Strømningsmålling

Kompetansemål:

- montere, konfigurere, kalibrere og idriftsettelse digitale og analoge målesystemer
- måle fysiske størrelser i automatiserte anlegg

Oppgaver

Oppgave 1

The rate of volumetric flow through *any* head-generating flow element is proportional to the square root of the differential pressure measured across it, so long as the flow regime is "fully-developed" turbulent:

$$Q \propto \sqrt{P}$$

Re-write this proportionality in the form of an equation, then solve for the new constant of proportionality (k) given these full-flow ratings for an orifice plate:

- Full flow $Q = 270$ m^3/h
- ΔP at full flow = 25 kPa

Now that you have a value for k, solve for the differential pressure across the orifice plate at these flow rates:

- $Q = 110$ m^3/h ; ΔP = ________ kPa
- $Q = 55$ m^3/h ; ΔP = ________ kPa
- $Q = 140$ m^3/h ; ΔP = ________ kPa
- $Q = 215$ m^3/h ; ΔP = ________ kPa

Suggestions for Socratic discussion

- Explain why we need not pay attention to maintaining compatible units of measurement for flow and pressure when solving this type of problem the way we did when using Bernoulli's equation directly.
- Why is it okay to use this general formula for *any* primary flow element based on differential pressure? There are many different types of flow elements (venturis, orifices, nozzles, Pitot tubes, segmented wedge tubes, etc.), each with its own unique design. What is common to all these elements that the same basic equation form may be used to describe the operation of them all?

file i00474

Oppgave 2

Suppose a 6 inch V-cone flow element is sized to generate a ΔP of 30 kPa at a flow rate of 160 m^3/h. Determine the new differential pressure instrument calibration ranges if this same flow element will now be used to measure the following water flow ranges:

- Q range = 0 to 110 m^3/h ; ΔP range = ________
- Q range = 0 to 140 m^3/h ; ΔP range = ________
- Q range = 0 to 180 m^3/h ; ΔP range = ________
- Q range = 0 to 230 m^3/h ; ΔP range = ________

Suggestions for Socratic discussion

- If the density of the fluid being measured by this flowmeter were to suddenly change, would it affect the *zero*, the *span*, or the *linearity* of the flowmeter's calibration?

file i00475

Oppgave 3

A horizontal venturi tube at a seawater desalinization plant is sized to produce 37.25 kPa while flowing at 1400 m^3/h of sea water (at a density of 1.025 grams per cubic centimeter).

Calculate the differential pressure produced by this same venturi tube at a flow rate of 740 m^3/h, and at a lighter density of 1.01 g/cm^3.

Assuming a water density of 1.03 g/cm^3 and a measured differential pressure of 3.1 PSID, calculate the volumetric flow rate through the venturi tube.

Assuming a water density of 1.02 g/cm^3 and a measured differential pressure of 12 kPaD, calculate the volumetric flow rate through the venturi tube.

Suggestions for Socratic discussion

- What is the purpose of a "desalinization" plant, and where might you expect to find one?

file i04043

Oppgave 4

A Foxboro pneumatic square root extractor has a calibrated range of 3 to 15 PSI for both input and output. Complete the following table of values for this relay, assuming perfect calibration (no error). Be sure to show your work!

Input signal (PSI)	Percent of input span (%)	Percent of output span (%)	Output signal (PSI)
5			
13			
	50		
	30		
		80	
		15	
			7
			12

Suggestions for Socratic discussion

- Why are pneumatic square-root extractors all but obsolete in modern industry? What has replaced their functionality?
- Share problem-solving techniques for obtaining answers to this problem.

