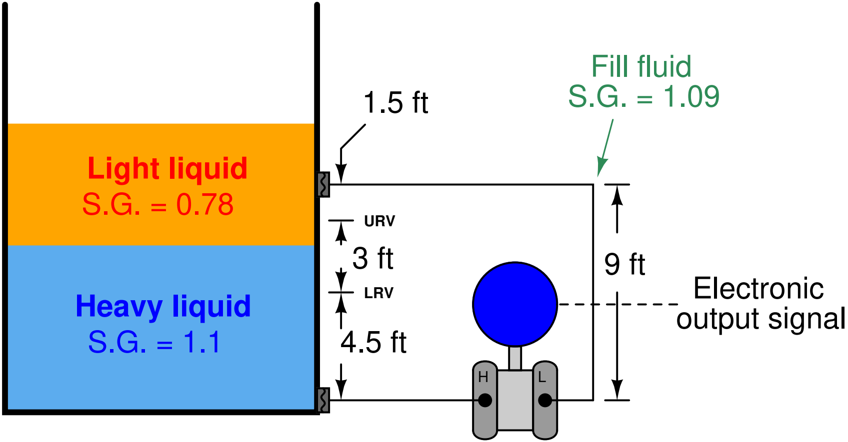
$$\gamma_1 h_1 + \gamma_2 h_2 - \text{Constant}$$

Interface level = LRV

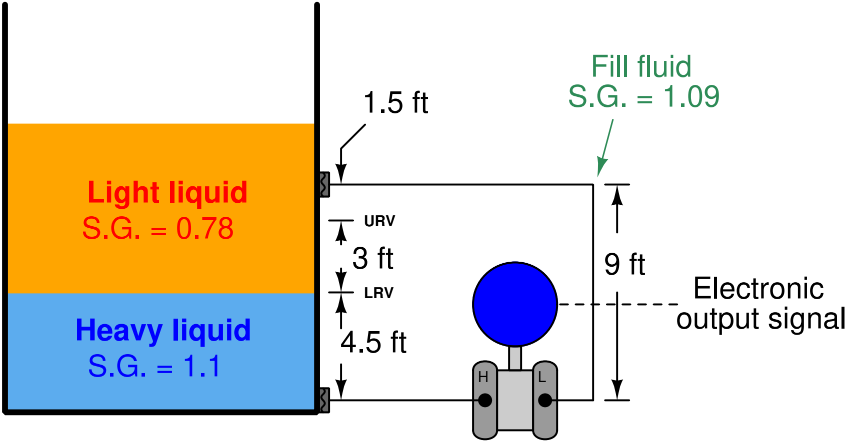


Interface level = URV




Fill fluid
S.G. = 1.09
1.5 ft
Light liquid
S.G. = 0.78
URV
3 ft
LRV
4.5 ft
9 ft
Heavy liquid
S.G. = 1.1
Electronic
output signal
H
L

LRV interface level condition



$$P_{high} = 4.5 \text{ feet of heavy liquid} + 4.5 \text{ feet of light liquid}$$

$$P_{high} = 54 \text{ inches of heavy liquid} + 54 \text{ inches of light liquid}$$

$$P_{high} \text{ "W.C.} = (54 \text{ inches of heavy liquid})(1.1) + (54 \text{ inches of light liquid})(0.78)$$

$$P_{high}\ ''\text{W.C.} = 59.4\ ''\text{W.C.} + 42.12\ ''\text{W.C.}$$

$$P_{high} = 101.52 \text{ "W.C.}$$

$$P_{low} = 9 \text{ feet of fill fluid}$$

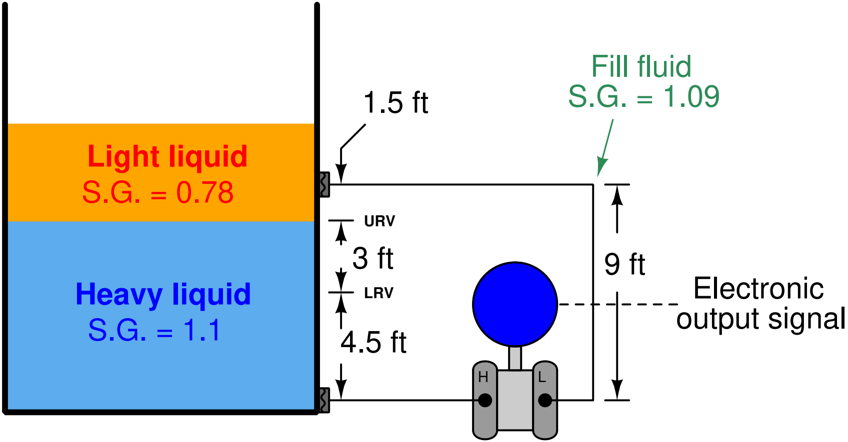
$$P_{low} = 108 \text{ inches of fill fluid}$$

$$P_{low} \text{ "W.C.} = (108 \text{ inches of fill fluid})(1.09)$$

$$P_{low} = 117.72\ \text{"W.C.}$$

$$P_{LRV} = 101.52\ \text{"W.C.} - 117.72\ \text{"W.C.} = -16.2\ \text{"W.C.}$$

URV interface level condition



$$P_{high} = 7.5 \text{ feet of heavy liquid} + 1.5 \text{ feet of light liquid}$$

$$P_{high} = 90 \text{ inches of heavy liquid} + 18 \text{ inches of light liquid}$$

$$P_{high} \text{ ''W.C.} = (90 \text{ inches of heavy liquid})(1.1) + (18 \text{ inches of light liquid})(0.78)$$

$$P_{high} \text{ "W.C.} = 99 \text{ "W.C.} + 14.04 \text{ "W.C.}$$

$$P_{high} = 113.04 \text{ "W.C.}$$

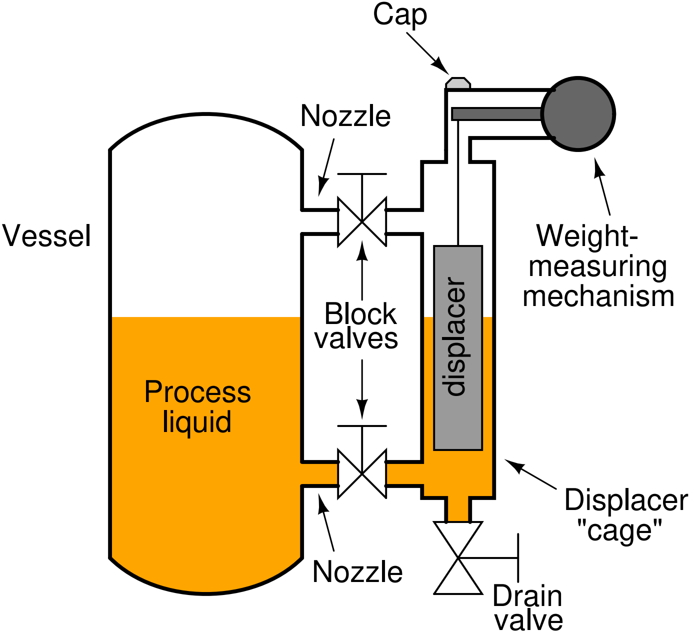
$$P_{URV} = 113.04 \text{ "W.C.} - 117.72 \text{ "W.C.} = -4.68 \text{ "W.C.}$$

Interface level	Percent of range	Differential pressure at transmitter	Transmitter output
4.5 ft	0 %	−16.2 "W.C.	4 mA
5.25 ft	25 %	−13.32 "W.C.	8 mA
6 ft	50 %	−10.44 "W.C.	12 mA
6.75 ft	75 %	−7.56 "W.C.	16 mA
7.5 ft	100 %	−4.68 "W.C.	20 mA

—

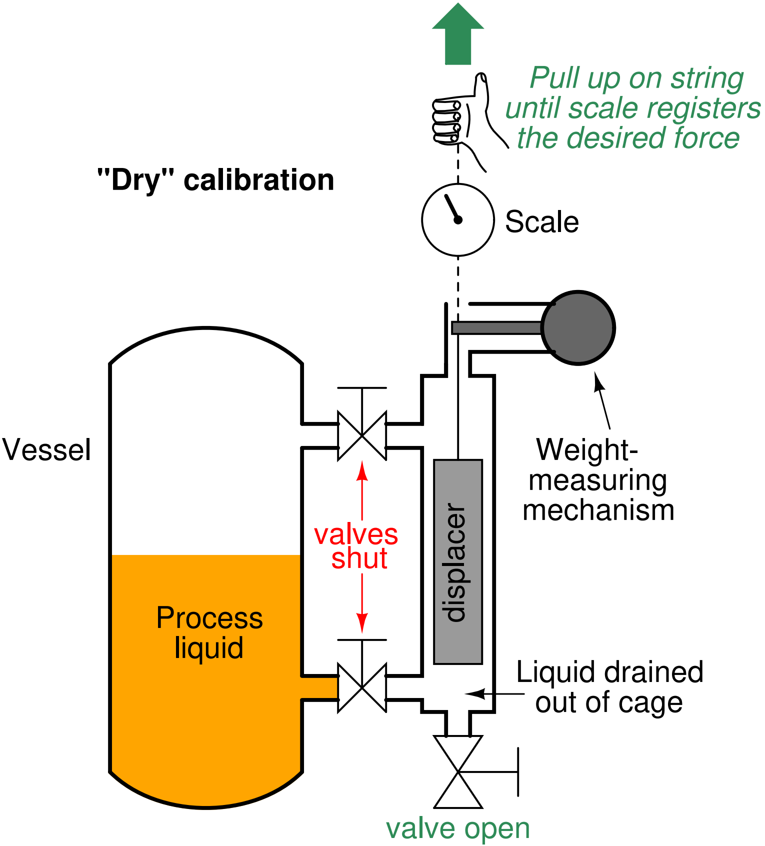
$$\text{Span in "W.C.} = (36 \text{ inches})(1.1 - 0.78)$$

Span = 11.52 "W.C.