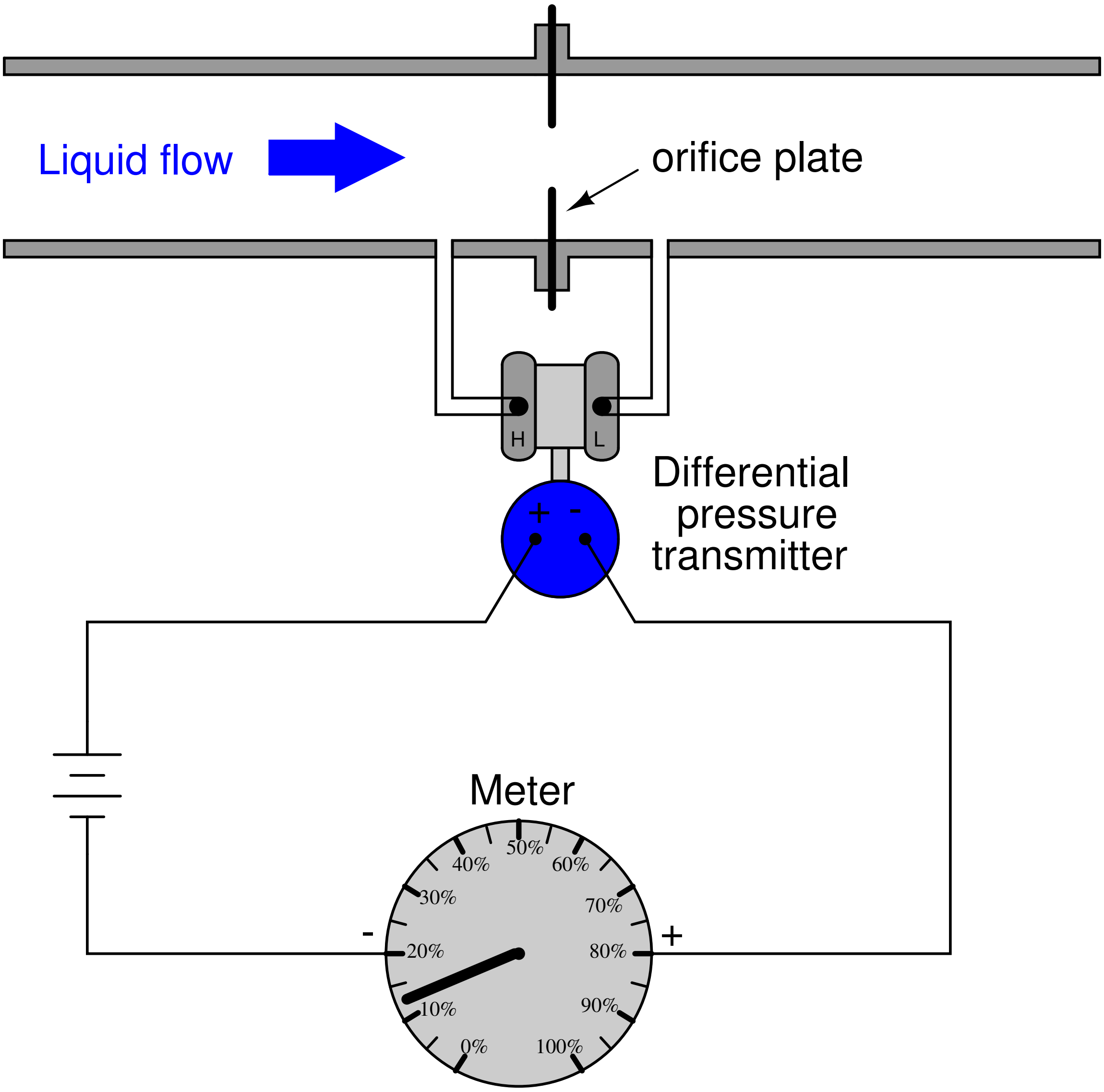
file i00100

Oppgave 5

Calculate the volumetric flow rate (in units of cubic meters per minute) for water flowing out of the 25.4 cm diameter (ID) discharge pipe of a centrifugal pump at a velocity of 7.62 meter per second. Then, convert that flow rate into units of gallons per minute.
file i00732

Oppgave 6

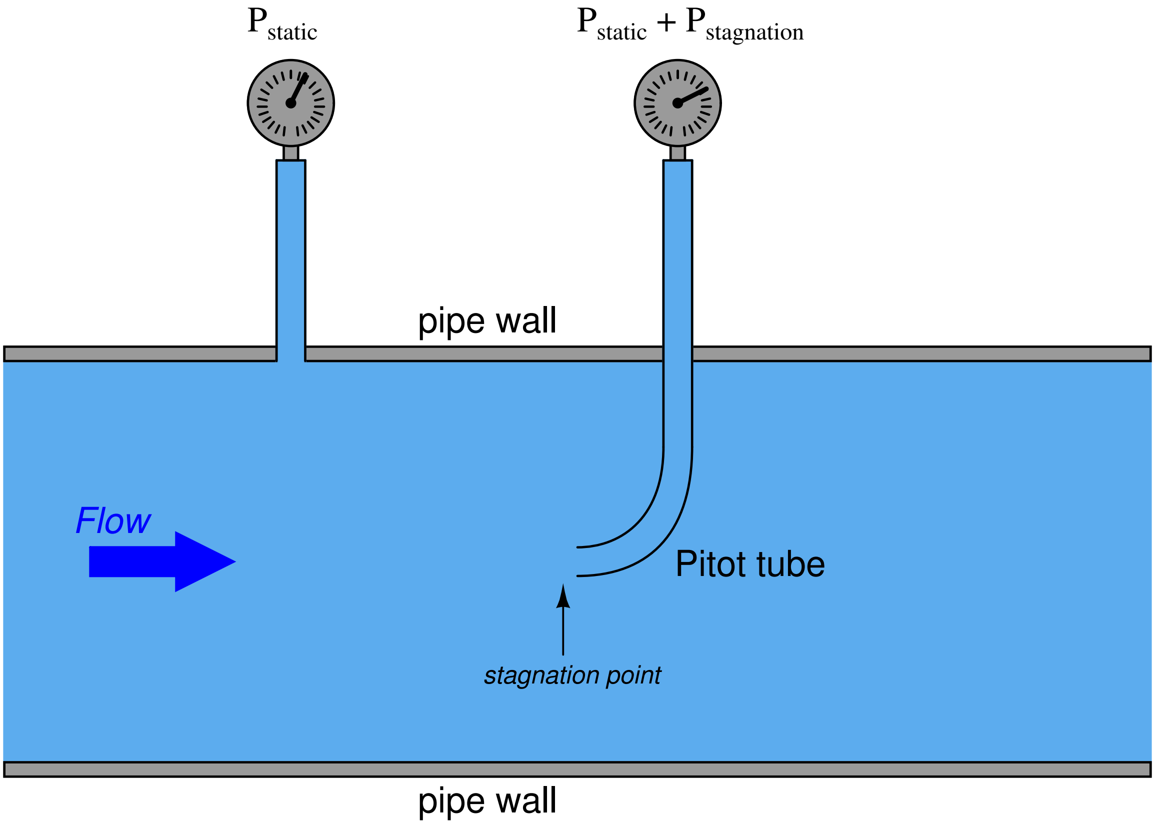
What will be wrong with this measurement system if we connect a linear-scale indicator (an electrical meter movement responding to the transmitter's current signal) to the transmitter's output, and try to measure fluid flow along this scale? Assume the transmitter has been properly calibrated to output full current (typically 20 mA) at full flow through the orifice plate.



Hint: what will the meter indicate when the actual flow rate is at 0%, 50%, and 100%?
file i00483

Oppgave 7

As fluid flows past a stationary object such as a *Pitot tube*, the fluid immediately in front of the tube comes to a full stop. This is called a *stagnation point*, and the pressure resulting from the complete loss of velocity at the stagnation point is called the *stagnation pressure*.



Manipulate Bernoulli's equation to show how this stagnation pressure is determined by fluid velocity (v).
file i02981

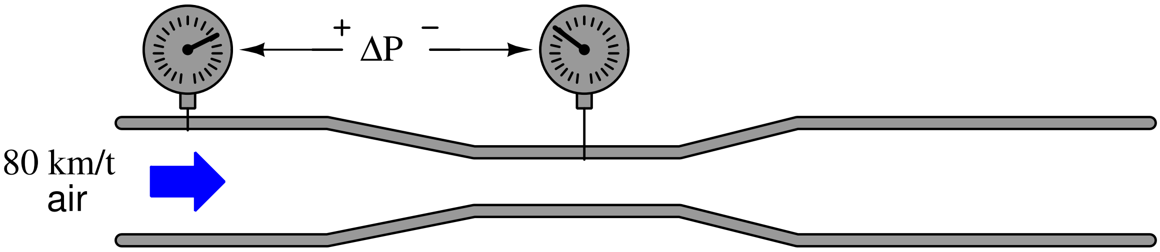
Oppgave 8

Calculate the pressure developed by a Pitot tube measuring air speed at 80 km/h, at sea level ($\rho_{air} = 1.21114$ kg/m^3).

Also, how much pressure will the Pitot tube develop at twice the air speed (160 km/h)?
file i02982

Oppgave 9

Calculate the differential pressure developed by an open venturi tube measuring air speed at 80 km/h, at sea level (ρ_{air} =1.21114 kg/m^3, where the throat diameter is one-half that of the entrance diameter:



Also, how much pressure will the venturi tube develop at twice the air speed (160 km/h)?
file i02984

Oppgave 10

Read the whitepaper published by Rosemount on the topic of top-mounting DP flowmeters on steam lines ("Top Mount Installation for DP Flowmeters in Steam Service", document 00870-0200-4809, copyright August 2009) and answer the following questions:

Why has the traditional recommendation for DP flow transmitter on steam lines been to locate the transmitter *below* the line?

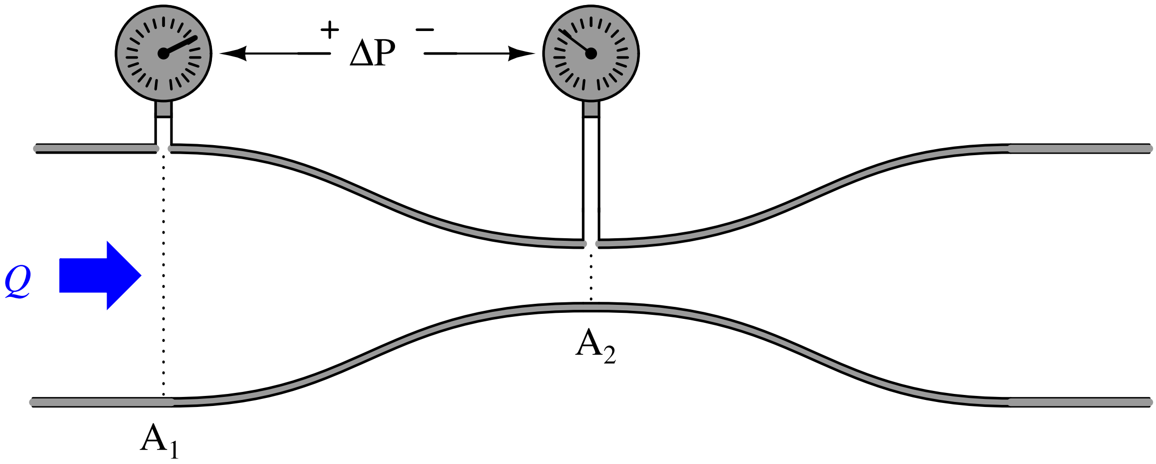
What kind(s) of problem(s) are typically experienced with below-pipe mounting of DP flow transmitters in steam line applications?

Can DP flowmeters *always* be top-mounted? If not, what limitations dictate whether or not to top-mount?

Why shouldn't Annubar-style flow elements be mounted *vertically* in a steam pipe, but rather should be canted at least 15 degrees from vertical?
file i03488

Oppgave 11

From Bernoulli's equation, develop a formula for calculating volumetric flow rate (Q) given differential pressure drop ΔP between two flow streams with differing cross-sectional areas (A_1 and A_2). Assume an incompressible fluid (ρ = constant) flowing along a level path ($z_1 = z_2$), and recall that volumetric flow rate is equal to the product of cross-sectional area and fluid velocity ($Q = Av$).



Bernoulli's equation:

$$z_1 \rho g + \frac{v_1^2 \rho}{2} + P_1 = z_2 \rho g + \frac{v_2^2 \rho}{2} + P_2$$

file i02983

Oppgave 12

Two flow-indicating instruments employ a common orifice plate to measure the flow of water through a pipe. The full differential pressure generated by this orifice plate at its rated flow of 800 GPM is 120 inches water column (120 "WC):