Cap
Nozzle
Vessel
Weight-
measuring
mechanism
Block
valves
displacer
Process
liquid
Displacer
"cage"
Nozzle
Drain
valve

$$F = \gamma V$$


FISHER


"Dry" calibration
Pull up on string until scale registers the desired force
Scale
Weight-measuring mechanism
Vessel
valves shut
displacer
Process liquid
Liquid drained out of cage
valve open

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

l

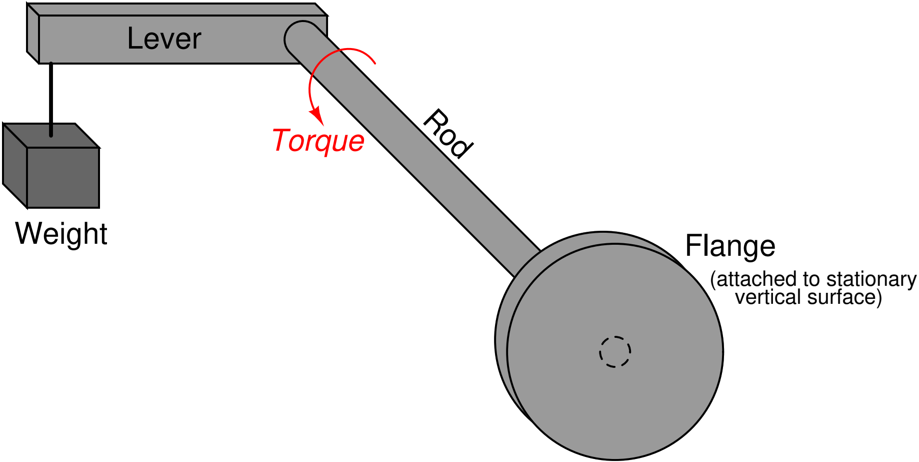
$$F_{buoyant} = \gamma V$$

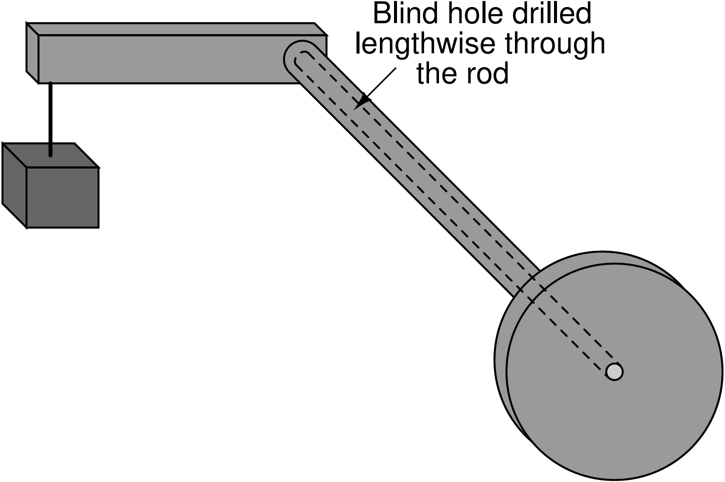
$$F_{buoyant} = \gamma \pi r^2 l$$

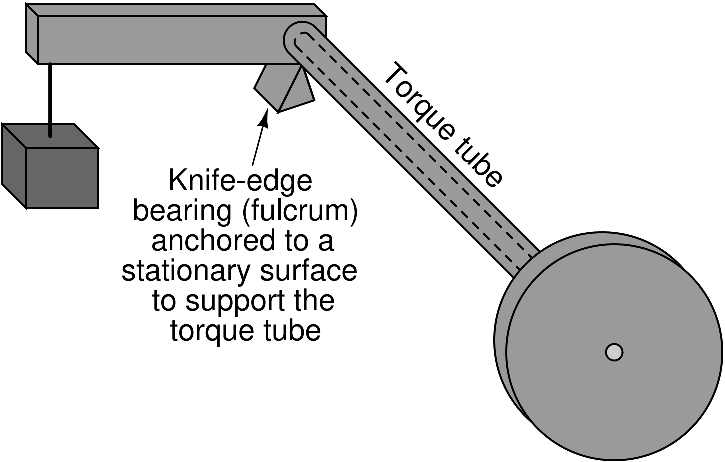
$$\gamma = \left(\frac{57.3\ \mathrm{lb}}{\mathrm{ft}^3}\right)\left(\frac{1\ \mathrm{ft}^3}{12^3\ \mathrm{in}^3}\right) = 0.0332\frac{\mathrm{lb}}{\mathrm{in}^3}$$

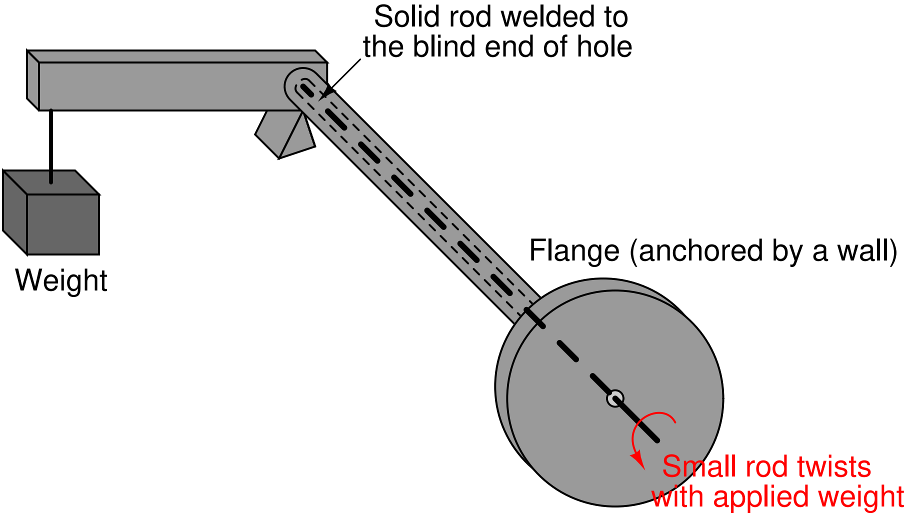
$$V = \pi r^2 l = \pi(1.5 \text{ in})^2(24 \text{ in}) = 169.6 \text{ in}^3$$

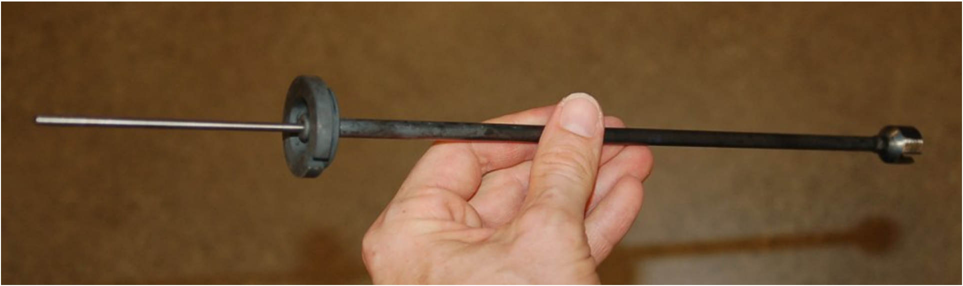
$$F_{buoyant} = \gamma V = \left(0.0332 \frac{\text{lb}}{\text{in}^3}\right)\left(169.6\ \text{in}^3\right) = 5.63\ \text{lb}$$

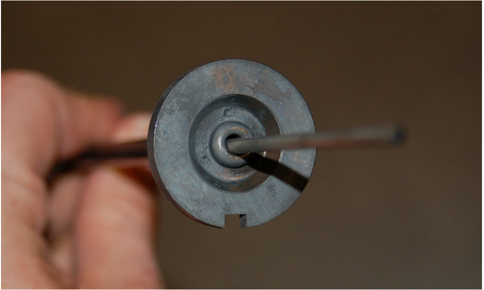

Lever
Weight
Torque
Rod
Flange
(attached to stationary
vertical surface)