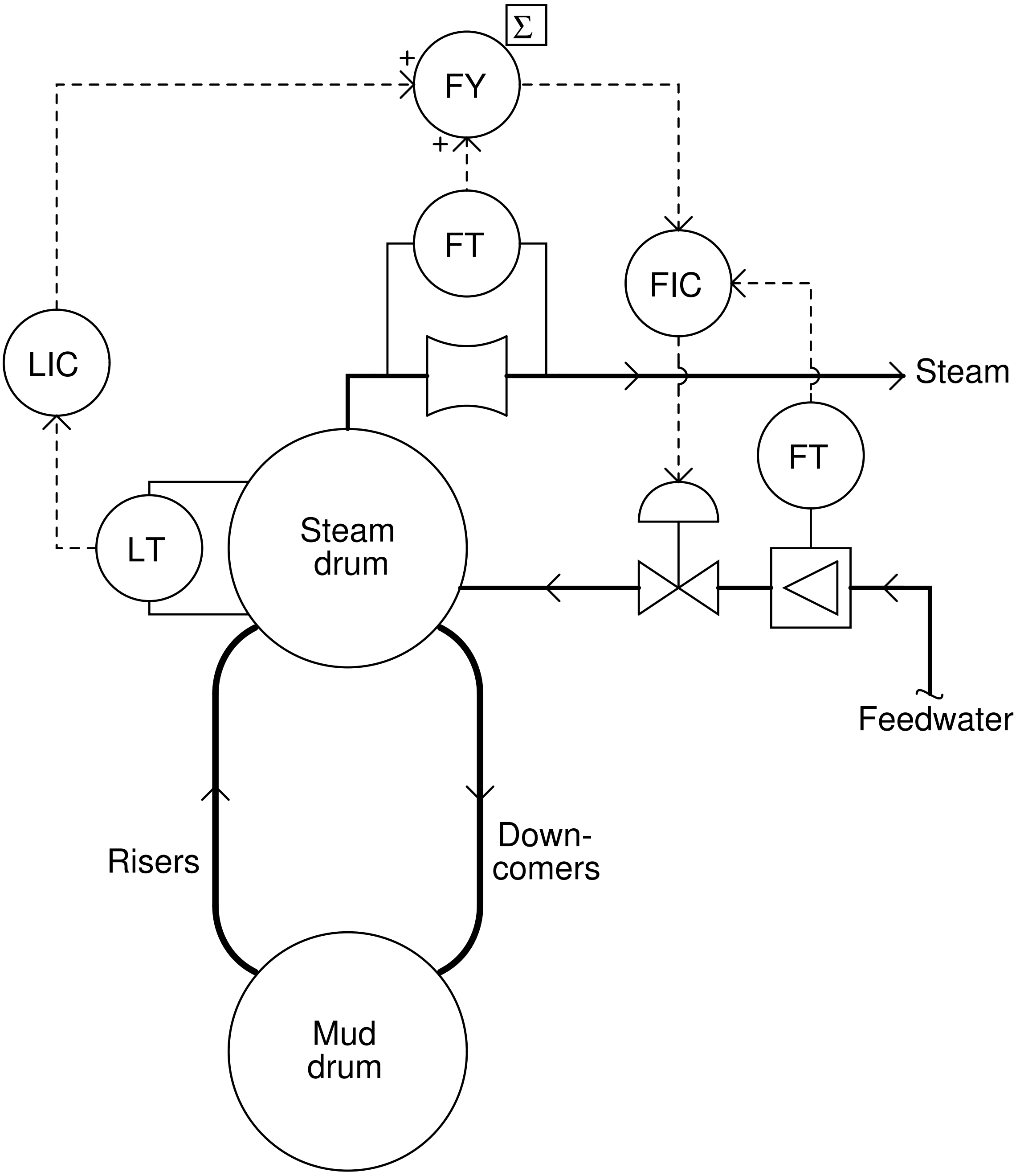
- Receiver gauge (3-15 PSI input) connected to the output of a pneumatic DP transmitter connected across the orifice, registering 385 GPM on a 0-800 GPM square-root scale

- Panel-mounted indicator (3-15 PSI) connected to the output of the same pneumatic DP transmitter, registering 403 GPM on a 0-800 GPM square-root scale

Based on this information, where do you think the calibration error is located? If there isn't enough information yet to pinpoint the location of the error, devise a test to reveal where the error is.
file i00733

Oppgave 13

A venturi tube is used to measure the flow rate of steam exiting a power boiler:



Supposing this venturi tube normally develops a differential pressure of 100 inches water column at a flow rate of 970 pounds per minute with a steam density of $\rho = 1.33$ lbm/ft^3, calculate the following:

- Differential pressure at 700 lbm/min mass flow = ________
- Differential pressure at 550 lbm/min mass flow and $\rho = 1.30$ lbm/ft^3 = ________
- Mass flow rate at 90 "W.C. = ________
- Mass flow rate at 43 "W.C. and $\rho = 1.35$ lbm/ft^3 = ________

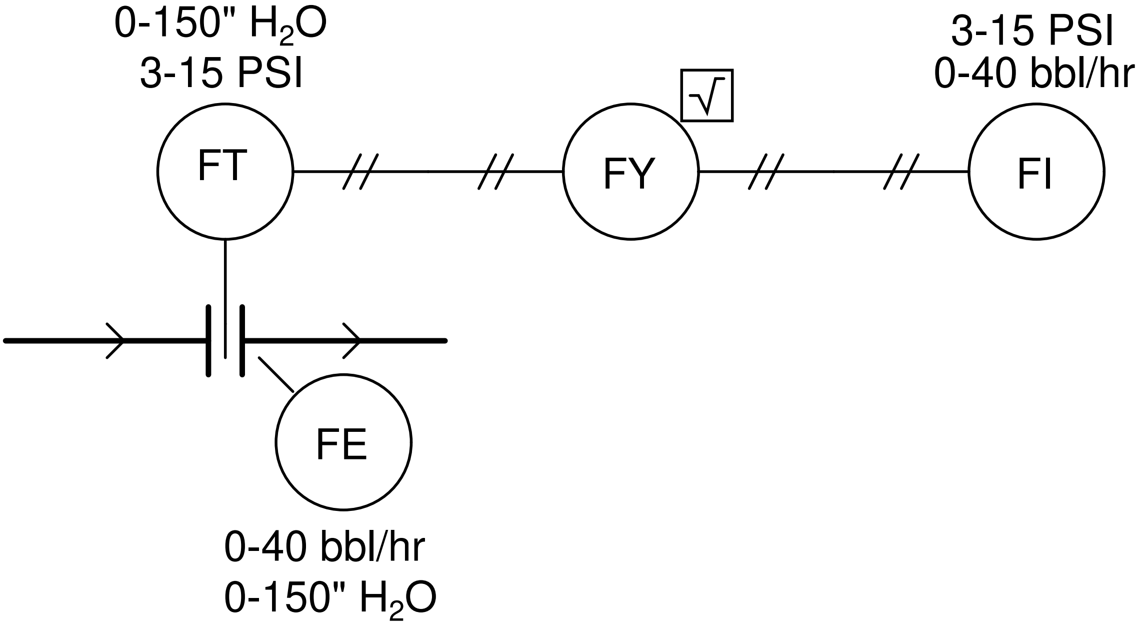
Suggestions for Socratic discussion

- Explain why both steam flow and water flow are best measured in *mass* units rather than volumetric in this process application.
- Identify some factors that could realistically cause the steam's density to change.