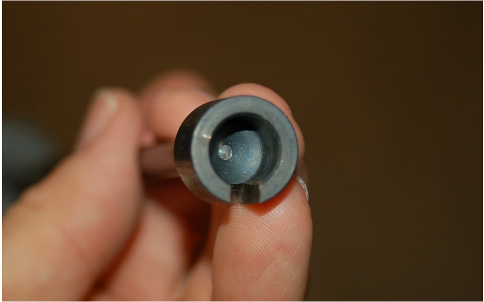

Blind hole drilled
lengthwise through
the rod

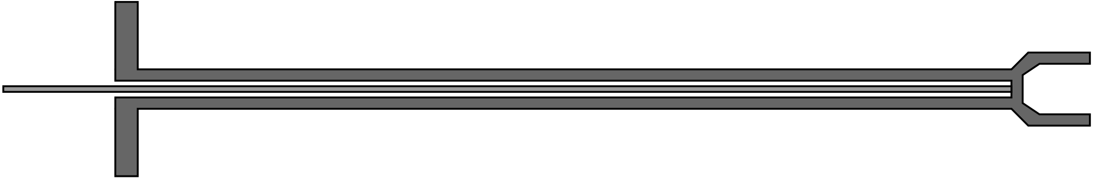

Torque tube
Knife-edge bearing (fulcrum) anchored to a stationary surface to support the torque tube

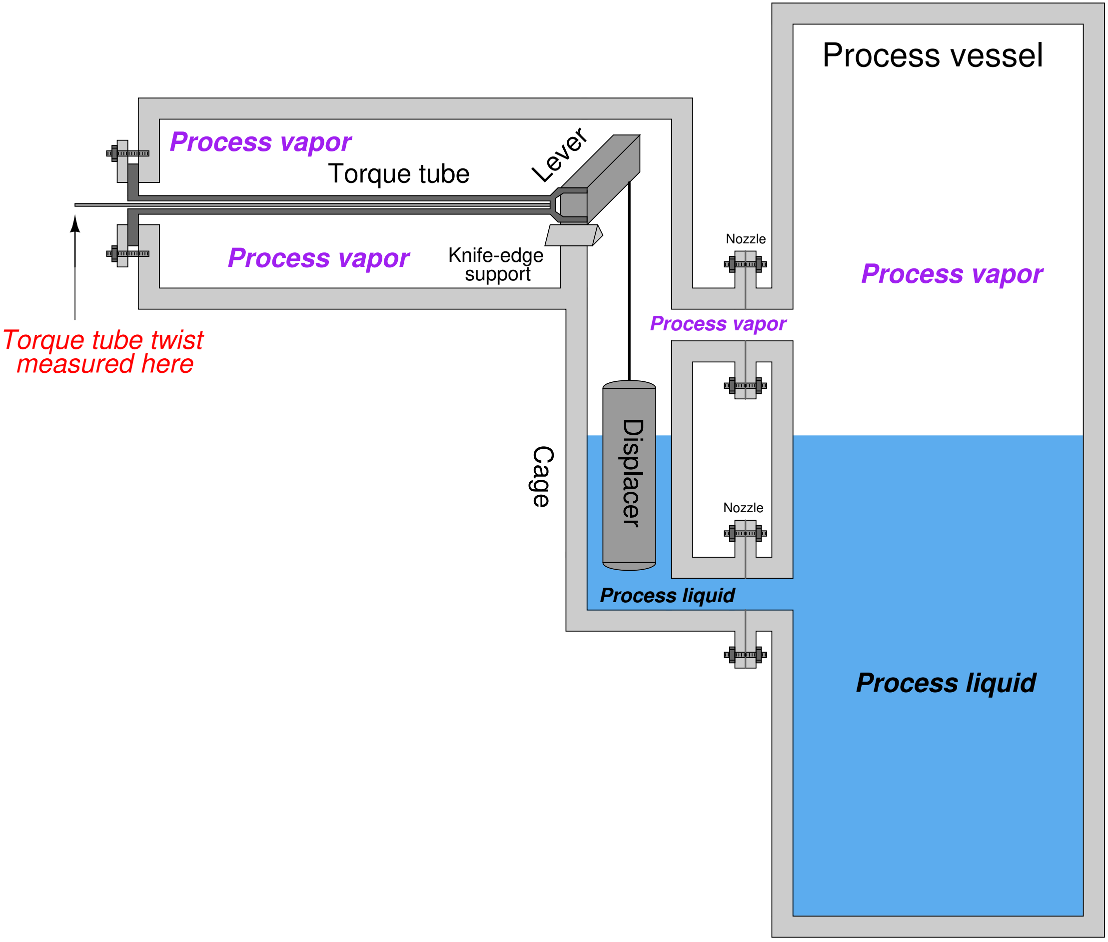

Solid rod welded to
the blind end of hole
Flange (anchored by a wall)
Weight
Small rod twists
with applied weight







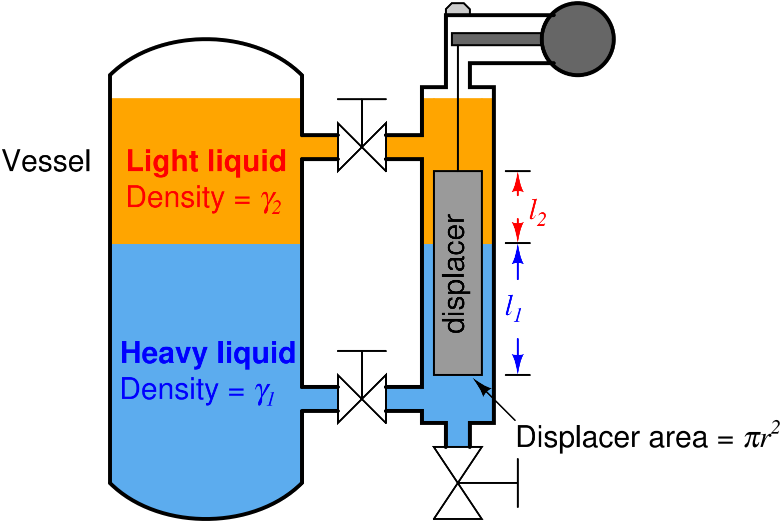



Process vessel
Process vapor
Torque tube
Lever
Process vapor
Knife-edge support
Nozzle
Process vapor
Process vapor
Torque tube twist measured here
Cage
Displacer
Nozzle
Process liquid
Process liquid


6
7
8
9
10

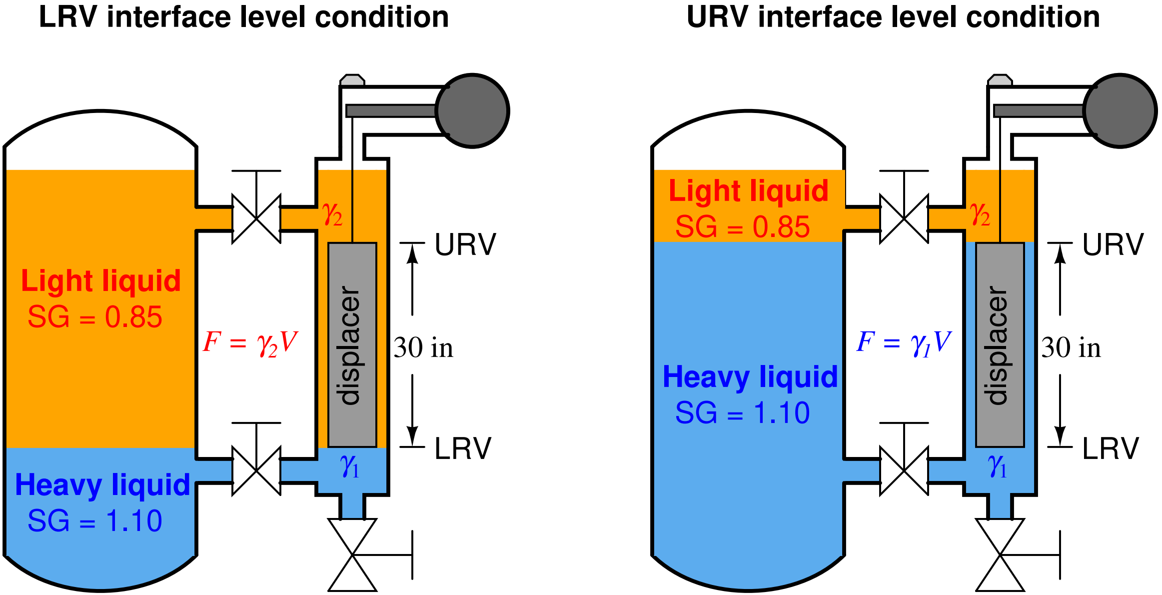
$$F_{buoyant} = \gamma_1 V_1 + \gamma_2 V_2$$

$$\pi r^2$$


Vessel
Light liquid
Density = γ_2
Heavy liquid
Density = γ_1
displacer
l_2
l_1
Displacer area = πr^2

$$F_{buoyant} = \gamma_1 \pi r^2 l_1 + \gamma_2 \pi r^2 l_2$$

$$F_{buoyant} = \pi r^2(\gamma_1 l_1 + \gamma_2 l_2)$$



LRV interface level condition
URV interface level condition
Light liquid
SG = 0.85
Heavy liquid
SG = 1.10
$F = \gamma_2 V$
γ_2
γ_1
displacer
URV
LRV
30 in
Light liquid
SG = 0.85
Heavy liquid
SG = 1.10
$F = \gamma_1 V$
γ_2
γ_1
displacer
URV
LRV
30 in

$$F_{buoyant}\ (\mathrm{LRV}) = \gamma_2 V = \gamma_2 \pi r^2 l$$

$$F_{buoyant}\ (\text{URV}) = \gamma_1 V = \gamma_1 \pi r^2 l$$

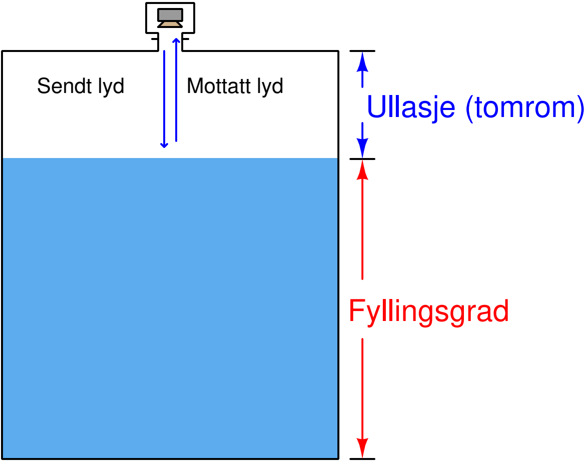
$$\gamma_1 = \left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)(1.10) = 68.6\ \frac{\text{lb}}{\text{ft}^3} = 0.0397\ \frac{\text{lb}}{\text{in}^3}$$

$$\gamma_2 = \left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)(0.85) = 53.0\ \frac{\text{lb}}{\text{ft}^3} = 0.0307\ \frac{\text{lb}}{\text{in}^3}$$

$$F_{buoyant}\ (\mathrm{LRV}) = \left(0.0307\ \frac{\mathrm{lb}}{\mathrm{in}^3}\right)\pi(1.375\ \mathrm{in})^2(30\ \mathrm{in}) = 5.47\ \mathrm{lb}$$

$$F_{buoyant}\ (\mathrm{URV}) = \left(0.0397\ \frac{\mathrm{lb}}{\mathrm{in}^3}\right)\pi(1.375\ \mathrm{in})^2(30\ \mathrm{in}) = 7.08\ \mathrm{lb}$$

Interface level (inches)	**Buoyant force** (pounds)
0	5.47
7.5	5.87
15	6.27
22.5	6.68
30	7.08


Sendt lyd
Mottatt lyd
Ullasje (tomrom)
Fyllingsgrad

$$\text{Nivå} = \text{Tankens totale høyde} - \text{Ullasje}$$

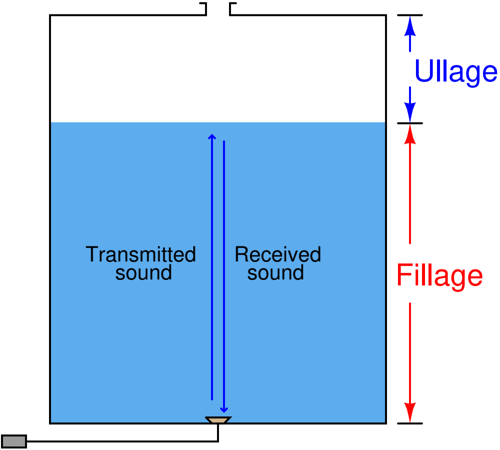
$$c = \sqrt{\frac{B}{\rho}}$$

C

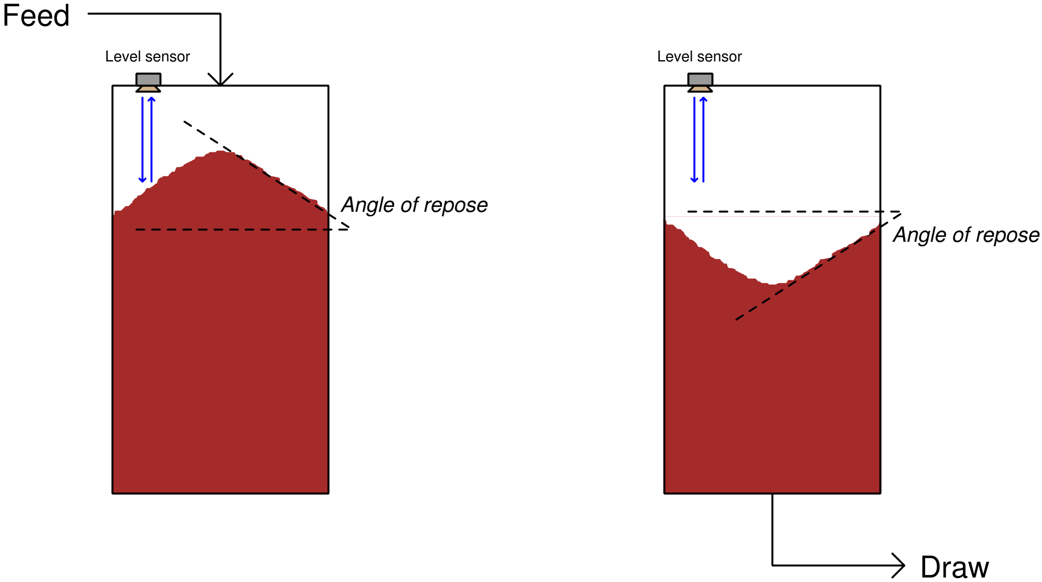
B

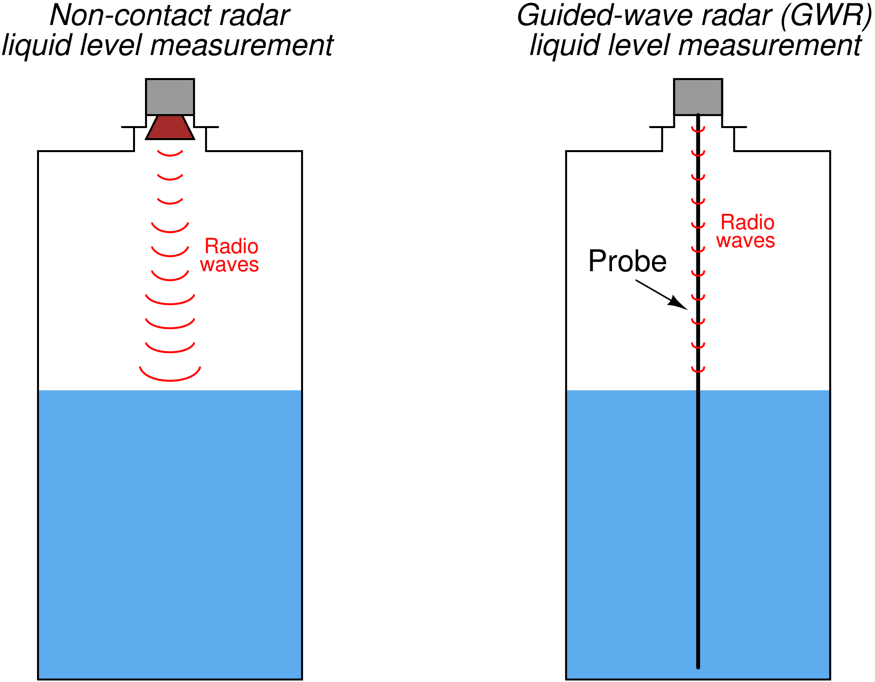

RELAY 1
RELAY 2
RELAY 3
RELAY 4
RELAY 5
LC-I Level Commander™
HI. TO
LO. TO
HEAD
FLOW
1
2
3
4
R1. HR
R2. HR
R3. HR
5
6
7
8
R1. ST
R2. ST
R3. ST
9
0
R5. HR
CE
#
MODE
TEST
R5. ST
DSP
ENT
Kay-Ray/Sensall, Inc.