file i04087

Oppgave 14

An orifice plate is used to measure the flow rate of diesel fuel exiting the processing unit at an oil refinery where the customary unit for liquid flow measurement within refineries is "barrels per hour" (bbl/hr). Calculate the following parameters in this flow measurement loop, at two different flow rates (10 bbl/hr and 31 bbl/hr):



- **At a flow rate of 10 bbl/hr:**
- Orifice plate ΔP = ________ " H_2O
- Differential pressure transmitter output signal = ________ PSI
- Square root extractor output signal = ________ PSI
- Flow indicator reading = ________ bbl/hr

- **At a flow rate of 31 bbl/hr:**
- Orifice plate ΔP = ________ " H_2O
- Differential pressure transmitter output signal = ________ PSI
- Square root extractor output signal = ________ PSI
- Flow indicator reading = ________ bbl/hr

file i00725

Oppgave 15

Read selected portions of the Rosemount Orifice Plate Elements manual ("1495 Orifice Plate, 1496 Flange Union, 1497 Meter Section, Installation & Operation Manual" publication 00809-0100-4792 Revision AA), and answer the following questions:

Page 3-1 of this manual (Figure 3-1) shows a typical "flange union" whereby an orifice plate is sandwiched between two pipe flanges. Page 4-1 (Figure 4-1) of the manual shows something called a "meter section," which serves a similar purpose. Identify the difference between a "meter section" and a normal "flange union." Explain in your own words why anyone might choose to install a "meter section" instead of a regular flange for their orifice plate flowmeter application.

Appendix C shows standard lengths for meter section tubes. Calculate the typical upstream straight-pipe length (as a ratio of pipe diameters), and also calculate the typical downstream straight-pipe length (as a ratio of pipe diameters), based on the standard lenghts and inside diameters (I.D.) shown in this table.

Appendix A of this manual provides information regarding the proper upstream and downstream straight-pipe requirements for different orifice plate installations. Based on what you read in this appendix, identify the most "challenging" installations for orifice plate elements (i.e. which applications require the longest straight-pipe runs to achieve good accuracy?).

Suppose we have an orifice plate flowmeter installation where there are two pipe elbows (not in the same plane) upstream of the orifice, an orifice plate with a beta ratio of 0.6, and no "straightening vanes" installed. Determine the minimum number of straight-pipe diameters needed upstream and downstream of the orifice plate for good performance in this installation.

Suggestions for Socratic discussion

- Why is the required straight-pipe length *upstream* of an orifice plate greater than the required straight-pipe length *downstream* of an orifice plate?
- Does the presence of straightening vanes in an orifice meter run affect only the upstream straight-pipe lengths requirement, or also the downstream straight-pipe length requirement?
- Why do you suppose a pair of pipe elbows in different planes produces a different amount of large-scale turbulence than a pair of pipe elbows in the same plane?
- If the amount of straight pipe between two elbows is increased, will the straight-pipe requirements between those elbows and the orifice plate be affected or not? Explain why.

file i04046

Oppgave 16

A 5 inch diameter flow nozzle measuring volumetric flowrate of petroleum naphtha ($\gamma = 41.5$ lb/ft^3) develops a differential pressure of 75 inches water column at a flow rate of 280 GPM. Calculate the following:

- Differential pressure at 130 GPM = ________
- Differential pressure at 210 GPM and $\gamma = 42.0$ lb/ft^3 = ________
- Flow rate at 40 "W.C. = ________
- Flow rate at 24.1 "W.C. and $\gamma = 41.0$ lb/ft^3 = ________

Suggestions for Socratic discussion

- What realistic factors could cause the weight density of a liquid such as naphtha to change from 41.5 lb/ft^3 to 41.0 or 42.0 lb/ft^3?

file i04048

Oppgave 17

A vertical venturi tube measuring mass flowrate of high-pressure steam ($\rho = 1.3$ lbm/ft^3) develops a differential pressure of 110 inches water column at a flow rate of 500 pounds per minute. Calculate the following:

- Differential pressure at 230 lbm/min mass flow = ________
- Differential pressure at 409 lbm/min mass flow and $\rho = 1.25$ lbm/ft^3 = ________
- Mass flow rate at 95 "W.C. = ________
- Mass flow rate at 51 "W.C. and $\rho = 1.35$ lbm/ft^3 = ________

Suggestions for Socratic discussion

- What significance is there in using the unit of "pounds mass" (lbm) instead of "pounds force" (lbf) in these quantities? Is there an appropriate application for using lbf instead?
- What realistic factors could cause the weight density of a vapor such as steam to change from 1.3 lbm/ft^3 to 1.25 or 1.35 lbm/ft^3?

file i04049

Oppgave 18

Suppose you are calibrating a DP transmitter to go into service as a flow transmitter, measuring differential pressure generated by a segmental wedge flow element. This is a "smart" electronic transmitter with square-root characterization capability, which you decide to activate for this application.

Calculate the ideal current signal values at the following calibration pressures, assuming a calibrated range of 0 to 150 inches water column:

Input pressure (" W.C.)	Output current (mA)
0	
45	
75	
90	
110	
150	

Furthermore, suppose you performed an "As-Found" test on this DP transmitter and found it to respond as such:

Input pressure (" W.C.)	Output current (mA)
0	4.3
45	13.06
75	15.61
90	16.69
110	18.0
150	20.3

What type of calibration error is this (e.g. *zero* shift, *span* shift, or *nonlinearity*), and do you suspect it lies with the sensor or with the digital-to-analog converter? In other words, do you need to perform a *sensor trim* or an *output trim* on this instrument?

Suggestions for Socratic discussion

- Explain the difference between a *sensor trim* and an *output trim* in a "smart" transmitter.
- What tool(s) would you need to perform a sensor trim on a smart transmitter?
- What tool(s) would you need to perform an output trim on a smart transmitter?

file i04051

Oppgave 19

Suppose you are calibrating a panel-mounted indicator to be used for displaying flow rates, based on the signal coming from a (linear) DP transmitter sensing pressure across a venturi tube. The DP transmitter is an analog electronic transmitter with a linear characteristic, which means the panel-mounted indicator must be configured for square-root characterization.

Calculate the ideal display value at the following input currents, assuming a calibrated range of 0 to 700 GPM for the indicator:

Input current (mA)	Displayed flow (GPM)
4	
6	
9.3	
13	
14.8	
20	

Suggestions for Socratic discussion

- Suppose this analog transmitter were connected to an analog meter to indicate flow. How could the necessary square-root characterization be performed when all the components are analog and not digital?

file i04052

Oppgave 20

Elevation (z) and pressure (P) readings are taken at two different points in a piping system carrying liquid benzene ($\gamma = 56.1$ lb/ft^3):

$z_1 = 50$ inches $\quad z_2 = 34$ inches

$P_1 = 70$ PSI $\quad P_2 = 69$ PSI

Calculate the fluid velocity at point 2 (v_2) if the velocity at point 1 is known to be equal to 5 feet per second ($v_1 = 5$ ft/s).

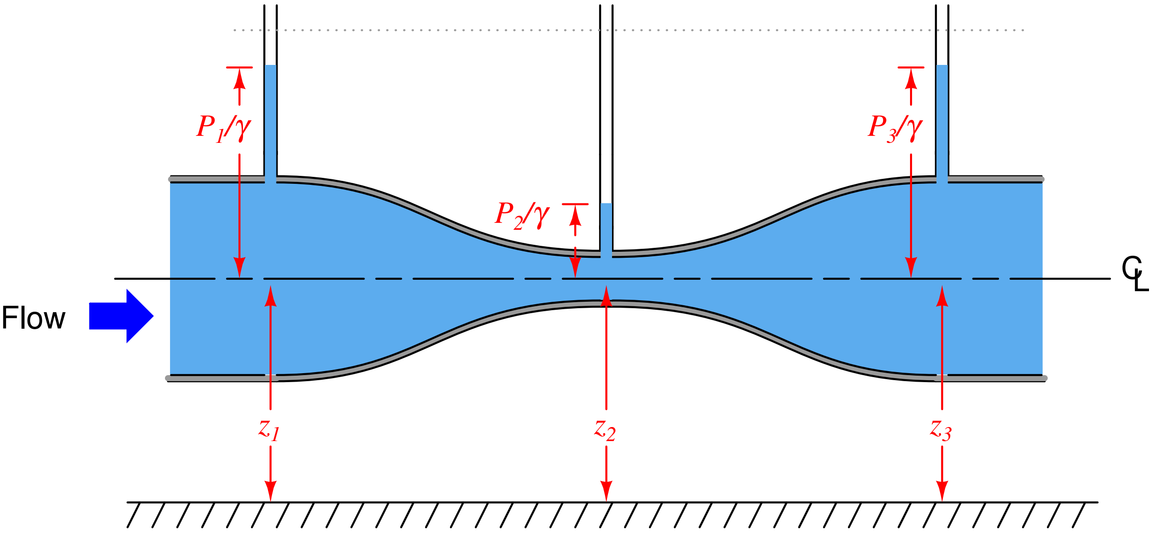
Bernoulli's equation:

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = z_2\rho g + \frac{v_2^2\rho}{2} + P_2$$

file i02988

Oppgave 21

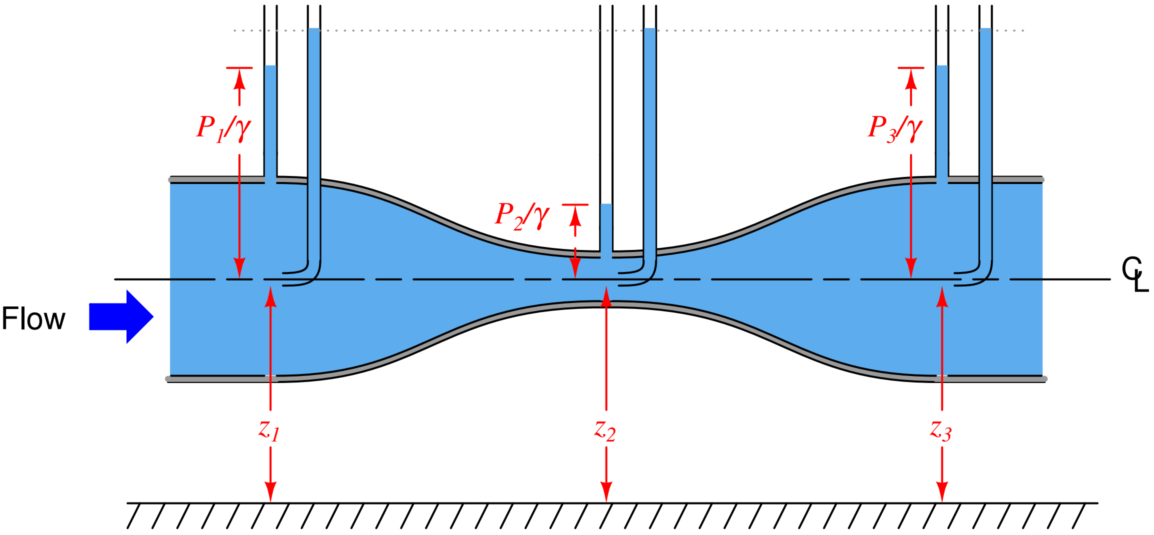
Single-tube manometers (called *piezometers*, which literally means “pressure meters”) installed on a level venturi tube clearly show the difference in pressure at different points within the tube. These pressure differences, of course, are due to the exchange of energy between potential and kinetic forms:



Note that the following form of Bernoulli’s equation is used to describe pressure and height in the diagram, for the purpose of expressing all terms as vertical distances (in units of feet). This is why pressure is shown as P/γ instead of just P:

$$z_1 + \frac{v_1^2}{2g} + \frac{P_1}{\gamma} = z_2 + \frac{v_2^2}{2g} + \frac{P_2}{\gamma}$$

If we install three more piezometer tubes – this time with their tube ends facing the direction of oncoming liquid flow (called *Pitot tubes*) – we see something quite interesting: the heights of liquid in all the new tubes are equal.