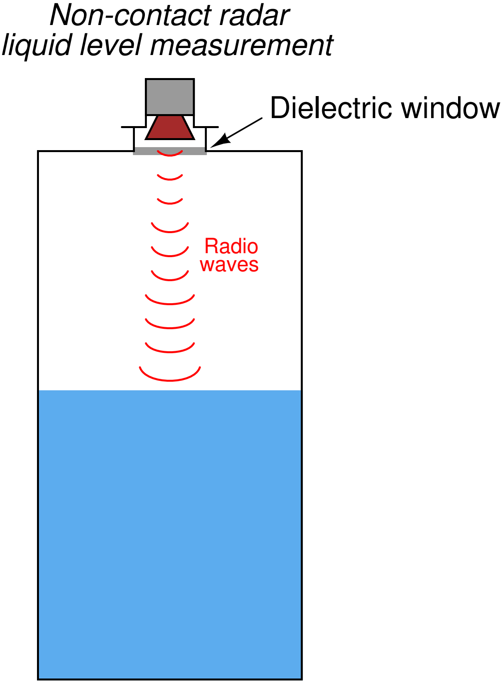

MILLTRONICS
ST-25C
SERIAL #
MADE IN CANADA


Ullage
Transmitted sound
Received sound
Fillage

$$\text{Ullage} = \text{Total height} - \text{Fillage}$$


Feed
Level sensor
Angle of repose
Level sensor
Angle of repose
Draw


Non-contact radar
liquid level measurement
Radio
waves
Guided-wave radar (GWR)
liquid level measurement
Radio
waves
Probe


Non-contact radar
liquid level measurement
Dielectric window
Radio
waves

$$2.9979 \times 10^8$$

ϵ

v

ϵ_r

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

$$PV = nRT$$

$$\rho = \frac{n}{V} = \frac{P}{RT}$$

$$\frac{PT_{ref}}{P_{ref}T}$$

$$\frac{\rho}{\rho_{ref}}$$

$$\epsilon_r = 1 + (\epsilon_{ref} - 1)\frac{PT_{ref}}{P_{ref}T}$$

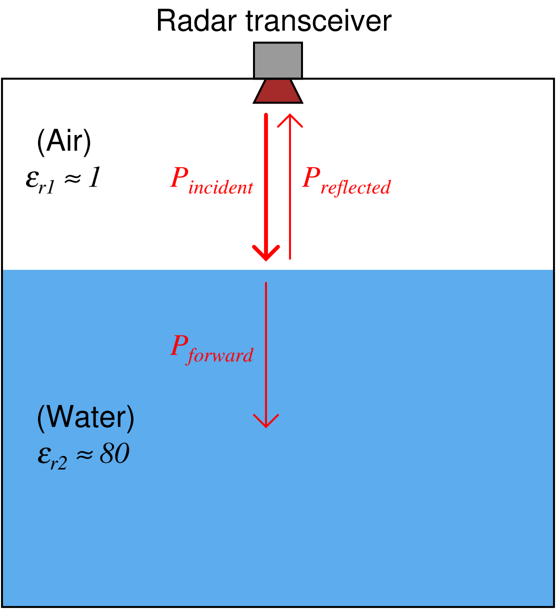
T

ϵ_{ref}

$$P_{ref}$$

T_{ref}

$\approx$



Radar transceiver
(Air)
$\varepsilon_{r1} \approx 1$
$P_{incident}$
$P_{reflected}$
$P_{forward}$
(Water)
$\varepsilon_{r2} \approx 80$

R

$$R = \frac{\left(\sqrt{\epsilon_{r2}} - \sqrt{\epsilon_{r1}}\right)^2}{\left(\sqrt{\epsilon_{r2}} + \sqrt{\epsilon_{r1}}\right)^2}$$

ϵ_{r1}

ϵ_{r2}

$$\frac{P_{forward}}{P_{incident}}$$

$$1 - R$$

$$R = \frac{\left(\sqrt{\epsilon_r} - 1\right)^2}{\left(\sqrt{\epsilon_r} + 1\right)^2}$$

$$\epsilon_r \approx 1$$

$$\epsilon_r \approx 80$$

-1.95

-15.3

$$\epsilon_r \approx 42$$

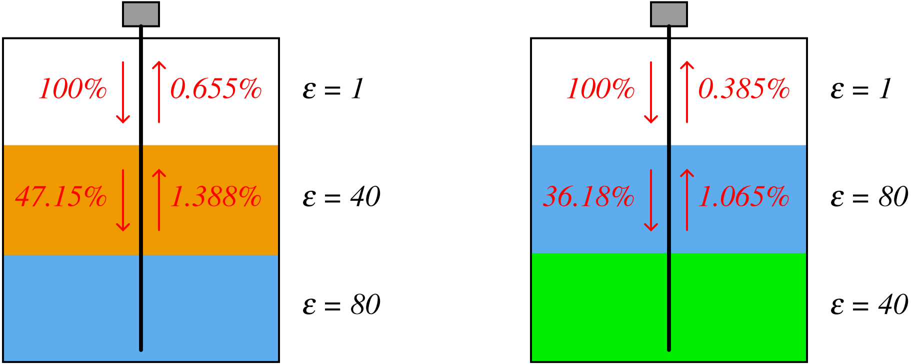
$$R = 0.5285$$

$$R = 0.02944$$

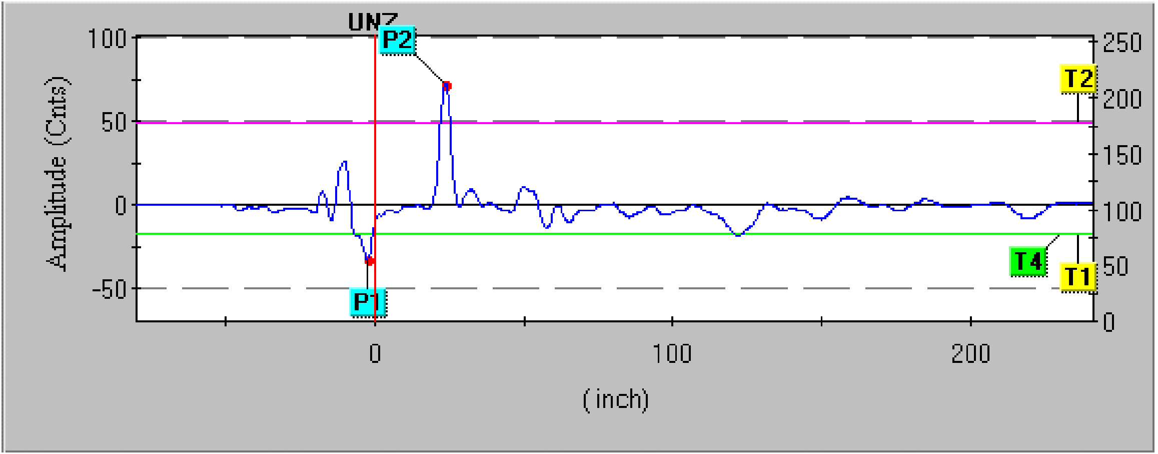
$$R = 0.6382$$

$$R = \frac{(\sqrt{\epsilon_r}-1)^2}{(\sqrt{\epsilon_r}+1)^2}$$

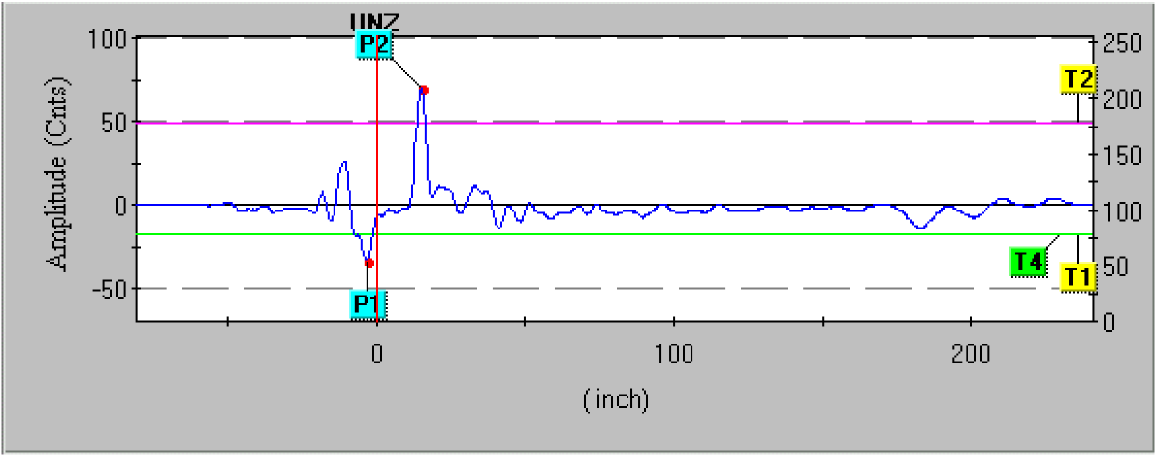
Signal power strengths en route and reflected off of the liquid-liquid interface



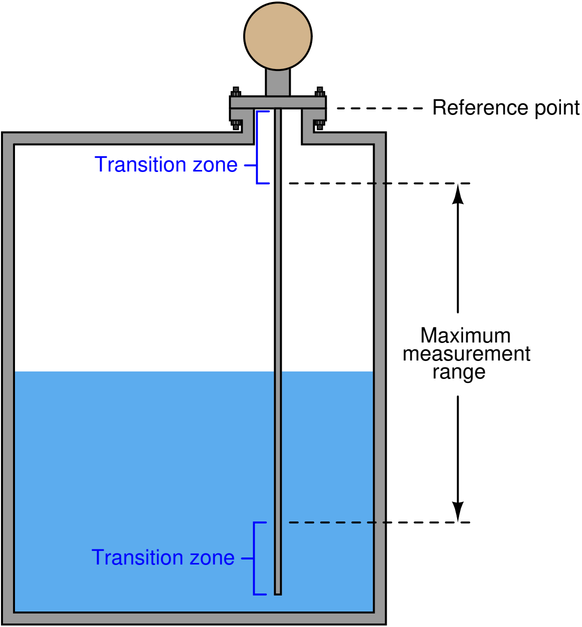
$$\approx 3 \times 10^8$$

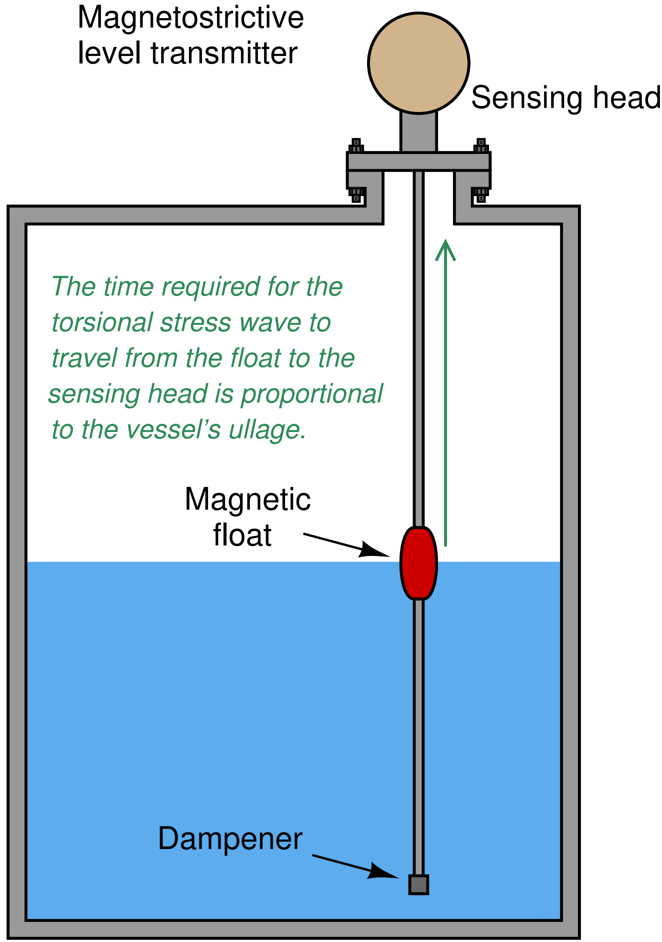


UNZ
P2
T2
T4
T1
P1
Amplitude (Cnts)
100
50
0
-50
250
200
150
100
50
0
0
100
200
(inch)



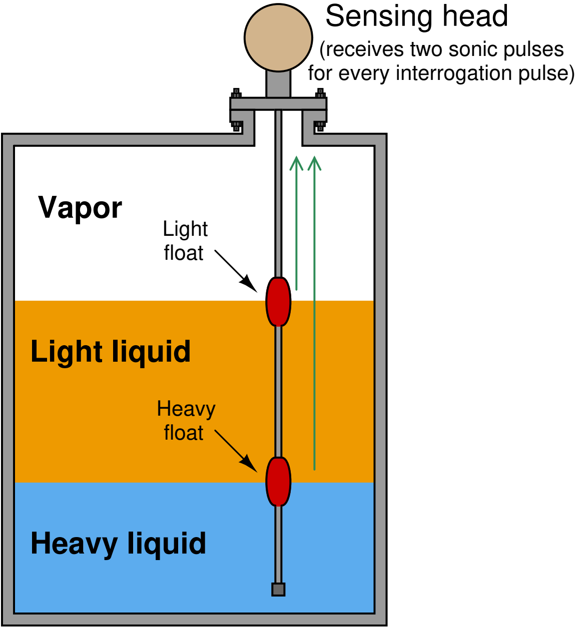
UNZ
P2
P1
T2
T4
T1
100
50
0
-50
250
200
150
100
50
0
Amplitude (Cnts)
0
100
200
(inch)

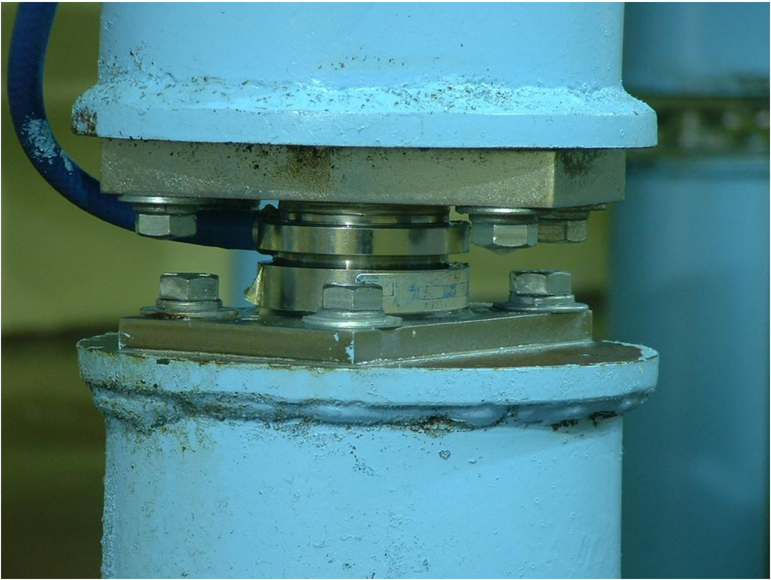

Reference point
Transition zone
Maximum
measurement
range
Transition zone

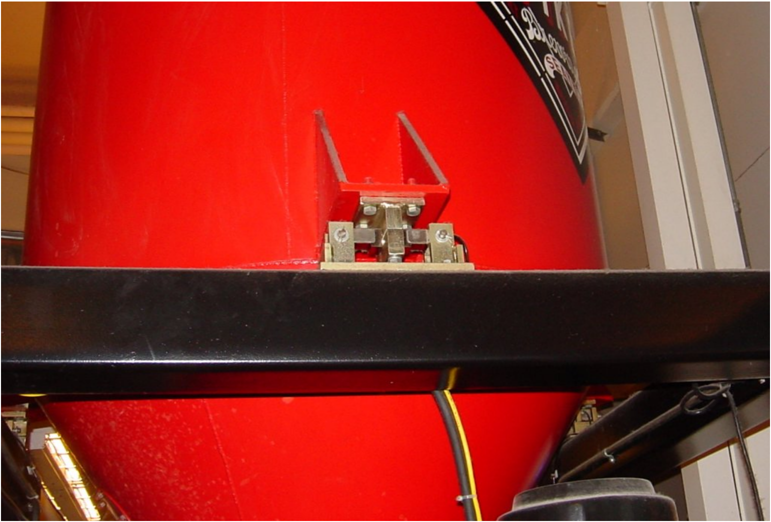

Magnetostrictive
level transmitter
Sensing head
The time required for the torsional stress wave to travel from the float to the sensing head is proportional to the vessel's ullage.
Magnetic
float
Dampener

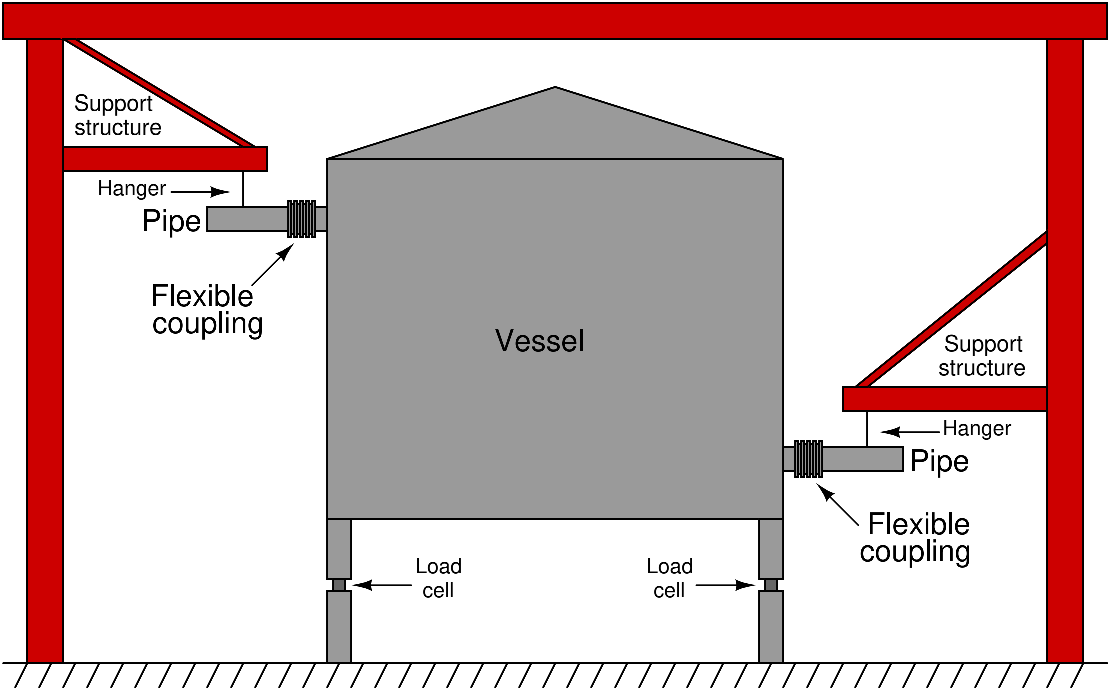
$$3 \times 10^3$$

$$3 \times 10^8$$


Sensing head
(receives two sonic pulses
for every interrogation pulse)
Vapor
Light
float
Light liquid
Heavy
float
Heavy liquid





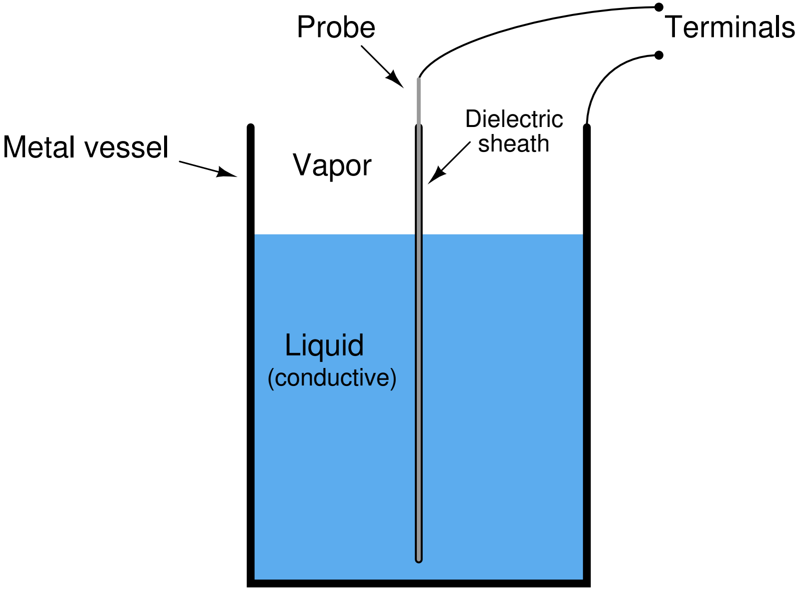

Support structure
Hanger
Pipe
Flexible coupling
Vessel
Support structure
Hanger
Pipe
Flexible coupling
Load cell
Load cell

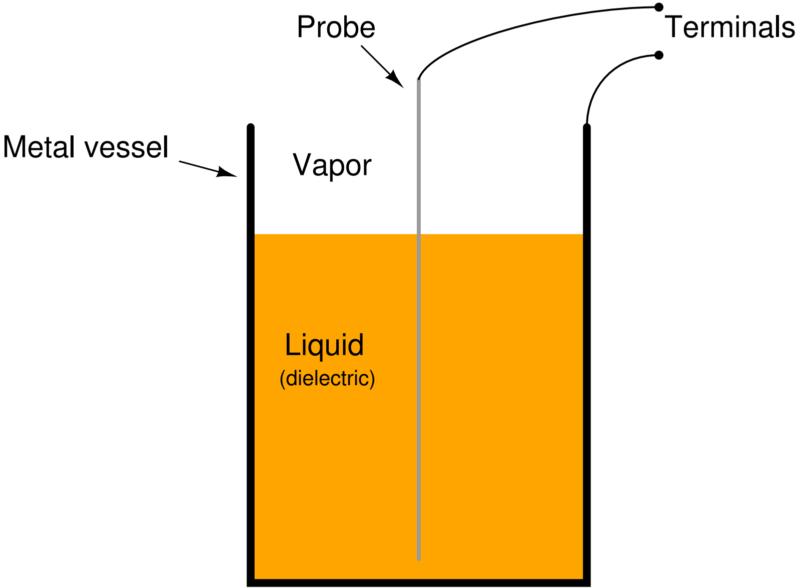
$$F = ma$$

$$C = \frac{\epsilon A}{d}$$

C

d

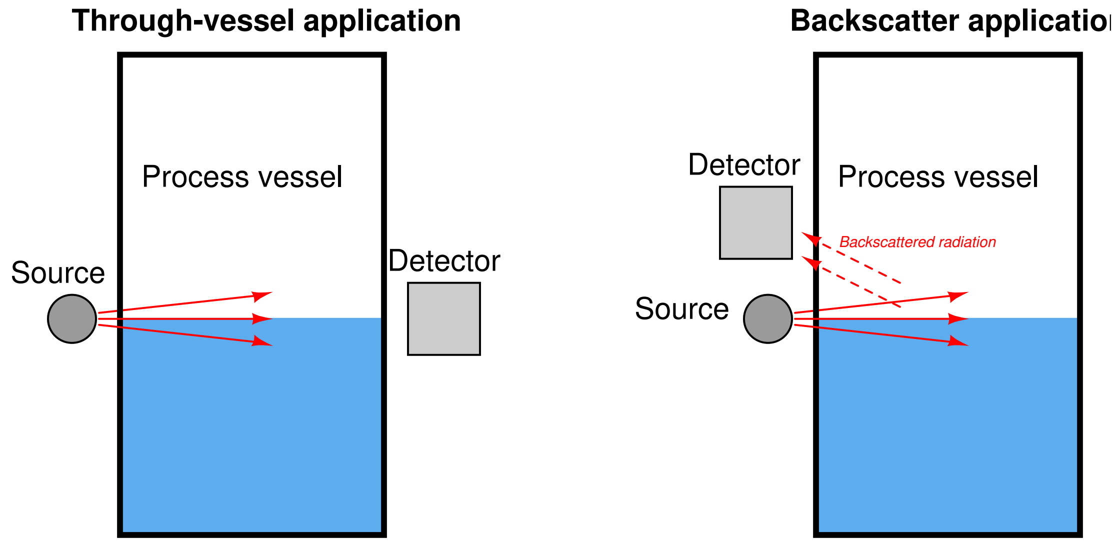

Probe
Terminals
Dielectric
sheath
Metal vessel
Vapor
Liquid
(conductive)

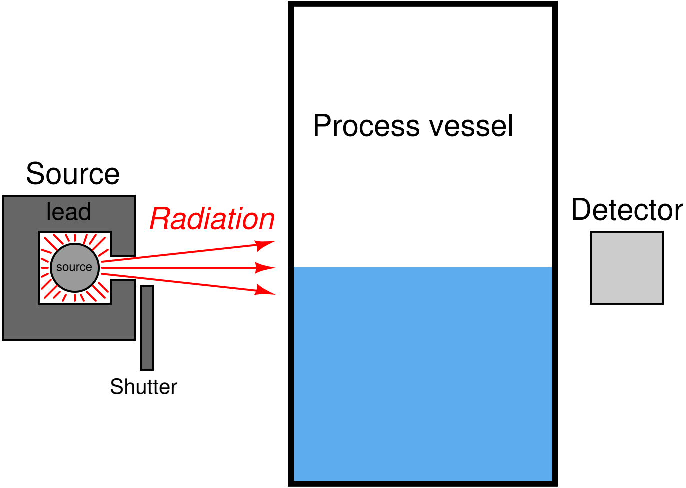

Probe
Terminals
Metal vessel
Vapor
Liquid
(dielectric)

α

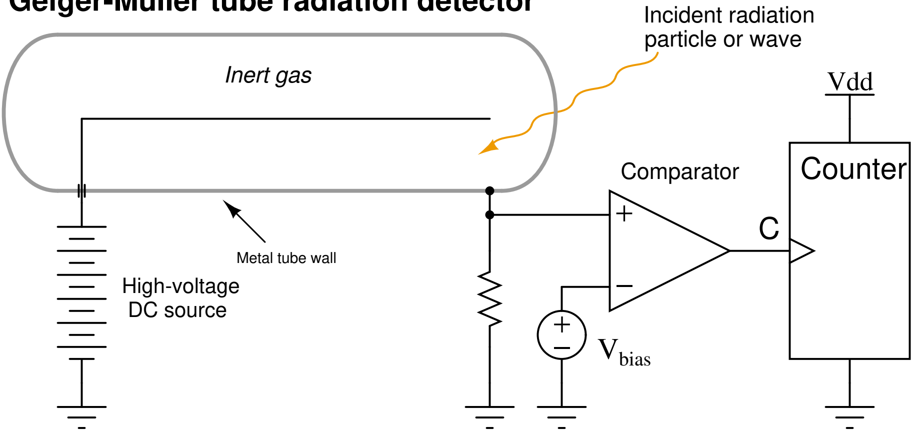
β

n


Through-vessel application
Process vessel
Source
Detector
Backscatter applicatio
Detector
Process vessel
Backscattered radiation
Source