What accounts for the difference in height between liquid columns in the three sets of piezometers? How come the Pitot tube piezometers all register the same height? What is the significance of the line where all the Pitot tube piezometer liquid levels are equal?

file i02980

Svar

Svar 1

Partial answer:

- $Q = 110$ m^3/h ; ΔP = 4.15 kPa
- $Q = 55$ m^3/h ; ΔP = 1.04 kPa
- $Q = 140$ m^3/h ; ΔP = 6.75 kPa
- $Q = 215$ m^3/h ; ΔP = 15.85 kPa

Svar 2

Partial answer:

- Q range = 0 to 110 m^3/h ; ΔP range = 0-14.18 kPa
- Q range = 0 to 140 m^3/h ; ΔP range = 0-22.97 kPa
- Q range = 0 to 180 m^3/h ; ΔP range = 0-37.97 kPa
- Q range = 0 to 230 m^3/h ; ΔP range = 0-62.00 kPa

Svar 3

Partial answer:

$\Delta P = 10.25$ kPa at 740 m^3/h and 1.01 g/cm^3

$Q = 1058$ m^3/h flow rate at 3.1 PSID and 1.03 g/cm^3

$Q = 796.6$ m^3/h flow rate at 12 kPaD and 1.02 g/cm^3

Svar 4

Input signal (PSI)	Percent of input span (%)	Percent of output span (%)	Output signal (PSI)
5	16.67	40.82	7.899
13	**83.33**	**91.29**	**13.95**
9	50	70.71	11.49
6.6	30	54.77	9.573
10.68	64	80	12.6
3.27	**2.25**	15	**4.8**
4.333	11.11	33.33	7
9.75	56.25	75	12

Values shown in bold-faced type are those given to students in the "Answer" section.

Svar 5

$Q = Av = \pi(\frac{0.254m}{2})^2 \cdot 7.62 = 0.386$ m^3/s = 6120 GPM

Svar 6

At 0% flow and 100% flow rates, the meter will indicate accurately. It will be very much in error at any point in between. At 50% true flow rate, for example, the meter will only indicate 25%, since the differential pressure drop generated by the orifice plate will only be that much at the half-flow rate.

Follow-up question: identify a way we may correct this system so that all the points along the indicator's scale accurately reflect flow rate through the orifice.

Svar 7

Bernoulli's equation:

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = z_2\rho g + \frac{v_2^2\rho}{2} + P_2$$

Assuming no change in height (z) is involved:

$$\frac{v_1^2\rho}{2} + P_1 = \frac{v_2^2\rho}{2} + P_2$$

Knowing that P_1 is the static pressure and that P_2 is equal to $P_{static} + P_{stagnation}$:

$$\frac{v_1^2\rho}{2} + P_{static} = \frac{v_2^2\rho}{2} + P_{static} + P_{stagnation}$$

$$\frac{v_1^2\rho}{2} = \frac{v_2^2\rho}{2} + P_{stagnation}$$

Knowing that v_2 is zero at the stagnation point:

$$\frac{v_1^2\rho}{2} = P_{stagnation}$$

Therefore, $P_{stagnation} = \frac{1}{2}v^2\rho$

Svar 8

P at 80 km/h = 276.82 Pa

P at 160 km/h = 1107.3 Pa

Svar 9

Tar utgangspunkt i Bernoulli

$$z_1\rho g + \frac{v_1^2\rho}{2} + P_1 = z_2\rho g + \frac{v_2^2\rho}{2} + P_2$$

Samme høyde z ledd faller vekk

$$\Downarrow$$

$$\frac{v_1^2\rho}{2} + P_1 = \frac{v_2^2\rho}{2} + P_2$$

Snur med hensyn på ΔP

$$\Downarrow$$

$$P_1 - P_2 = \Delta P = \frac{v_2^2\rho}{2} - \frac{v_1^2\rho}{2} = \frac{\rho}{2}(v_2^2 - v_1^2) = \frac{\rho}{2}\left(\left(v_1\left(\frac{D_1}{D_2}\right)^2\right)^2 - v_1^2\right) =$$

$$\frac{1.21114}{2}\left(\left(22.22\left(\frac{2}{1}\right)^2\right)^2 - 22.22^2\right) = 4485.6Pa$$

ΔP at 80 km/h = 4485.6 Pa

ΔP at 160 km/h = 17942 Pa

Svar 10

Why has the traditional recommendation for DP flow transmitter on steam lines been to locate the transmitter *below* the line? *Below-line mounting in steam service helps protect the transmitter against damage from high steam temperatures.*

What kind(s) of problem(s) are typically experienced with below-pipe mounting of DP flow transmitters in steam line applications? *Measurement errors at low DP values due to uneven water columns in "wet leg" impulse lines. The water in the wet impulse legs can also freeze in cold weather.*

Can DP flowmeters *always* be top-mounted? If not, what limitations dictate whether or not to top-mount? *Top-mounting is applicable only for certain limited temperature ranges. Otherwise, the pipe is simply too hot and the transmitter will be "cooked" to death.*

Why shouldn't Annubar-style flow elements be mounted *vertically* in a steam pipe, but rather should be canted at least 15 degrees from vertical? *To avoid measurement errors due to water running alongside the bottom of the steam line, impacting the lowest port on the Annubar element.*

Svar 11

Assuming no difference in height (z):

$$\frac{v_1^2\rho}{2} + P_1 = \frac{v_2^2\rho}{2} + P_2$$

$$P_1 - P_2 = \frac{v_2^2\rho}{2} - \frac{v_1^2\rho}{2}$$

$$\Delta P = \frac{\rho}{2}\left(v_2^2 - v_1^2\right)$$

$$\frac{2\Delta P}{\rho} = v_2^2 - v_1^2$$

$$\text{If } Q = Av \text{ then } v = \frac{Q}{A}$$

$$\frac{2\Delta P}{\rho} = \left(\frac{Q}{A_2}\right)^2 - \left(\frac{Q}{A_1}\right)^2$$

$$\frac{2\Delta P}{\rho} = \frac{Q^2}{A_2^2} - \frac{Q^2}{A_1^2}$$

$$\frac{2\Delta P}{\rho} = \frac{Q^2A_1^2}{A_1^2A_2^2} - \frac{Q^2A_2^2}{A_1^2A_2^2}$$

$$\frac{2\Delta P}{\rho} = Q^2\frac{A_1^2 - A_2^2}{A_1^2A_2^2}$$

$$Q^2 = \left(\frac{A_1^2A_2^2}{A_1^2 - A_2^2}\right)\left(\frac{2\Delta P}{\rho}\right)$$

$$Q = \sqrt{\frac{A_1^2A_2^2}{A_1^2 - A_2^2}}\sqrt{\frac{2\Delta P}{\rho}}$$

$$Q = \frac{A_1A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{\frac{2\Delta P}{\rho}}$$