Process vessel
Source
lead
source
Radiation
Detector
Shutter

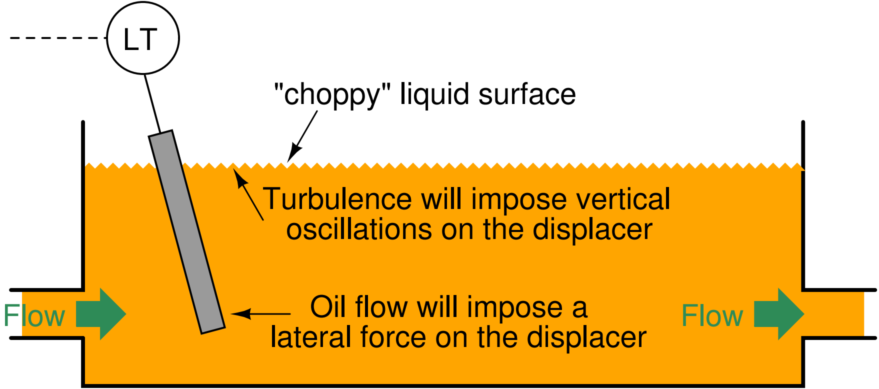
Geiger-Muller tube radiation detector

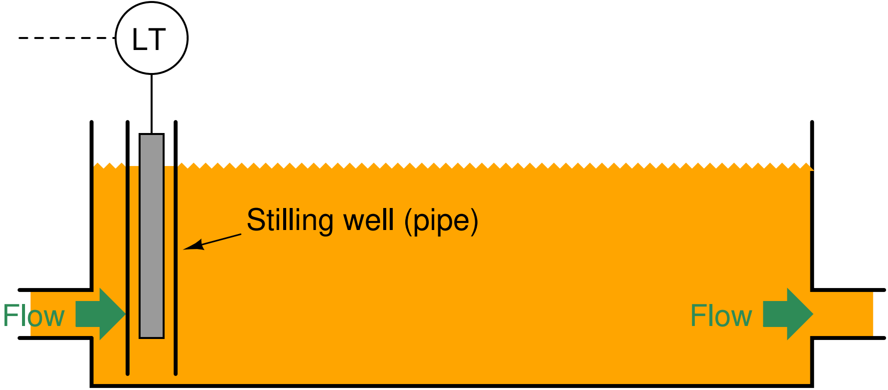



x100
HV
bat.
off
fast
response
off
audio

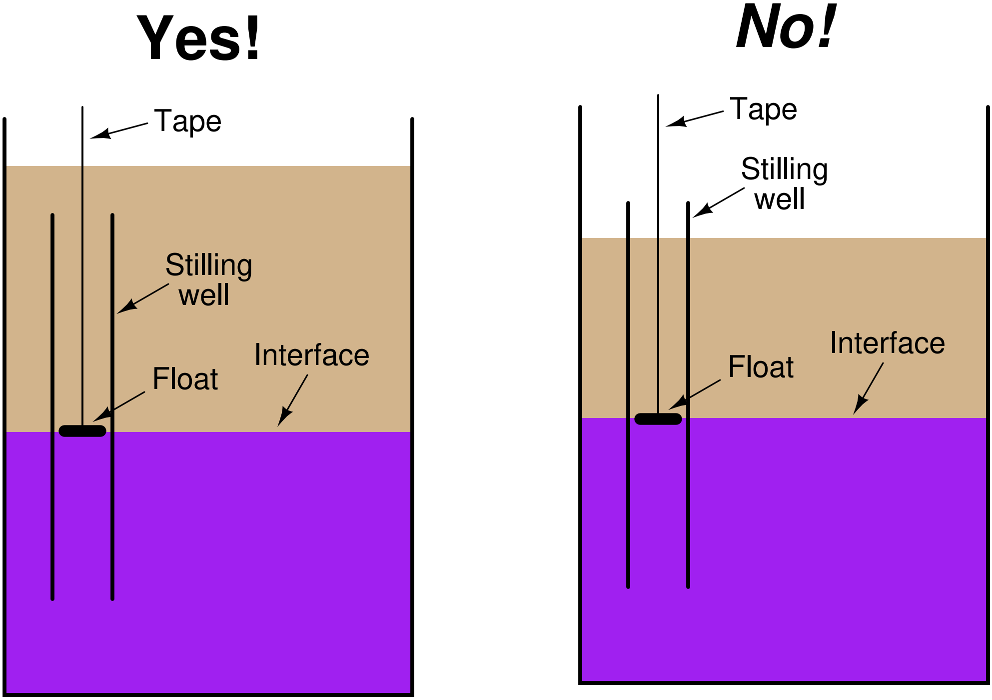
10

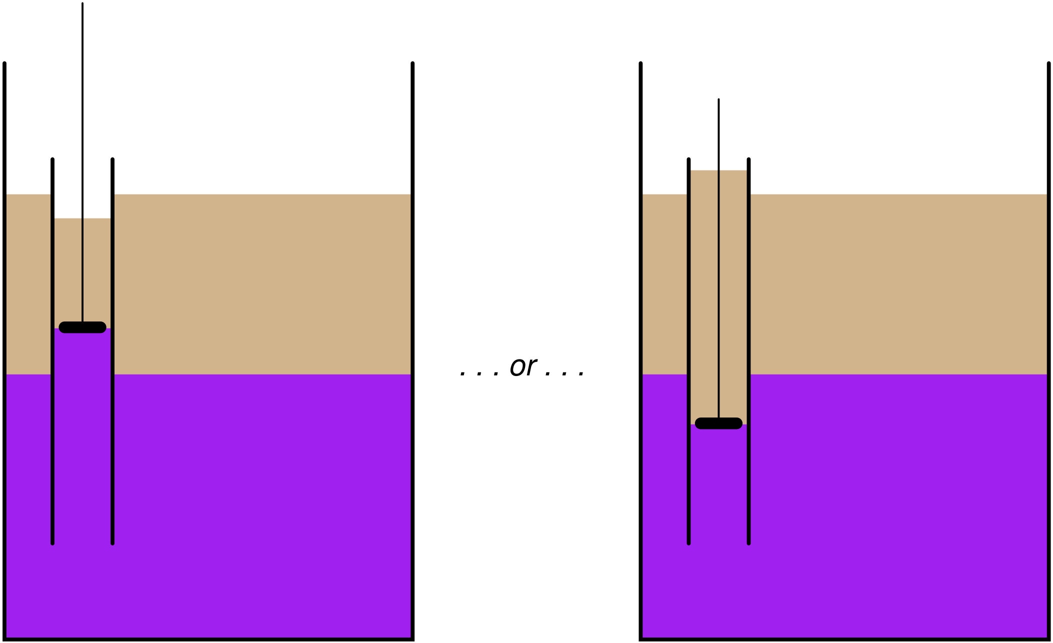
7

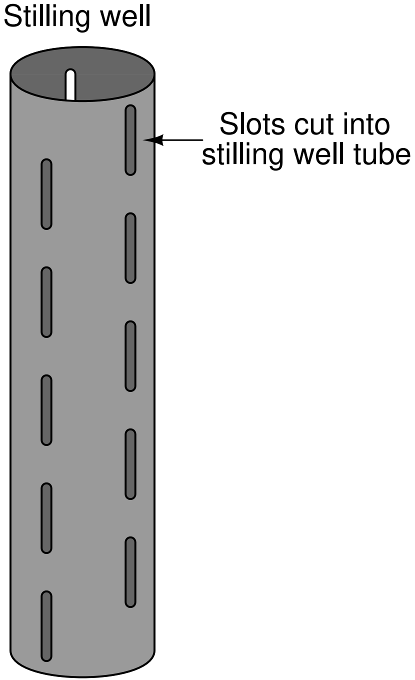

LT
"choppy" liquid surface
Turbulence will impose vertical oscillations on the displacer
Oil flow will impose a lateral force on the displacer
Flow
Flow



LT
Stilling well (pipe)
Flow
Flow


Yes!
Tape
Stilling well
Float
Interface
No!
Tape
Stilling well
Float
Interface


. . . or . . .


Stilling well
Slots cut into
stilling well tube

$$P = \frac{F}{A}$$

$$F_{buoyant} = \gamma V$$

$$x = vt$$

t

$$C = \frac{\epsilon A}{d}$$