Where,
Q = Volumetric flow rate (ft^3/s)
A_1 = Large flow area (ft^2)
A_2 = Small (throat) flow area (ft^2)
ΔP = Differential pressure drop (lb/ft^2)
ρ = Mass density of fluid (slugs/ft^3)

Svar 12

We cannot tell exactly where the problem is, but we know it must be either in the receiver gauge or in the panel-mounted indicator (assuming only one fault in the system).

One test would be to block and equalize the DP transmitter's manifold, to see which indicator goes closest to zero. Chances are, the error is (at least) a zero shift, and as such should reveal itself in this test. Whichever indicator goes exactly to zero during this test is good; whichever one reads some non-zero value during this test is in error.

Another test would be to use a pressure gauge to measure the 3-15 PSI pneumatic signal coming from the transmitter. If the pressure is 5.78 PSI, the receiver gauge is good and the panel-mounted indicator must be in error. If the pressure is 6.05 PSI, the receiver gauge is in error and the panel-mounted indicator is good.

Svar 13

Partial answer:

- Differential pressure at 550 lbm/min mass flow and $\rho = 1.30$ lbm/ft^3 = $\underline{\textbf{32.89 "W.C.}}$
- Mass flow rate at 90 "W.C. = $\underline{\textbf{920 lbm/min}}$

Svar 14

Partial answer:

- **At a flow rate of 10 bbl/hr:**
- Differential pressure transmitter output signal = $\underline{\textbf{3.75}}$ PSI
- Square root extractor output signal = $\underline{\textbf{6}}$ PSI

- **At a flow rate of 31 bbl/hr:**
- Orifice plate ΔP = $\underline{\textbf{90.09}}$ " H_2O
- Flow indicator reading = $\underline{\textbf{31}}$ bbl/hr

Svar 15

Svar 16

Partial answer:

- Differential pressure at 210 GPM and $\gamma = 42.0$ lb/ft^3 = **42.70 "W.C.**
- Flow rate at 40 "W.C. = **204.5 GPM**

Svar 17

Partial answer:

- Differential pressure at 230 lbm/min mass flow = **23.28 "W.C.**
- Mass flow rate at 51 "W.C. and $\rho = 1.35$ lbm/ft^3 = **346.9 lbm/min**

Svar 18

Partial answer:

Input pressure (" W.C.)	Output current (mA)
0	
45	12.76
75	
90	
110	17.70
150	20

Svar 19

Partial answer:

Input current (mA)	Displayed flow (GPM)
4	0
6	
9.3	402.9
13	525
14.8	
20	

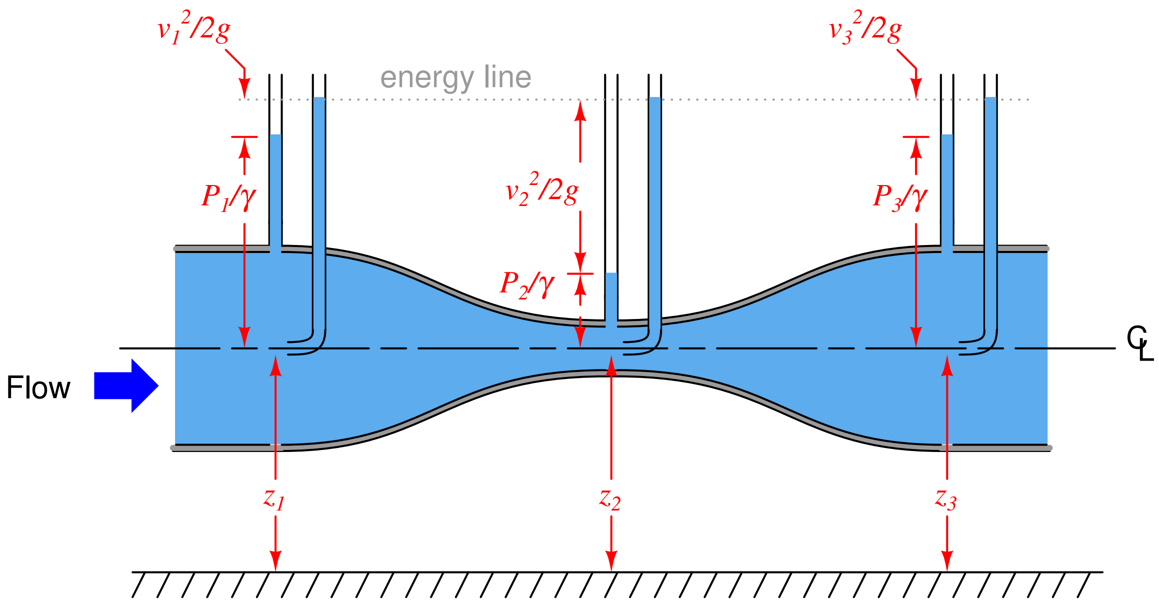
Svar 20

$v_2 = 16.57$ ft/s

Note that the two pressures are given in units of PSI (not pounds per square *foot*), and that the two heights are given in inches instead of feet. Also, $\rho_{benzene} = 1.753$ slugs/ft^3.

Svar 21

The difference in height is due to the "velocity head" at each point:



The line where all the Pitot tube piezometers match is sometimes called the *energy line* of the system.

Follow-up question: in a realistic piping system, this energy line has a downward slope. Explain why: